Remote Sensing of Nepal's Forests and Trees: Ascertaining the Front Line of Human-Induced Tree Cover Change

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Remote Sensing, Tree cover change, Forest

ABSTRACT

Synoptic, remote sensing of the national-scale, societal response of trees and forests to human driving forces in Nepal has been a wicked problem. This problem is a complex of four ancillary issues, namely, minimum mapping unit, radiometric scatter due to terrain, modeling of human dimensions, and democratizing robust environmental analysis. Beginning with the November 2018 conference convened by the East-West Center (EWC), USA, in Nepal, the state-of-the-art and key works in this problem-solving has been reviewed in this paper. Though this technology has improved the detection of forest and tree changes due to human driving forces at earlier stages, it is still not robust enough to inform global and national policy.

1. INTRODUCTION

Remote Sensing has been used to monitor synoptic, spatiotemporal changes in tree and forest cover due to human driving forces and societal responses. It is desirable to detect such changes as early as possible, in units that can be used over large scales such as nations and globes. However, the state-of-the-art in remote sensing of forest and trees for these scales are constrained to detecting only "latter" stages of changes. These "latter stages" refer to "forests or tree cover" of woody vegetation plots over 0.5 ha, 30% crown cover, and 30 m spatial resolutions, such as the Global Forest Cover (Hansen et al., 2013), following FAO protocol (Lambrechts, Wilkie and Rucevska, 2009; FAO, 2014). However, the Forest Resources Assessment (FRA) of the Government of Nepal, stretched the lower threshold of "forests" to include woody plots with 10% crown cover at spatial resolution of 5 m (Khanal et al., 2014). But the United Nations Framework Convention for Climate Change, UNFCCC, recommends even lower threshold of 0.05-1 ha with 10-30% canopy for identifying forests and trees for global carbon sequestration assessments (Sasaki and Putz, 2009).

For detecting front-line, individual tree stands, the definite precursors of the wide-scale, tree and forest recolonization of abandoned farms and public lands over the past 40 years in Nepal, it is necessary to detect such changes in plots less than 0.5 ha, with less than 10% crown cover (Rudel et al., 2016; Fox, 2018). This has been technically possible with finer spatial scales of 5 m, 2 m and even 0.5 m of IKONOS and QuickBird satellite imageries, tested in Jumla (Uddin et al., 2015) but difficult to upscale it to national level due to various problems (Saksena, 2018; Hurni, 2018; and Smith, 2018). For these reasons, even the "best" global data for tree cover change provided by Hansen et al., (2013) have reached accuracies of only 75% (Weiss and Peterson, 2015) versus acceptable levels over 85%, achieved for national FRA (Pokharel, 2018).

2. East-West Center Conference in Nepal, Nov 29-30, 2018

Reviewing the state-of-the-art in the remote sensing of tree and forest cover change, a conference was convened by the EWC, USA, in Nepal on November 29-30 (Fox, 2018). This conference compared three Landsat datasets for Nepal from 1988 to 2017, based on their suitabilities: a) by the International Center for Integrated Mountain Development, ICIMOD; b) by Hansen et al., (2013); and c) by the EWC/OSU (Smith, 2018) with the FRA RapidEye (Pokharel, 2018) and other relevant works. The suitabilities were analysed by quantifying the rate, extent, and socioeconomic importance to understand tree transition over the last three decades of Landsat satellite data and spatial modeling. Here, it was concluded that whilst significant progress had been achieved, critical problems persisted, in the smallest spatial units that could be sampled, economically with acceptable accuracy and precision, to ascertain the earlier stages of tree response to human dimensions on mountains. These problems are analyzed and discussed and in this paper.

This Conference was convened by Jeff Fox who has been familiar with the challenges and approaches of working with Nepal forestry, community forestry and remote sensing from the 1980s (Fox, 2016). Accordingly, he had assembled a team of experts to explore how remote sensing could more effectively ascertain tree recovery and Community Forests at national scales. These experts included Alexander C Smith (Smith_a, 2018), a doctoral student of Remote Sensing and Community Forestry at the OSU who had worked on Nepal Community Forestry for his Masters and was now working on his PhD on a NASA funded grant; his Professor, Jamon Van Den Hoek, an expert on Google Earth Engine; Dr. Kasper Hurni of University of Bern, an expert on topographic corrections for Landsat Time Series database; and ecological modelers, with particular experience on Nepal tree and forest cover change linked human dimensions from EWC and NASA, Sumeet Saksena and Atul Jain. This team interacted with participants from the FRA, Deputy Director Yam Pokharel, and Community Forest Division Chief Anuja Sharma; ICIMOD's remote sensing experts, Kabir Uddin and Mir Matin, on national and regional modeling of decadal landuse land cover changes; experts on sub-regional remote sensing studies by HELVETAS for Churia (Pokharel et al., 2018) and watersheds (Shrestha, 2018), and other ground level studies of tree and community forestry change by the Institute of Forestry; and other individual researchers. I have also contributed my own NASA-funded, doctoral research experience at Clark University, on 'The Pattern and Conditions for Forest Increase over the Himalaya' using Advanced Very High Resolution Radiometer (AVHRR) (Wikipedia, 2019) using Time Series Analysis.

3. Why is this Problem Important?

Single trees and ultimately entire forest patches respond to driving forces of human dimensions from individual decision-making on whether to out-migrate or stay on farms; whether to steal fuelwood and fodder from forests for livelihoods; or come together in legal community forestry user groups; or at large, on what policies the government make and implement on forest logging, forest protection, permits for forest clearance for development of airports, transmission lines, gas pipes and roads; or to permit political disturbance overcutting during Maoist rebellion; or government sponsored forest cutting to generate votes; and finally, to fail to control population pressures for forest lands and products due to inadequate forest protection institutional machinery.

Tree dynamics which were undetectable by conventional remote sensing include the farm and social forestry trees which were coming up on the abandoned, farming landscapes due to outmigration or the reduction of population pressure for livelihoods. Such trees on farm lands, groves, roadsides or scattered shrubs would need up to 30-40 years, or more to reach a 'visible' stage as per the aforementioned FAO remote sensing protocol.

Various solutions for detecting tree and forest changes have been explored. Generally, the smaller the pixel, the more weight a few trees' crowns will have, to swing the net pixel reflectance signature to 'tree' category, especially if they cover over 50% of the pixel. Nepal recently used RapidEye (Wikipedia, 2018) satellite images with spatial resolution of 5 m and this is partly a reason for national forest increase over its 1994 forest area by 5.14% (Khanal et al., 2016). The use of complex algorithms for principal components and maximum-margin hyperplanes has enabled the discrimination of early stages, such as 10% crown cover, by reducing errors due to spatial collinearity (DFRS, 2015; Guo et al., 2015; Saksena, 2018); and similarly, due to terrain reflectance (Hurni, 2018)

Millette et al., (1995) tried to detect by remote sensing unsuccessfully, the increased incidence of tin roofs, as a measure of village affluence, over thatched huts from bare terrace surfaces, because of an excess of noise over signals in pixels. Similarly, even with sophisticated, pre-processing of remotely sensed time series data from 1977 to 2010, econometric modelers at the International Food Policy Research Institute, IFPRI, were able to explain only 56% of the total variation in village household income as a function of tree cover change (Man Li et al., 2015). With the latest cutting-edge, terrain correction pre-processing for 2001-2016 Landsat imageries, Saksena (2018) could explain upto 69% of variation in tree cover change with village level human factors.

Additionally, even the widespread Community Forestry which now cover over 2 million ha (FECOFUN President Speech, 2018) could be partially 'invisible' when they are in forest patches, less than 0.5 ha, scattered on terraces of varying terrain (Sharma, 2018), constraining verifiable estimates of net forest and tree cover by global remote sensing for the Measuring, Reporting, and Verification, MRV, protocol for seeking carbon trade dividends and compensation for the carbon sequestration by the large community forestry area (Acharya et al., 2009). According to the latest and official *Forest User Groups (FUGs) Records available in MIS, Department of Forests, Babar Mahal, Kathmandu, dated Aug 15, 2017, of the 1.8 million ha under community forests, 46 forests were under 0.5 ha, hence totally invisible to remote sensing; and 486 such forests were between 0.5-2.00 ha, whose measurements maybe subject to errors due to terrain and partial pixel overlay (Community Forestry Database, 2019).* Community Forests range from less than 1 ha to 4000 ha, with 60% under 100 ha and 40% under 50 ha (Sharma, 2010).

The conventional remote sensing used for forest cover analysis are appropriate for measuring large swathes of forest lands, clear-felled by loggers (Hansen et al., 2003 and Hansen et al., 2013; Roy et al., 2013) but not good for Selection Silviculture, pick and choose forest trees cut, used by encroachers and illegal cutters (Fox, 2018). When trees are mined from within forests, making them thinner or with lesser crown densities, resulting in forest degradation, even with no change in area, it is less easy to ascertain, even by remote sensing (Millette et al., 1993). It is also impractical to verify all such areas on foot (Rayamajhi and Tachibana, 2018); therefore, remote sensing has been necessary with all the needed processing.

Nonetheless, we still do not have adequate means to monitor nationwide the front-line ground effects of forest policy applications exclusively through remote sensing but have to depend on extensive ground-truthing. This was done for the four-year 2010-2014 FRA (DFRS, 2015). It reported a 5.14% increase in forest area from 1994-2014 (Khanal et al., 2016) but this public impression of forest increase discourse was obfuscated with counter-claims of deforestation of 0.83% from 2001-2016, in a June 4, 2018 news (Kathmandu Post, 2018), quoting research, using Global Forest Watch satellite database (Hansen et al., 2013) by Sujata Shrestha, et al., (2018).

This was the backdrop for the 2018 Annapurna conference. The key problem of measuring forest and tree cover change on Nepal Mountains can be broken down to four sub-problems as follows:

Problem one : Measurement of Forest and Tree Cover Dynamics

Problem two : Radiometric Errors due to Mountain Terrain

Problem three : Modeling Human Dimensions of Forest and Tree Cover Dynamics

Problem four: Democratization of Robust Remote Sensing Analysis of Forest/Tree Cover

4. Problem one: Measurement of Forest Patch and Tree Cover Dynamics

What is a "forest"? This is a vexing remote sensing problem: or what is the 'smallest visible forest spatial unit', or the Minimum Mapping Unit, the MMU, for "forest" (Saura, 2002)? When satellites were used for remote sensing, the platforms were at least 500 km above the surface of the earth, so small patches were difficult to identify (Jensen et al., 1999). Satellites can only identify or characterize an event or process if the event/process produces a measurable change (spatial, temporal, and spectral) on the Earth's surface. Satellite imagery are most often designed for systematic monitoring of condition of the Earth's surface rather than supporting visual interpretation or feature detection (Hoek, et al., 2018). The spatial resolutions of satellite remote sensing have steadily improved from the 79 m of the earliest Multi-Spectral Scanner (MSS) to 0.5 m for IKONOS, and QuickBird, but the standard is FAO/Landsat resolution of 30 m because of costs and easy availability: the exception was the 5 m RapidEye used for Nepal FRA (Pokharel, 2018). Therefore, tree and forest patches under these specifications have been "invisible" for global and national forest monitoring.

There have been several strategies to circumvent the cost and technical limitations for finer resolution remote sensing for large scale forest and tree cover change mapping. For instance, during my doctoral research at Clark University (Tuladhar, 1995), I used time series analysis of 1985-95, with 3650 daily images of 1 km spatial resolution AVHRR, to robustly enhance the discernment of woody tree vegetation, after encountering limitations in the two-date, $7000 Landsat images, for my professors' research on Nepal mountains for *Regions at Risk* (Millette, et al., 1993; Kasperson et al., 1995). Time Series with AVHRR had been successfully used to monitor El Nino vegetation effects in Africa and China so I applied this to Nepal forest to uncover a net national increase in woody vegetation, a finding later corroborated by JAFTA (2001) and Nepal FRA, 2010-2014 study (DFRS, 2015; Khanal et al., 2016). The AVHRR 1 km spatial resolution have now been bested with Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery data at 0.5 km resolution (Hansen et al., 2003) and used for regional land cover mapping in the ICIMOD mountains (Uddin, 2018).

The amount of all the woody vegetation in a pixel would affect the amount of Normalized Difference Vegetation Index, NDVI, score for large landscape; the total amount of woody vegetation per pixel would increase or decrease its total Vegetation Index (Tuladhar, 1995). For this vegetation index, the theory was to assess the difference in energy capture from reflectance of woody vegetation versus that of other mixed or homogenous land cover types (Lillesand et al., 2014; Crowther et. al., 2015).

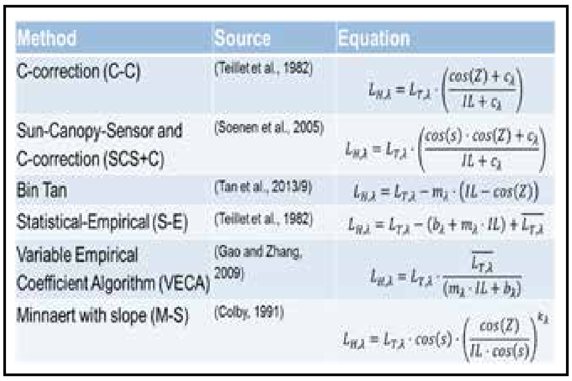
Other techniques include pre-processing for clouds, object-based image analysis, and hyperspectral multivariate analysis, from 4 for MSS, to 7 for TM, and 8 for Enhanced Thematic Mapper (ETM) (Guo et al., 2015; Hansen et al., 2003; Hansen et al., 2013; Uddin, 2018) that have improved remote sensing accuracy upto 75%; good, but less than the desirable accuracies of over 85%.

5. Problem two: Radiometric Error due to Terrain

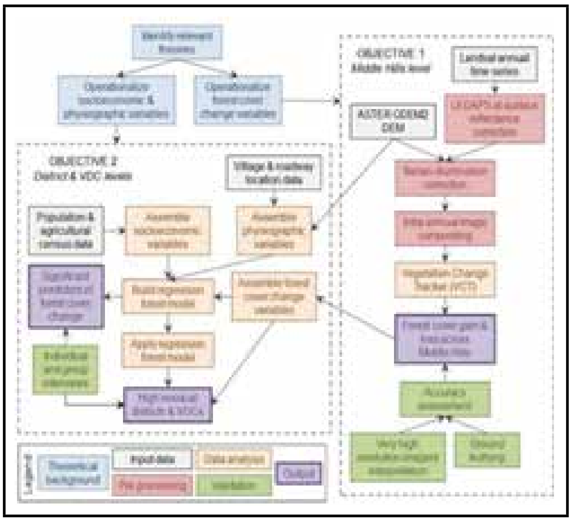
Another wicked problem is the errors due to inadequately corrected radiometric dispersion by the mountain terrain in conventional Digital Elevation Model of the Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model, ASTER

G-DEM (Digital Geography, 2019), second generation DEM (Digital Geography, 2019), the Shuttle Radar Topography Mission or SRTM (Georgopoulos, 2015; Guo et al., 2015; Internet Archive Wayback Machine, 2019). These models, available for the globe for 30 m contours, have been unable to distinguish land covers due to a lot of noise (Bhattarai et al., 2009; Bajracharya et al., 2009). Worse, radiometric scatter is exacerbated by a Nepal's mountain specificity (Jodha and Shrestha, 2012): the tremendous diversity of terrain (Ishtiaque et al., 2017; Guo et al., 2015). To reduce terrain-induced radiometric uncertainties, spatial statistical corrections for collinearity and autocorrelations on Digital Terrain Models or DTM have been explored to produce principal components for more robust discrimination (Guo et al., 2015; DFRS, 2015); in particular, for three Nepal mountain, satellite imageries datasets of, a) ICIMOD decadal data for 1990, 2000 and 2010; b) Hansen et al., (2013) global forest cover database for 2000-2016; and c) the EWC/OSU database for 1988 to 2016, (Hurni, 2018; Table below). This revealed that differences crept in for slope class 4 to 5 (Smith_b, 2018), due to diffraction and diffuse back radiation on mountain terrain (Hurni, 2018). So a major section of the EWC study of community forestry and tree cover dynamics has been devoted to using the best trigonometric corrections of Hurni (2018) below to Fox's methodology (Objective 1 box), below:

a) Hurni's Terrain Corrections Tested for Nepal Satellite Data from 1988-2016, Left:



Method	Source	Equation
C-correction (C-C)	(Teillet et al., 1982)	$L_{H,\lambda} = L_{T,\lambda} \cdot \left(\frac{cos(Z) + c_\lambda}{IL + c_\lambda} \right)$
Sun-Canopy-Sensor and C-correction (SCS+C)	(Soenen et al., 2005)	$L_{H,\lambda} = L_{T,\lambda} \cdot \left(\frac{cos(s) \cdot cos(Z) + c_\lambda}{IL + c_\lambda} \right)$
Bin Tan	(Tan et al., 2013/9)	$L_{H,\lambda} = L_{T,\lambda} - m_\lambda \cdot (IL - cos(Z))$
Statistical-Empirical (S-E)	(Teillet et al., 1982)	$L_{H,\lambda} = L_{T,\lambda} - (b_\lambda + m_\lambda \cdot IL) + \overline{L_{T,\lambda}}$
Variable Empirical Coefficient Algorithm (VECA)	(Gao and Zhang, 2009)	$L_{H,\lambda} = L_{T,\lambda} \cdot \frac{\overline{L_{T,\lambda}}}{(m_\lambda \cdot IL + b_\lambda)}$
Minnaert with slope (M-S)	(Colby, 1991)	$L_{H,\lambda} = L_{T,\lambda} \cdot cos(s) \cdot \left(\frac{cos(Z)}{IL \cdot cos(s)} \right)^{k_\lambda}$



b) Objective 1: 1988-2016 Tree Cover Change Methodology, Fox (2018): *Right*

Have these errors been tamed? Not Really. Terrain correction algorithms, despite their sophistications and power, have not captured the full range of variability of forest and tree landscapes over the entire Nepal Mountains. So, for those who cannot afford the expensive ground-truthing, certain "standard" satellite imagery have been used as Bench Marks, like Google Earth imagery (Tuladhar, 2015; Uddin, 2018; Pokharel, 2018).

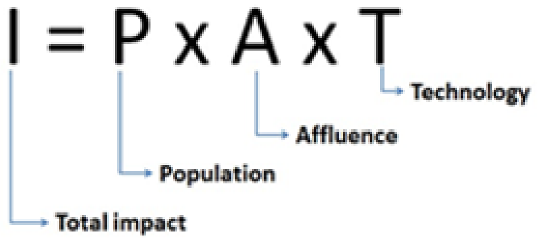
6. Problem three: Modeling Human Dimensions of Forest and Tree Change

The whole rationale for studying and improving remote sensing of forest and trees is to understand the human dimensions of landscape changes (Kasperson et al., 1989). HDGEC, or the Human Dimensions of Global Environmental Change, include Human Driving Forces and Societal Response Patterns (Ehrlich and Holdren, 1971). In Third World Countries, Population (P) is the overwhelming driver (Chowdhury, 2006; UN_REDD/REDD Cell, 2014; Wang and Wu, 2019) whereas in First World, it is Affluence (A) and Technology (T) (Meyer and Turner, 1994; Rudel et al., 2016; Shrestha et al., 2018). Scholars later expanded this concept to IPATIC, to include Institutions (I) and Culture (C) (Meyer and Turner, 1994). Research on Nepal Driving forces across scales include, for instance, Bhattarai and Conway, 2008; Bhattarai et al., 2009; Pandey, et al., 2016; Ishtiaque et al., 2017; and Saksena, 2018. Scale and the determination of quantifiable, social variables for human dimensions have been challenges for these modeling (Meyer and Turner, 1994; Hansen et al., 2013; Khanal et al; 2016; Saxena, 2018; World Resources Institute, 2019).

Societal Responses come from the Hazard School (White, 1961) which use neoclassical fundamental concepts of the Rational Man and Bounded Rationality to explain why people and firms at different scales make what seems like ‘irrational choices’, to live in dangerous areas (Burton et al., 1978; Kasperson et al., 1995). This is because such “rational decision making” occurs in a bounded rationality of a range of choices delimited by access to information by class, region, education and other institutional factors (Allan, 1986; Brookfield, 1988; Allan, 1995; Schweik, et al., 2003). The HDGEC has used these concepts to quantitatively model these factors across scales from global, regional to national scales in Land Use and Land Cover Change, LULC, Disaster, and Climate Change Vulnerability Studies (Matin, 2018; Ishtiaque et al., 2017; Gilani, 2015; Guo et al., 2015; K.C. et al., 2012; Ministry of Environment, Government of Nepal, 2010; Turner II et al., 2002; Meyer and Turner, 1994).

Modeling human dimensions of forest and tree cover change through remote sensing presents a unique problem of spatial scale. Most national studies work with *district level* data on spatiotemporal changes in trees and forest change with social data (K.C. et al., 2012). However, the EWC/OSU has modeled at the *village level*, the link between human factors such as community forestry and outmigration with tree cover changes for 1988-2016 (Fox, 2018; Saksena, 2018). What type of social data is available at different scales is both a theoretical and a methodological challenge. For instance, population data from census is available for district, village to global and regional scales; but not governance data, presumably a major cause of success of community forestry in Nepal, relating to Institutions (I) in IPATIC, is available in georeferenced forms (Schweik, et al., 2003; Bhattarai and Conway, 2008; Matin, 2018). Further other social drivers include: socioeconomic variables of income, source of income, number of people per household, education, gender, number of livestock, etc. while biophysical and spatial variables could include aspect, slope, elevation, distance from markets (Schweik, et al., 2003; Saksena, 2018). Researchers trying to relate migration, remittance and other socioeconomic variables to empirically georeferenced tree cover and forest cover changes have found modeling difficult, with only modest R^2 and limited remote sensing accuracies (Bhattarai and Conway, 2008; Bhattarai et al., 2009; Man Li et al., 2015; Ishtiaque et al., 2017; Fox, 2018; Saksena, 2018; Shrestha, 2018). Current IPAT models fail when we try to count individual trees, instead of forest patches, as the empirical traces of societal driving forces and response processes at the pixel level, because interpolating from higher-order pixels of 1 km to 30 m spatial resolutions introduces Modifiable Area Unit Problems (MAUP) for mixed boundary pixels in addition to terrain-induced errors (Saksena, 2018; Smith_b, 2018).

7. Problem four: Democratization of Remote Sensing of Forest & Tree Cover Dynamics



Remote Sensing by satellites has traditionally been a specialist preserve, requiring specialized skills, expensive access to data, hardware and software; so it often requires government agencies with external financial and technical support to carry out large national studies as has been the case till FRA 2014. However, this is rapidly changing. Individual specialists with access to free satellite imagery and widely available software have been able to carry out extensive remote sensing as with El Nino effects in China and Africa and Nepal Himalaya forestry change at Clark University in 1995, and, at University of Massachusetts at Boston, in 2018, (Shrestha et al., 2018). The democratization of remote sensing to non-specialists, akin to Google Earth Pro or Microsoft Office, have been greatly improved with the publicly accessible, Hansen's Global LUCC data base and Google Earth Engine which are continuously updated and upgraded global satellite imagery. Google Earth Engine is a web-based tool for interactive data exploration that provides access to over 20 Petabytes of 40 years of satellite imagery (with daily updates), with algorithms to analyze those data (as well as your own data), that has revolutionized large volume image processing to allow calculating, visualizing, and exporting EWC/OSU Nepal forest cover products (Hoek et al., 2018). The Google Earth Engine (GEE), however, still has limitations with algorithms to minimize radiometric scatter due to high mountain slopes and spatial resolutions that cannot detect the front line of individual tree level response to depopulation, outmigration, community forestry governance etc. The Global Forest Watch is more user-friendly by not requiring any coding skills to access Hansen's data base and Google Earth Engine (World Resources Institute, 2019).

Because of these known sources of errors, Nepal forestry and tree data based on global land cover analysis maybe off by as much as 30%, on top of overall accuracy of 70% (Smith_a, 2018). So the "best" solution, over other cutting-edge remote sensing analysis of Nepal, is actual ground-truthing, to identify vegetation structure and function, which Nepal government has done for FRA 2014 but global data bases cannot afford do it (Hurni, 2018). For FRA 2014, for instance, upto 50,000 + permanent, Global Positioning System (GPS) tagged plots and trees all over Nepal tested and measured by hundreds of well-trained specialists over 4 year period of remote sensing projects, at a great expense of 1.7 billion rupees of bilateral government technical support (DFRS, 2015; Pokharel, 2018). The overall accuracy was 97.9%.

8. Conclusions:

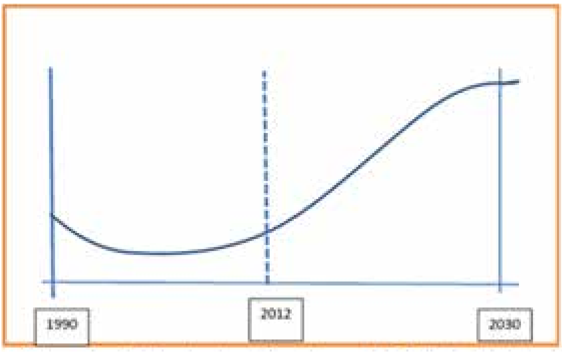
This review suggests substantial, but not satisfactory, progress in ascertaining the early stages of the human dimensions of Nepal's forest and tree change. For instance, while the discourse of Nepal's forest change was swinging from the Himalayan Theory of Environmental Degradation (THED) inspired population driven deforestation from the 1980s (Eckholm, 1976) to a net forest increase of 5.14% from 1994-2014, after FRA 2010-2014 (DFRS, 2015), it is again muddled, in the public perception, by reports of deforestation of 0.83% from 2000-2016 by Global Forest Watch (Shrestha et al., 2018). Forests Increase or Decrease? The Public is confused, although the two assessments measure two different phenomena. This confusion has been analysed as due to: a) MMU, b) Forest and Tree Crown Density definition, c) Forest Plot Size, d) Hyperspectral and Time Series Discriminant Analysis, e) Radiometric Error due to Terrain, f) MAUP, g) Ground Truthing, h) Segmented Expertise, and i) Operationalizing of Holistic Theories of HDGEC on Tree Cover Change in Nepal.

Amongst the aforementioned issues, Segmented Expertise and the Operationalizing of Holistic Theories deserve explication. Segmented expertise refers to sectors of works on forest and tree cover change that have made substantial progress but have been constrained by the lack of expertise in more holistic analysis. First, is the series of four, national-scale forest change assessments made by the Government of Nepal technicians, with the financial and technical assistance of international parties from 1964 to 2014, involving latest technology, from aerial photography, Landsat satellite imagery, GIS, using RapidEye, LIDAR and extensive field ground truthing of permanent sample plots (DFRS, 2015). These reports are considered officially authoritative though holistically, not necessarily the most robust, because the foresters who work in these have strong training and expertise in forest biology and ecology, together with ground reality experience but their mastery of remote sensing theory and skills involving the math, science, survey and computer programming skills are less than cutting-edge. This is generally true of individual foresters, botanists, or natural resource managers who have worked on landuse land cover changes with remote sensing in Universities abroad.

Unlike foresters, however, ICIMOD technicians have a surfeit of skills in computer analysis, programming, access to the cutting-edge hardware, software, online access, and institutional support for international cooperation (Matin, 2018) and they have produced highly attractive studies that fall short of analytical rigor (Manandhar, 2014; Gilani, 2015) and ground-truthing accuracy (Uddin, 2018) because technicians lack strong background in forestry, ecology, environmental science, field verification knowledge, and almost zero familiarity with holistic geographical or economic theories of global environmental change that link spatial changes in forests and trees with human dimensions such as community forestry, outmigration, remittance, despite their copious productivity (Bajracharya et al., 2009; Jodha and Shrestha, 2012; Matin, 2018).

The other sector of segmented expertise are scattered in fewer works by individual experts in pursuit of graduate degrees in geography, engineering, natural resources at foreign universities. They include Amulya Tuladhar who pursued a NASA-funded doctoral research to link the patterns and causes of tree cover change in the Nepal Himalayas in 1995 to more recent Him Lal Shrestha, who modeled forest and tree change in watersheds as a function of human dimensions to predict the changes to 2030. These studies are holistically, more robust than either the abovementioned foresters', or the computer engineers', in that they have the exposure to holistic theories *and* access to cutting-edge, remote sensing analytical tools afforded with international institutional resources. But these studies lack sustained resources for longer term, leading-edge research analysis that needs institutionally backed support to access the latest development in hardware, software, theories and trainings. This is where the EWC of the University of Hawaii has come in, for research on the 25 years of tree and forest cover change remote sensing in Nepal.

Besides segmented expertise, another confounding problem is the paucity of holistic theory and methodology. There is a need to update, upgrade and test the theories of HDGEC on Nepal tree and forest change. What is happening in national scale forest and tree change and how is that changing with time, space, and scale are mostly empirical problems of remote sensing and ground truthing? Why is this happening? Due to community forestry, outmigration, transition of subsistence agricultural economy to service-based urban market economy, econometric variables, or due to ecological resilience? All these are *possible,* partial or holistic explanations, for spatiotemporal distribution of tree cover and forest change in Nepal. Agricultural economists of the International Food Policy Research Institute tried to model outmigration and remittance with village level forest and tree cover change using remote sensed Landsat imageries (Man Li et al., 2015; and Guo et al., 2015), and cultural anthropologists linked watershed level changes in forest and tree cover change with local livelihood changes (Shrestha and Brown, 1995) or institutional governance (Schweik et al., 2003) while geographers such as Tuladhar of Clark University have drawn on HDGEC research to study spatiotemporal patterns of forest change with human dimensions of driving forces and societal responses (Tuladhar, 1995).



According to the theory of Driving Forces for Nepal, for instance, the Theory of Himalayan Environmental Degradation (THED) (Eckholm, 1976) posited that population growth was the major cause of deforestation in Nepal hills, leading to a suite of societal response in increasing scale from Man and Biosphere studies (MAB) (UNESCO, 1973) to Integrated Watershed Management studies in Jhikhu Khola over 15 years (Providoli et al., 1995), as well as large scale Resources Conservation Project (RCUP), in mid-1980s to the successful community forestry program resulting in 2 million ha or 35% of Nepal's forestry, leading to forest recovery in the hills, the societal response noted first a decline in rate of deforestation, e.g. from 1947 to 1970s, see figure of, **Overall Land Use Dynamics of Jhikhu 1947-90** (Shrestha and Brown, 1995) and then the upswing from 1970s to 1990; a trend, first documented in Jhikhu Khola, and confirmed over and over again all over Nepal in many subsequent studies (Pokharel et al., 2018; DFRS, 2018) including a national forest increase of 5% from 1994-2014, as overall population pressure on forests and trees declined with the Demographic Transition population growth rate decline from 2.25% to 1.25% from 1991-2011, and the depopulation of one-third of Nepal's 75 districts of 2 million people in last census and the gradual decline of agricultural based livelihoods to 65% of the national population.

For a more coherent theorization of the overall trajectory of environmental change in the Nepal Himalayas, Kasperson et al., (1995) studied Nepal along with 9 *Regions at Risk* of the world as a whole, and concluded that the trajectory for Nepal was not "critical", or likely collapse in the next generation, but impoverished to endangered, and likely to improve in the coming decades (see figure, from 2012-2030). They noted that economic growth and well-being was increasing, along with the increasing societal learning due to increasing signals of environmental distress; so the net degradation rate of environment was declining aided by natural ecological resilience of Nepal Mountains was improving.

The current research of EWC/OSU on 25 years of community forestry and tree cover dynamics aims to bring the latest in remote sensing technology to investigate the relative roles of outmigration and community forestry change using the most accurate data set of 1988-2016. We are now approaching an era where exclusive government discourse based on its privileged access to data and expertise can now be challenged and supplemented by independent researchers and local people with smart phones and rudimentary knowledge of remote sensing and access to powerful satellite imagery database and applications. Forest Watcher is one such smartphone application developed by Global Forest Watch to enable any user to monitor and map in georeferenced accuracy any forest and tree cover change on the ground he or she can visit (World Resources Institute, 2019).

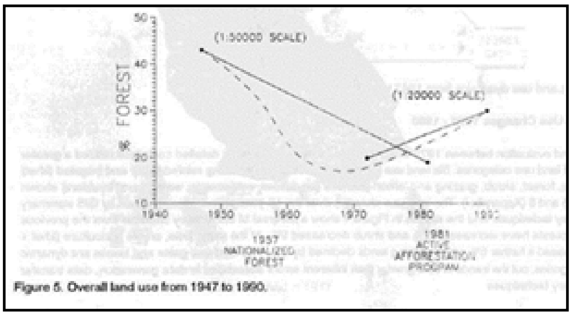


Figure 5. Overall land use from 1947 to 1990.

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