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Forest cover changes in Bhutan: Revisiting the forest transition

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ABSTRACT

Reforestation is observed in several tropical countries, mostly in marginal lands including mountain environments. Bhutan, a landlocked and mountainous country characterized by a long tradition of environmental preservation, is considered as one of the few tropical countries which has experienced a recent forest transition, i.e., a shift from net loss to net increase of forest cover. However, doubts persist regarding the contemporary evolution of forest cover in Bhutan as two recent studies reported opposite trends. The objective of this study was to assess whether a forest transition did indeed recently take place in Bhutan. We used topographically corrected Landsat images from 1990, 2001/2002, and 2011 to detect and quantify forest cover change trajectories over Bhutan. Results of the land cover classifications confirmed that forest cover in Bhutan remained very stable, with a forested area covering more than 60% of the country. For both time periods, gross and net forest cover changes were remarkably small. A trend reversal occurred as a net forest loss of 91 km^2 during the 1990s was followed by a net forest gain of 52 km^2 during the following decade. This small transition resulted from both an increase in rates of forest gain and a decrease in rates of forest loss, mostly affecting the broadleaf forest ecosystem of southern low-elevation districts. Northern districts covered by coniferous forests did not contribute to the forest transition. A spatially explicit comparison of our forest cover change maps with two previous studies highlighted the importance of a robust validation of change detection results and of a topographic correction of remote sensing images in rugged environments, as performed in this study. These recent forest cover changes can be explained by socio-economic and political changes associated with the opening of the country to trade, which induced a gradual transition from subsistence shifting cultivation to market-oriented agriculture. This study confirmed that the high forest cover of Bhutan was maintained since 1990, with a slight increase during the 2000s.

1. Introduction

Reforestation has been observed in several tropical countries, sometimes leading to forest transitions, i.e., shifts from net loss to net increase of forest cover at a national scale. Typically, reforestation occurs mostly in marginal lands including mountainous environments, which are less favorable for agriculture compared to lowlands. One of the tropical countries where a forest transition has been reported is the Kingdom of Bhutan, with a turning point around 1975–1990 (Meyfroidt & Lambin, 2011).

Even though several studies highlighted a recent forest transition in some tropical countries (e.g., in Vietnam and Costa Rica, Meyfroidt, Rudel, & Lambin, 2010), a recent global-scale study by Hansen et al. (2013) detected no net reforestation in any tropical country, except for Cuba, during the 2000–2012 period. Reliable monitoring of forest cover changes is important to support land use and environmental policies. Such a task is particularly challenging in the Himalayas, which combine a rugged topography, a persistent cloud cover, and fragmented land use. Over the recent decades, the Himalayan region experienced rapid land-use changes driven by population and economic growth (Pandit, Sodhi, Koh, Bhaskar, & Brook, 2007; Qasim, Hubacek, Termansen, & Khan, 2011). Major trends were increased grazing intensity in pastures and forests, and a progressive shift from traditional crop farming and animal husbandry systems to market-oriented agriculture (Saxena, Maikhuri, & Rao, 2005; Semwal et al., 2004; Tiwari, 2000). The objective of

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this study is to assess whether a forest transition did indeed recently take place in Bhutan.

2. Background

Bhutan is a mountainous country of ~38,000 km^2 landlocked between China to the north and India to the south. The extreme ruggedness of the terrain, with elevation spanning from around 100 m in the southern Himalayan foothills to more than 7000 m in the northern peaks, determines variations in ecological conditions along a latitudinal gradient (FAO, 1999). The sub-tropical zone dominated by broadleaved forest extends up to 1800 m. In the temperate zone, up to 4500 m, broadleaved species are progressively replaced by conifers. At higher elevations, the Himalayan zone is covered by shrubs, alpine meadows, rock outcrops and permanent snow. Population density is low (16 inhabitants per km^2 in 2005), with settlements concentrated in the main valleys (OCC, 2006).

The Himalayas are a young mountain range, still undergoing an important uplift making it particularly prone to landslides and surface erosion (Tiwari, 2000), which can be exacerbated by land cover changes (Guns & Vanacker, 2013; Qasim et al., 2011; Semwal et al., 2004) and climate change (Hoy, Katel, Thapa, Dendup, & Matschullat, 2015). The Himalayas (Pandit et al., 2007; Saxena et al., 2005), and Bhutan in particular (Hoy et al., 2015; Siebert, Belsky, Wangchuk, & Riddering, 2015; Zurick, 2006), feature an extremely high density of species richness. Bhutan is entirely within the Himalayan biodiversity hotspot (Mittermeier, Turner, Larsen, Brooks, & Gascon, 2011). The forested environment of Bhutan provides essential ecosystem services for its local population and those living downstream (Kubiszewski, Costanza, Dorji, Thoennes, & Tshering, 2013). Economic development in Bhutan highly depends on hydroelectric power generation, which relies on forests to regulate water flows from upstream catchments (FAO, 1999). Land-use and land-cover changes in the Himalayas, by disrupting the hydrological cycle, affects the economy of downstream, densely populated plains of Pakistan and northern India (Saxena et al., 2005; Tiwari, 2000).

The traditional agricultural system of Bhutan combines subsistence swidden cultivation and extensive livestock rearing, with cattle supporting cropping through manure fertilization and draught power (Roder, Calvert, & Dorji, 1992; Wangchuk & Siebert, 2013; Wangchuk, Wurzinger, Darabant, Gratzer, & Zollitsch, 2014). This agricultural system thus depends on forests where cattle usually graze. Agro-ecological conditions explain the historical presence of two types of shifting cultivation (Roder et al., 1992; Siebert & Belsky, 2014). The grass fallow, or *pangshing*, is traditionally practiced in central and northern districts, at high altitude. The tree or bush fallow, or *tseri*, is the standard system in the lower elevation southeastern districts. *Pangshing* requires a long fallow period if no input is added. Dominant crops are buckwheat, wheat and barley. Maize, rice and millet are predominantly cultivated in *tseri*. In the late 1980s, these traditional farming practices still prevailed, and agriculture was the main occupations for over 90% of the population (Roder et al., 1992).

The country recently moved out from economic and political isolationism through development policies seeking gradual modernization without jeopardizing cultural specificities (Walcott, 2011). Profound economic, social and political changes led to rapid urbanization (Walcott, 2009). Agriculture transitioned from subsistence to market-oriented, more intensive farming (Wangchuk & Siebert, 2013). However, the Bhutanese population is still mainly rural (69% in 2005), with over 60% of the active population involved in agriculture and forestry activities in 2011 (NSB, 2011; OCC, 2006). Agriculture is constrained by low access to improved technology, external inputs, credit, information, and markets for crop surplus. This explains the current policy priority of road improvement by national development plans (Tobgay & McCullough, 2008).

Environmental preservation is a deep-rooted tradition in the Buddhist Kingdom of Bhutan (Zurick, 2006). Several forest conservation policies have been implemented over the last decades, including a strict regulation of the forestry sector via its nationalization, the progressive ban of shifting cultivation, and the creation of protected areas (Jadin, Meyfroidt, & Lambin, 2015; MoAF, 2011). These measures must ensure that at least 60 percent of the country remain forested for all time, a requirement written in the first formal Bhutanese Constitution enacted in 2008 (RGoB, 2008). The Ministry of Agriculture and Forests recently headed a land cover mapping project combining 10 m resolution satellite imagery from 2006 to 2009 with extensive ground truthing to constitute a reference for planning and management of natural resources at local and national levels (NSSC & PPD, 2011). This assessment (LCMP-2010) estimated a national forest cover of 70.5% (Fig. 1), making Bhutan one of the world's most densely forested countries. The FAO Forest Resources Assessment reported a linear increase in forestlands between 1990 and 2015 by extrapolating estimates from two land cover assessments: the LUPP 1995 (based on 1989–1990 satellite imagery) for forest area in 1995 and the LCMP-2010 (based on 2006–2009 imagery) for 2010 (Fig. 1) (FAO, 2015). When compiling all past national land cover studies of Bhutan (Fig. 1), a long term trend is difficult to identify due to differences in methodologies, levels of rigor, and definitions of forest (Jadin et al., 2015; Van Noord, 2010).

Two recent scientific studies, based on Landsat imagery, also estimated national scale forest cover change (Fig. 1). The global forest change map of Hansen et al. (2013) measured a decrease in forest cover between 2000 and 2012 in Bhutan. By contrast, another study detected a net increase in forest cover during the same period and an even higher increase during the 1990s (Gilani et al., 2015). These two studies thus reached contradictory conclusions. None of these studies conducted a comprehensive validation of their change detection on Bhutan. This study resolves these contradictory results by providing a detailed analysis of recent forest cover changes in Bhutan based on topographically corrected Landsat images, change detection based on a combination of land cover classifications with vegetation indices, a quantitative assessment of the quality of the detection, and a comparative analysis with the previously mentioned studies. The results are then discussed in light of recent socio-economic changes affecting land use in Bhutan.

3. Data and methods

3.1. Data

Bhutan is almost entirely covered by 2 Landsat footprints. We selected six images from the USGS archive, taken at almost anniversary dates (Table 1). The first time period runs from 1990 to 2001 (eastern part of Bhutan) or 2002 (western part of Bhutan), and the second runs until late 2011. These two decades correspond to profound changes in agricultural practices and conservation policies in Bhutan. The four images of the 2000s had been processed to Standard Terrain Correction (Level 1T). Those from 1990, although orthorectified, were not available at the same preprocessing level.

The 90 m digital elevation model from the Shuttle Radar Topographic Mission (SRTM) was resampled to 30 m resolution using cubic convolution to be used for the topographic correction of Landsat images (Jarvis, Reuter, Nelson, & Guevara, 2008).