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Decadal land cover change dynamics in Bhutan

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ABSTRACT

Land cover (LC) is one of the most important and easily detectable indicators of change in ecosystem services and livelihood support systems. This paper describes the decadal dynamics in LC changes at national and sub-national level in Bhutan derived by applying object-based image analysis (OBIA) techniques to 1990, 2000, and 2010 Landsat (30 m spatial resolution) data. Ten LC classes were defined in order to give a harmonized legend land cover classification system (LCCS). An accuracy of 83% was achieved for LC-2010 as determined from spot analysis using very high resolution satellite data from Google Earth Pro and limited field verification. At the national level, overall forest increased from 25,558 to 26,732 km^2 between 1990 and 2010, equivalent to an average annual growth rate of 59 km^2/year (0.22%). There was an overall reduction in grassland, shrubland, and barren area, but the observations were highly dependent on time of acquisition of the satellite data and climatic conditions. The greatest change from non-forest to forest (277 km^2) was in Bumthang district, followed by Wangdue Phodrang and Trashigang, with the least (1 km^2) in Tsirang. Forest and scrub forest covers close to 75% of the land area of Bhutan, and just over half of the total area (51%) has some form of conservation status. This study indicates that numerous applications and analyses can be carried out to support improved land cover and land use (LCLU) management. It will be possible to replicate this study in the future as comparable new satellite data is scheduled to become available.

1. Introduction

Land cover (LC) change is one of the most important and easily detectable indicators of change in ecosystem services and livelihood support systems. Socioeconomic drivers can induce changes in LC that may disrupt socio-cultural practices and the institutions associated with managing natural resources, which in turn increases people's vulnerability to climate change (Agarwal et al., 2002; Lambin and Meyfroidt, 2010). LC assessment and monitoring of LC dynamics are essential for the sustainable management of natural resources, environmental protection, and food security (Foley et al., 2005; Jin et al., 2013).

Remotely sensed datasets and geospatial tools provide a unique possibility for quantifying changes happening on the earth's surface, whether through human impact or climate change, over time (Huang et al., 2009). Multi-temporal LC change analysis and simulation based on coarse to very high resolution satellite images is becoming a well-established technique, recognized among the scientific community and in civil society (Boggs, 2010; Gu et al., 2007; Kumar et al., 2011; Niraula et al., 2013; Townshend et al., 2012; Vogelmann et al., 2012; Xue et al., 2008).

Selection of appropriate satellite images, standard classification schema, and methods are key challenges for LC change analysis at national to region level (Herold et al., 2008; Townshend et al., 2012; Xin et al., 2013). Accuracy assessment is necessary to ensure the reliability of the derived LC maps; it can be based on different sources including ground-based and ancillary information (Foody, 2010; Olofsson et al., 2013). Satellite image interpretation and categorization of features should be easy for others to adopt and replicate as and when new satellite data become available (Foley et al., 2005).

The Landsat satellite time series imagery is freely available and has long been used as a valuable source for monitoring ecosystem

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change (Vogelmann et al., 2012; Xian et al., 2009), forest cover (Bhattarai et al., 2009; Niraula et al., 2013; Qamer et al., 2012; Townshend et al., 2012), agricultural yields (Abtew and Melesse, 2013; Lyle et al., 2013), and urban growth (Yuan et al., 2005). Hansen and Loveland (2012) have reviewed a number of large area LC change and monitoring products using Landsat imagery. A land cover classification system (LCCS) provides a comprehensive and systematic classification legend for defined LC features that can be recognized and compared with other descriptions from anywhere in the world (Gregorio, 1998). Legends based on LCCS such as GlobCover 2005–06 (Arino et al., 2007) and 2009 (Bontemps et al., 2011) are much appreciated and have been adopted in a number of sub-national, national, regional, and global LC studies. Object or segmentation-based image classification is considered to be better for change detection than conventional pixel-based satellite image classification algorithms (Blaschke, 2010; Duveiller et al., 2008; Raši et al., 2011).

In 2007, the Intergovernmental Panel on Climate Change (IPCC) Assessment Report-4 has recognized the Hindu Kush Himalayan (HKH) region as a “data-deficit area” and although scientists and institutions are attempting to fill some of the gaps (Singh et al., 2011), this remains broadly true. Bhutan is a landlocked country in the eastern Himalayas, rich in natural resources in the form of forest, stunning biodiversity, and water resources. Although a number of LC maps are available for Bhutan from different sources, as yet no comprehensive, systematic, well-recognized temporal assessment has been carried out. Noord (2010), in a review, showed that forest cover studies of Bhutan carried out using different remotely sensed data, methods, definitions, and legends provided diverse results at the national level.

LC change studies provide information about the past and current situation and can be used to predict likely future trends, which is crucial for developing effective plans for natural resource management. The study described here aims to provide basic LC data for Bhutan at national and sub-national level, thus filling an important gap. The study used consistent and standard satellite datasets, methodology, and definitions of features. Bhutan has a unique position among developing countries in terms of forest cover and conservation area: forest, including scrub forest, covers approximately 75% of the total land area, and approximately 52% of the total land area has some form of conservation status, the greater part as a protected area (Noord, 2010). Thus this study focused on analysing LC change related to forest and protected areas. Due to the marked altitudinal variation in the country, LC was also analysed at different elevations. An LCCS-based LC scheme was developed in close consultation with national partners at a workshop and used in the study. The accuracy of the classified maps was assessed from reference ground points and high resolution Google Earth Pro images. A web-based tool was developed to facilitate dissemination and enable online data analysis.

2. Materials and methods

2.1. Description of study area

Bhutan is a landlocked country in the eastern Himalayas lying between 88°45′ and 92°10′ E and 26°40′ and 28°15′ N, with a total geographic area of 38,394 km^2 (Fig. 1). The elevation ranges from 200 masl in the south to more than 7000 masl in the north, and the climate varies with altitude. The whole country is divided into twenty districts (local government level- dzongkhags), which are further divided into 205 sub-districts (grass root level – gewogs). The population in 2005 was 634,982, giving an overall population density of 16 persons per km^2; 69% live in rural areas and 31% in urban areas (NSB, 2005). According to the Department of Forests and Parks Services, Ministry of Forest and Agriculture, 19,677 km^2 of land (51% of the total area) has protected status, 16,396 km^2 in nine protected areas and 3307 km^2 in twelve biological corridors (areas set aside to connect one or more protected areas and conserved and managed for the safe movement of wildlife). Bhutan

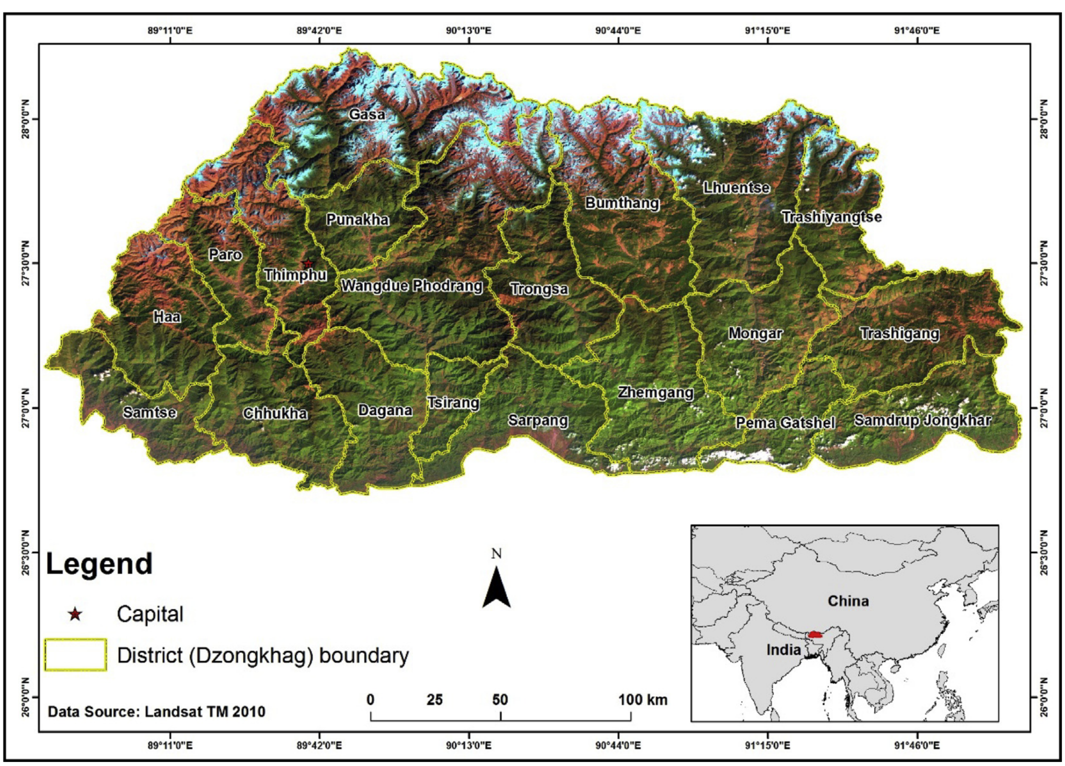

Fig. 1. Map of study area.