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Integration of WorldView-2 and airborne LiDAR data for tree species level carbon stock mapping in Kayar Khola watershed, Nepal

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ABSTRACT

Integration of WorldView-2 satellite image with small footprint airborne LiDAR data for estimation of tree carbon at species level has been investigated in tropical forests of Nepal. This research aims to quantify and map carbon stock for dominant tree species in Chitwan district of central Nepal. Object based image analysis and supervised nearest neighbor classification methods were deployed for tree canopy retrieval and species level classification respectively. Initially, six dominant tree species (*Shorea robusta, Schima wallichii, Lagerstroemia parviflora, Terminalia tomentosa, Mallotus philippinensis and Semecarpus anacardium*) were able to be identified and mapped through image classification. The result showed a 76% accuracy of segmentation and 1970.99 as best average separability. Tree canopy height model (CHM) was extracted based on LiDAR's first and last return from an entire study area. On average, a significant correlation coefficient (r) between canopy projection area (CPA) and carbon; height and carbon; and CPA and height were obtained as 0.73, 0.76 and 0.63, respectively for correctly detected trees. Carbon stock model validation results showed regression models being able to explain up to 94%, 78%, 76%, 84% and 78% of variations in carbon estimation for the following tree species: *S. robusta, L. parviflora, T. tomentosa, S. wallichii* and others (combination of rest tree species).

Introduction

A number of different methods are currently being used to measure aboveground biomass (AGB) and consequently, the stock of forests. Lu (2006) reviewed and summarized some of these approaches to estimate forest biomass based on field measurements, remote sensing (RS) and geographic information systems (GIS). RS approaches provide an alternative to traditional methods which give spatially explicit information and enable repeated monitoring, even in remote locations, in a cost-effective way (Patenaude et al., 2005). With its capacity to provide spatial, temporal and spectral information, RS can estimate sequestered carbon more accurately and thus meet the requirements of the Kyoto Protocol and the United Nations collaborative programme on reducing emissions from deforestation and forest degradation (REDD) (Gibbs et al., 2007; Joseph et al., 2013).

Optical remote sensing measurements have been widely used in studies that link AGB measurements from the field to satellite observations, based on sensitivity of the optical reflectance to variations in canopy structure. (Song and Dickinson, 2008). Medium spatial resolution data, such as Landsat TM, provides the potential for AGB estimation at a national and regional level, but the mixed

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pixels, cloudy weather and data saturation are found to be problems in complex biophysical environments (Lu, 2005). Although RADAR backscatter can penetrate through clouds, it poses a saturation problem in tropical forest environments where AGB levels generally exceed 200–250 Mg/ha (Ustin, 2004). Sometimes mountainous and hilly conditions further increase the errors (Thapa et al., 2014b; Toan et al., 2004). To overcome this problem, active optical RS sensors, e.g., airborne laser scanning or airborne LiDAR, offer promising mapping techniques to estimate forest biomass as no saturation is observed at high biomass levels (Patenaude et al., 2005; Huang et al., 2013). Lefsky et al. (2002) and Lim et al. (2003) both reviewed the potential of LiDAR devices for retrieving forest parameters. LiDAR data was used to estimate the biomass of the Douglas fir western hemlock (Means et al., 1999), temperate mixed deciduous forest biomass (Ahmed et al., 2013; Peduzzi et al., 2012), tropical forest biomass (Asner et al., 2012; Kronseder et al., 2012), tree height and stand volume (Yamamoto et al., 2010), stand height (Wulder and Seemann, 2003), tree crown diameter (Kwak et al., 2007; Popescu et al., 2003) and canopy structure (Lovell et al., 2003). Other researches tend to indicate that either the use of LiDAR data alone, or its use in combination with other sensor or ancillary data, provides an important data source for forest parameters estimation (Drake et al., 2003; Hyde et al., 2006). Holmgren et al. (2008) presented the benefits of integrating Quickbird multispectral imagery and high-density LiDAR data for individual tree-based classification, increasing the accuracy of observation from 88 to 96%. Similarly, Leckie et al. (2003) fused high-density LiDAR data and digital camera imagery for suitable tree crown isolation and tree height measurement; the results showed 80–90% correspondence with ground reference tree delineation. Crown diameter or crown projection area (CPA) can be obtained from very high resolution (VHR) satellite imagery, whereas tree height can be easily obtained from the canopy height model developed from LiDAR data. Several studies (Breidenbach et al., 2010; Gautam et al., 2010; Huang et al., 2009; Jochem et al., 2011; Katoh et al., 2009; Kim et al., 2010; Lindberg et al., 2008; Lu, 2006; Thapa et al., 2014a) also showed that the integration of VHR satellite images and airborne LiDAR data provide an accurate and efficient measurement of AGB in a variety of forest types and in extensively larger areas.

Nepal falls under the category of data-scarce countries, especially in terms of derived remotely sensed data products. This study was conducted in one of the REDD+ pilot project site where community forestry programme was introduced 30 years ago to reduce deforestation and forest degradation (ICIMOD, 2012). The objective of this paper is to develop an approach for a more accurate estimation of carbon stock for broadleaved tree species predominantly found in Nepal's tropical forests, testing the use of WorldView-2, airborne LiDAR and field data. In this paper, image segmentation technique was adopted for delineation of individual tree crowns from VHR WorldView-2 image. Similarly, LiDAR based canopy height model (CHM) was statistically evaluated through field-based tree height information.

Materials and methods

Study area

Kayar Khola watershed in the north-eastern part of Chitwan district, Nepal, covers an area of 800 ha and encompasses plains and small Siwalik Hills in its territory. Altitude in the watershed ranges from 235 to 1935 above mean sea level (amsl). The average maximum and minimum temperature of the district is 30 and 16 degrees Celsius, respectively. The average annual rainfall of the district is 1510 mm/year. Of the total area, 5821 ha is covered by forests, of which 2384 ha are community forests (CFs) managed by at least 16 community forests user groups (CFUGs). Out of sixteen organized CFUGs in the study area, only seven CFs from three different village clusters, covering an area of 871 ha, were selected for this research, representing diverse types of forest structures (Fig. 1). Site selection is based on area accessibility in terms of steepness, road distance from Kathmandu (the capital city), data availability, variation in terrain, and prior implementation of REDD+ pilot project.

Mixed forests exist within the watershed, with *Shorea robusta* (Sal) being the most dominant species, mostly found in the southern aspects and in lower altitudes of the northern aspects of the watershed. *Schima wallichii* (Chilaune), followed by a few other associated species, such as *Lagerstroemia parviflora* (Botdhairo), *Adina cordifolia* (Haldu), *Terminalia tomentosa* (Asna), *Syzizium cumini* (Jamun), *Ficus racemosa* (Dumri), *Terminalia bellirica* (Barro), *Rhus wallichii* (Kag Bhalayo), *Bombax ceiba* (Simal), *Garuga pinnata* (Dabdabe), and *Albizia* species thrive in the area.

Data and software used

The number of sample units were calculated using Eq. (1) developed by Husch et al. (2003). From 22 September to 20 October 2011, a total of 75 plots were measured in seven CFs of the watershed, although it was intended through formula to measure only 72 plots. On each 500 m^2 circular plot, the DBH, height, and species of existing trees were recorded. Ordinary global positioning system (GPS) receiver for location identification, TruPulse 360 B for tree height measurement and diameter tape for DBH measurement, were used in the field. DBH, height and crown diameter of each major dominant tree species was analysed and presented in box-whisker plot to identify outliners and to further process the data.

$$N_{\text{plots}} = t^2 \times \text{CV}^2 \left(\frac{1}{E}\right)^2 \tag{1}$$

where N_{plots} is the minimum number of sample plots, t^2 is the value of the student's distribution for N_{plots} at desired probability, CV^2 is coefficient of variation (%) of diameter at breast height (DBH) of trees to be sampled and E is the estimated allowable error or desired precision (%) for DBH of trees sampled. Twenty per cent (20%) is the common starting point for E (Husch et al., 2003).

The study used ortho-rectified WorldView-2 first commercial 8 bands VHR satellite imagery obtained on 25 October 2010. It has a VHR spectral coverage that includes two bands of blue (blue and coastal blue), followed by green, yellow, red, rededge and two bands of near infrared (NIR1 and NIR2). The imagery has 2 m multispectral and 0.5 m panchromatic spatial resolution. The NIR1 band has the potential to identify vegetation type at species level (Pu and Landry, 2012).

Airborne LiDAR data was acquired between 16 March and 2 April 2011 using Leica ALS-40 sensor positioned on a helicopter at 2000 m flying altitude, with average point density of 0.8 /m^2 at the ground level and sensor scan speed of 20.4 lines/s. LiDAR data was acquired at average horizontal and vertical accuracies of 0.45 m each.

Image processing was done in ERDAS Imagine, LiDAR in LAStools, Quick Terrain Modeller and ArcMap used for mapping and XLStat, SPSS and R studio for statistical analysis. Image segmentations were done in eCognition Developer. The methodological flow diagram for this research is shown in Fig. 2.

Pre-processing of remotely sensed data

For this study, ortho-rectified WorldView-2 multispectral images of 2 m resolution and panchromatic imagery of 0.5 m resolution were fused to get a pan-sharpened image of 0.5 m spatial resolution using hyperspherical color sharpening (HCS)