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'Surface area' based above ground woody forest biomass carbon estimation: A case study of Kolasib District, Mizoram, India

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Abstract: The present study aims at estimating above ground woody forest biomass carbon stock of Kolasib district, Mizoram based on both 'planimetric' as well as 'surface area'. Surface area is the actual available area for plants and animals of a region for their establishment and development. Geo-referenced orthorectified satellite image (Landsat ETM+) of the year 2001 was classified following hybrid method. The planimetric classified map was then integrated with slope map to get the surface area of each land use/cover. The planimetric area of Kolasib district is 1,382 km^2, whereas surface area was estimated as 1,490 km^2. The total above ground woody biomass carbon estimated as per planimetric and surface area were 2,404 and 2,587 thousand tonne, respectively with a net difference of 183 thousand tonne. This study, therefore, accentuates the surface area based estimation of biomass carbon in regional and global scale to understand the forestry options to mitigate climate change.

Key words: Bamboo, carbon stock, GIS, *Melocanna baccifera*, planimetric area, remote sensing, woody biomass.

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Introduction

The need for mapping forest biomass is ever-increasing since the Montreal and Kyoto protocols. Quantification of biomass is required as the primary inventory data to understand pool changes and productivity of tropical forests (Esser 1984). United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol recognized the role of forests in carbon sequestration, specifically Article 3.3 and 3.4 of the Kyoto Protocol pointed out forest as potential carbon storage (UNFCCC 1997). Tropical forests play a vital role in terms of overall carbon budget of the globe and account for roughly 20 percent of total terrestrial carbon stock (Dixon *et al.* 1994). More recent estimates show that tropical forests contain about 40 % of global terrestrial carbon that account for more than half of global gross primary productivity (Beer *et al.* 2010; Pan *et al.* 2011).The most challenging mission in the coming years for mankind, probably, is to manage the carbon budget of the globe. However, ground assessment of biomass carbon has been found insufficient to present spatial extent of the biomass (Roy & Ravan 1996). Baccini *et al.* (2008) and Mitchard *et al.* (2011) observed that huge uncertainty prevails about the amount and spatial variations in above ground biomass and carbon stocks. Precise estimation of forest biomass carbon is, therefore, of extreme importance as because accurate and authentic data/information is the prerequisite for scientific resource management.

Biomass related studies have become impor-

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tant for studying ecosystem productivity, carbon budgets, nutrient allocation, national development planning (Alban *et al.* 1978; Brown *et al.* 1999; Crow 1978; Pande *et al.* 2010; Ryu *et al.* 2004; Saatchi *et al.* 2011; Zheng *et al.* 2004) and due to the growing awareness of carbon credit system world over (Kale *et al.* 2004). Biomass along with vegetation type is considered important components affecting biosphere-atmosphere interactions. The measurements of biomass per unit area and productivity have been set as one of the goals for International Geosphere-Biosphere Programme (IGBP). The aboveground biomass and age maps can be used as baseline information for future landscape level studies such as quantifying the regional carbon budget, accumulating fuel, or monitoring management practices (Zheng & Yan 2002). In Indian context, biomass carbon studies have been published by Rai (1984), Tiwari (1992), Ravindranath *et al.* (1997), Haripriya (2000), Lal & Singh (2000), Roy & Ravan (2001), Chhabra *et al.* (2002), Manhas *et al.* (2006) and others. Rai (1984) has estimated component-wise biomass using destructive sampling methods in tropical rainforests of the western ghats. Roy *et al.* (1986) assessed the work on biomass estimation using remote sensing techniques and suggested multistage approach using wide swath and narrow swath satellites like National Oceanic and Atmospheric Administration (NOAA) and Indian Remote sensing Satellite (IRS) 1A or 1B respectively for national biomass mapping. With the advent of state of the art satellite technology, Landsat ETM+, NOAA AVHRR, SPOT, MODIS and ASTER satellite data have been proved to be extremely potent tool for assessing terrestrial biomass and carbon pools. Ravindranath *et al.* (1997) estimated a marginal net sequestration of 5 Tg C for Indian forests based on the year 1986. Haripriya (2000) used Forest Survey of India (FSI) data on growing stock (FSI 1995) and inventory data of various FSI inventory reports and estimated the above-ground woody biomass in Indian forests as 2782.88 million tons. Chhabra *et al.* (2002) used FSI data of 1995 and estimated the forest biomass carbon pool of India that ranged between 3871.2 to 3874.3 Tg C. Along with national level biomass esti-mation, many regional and patch level biomass carbon estimation studies were also carried out. Roy & Ravan (2001) estimated patch level biomass of 394.7 thousand tonne for different vegetation types in Madhav National Park, Shivpuri district, Madhya Pradesh by extrapolating values from plot to stratum, using satellite remote sensing technology. Pande *et al.* (2010) emphasized the importance of biomass assessment for national development planning as well as for scientific studies of ecosystem productivity, carbon budgets etc. Devagiri *et al.* (2013) assessed aboveground bio-mass and carbon pool in different vegetation types of south western part of Karnataka using spectral modeling. The total aboveground biomass carbon in three districts of Kodagu, Hassan and Mysore were estimated to be 3 Mt C. Joshi & Ghose (2014) found comparatively low aboveground biomass ranging from 8.9 to 50.9 t ha^{-1}, highly affected by tidal inundation, in the Sundarbans mangrove swamps depending on the structural characteristics of different communities. Forest Carbon stocks of Odisha state was estimated as 444.05 Mt, of which 159.76 Mt was estimated as biomass and 284.29 Mt as soil organic carbon (Sahu *et al.* 2015). Upadhaya *et al.* (2015) estimated the above and below ground biomass under two forest management regimes in Meghalaya, India and recorded higher total tree biomass in wildlife sanctuary (382 Mg ha^{-1}) than the reserved forest (250 - 332 Mg ha^{-1}).

There are many sources of errors that can affect the estimation of forest biomass. Broadly, these errors may be categorized as sampling error (errors in sampling scheme, sample size, estimation procedure and inherent variability of the variable of interest), measurement error (instrument error, recording error, and error due to the nature of the object being measured), statistical or model error (error in model that describes the relation of biomass and tree variables) (Jenkins *et al.* 2003). Another source of error which is seldom addressed, results from the irregular and undulating nature of the earth surface. Landscape area is usually presented in terms of planimetric area but a square kilometer in mountainous area does not represent the same extent of land area as a square kilometer in the plane (Jenness 2000). Thematic map of a hilly terrain hardly incorporates the details of an undulating terrain. Estimation of the resources which is based on these 'planimetric' maps, therefore, bound to carry the inaccuracy and errors that the original planimetric map carries. Remote sensing based mapping and biomass studies often involve sampling of study area and then spatial extrapolation of the information. Errors generated due to terrain irregularity, therefore, get accumulated in a remote sensing based study. Introducing 'surface area' based study would definitely increase the overall accuracy of the land use/cover

Fig. 1. Location of Kolasib district in Mizoram.

study as well as biomass carbon estimation. Hobson (1972) described some early computational methods for estimating surface area and discussed the concept of surface-area ratios. Beasom (1983) described a method for estimating land surface ruggedness based on the intersections of sample points and contour lines on a contour map. Jenness (2000) described a similar method based on measuring the density of contour lines in an area.

The present study aims at developing a raster based methods and estimating aboveground woody biomass (AGWB) carbon stock of Kolasib district, Mizoram based on both 'planimetric' and 'surface area'. Variation in estimation of area, numbers of trees/bamboos, aboveground woody biomass and carbon stock due to change of approach from planimetric to surface area are some of the issues addressed in this article.

Materials and methods

Study area

Kolasib district (92° 30' 31" to 92° 54' 00" E and 23° 57' 34" to 24° 22' 21" N with a total area of 1,382 km^2) of Mizoram, India was selected for the present study (Fig. 1). The altitude ranges from 55 to 1,200 m. The average annual rainfall varies from 3,000 mm to 3,500 mm and temperature of the study area ranges from 5 °C in winter and as high as 35 °C in summer. The forest types prevailing includes- Assam valley tropical wet evergreen forest- Dipterocarpus (1B/C1), Cachar tropical evergreen forest (1B/C3), Cachar tropical semi-evergreen forest (2B/(2s2/C2), Moist bamboo Brakes (2B/E3) and Secondary moist bamboo brakes (2B/E3) (Champion & Seth 1968).

Methods

Ortho-rectified Landsat ETM+ image for the year 2001 was downloaded from the Global Land Cover Facility image library (http://glcf.umiacs.umd.edu). Other data includes Survey of India (SOI) topographic sheets (1:50,000 scale), IRS ID panchromatic image, forest cover map and vegetation thematic map (prepared by Forest Survey of India, Dehradun in 1981-83). The software used includes ArcGIS package, ERDAS Imagine and Microsoft office 2007.

SOI toposheets were first georeferenced and re-projected to Universal Transverse Mercator (UTM) projection (Datum: WGS 84; Zone: 46); features like contours, roads, rivers, streams and settlements were digitized and updated using IRS ID PAN image. A digital elevation model (DEM) was generated from contours (20 m interval), drainage and spot height information from SOI toposheets. Reconnaissance survey was undertaken for broad understanding of the study site

Table 1. Description of land use/ cover classes along with their visual interpretation keys.

Land use/cover classes	Classification criteria			Visual Interpretation key for land use/cover classification			
	Description	Presence of bamboo (in percentage area)	Crown density (%)	Tone	Texture	Pattern	Association
Dense miscellaneous forest	Forest dominated mainly by trees of different species	0 - 20	> 40	Bright and dark red	Fine, medium and coarse	Irregular	Mostly on steeper slopes, generally between 16 - 30^{o} and comparatively inaccessible areas
Open miscellaneous forest	Forest dominated mainly by trees of different species	0 - 20	10 - 40	Medium red	Medium and coarse	Irregular	Steeper slopes but comparatively accessible areas
Dense mixed bamboo forest	Forest dominated by both Tree as well as bamboos	20 - 80	> 40	Medium to light red with maroon tinge	Medium, Coarse	Irregular	No definite association
Open mixed bamboo forest	Forest dominated by both Tree as well as bamboos	20 - 80	10 - 40	Medium to light red	Medium, coarse	Irregular	No definite association
Dense pure bamboo forest	Forest dominated mainly by bamboos	> 80	> 40	Pinkish to light red	fine/smooth texture	Irregular	Open areas, near shifting cultivation
Open pure bamboo forest	Forest dominated mainly by bamboos	> 80	10 - 40	Pinkish red	fine/smooth texture	Irregular	Open areas, near shifting cultivation
Scrub	Inferior tree growth chiefly of small or stunted trees, dominated mainly by grasses, reeds, bushes etc with scattered trees here and there		< 10	Bluish green with light reddish tinge	Medium	Irregular	
Abandoned jhum	Jhum (Shifting cultivation) was practiced earlier but kept fellow presently which results in woody secondary growth, grasses or bamboo growth.			Dull red with blue tinge	Medium Coarse	Regular	Gentle to steep slope
Current jhum	Jhum (Shifting cultivation) is practiced presently.			Light blue green	Medium	Regular	Gentle to steep slope

Contd...

Table 1. Continued.

Land use/ cover classes	Classification criteria			Visual Interpretation key for land use/cover classification			
	Description	Presence of bamboo (in percentage area)	Crown density (%)	Tone	Texture	Pattern	Association
Open/barren land	Open/barren land includes exposed rocks with no or scanty vegetation growth, often small grasses, mosses etc.			Cyan, Greenish cyan	Fine and medium	Irregular	Open areas, very steep slope, river bed
Settlement	All kind of Human habitation. This includes village, city sites, industrial area, grave yards, grounds, houses, colonies etc.			Cyan, greenish cyan	Medium	Regular	Shape and feature association
Water	This class includes lakes, reservoir, river, pools etc.			Light blue, dark Blue, black	Smooth	Regular	Shape and feature association

and to get acquainted with the general patterns of vegetation, forest types and topography of the area. The major vegetation types, their floristic composition, physiognomy, physiographic distribution in the field and variation, tonal patterns and texture were observed on the satellite image which would be helpful for classification. Land use/cover classes identified both on field and satellite image are shown in Table 1. Here it is to be noted that, the main criteria for classification of forests (Sl. No. 1 to 6) are on field ocular estimation of 'presence of bamboo in percentage area'. This is because bamboo is one of the most dominant plants in Mizoram and play significant role in overall ecology, economy and socio-cultural scenario of the state. The outline of methodology for generation of land use/cover map is given in Fig. 2.

Image classification

The image downloaded was already geometrically rectified; contrast enhancement (lookup table stretch) of the image was performed as radiometric enhancement. A hybrid approach that combines the advantages of both automated and manual methods was followed to produce the land use/cover map. First, a 'preliminary classified map' was generated by unsupervised classification following iterative self organizing data analysis technique (ISODATA). Initially, supervised classification technique was applied but that did not yield the desired result. Supervised classification is more appropriate when relatively few classes are to be identified or when homogeneous regions that represent each class can be easily identified (ERDAS Inc. 2005). In the present study, supervised classification of 'mixed bamboo forest', which is highly heterogeneous in nature and covers about 23.6 % of the study area, showed excessive mixing of signatures from other surrounding classes and as a result accuracy of overall classification decreased to a great extent. Unsupervised classification, on the other hand, showed less intermixing of signatures and resulted preliminary land use/cover map with better accuracy than supervised classification. This is why despite of collecting good numbers of ground truth information, unsupervised classification algorithm was preferred over supervised classification algorithm for the present study. The 'preliminary classified map' generated by unsupervised classification was then refined using onscreen visual interpretation. The accuracy of 'refined' map was further improved or streamlined by incorporating ancillary data following a 'post

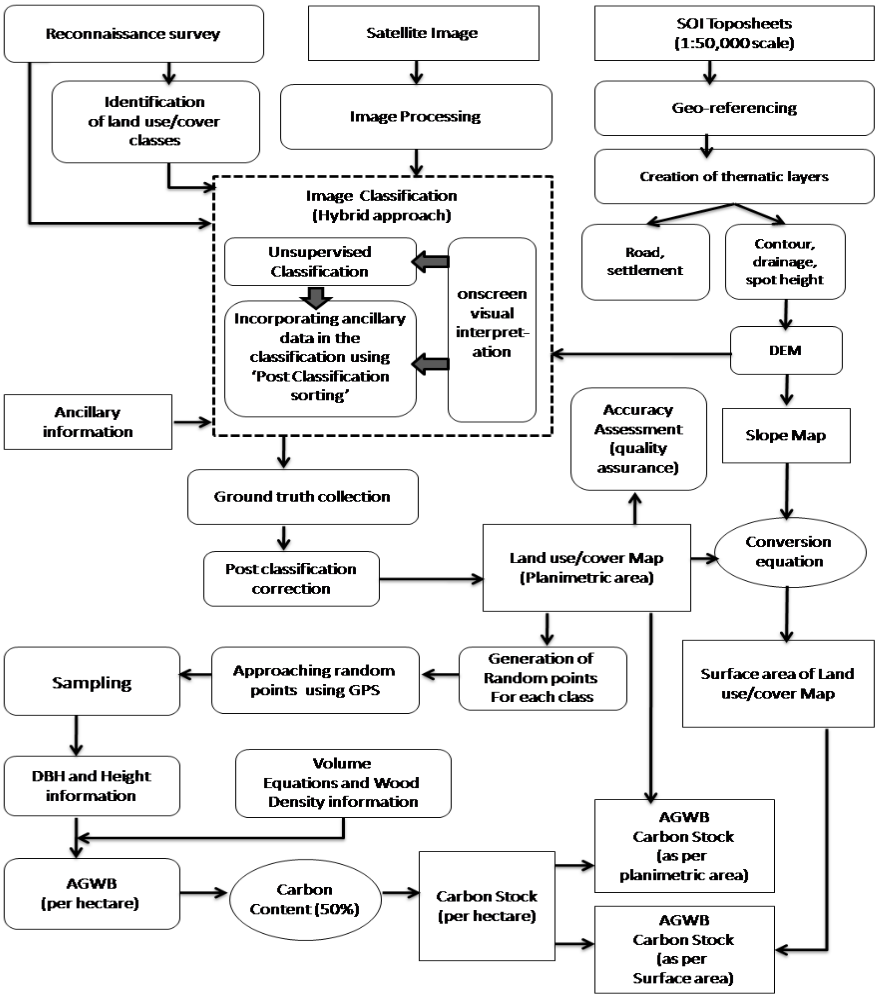

Fig. 2. Methodology for generation of land use/cover map and estimation of AGWB carbon.

classification sorting' method (Jensen 1996). The collected ground truth information was utilized in generation of visually interpreted land use/cover map and in accuracy assessment, the details of which are given subsequently.

On screen visual interpretation

Based on the ground truth information that was correlated with the standard false colour composite of satellite image (Landsat ETM+ band 4, 3 and 2) an interpretation key for land use/cover classification was developed. The minimum mappable unit for the interpretation criteria was one hectare. The interpretation key used for the present study is shown in Table 1.

Post classification sorting

Ancillary data were incorporated following 'post classification sorting' method (Hutchinson 1982) where the application of very specific rules to initial remote sensing classification results and spatially distributed ancillary information are used (Jensen 1996). Slope and altitude maps were created from the DEM. Specific rules of *'if-then'* were developed based on prior knowledge of the study area gathered during survey, field sampling and from other secondary data/information. The rules were applied to the slope map, altitude map and initial remote sensing classification to improve the classification accuracy (Table 2). For example, in Mizoram shifting cultivation is generally practiced in gentle to steep slope and bamboos are generally found in comparatively lower elevation. Therefore, wherever shifting cultivation was found in a plane/ very steep slope or bamboo area in higher elevation, the area was demarcated for more ground truth investigations. Other ancillary

Table 2. Details of the 'if-then' rules used.

If							
Initial land use/cover map (2001) =	Slope (°) =	Altitude (m) =	Vegetation thematic map (1981-83) =	Topographic map (1976) =	Forest Cover map (2001) =	Then	Action taken
Shifting cultivation	0° > 60°	≤ 200 > 600	Miscellaneous forest	Forest	Dense Forest	Chances of 'shifting cultivation' = very low	If substantial area (> 1 ha), more ground truth points were taken, else ignored or merged to the nearest / surrounding class
Pure bamboo	> 60°	> 600	Miscellaneous forest	Forest	Dense Forest	Chances of 'Pure bamboo' = very low	
Dense forest	0° > 60°	≤ 200	Bamboo	Bamboo	Open or non forest	Chances of 'Dense forest' = very low	
Abandoned jhum/ Pure bamboo	1 - 15° 16 - 30° 31 - 45° 46 - 60°	201 - 400 401 - 600	Bamboo/ Miscellaneous forest	Bamboo/ Forest	Open forest	Chances of 'Abandoned jhum'/ 'Pure bamboo' = high	

information including forest cover map from FSI, information from field survey, topographic maps, vegetation thematic maps were also incorporated.

Accuracy assessment

The accuracy of the classification was assessed using ground information of sample points and satellite images of higher spatial resolution (ETM+ Panchromatic band with a spatial resolution of 15 m, IRS 1D panchromatic image with spatial resolution of 5.8 m and Google earth). A total of 240 ground truth points (157 on grounds + 83 on high resolution images) were located on land use/ cover classes proportionate to their area. A total of 80 ground truth points were collected from miscellaneous forests, followed by mixed bamboo forests (55 points), pure bamboo forests (40 points), jhum land including abandoned and current jhum (28 points), and others including scrub, open-barren land, water and settlement (37 points). The K_{hat} statistic (an estimate of KAPPPA) was computed using the following formula (Congalton *et al.* 1983):

$$K_{hat} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

where, r is the number of rows in the matrix, x_{ii} is the number of observations in the row i and column i , and x_{i+} x_{+i} are the marginal totals for row i and column i respectively. N is the total number of observations. Post classification correction of land use/cover map was done based on the ground truth information collected from field and high resolution images.

Calculation of surface area

A raster based method (Das 2012) of calculating surface-area grids was followed in the present study. The equation used in the conversion of 'Planimetric area' of each pixel to 'Surface area' is—

Surface Area = Planimetric Area/cosine (Slope Angle)

where,

- 'Surface Area' is the area of the tilted plane (hypotenuse) on the terrain surface corresponding to a rectangle on the planimetric reference grid.
- 'Planimetric Area' is the area of the rectangle on the planimetric reference grid (base = Land use/ cover map).
- 'Slope Angle' (θ) is the inclination of the tilted plane with respect to the horizontal reference grid (slope map derived from DEM) (Fig. 3).

Biomass carbon estimation

A probability proportionate stratified random sampling was adopted and the optimal sample plots for each class was calculated at the rate of 0.01 % sampling intensity for the present study. A total of 145 sample plots with a size of 0.1 ha were randomly selected on various classes. The sampling intensity achieved was 0.0125 % of the total geographical area and the results of the survey

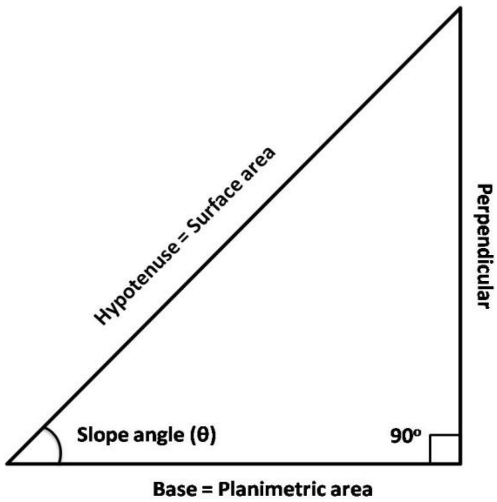

Fig. 3. Relation among surface area, planimetric area and slope angle.

would be at the precision level of ± 10 % at 95 % probability level. Diameter and height information of each tree belonging to each sample plot was recorded as an input to volume equation for that tree. Volume of trees (m^3) was calculated from the volume equations generated by Forest Survey of India (FSI) and Forest Research Institute (FRI), Dehradun. A general volume equation (miscellaneous) generated by FSI was used for species for which equations are not available (FSI 1996).

Carbon stock was calculated using the following equation:

$$\text{Carbon stock} = V \times WD \times CC$$

where, V is the standing volume (stem wood) (m^3), WD is the wood density (kg m^{-3}) i.e. specific gravity and carbon content (CC) was calculated assuming that about 50 % of the dry weight of plant biomass is carbon (FAO 2003).

AGWB (tonne) of each tree was calculated multiplying tree volume (m^3) and wood Density (t m^{-3}). The estimated volume or growing stock was converted into biomass by using specific gravity (FAO 1997; Limaye & Sen 1956; Rajput *et al*. 1996). The same was repeated for all trees in the whole sample plot. Regression equation (DBH vs. dry weight) generated by Das (2012) was used for biomass estimation of bamboo including Muli bamboo (*Melocanna baccifera*), Rawnal (*Dendrocalamus longispathus)* and Phulrua *(Dendrocalamus hamiltonii)*. AGWB per unit area was calculated by dividing the total AGWB of all sample plots with total area of all sample plots. AGWB per unit area information then multiplied with planimetric and surface area of each land use/cover class to get the AGWB of that land use/cover class as per planimetric and surface area approach respectively. The simplified flow of methodology is given in Fig. 2.

Results

Altitude and slope wise surface area distribution

The planimetric area (PA) of Kolasib district, Mizoram is 1,382 km^2 whereas surface area (SA) was estimated to be 1,490 km^2, the difference is as much as 108 km^2. Kolasib district was divided in to four altitude classes: ≤ 200 m, 201 - 400 m, 401 - 600 m and > 600 m. The maximum difference was found to be about 42 km^2 in altitude class 201 - 400 meter (Fig. 4). This is because, altitude class '≤ 200 m' though covers the highest area, possess gentler slope in comparison to '201 - 400 m' class. Whereas, altitude class '401 - 600 m' and '> 600 m' possess steeper slope but covers lesser area then altitude class '201 - 400 m'. The study area was divided into six slope classes, namely, 0^o (or flat), 1 - 15^o, 16 - 30 ^{o}, 31 - 45^o, 46 - 60^o and more than 60^o. In 31 - 45° slope category, difference between sur-face and planimetric area is 29 km^2, which is the highest among all slope classes (Fig. 4). The difference between surface and planimetric area is less in slope class 0^o, 1 - 15^o and 16 - 30^o which possess higher total area but gentler slope than 31 - 45°. The case is just opposite for slope class 46 - 60^o and > 60^o. Surface area of land use/ cover class is a function of both slope angle of each pixel and total area of all pixels; slope class 31 - 45° scores high in both the cases, hence possess greater differences between planimetric and surface area.

Surface area of each land use/ cover classes

Kolasib district was classified in to twelve land use/cover classes. The overall classification accuracy was estimated to be 87.1 % whereas K_{hat} statistic of 85.8 % was achieved which imply that the classification process was avoiding 85.8 % errors of a completely random classification.

Dense miscellaneous forest dominates with a planimetric area of 437 km^2 and occupies 31.6 % of the total geographical area. Surface area, on the other hand, for the same class was estimated to be 469 km^2 with a difference of about 32 km^2. The details of planimetric area of other land use/cover classes and their corresponding surface area are shown in Fig. 5.

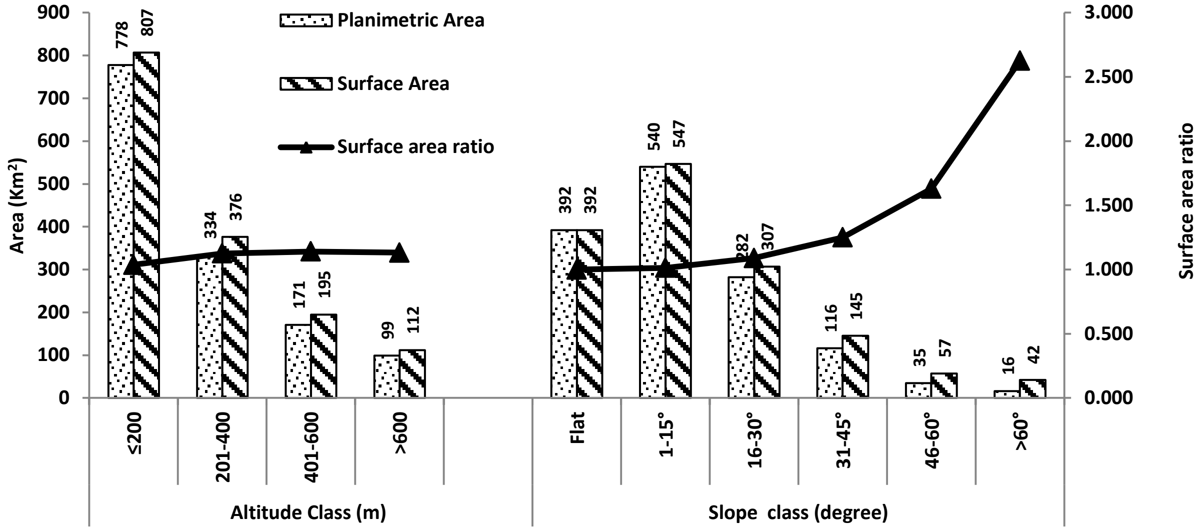

Fig. 4. Planimetric and surface area distribution in each altitude and slope classes.

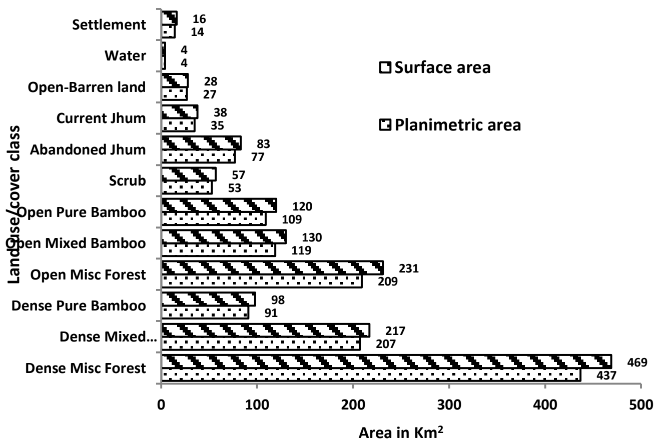

Fig. 5. Planimetric and surface area distribution for each land use/ cover types.

Number of trees and bamboos

Number of trees, Muli and other bamboos per unit area for each land use /cover is shown in Table 3. As far as number of trees per unit area is concerned, Dense miscellaneous forest dominates with 231 ± 35.7 trees ha^{-1} followed by other categories. For Muli bamboo (*Melocanna baccifera*), dense pure bamboo class dominates with 18,000 ± 1101.6 bamboos ha^{-1}, whereas for other bamboos (*Dendrocalamus longispathus, D. hamiltonii* and *D. strictus*) it is the dense mixed bamboo type of forests which dominates with 158 ± 20.2 bamboos ha^{-1}. The total number of trees as well as bamboos estimated for each land use/ cover as per planimetric and surface area shows substantial difference between the two estimations (Table 3). The difference in number of trees as per estimation of planimetric and surface area is 1,392 thousand whereas Muli bamboo is found to be 41,857 thousand higher in case of surface area based estimation.

Aboveground woody biomass carbon stock

Dense miscellaneous forest possess the highest tree AGWB carbon per unit area (17.81 ± 2.75 t ha^{-1}) followed by Dense mixed bamboo (13.0 ± 1.67 t ha^{-1}) and Open miscellaneous forest (10.32 ± 2.01 t ha^{-1}). Abandoned Jhum (0.93 ± 0.22 t ha^{-1}) and Scrub (0.66 ± 0.30 t ha^{-1}) possess the lowest tree AGWB carbon per unit area. Dense pure bamboo (28.60 ± 1.75 t ha^{-1}) and Scrub land (0.05 ± 0.02 t ha^{-1}), on the other hand, possess the highest and lowest AGWB carbon per unit area for Muli Bamboo respectively (Table 4).

The highest total AGWB carbon stock (tree + Muli bamboo + other bamboo) per unit area in Kolasib district was found in Dense pure bamboo (32.42 ± 1.98 t ha^{-1}) followed by Dense mixed bamboo forest (27.08 ± 3.49 t ha^{-1}), Dense miscellaneous forest (18.88 ± 2.92 t ha^{-1}), Open pure bamboo (18.08 ± 2.36 t ha^{-1}), Open mixed bamboo (14.35 ± 2.81 t ha^{-1}), Open miscellaneous forest (12.52 ± 2.44 t ha^{-1}), Abandoned Jhum (11.90 ± 2.84 t ha^{-1}) and Scrub (0.74 ± 0.33 t ha^{-1}). Rests of the classes are devoid of AGWB carbon stock. All

Table 3. Total number of trees and bamboos.

Land use/ cover classes	Tree				Muli bamboo				Other bamboo			
	Number of trees ha^{-1} (mean ± SD)	Total Number (in '000)			Number of Muli bamboo ha^{-1} (mean ± SD)	Total Number (in '000)			Number of other bamboo ha^{-1} (mean ± SD)	Total Number (in '000)		
		As per PA	As per SA	Diffe-rence		As per PA	As per SA	Diffe-rence		As per PA	As per SA	Diffe-rence
Dense miscellaneous forest	231±35.7 (N = 35)	10,106	10,850	744	580±89.7 (N = 35)	25,329	27,194	1,865	32±4.9 (N = 35)	1,397	1,500	103
Dense mixed bamboo	153±19.5 (N = 23)	3,171	3,323	152	7000±893.9 (N = 23)	144994	151940	6,945	158±20.2 (N = 23)	3,273	3,429	157
Dense pure bamboo	54±3.3 (N = 13)	490	530	40	18000±1101.6 (N = 13)	163179	176592	13,413	146±8.9 (N = 13)	1,324	1,432	109
Open miscellaneous forest	131±25.6 (N = 25)	2,737	3,019	282	800±156.1 (N = 25)	16,752	18,481	1,729	48±9.4 (N = 25)	1,005	1,109	104
Open mixed bamboo	103±20.2 (N = 16)	1,228	1,336	109	3250±636.6 (N = 16)	38,696	42,117	3,422	97±19.0 (N = 16)	1,155	1,257	102
Open pure bamboo	41±5.3 (N = 15)	448	494	47	9560±1246.3 (N = 15)	104104	114957	10,853	79±10.3 (N = 15)	860	950	90
Scrub	14±6.3 (N = 7)	76	81	5	30±13.5 (N = 7)	160	170	10	9±4.0 (N = 7)	48	51	3
Abandoned jhum	20±4.8 (N = 11)	153	166	13	5433±1295.5 (N = 11)	41,645	45,267	3,621	67±16.0 (N = 11)	514	558	45
Total	93.5±15.1 (N = 145)	18,409	19,799	1,392	5581.7±679.1 (N = 145)	534,859	576,718	41,858	79.5±11.6 (N = 145)	9,576	10,288	712

Table 4. Total AGWB carbon for trees and bamboos.

Land use/ cover classes	Tree			Muli bamboo			Other bamboo			Total			
	Mean AGWB carbon ($t\ ha^{-1}$) (mean+SD)	AGWB Carbon (in '000 tonne)		Mean AGWB carbon ($t\ ha^{-1}$) (mean+SD)	AGWB Carbon (in '000 tonne)		Mean AGWB carbon ($t\ ha^{-1}$) (mean+SD)	AGWB Carbon (in '000 tonne)		Mean AGWB carbon ($t\ ha^{-1}$) (mean+SD)	Total AGWB carbon (in '000 tonne)		
		As per PA	As per SA		As per PA	As per SA		As per PA	As per SA		As per PA	As per SA	Diffe-rence
Dense miscellaneous forest	17.81±2.75	777.79	834.96	1.07±0.17	46.52	49.93	0.01±0.002	0.48	0.52	18.88±2.92 (N = 35)	824.78	885.41	60.63
Dense mixed bamboo	13.00±1.67	269.22	282.12	13.70±1.76	283.77	297.37	0.39±0.05	8.03	8.41	27.08±3.49 (N = 23)	561.02	587.90	26.88
Dense pure bamboo	3.30±0.20	29.94	32.39	28.60±1.75	259.29	280.58	0.52±0.03	4.72	5.11	32.42±1.98 (N = 13)	293.95	318.09	24.14
Open miscellaneous forest	10.32±2.01	216.19	238.47	2.00±0.39	41.89	46.20	0.20±0.04	4.14	4.56	12.52±2.44 (N = 25)	262.21	289.23	27.02
Open mixed bamboo	8.35±1.64	99.40	108.20	5.75±1.13	68.45	74.52	0.25±0.05	2.95	3.21	14.35±2.81 (N = 16)	170.80	185.93	15.13
Open pure bamboo	1.91±0.25	20.84	23.01	15.90±2.07	173.16	191.19	0.27±0.04	2.92	3.23	18.08±2.36 (N = 15)	196.93	217.43	20.50
Scrub	0.66±0.30	3.53	3.75	0.05±0.02	0.27	0.28	0.03±0.01	0.15	0.16	0.74±0.33 (N = 7)	3.95	4.19	0.24
Abandoned jhum	0.93±0.22	7.12	7.74	10.70±2.55	82.00	89.14	0.27±0.06	2.08	2.26	11.90±2.84 (N = 11)	91.20	99.14	7.94
Total	7.05±1.13	1424.0	1530.6	9.72±1.23	955.3	1029.2	0.24±0.04	25.5	27.5	17.02±2.40 (N = 145)	2404.8	2587.3	182.49

the classes were regrouped into five classes and a thematic map showing 'AGWB carbon stock per unit area' was generated (Fig. 6). The difference between AGWB carbon stock estimation based on planimetric and surface area, was 183 thousand tonne (Table 4).

F-test in one-way analysis of variance was used to assess whether the mean biomass from different land use/cover classes varies significantly or not (Table 5). It was found that deviations among sample means are highly significant. Therefore, we conclude that all samples are from different population (or stratum) and the mean AGWB of all the land use/ land cover classes vary significantly.

Discussion

Land is the most important of all resources as it practically supports and controls the quality and quantity of all other resources including forests, agriculture, water etc. Precise estimation of area of land use/cover is of immense significance from ecological, economic and administrative view point. Land use/cover study in a hilly terrain, therefore, should always be based on surface area rather than planimetric area. This is simply because of the fact that unlike simple 'planimetric area', 'surface area' gives a better idea of the topographical variation and roughness of the terrain. Surface area provides a better estimate of the land area available to the flora and fauna. A surface area based biomass study would definitely give a better and comparatively 'near real' estimation of biomass.

There would not be much difference between planimetric and surface area of a given 'plane' landscape. But, in a hilly terrain, the difference is tremendous and should not be ignored. Surface area of a pixel of 30 m × 30 m, which has a fixed planimetric area of 900 m^2, in different slope classes is shown in Fig. 7. The area difference between surface and planimetric area is nil in 0^o slope and as good as 9426.3 m^2 in 85^o slope. This is because of the fact that with increasing slope angle (θ) slope length (or hypotenuse) also increases and results subsequent increase in surface area. Practically, getting 90^o slope in nature is rare. Nevertheless, if 90^o slope even found, it hardly possesses any vegetation cover, so is in the case of 85^o or nearby slope classes. However, 45^o slope which is very common in any hilly region shows a difference of about 372.8 m^2, which if aggregated for the whole study area would give a thumping difference between planimetric and surface area. These classes of slope (45^o or close to it) often possess dense vegetation cover (as in the case of present study) and therefore play a very important role in the overall quantification of forest resources including biomass carbon.

As far as our present study area is concerned, the differences in planimetric and surface area in each slope classes for each land use/ cover is shown in Fig. 8. Clearly, slope category 31 - 45° is showing the maximum difference in almost all land use/ cover classes. This can be explained by the concept called 'Surface-area ratio'. The surface-area ratio of any particular region on the landscape can be calculated by dividing the surface area of that region by the planimetric area. The surface/ planimetric area ratio grids are useful as a measure of topographic roughness or ruggedness over an area (Jenness 2000). Slope class 31 - 45^o covers an area of 145 km^2 (10 % of the geographical area) and have a surface area ratio of 1.247. Slope classes below 31 - 45° category (flat, 1 - 5°, 6 - 15°, 16 - 30°) possess greater area but lower surface-area ratio, where as slope classes higher than 31 - 45° category (46 - 60° and > 60°) possess higher surface-area ratio but lesser area (Fig. 4).

The difference between planimetric and surface area in Kolasib district is 108 km^2, any estimate of number of plants, biomass and carbon stock would show huge difference due to this difference in area which are evident from the present study. Among all the land use/cover classes, the highest difference between surface and planimetric area is found in 'Dense miscellaneous forest' which occupies 32 km^2. That means, Dense miscellaneous forest which is probably the most important class in view of the biodiversity and carbon budget of the study site would always remain under estimated or inadequately estimated if 'surface area' based approach is not adopted. The same is true for other land use/ cover classes as well.

AGWB per unit area of Kolasib forests (34.0 t ha^{-1}) is here compared with data from other regions of Asia. Clearly Kolasib forest is poorer as far as aboveground woody biomass is concerned. As per Global Forest Resources Assessment 2010-main report (FAO 2010) average per unit area growing stock of South and Southeast Asian countries are 98.6 m^3 ha^{-1}. The growing stock (m^3 ha^{-1}) data were converted to aboveground biomass per unit area by multiplying with biomass conversion and expansion factor (BCEF) given in the same report. The BCEF is calculated as the

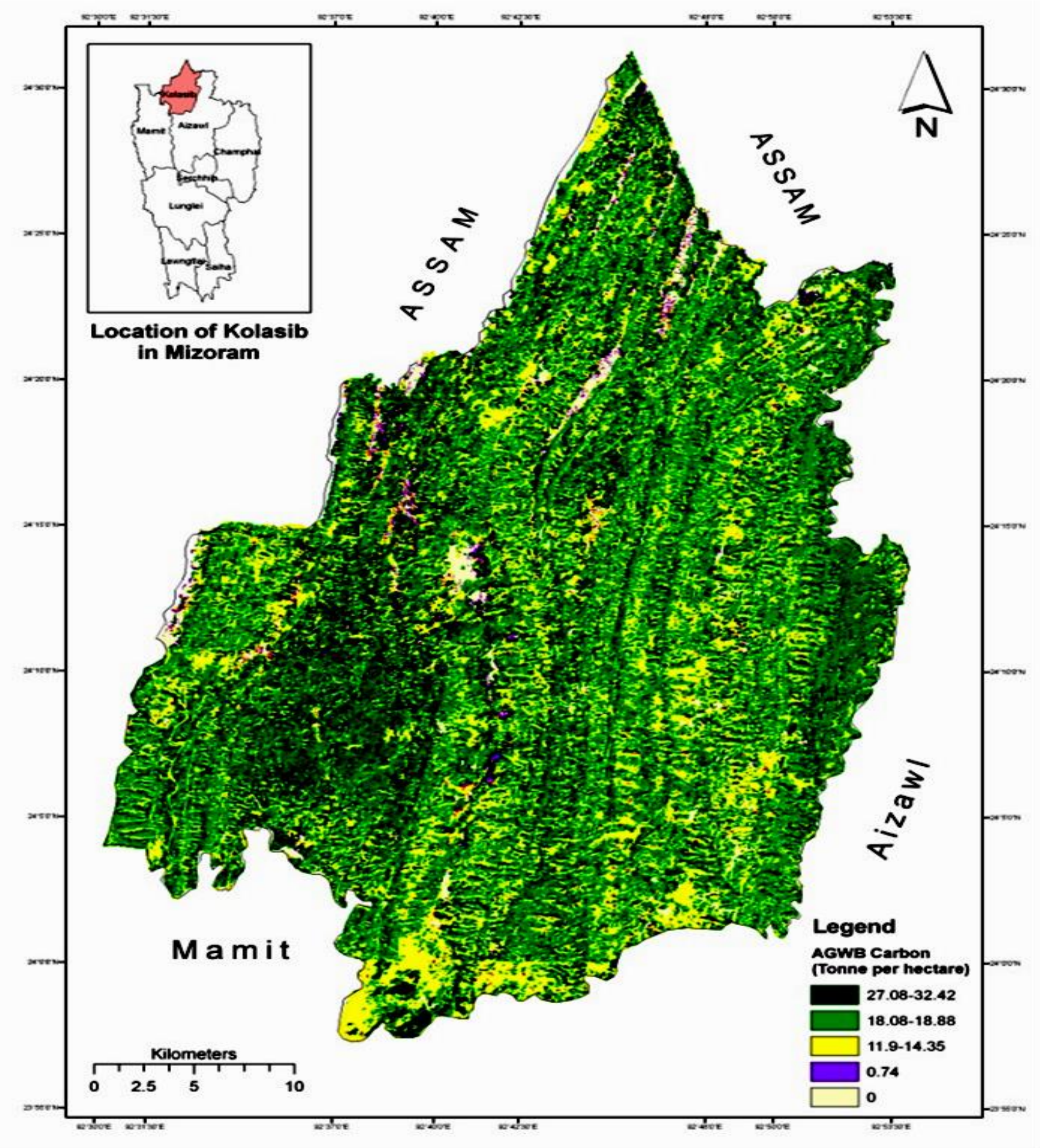

Fig. 6. AGWB Carbon stock per unit area in Kolasib district.

Table 5. Variance table.

Source of Variation	Sum of squares (SOS)	Degree of freedom (d.f.)	Mean square (M.S.)	F	F crit
Between LULC Classes	32651.8	7	4664.5	F = 155.9	0.05 *P* = 2.08
Residuals	4100.2	137	29.9		0.01 *P* = 2.77
Total	36752.0	144			

aboveground biomass in tonnes divided by growing stock in m^3 (FAO 2010). The aboveground biomass per unit area for South and Southeast Asian countries thus calculated out to be 141 t ha^{-1}. In the absence of the actual data on above ground woody biomass, if 96% of the total above ground biomass is considered as wood (Chidumayo 1990), AGWB per unit area of South and Southeast Asian forests comes as 135.9 t ha^{-1} which is far higher than Kolasib forest. The AGWB per unit area for East Asia and Western- Central Asia are estimated at 53.3 t ha^{-1} and 60.2 t ha^{-1}, respectively. AGWB per unit area for Asia as a whole and world are 94.3 t ha^{-1} and 106.6 t ha^{-1} respectively, much higher than Kolasib forest. Only northern African forests were found somewhat closer to Kolasib forest with AGWB per unit area of 35.4 t ha-1.

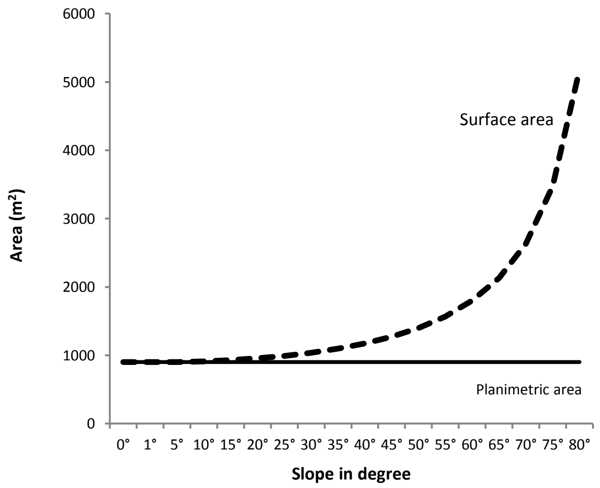

Fig. 7. Surface area of a pixel of 30 m x 30 m (planimetric area = 900 m^2) in different slope classes.

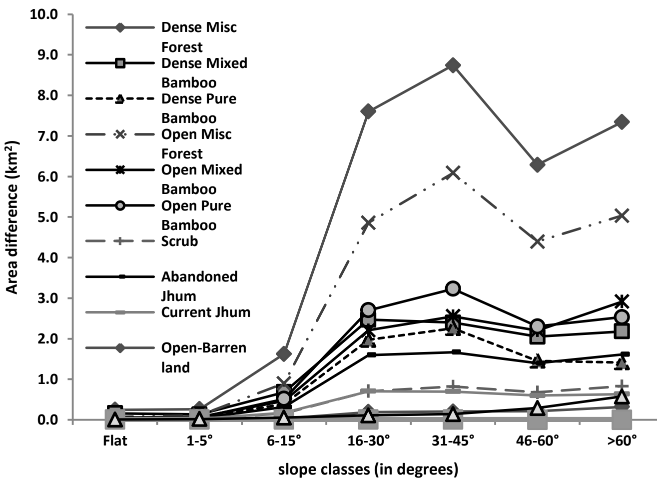

Fig. 8. Planimetric and surface area of each land use/cover in different slope classes.

As per Kaul *et al.* (2009), total biomass per unit area in Mizoram in the year 2002 was 46.89 t ha^{-1}, much lower than the all India average of 93.27 t ha^{-1}. Ratio of below ground biomass to aboveground biomass (R) was estimated from Chhabra *et al.* (2002) which is 0.27 for Mizoram. The aboveground biomass for Mizoram thus estimated at 34.23 t ha^{-1}, quite comparable with the present study. If forests of Kolasib district, Mizoram are compared with data from other states it is clear that most of the states of India barring Haryana (15.53 t ha^{-1}), Tripura (16.99 t ha^{-1}), Rajasthan (19.26 t ha^{-1}) and Goa (24.10 t ha^{-1}), are in a better position in terms of aboveground biomass per unit area. The other states of North East India are also positioned above Mizoram, lead by Assam (98.05 t ha^{-1}), Sikkim (96.36 t ha^{-1}), Arunachal (85.81 t ha^{-1}), Manipur (65.09 t ha^{-1}), Nagaland (42.72 t ha^{-1}) and Meghalaya (42.82 t ha^{-1}) (Kaul *et al.* 2009). The reason for low aboveground woody biomass in Kolasib forests may be attributed to tremendous degradation of natural forest induced by age old shifting cultivation practices in the region. Natural forest is cleared and burnt by Jhum cultivators and shifting cultivation is practiced subsequently. The cycle is usually for 1 - 3 years after that the plot is abandoned and allowed to regenerate. The forests results from secondary regeneration are usually low of biomass as in the case of Kolasib forests. The shifting cultivators or *'jhumias'* reside near by the Jhum land also degrade surrounding forest areas for their livelihood. The surface area based AGWB data of Kolasib district could not be compared with any other study because no such studies were found during literature survey.

The variation in area due to differences in approach (planimetric or surface area) largely influences the resource estimation. As for example, it was found that 744 thousand numbers of trees remained under estimated in dense miscellaneous forest alone due to 'planimetric approach' of resource estimation. The total underestimated numbers of trees are found to be 1392 thousands. Some 13,413 and 157 thousand of Muli and other bamboo were also found underestimated in dense pure bamboo and dense mixed bamboo classes, respectively. The total underestimated numbers of Muli and other bamboo in all land use/cover classes are estimated to be 41,857 and 712 thousands respectively. About 60.6 thousand tonne of AGWB carbon was found underestimated in dense miscellaneous forest category alone. The total underestimated AGWB carbon is found to be 182 thousand tonne.

One of the limitations of the present study is that it is based on a generalization; the study is based on an assumption that slope is true along the length or breadth of a pixel only and 'diagonal slope' was ignored. A vector or TIN based study gives a better and accurate surface area of a given landscape as it also considered the 'diagonal slope'. But the problem with TIN based study is that it is a bit complex in nature and neighborhood operations are difficult to process. The DEM was generated from contour information of 20 m interval which is good enough for such kind of studies, but more detailed DEM would definitely yield a better result.

Conclusions

The present study emphasized the importance of surface area based study, especially in hilly terrain, and developed a simplified raster based methodology to assess surface area and also analyzed how changes in approach bring about changes in resource estimation in terms of number of trees/bamboo and biomass carbon. The Mizo Hills (or Lushai Hills) are part of the Patkai range and clearly, such an undulating terrain requires a surface area based study. 'Near real' estimation and quantification of resources is the prerequisite for any scientific resource management and therefore becomes a focal point and main goal of any survey or mapping exercise. Biomass is an important resource that needs to be mapped and estimated as accurately as possible to properly understand the forestry options to mitigate climate change.

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References

Alban, D. H., D. A. Perala & B. E. Schlaegel. 1978. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. *Canadian Journal of Forest Research* **8**: 290-299.

Baccini, A., N. Laporte, S. Goetz, M. Sun & H. Dong. 2008. A first map of tropical Africa's above-ground biomass derived from satellite imagery. *Environmental Research Letters* **3**: 045011.

Beer, C., M. Reichstein, E. Tomelleri, P. Ciais, M. Jung, N. Carvalhais, C. Rodenbeck, M. Altaf Arain, D. Baldocchi, G. B. Bonan, A. Bondeau, A. Cescatti, G. Lasslop, A. Lindroth, M. Lomas, S. Luyssaert, H. Margolis, K. W. Oleson, O. Roupsard, E. Veenendaal, N. Viovy, C. Williams, F. I. Woodward & D. Papale. 2010. Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. *Science* **329**: 834-838.

Brown, S. L., P. Schroeder & J. S. Kern. 1999. Spatial distribution of biomass in forests of eastern USA. *Forest Ecology and Management* **123**: 81-90.

Beasom, S. L. 1983. A technique for assessing land surface ruggedness. *Journal of Wildlife Management* **47**: 1163-1166.

Champion, H. G. & S. K. Seth. 1968. *A Revised Survey of Forest Types of India.* Govt. of India Press, Delhi.

Chhabra, A., S. Palria & V. K. Dadhwal. 2002. Growing stock-based forest biomass estimate for India. *Biomass and Bioenergy* **22**: 187-194.

Chidumayo, E. N. 1990. Above-ground woody biomass structure and productivity in a Zambezian woodland. *Forest Ecology and Management* **36**: 33-46.

Congalton, R., R. Oderwald & R. Mead. 1983. Assessing Landsat classification accuracy using discrete multivariate analysis statistical technique. *Photogrammetric Engineering & Remote Sensing* **49**: 1671-1678.

Crow, T. R. 1978. Biomass and production in three contiguous forests in northern Wisconsin. *Ecology* **59**: 265-273.

Das, D. J. 2012. *A Study on Impact of Shifting Cultivation on Landuse/ Landcover in Mizoram, using Geospatial Tools*. Ph.D. Thesis, FRI University, Dehradun. India.

Devagiri, G. M., S. Money, S. Singh, V. K. Dadhwal, P. Patil, A. Khaple, A. S. Devakumar & S. Hubballi. 2013. Assessment of above ground biomass and carbon pool in different vegetation types of south western part of Karnataka, India using spectral modeling. *Tropical Ecology* **54**: 149-165.

Dixon, R. K., S. Brown, R. A. Houghton, A. M. Solomon, M. C. Trexler & J. Wisniewski. 1994. Carbon pools and flux of global forest ecosystems. *Science* **263**: 185-190.

ERDAS Inc.. 2005. *ERDAS Imagine: Field Guide.* 4th edn., Atlanta Georgia. http://www.gis.usu.edu/manuals/labbook/erdas/manuals/FieldGuide.pdf (accessed on 24 September 2013)

Esser, G. 1984. The significance of biospheric carbon pools and fluxes for atmospheric CO_2: a proposed model structure. *Progress in Biometeorology* **3**: 253-294.

FAO. 1997. Estimating biomass and biomass change of tropical forests-a primer, FAO forestry paper. *Food and Agriculture Organization of the United Nations*, Rome.

FAO. 2003. *Forest and Climate Change: Instruments Related to the United Nations Framework Convention on Climate Change and Their Potential for Sustainable Forest Management in Africa*. Food and Agriculture Organization of the United Nations. Rome. http://www.fao.org/docrep/005/ac836e/AC836E03.htm (accessed on 21 July 2013).

FAO. 2010. *Global Forest Resources Assessment 2010-Main Report*. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/013/i1757e/i1757e.pdf. (accessed on 25 September 2012)

FSI. 1995. *Extent, Composition, Density, Growing Stock and Annual Increment of India's Forests*. 1995, Forest Survey of India, Dehradun, India.

FSI. 1996. *Volume Equations for Forests of India, Nepal and Bhutan*. Forest Survey of India, Dehradun, Saraswati Press, Dehradun, India.

Haripriya, G. S. 2000. Estimation of biomass in Indian Forests. *Biomass and Bioenergy* **19**: 245-258.

Hobson, R. D. 1972. Surface roughness in topography: quantitative approach. pp. 225-245. *In*: R. J. Chorley (ed.) *Spatial Analysis in Geomorphology*. Harper & Row, New York, USA.

Hutchinson, C. F. 1982. Techniques for combining Landsat and Ancillary data for digital classification improvement. *Photogrammetric Engineering and Remote Sensing* **48**: 123-130.

Jenkins, J. C., D. C. Chojnacky, L. S. Heath & R. A. Birdsey. 2003. National-scale biomass estimators for United States tree species. *Forest Science* **49:** 12-35.

Jenness, J. 2000. *The Effects of Fire on Mexican Spotted Owls in Arizona and New Mexico.* Ph.D. Thesis, Northern Arizona University, Flagstaff, Arizona, USA. http://www.jennessent.com/downloads/owls_fire_thesis_jenness.pdf (accessed on 3 October 2011).

Jensen, J. R. 1996. *Introductory Digital Image Processing- A Remote Sensing Perspective*. 3rd edn. Prentice Hall, New Jersey.

Joshi, H. G. & M. Ghose. 2014. Community structure, species diversity, and aboveground biomass of the Sundarbans mangrove swamps. *Tropical Ecology* **55**: 283-303.

Kale, M., S. Singh, P. S. Roy, V. Deosthali & V. S. Ghole. 2004. Biomass equations of dominant species of dry deciduous forest in Shivpuri district, Madhya Pradesh. *Current Science* **87**: 683-687.

Kaul, M., V. K. Dadhwal & G. M. J. Mohren. 2009. Land use change and net C flux in Indian Forests. *Forest Ecology and Management* **258**: 100-108.

Lal, M. & R. Singh. 2000. Carbon sequestration potential of Indian forests, *Environmental Monitoring and Assessment* **60**: 315-327.

Limaye, V. D. & B. R. Sen. 1956. *Indian Forest Records: Timber Mechanics*. Government of India Press, New Delhi, India.

Manhas, R. K., J. D. S. Negi, Rajesh Kumar & P. S. Chauhan. 2006. Temporal assessment of growing stock, biomass and carbon stock of Indian Forests. *Climate Change* **74**: 191-221.

Mitchard, E., S. Saatchi, S. Lewis, T. Feldpausch, F. Gerard, I. Woodhouse & P. Meir. 2011. Comment on 'A first map of tropical Africa's above-ground biomass derived from satellite imagery'. *Environmental Research Letters* **6**: 049001.

Pan, Y., R. A. Birdsey, J. Fang, R. Houghton, P. E. Kauppi, W. A. Kurz, O. L. Phillips, A. Shvidenko, S. L. Lewis, J. G. Canadell, P. Ciais, R. B. Jackson, S. W. Pacala, A. D. McGuire, S. Piao, A. Rautiainen, S. Sitch & D. Hayes. 2011. A large and persistent carbon sink in the world's forests. *Science* **333**: 988-993.

Pandey, U., S. P. S. Kushwaha, T. S. Kachhwaha, P. Kunwar & V. K. Dadhwal. 2010. Potential of Envisat ASAR data for woody biomass assessment. *Tropical Ecology* **51**: 117-124.

Rai, S. N. 1984. Above ground biomass in tropical rainforests of western ghats. *Indian Forester* **110**: 754-764.

Rajput, S. S., N. K. Shukla, V. K. Gupta & J. D. Jain. 1996. *Timber Mechanics: Strength Classification and Grading of Timber*. ICFRE Publication-38, New Forest, Dehradun, India.

Ravindranath, N. H., B. S. Somashekhar & M. Gadgil. 1997. Carbon flows in Indian forests. *Climatic Change* **35**: 297-320.

Roy, P. S. & S. A. Ravan. 1996. Biomass estimation using satellite remote sensing data: An investigation on possible approaches for natural forest. *Journal of Biosciences* **21**: 535-561.

Roy, P. S. & S. Ravan. 2001. Landscape cover dynamics pattern in Meghalaya. *International Journal of Remote Sensing* **22**: 3813.

Roy, P. S, K. G. Saxena & D. S. Kamat. 1986. *Biomass Estimation Through Remote Sensing*. IIRS Technical Report, IIRS, Dehradun.

Ryu, S. R., J. Chen, T. R. Crow & S. C. Saunders. 2004. Available fuel dynamics in nine contrasting forest ecosystems in North America. *Environmental Management* **33**: 87-107.

Saatchi, S. S., N. L. Harris, S. Brown, M. Lefsky, E. T. A. Mitchard, W. Salas, B. R. Zutta, W. Buermannb, S. L. Lewisg, S. Hagen, S. Petrova, L. Whiteh, M. Silmani & A. Morel. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences USA*. doi: 10.1073/pnas.1019576108.

Sahu, S. C., J. Sharma & N. H. Ravindranath. 2015. Carbon stocks and fluxes for forests in Odisha (India). *Tropical Ecology* **56**: 77-85.

Tiwari, A. K. 1992. Component wise biomass model for trees: a non harvest technique. *Indian Forester* **118**: 404-410.

UNFCCC. 1997. *Kyoto Protocol to the UNFCCC*. United Nations Framework Convention on Climate Change. United Nations. http://.www.unfccc.de/

resource/docs/ convkp/kpeng.html (accessed on 19 July 2011).

Upadhaya, K., N. Thapa & S. K. Barik. 2015. Tree diversity and biomass of tropical forests under two management regimes in Garo hills of north-eastern India. *Tropical Ecology* **56**: 257-268.

Zheng, D. J., J. Rademacher, Chen T. Crow, M. Bresee, J. Le Moine & S. Ryu. 2004. Estimating above ground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA. *Remote Sensing of Environment* **93**: 402-411.

Zheng, S. & S. Yan. 2002. Research on application of remote sensing for vegetable coverage classification in Shaanxi Province. *Chinese Journal of Agrometeorology* **23**: 32-36.

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