Modeling above ground biomass and carbon stock of tropical forest of Nepal using very high resolution satellite images and airborne Lidar

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Background

- Healthy forests sequester and store more carbon compared to any other terrestrial ecosystem and are considered to be an important natural brake on climate change (Gibbs et al., 2007)

- Tropical forests are a large pool of carbon sinks and sources, estimation of carbon stock is crucial for understanding the global carbon cycle and to reduce the global warming (Sierra et al., 2007)

- Nepal being a UNFCCC signatory and a member of UN-REDD Programme, need to show its current status of carbon stored by forests and emitted from deforestation and forest degradation (MOFSC, 2009). Project with ICIMOD on developing Guidelines to assess carbon stock

- To meet the IPCC “Tier 3” standard of accuracy and lower level of uncertainty (Patenaude et al., 2005), it is crucial to precisely estimate the national forest carbon stocks in terms of biomass to develop a national REDD strategies in Nepal.

- Lidar data alone as well as in combination with other sensor or ancillary data, will provide an important data source for accurate forest biomass estimation (Drake et al., 2003; Hyde et al., 2006; Lim et al., 2003)
Carbon Estimation Methods

Traditional methods
Optical RS
VHR Imagery
Radar
LiDAR

Benefits and Limitation

Expensive, Time consuming laborious
No specific allometry
Most accurate

Mixed pixel inability to develop good model, Saturation
Easily available data and temporal

Reasonable accuracy
Identify individual tree
Expensive

Saturation problem
Ineffective in mountains
Can be accurate for young forest

Accurate but expensive

Uncertainty

Low
High
Low to medium
Medium
Low to medium

More accurate

Source: Gibbs et al., 2007

UNIVERSITY OF TWENTE.
CPA and AGB
DBH → AGB → Mapping carbon

Crown diameter

DBH

Segmentation

CPA

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Research Objective

Main Objective:

To develop an approach for accurate estimation of carbon stock using Worldview-2 satellite image and airborne LiDAR data in tropical broadleaved forests of Nepal.
Specific Objectives

1. To develop a canopy height model (CHM) for tropical broadleaved forest based on Lidar data and evaluate its accuracy

2. To determine the relationship among crown projection area (CPA), tree height and carbon stock of different tree species

3. To estimate/map carbon stock of study area using WorldView-2 satellite image and airborne LiDAR data
Study Areas
Methodological Framework

- WorldView-2 MSS
- WorldView-2 Pan
- Lidar data

Co-registration

Pan-sharpened image

Integration

Multi-resolution Segmentation

DSM-DTM

CHM

CPA and Lidar derived height

Multiple regression model

Above ground carbon stock

Species-specific allometric equation

Field measurement

Carbon map
Research Methods: Above ground carbon calculation from species specific allometric equation

\[ \ln(V) = a + b \times \ln(DBH) + c \times \ln(Ht) \] …… Species wise stem volume of tree adapted from Sharma & Pukkala (1990)

Stem biomass = Stem volume * Wood density

Total AGB = Stem biomass + Branch biomass + Foliage biomass

Total Carbon Stock = Total AGB*0.47

*Branch biomass and foliage biomass was calculated from component tree biomass ratio developed by Sharma & Pukkala (1990) and Sharma (2011)*
Research Methods: Canopy height model (CHM) generation

- Lidar data was processed in LasTools using several functions such as `lasground`, `blast2dem` and `lasgrid` for interpolation of elevation point.

- DTM was generated from ground point using 0.5 m interpolation.

- DSM was generated from non-ground points using 0.5 m interpolation.

- CHM was obtained by subtracting the DTM from DSM using raster calculator of ArcGIS.

- Height of individual trees was obtained from filtering of CHM using con function of raster calculator.
Research Methods: Multi-resolution image segmentation

**Processing steps**

1. Estimation of Scale parameter
2. Smoothening/Filtering
3. Segmentation of image
4. Shadow and cloud masking
5. Delineation of tree crowns
6. Watershed transformation
7. Morphology
8. Refining the shape of tree crowns

**Rule sets**

- **Convolution**
  - 07.188: convolution filter (Gauss Blur, 5x5), 'Layer 6' => 'Red Edge'
  - 06.781: convolution filter (Gauss Blur, 5x5), 'Layer 7' => 'NIR 1'
  - 09.469: convolution filter (Gauss Blur, 5x5), 'Layer 8' => 'NIR 2'
  - 07.344: convolution filter (Gauss Blur, 5x5), 'Layer 9' => 'CHM'

- **Segmentation**
  - 21 [shape:0.8 compact:0.6] creating 'Level 1'
  - unclassified with Brightness >= 270 and Brightness <= 450 at Level 1: Tree1
  - unclassified with Brightness < 270 at Level 1: Shadow
  - unclassified with CustRatio >= 1400 at Level 1: Cloud
  - Shadow with Mean NIR 2 >= 300 and Mean CHM >= 4 at Level 1: TREE
  - unclassified at Level 1: Tree2
  - Tree1, Tree2 at Level 1: TREE
  - Cloud at Level 1: merge region
  - Shadow at Level 1: merge region

- **Watershed**
  - TREE at Level 1: watershed transformation (7)

- **Morphology**
  - TREE at Level 1: closing
  - Shadow, TREE with Area <= 20 Pxl at Level 1: remove objects (merge by shape)
  - TREE with Roundness >= 1.1 at Level 1: remove objects (merge by shape)
  - TREE with Asymmetry >= 0.8 at Level 1: remove objects (merge by shape)
Results: Spectral separability of WorldView-2 image

How accurately WorldView-2 image can differentiate tree species on the basis of spectral separability?

Transformed Divergence
Best average separability: 1970.99
Results: CHM generation from Lidar data

a) DTM generated from last return

b) DSM generated from first return

c) CHM derived from DTM and DSM

d) CHM in 3D view (tree height)
Results: CHM generation

a) DSM generated from first return
b) DTM generated from last return
c) Canopy Height Model (CHM)
d) Subset of CHM (tree height) in 3D view
Canopy Height modeling & Segmentation

- Canopy Height Model
- Segmentation
Results: Accuracy assessment of CHM
How accurately the height of individual trees can be estimated from the Lidar derived CHM?

Summary of Fit

- Correlation coefficient: 0.871
- R Square: 0.759
- Adjusted R Square: 0.758
- Standard Error: 3.050
- Root Mean Square Error: 3.844
- RMSE %: 26.26
- Intercept: 2.270
- Slope: 0.854
- Observations: 205

- Pearson’s correlation test indicated statistically significant relationship between height measured from field and derived from Lidar.
- F-test showed indicated that there is no significant difference between height measured from field and derived from Lidar.
Results: Image segmentation

Panchromatic image

Pan-sharpened image
Results: Image segmentation

How accurate is the segmentation of CPA from WorldView-2 image in combination with Lidar data?

Measure of Closeness

Over segmentation: 0.29
Under segmentation: 0.34
D value: 0.33
(33% error of segmentation)

Total no of reference CPA: 344
1:1 spatial correspondence: 261
Segmentation accuracy: 75.87%
Results: Image Classification

What type of forest and tree species are found in each CFUG?

Forest cover classification

<table>
<thead>
<tr>
<th>Name of CFs</th>
<th>Class name</th>
<th>Overall accuracy (%)</th>
<th>Kappa statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devidhunga</td>
<td>Forest area</td>
<td>94%</td>
<td>0.75</td>
</tr>
<tr>
<td>Nebuwater</td>
<td>Forest area</td>
<td>86%</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Non-forest area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Janprogati B</td>
<td>Forest area</td>
<td>82%</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Non-forest area</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tree species classification

<table>
<thead>
<tr>
<th>Name of CFs</th>
<th>Number of species classified</th>
<th>Overall Accuracy (%)</th>
<th>Kappa statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devidhunga</td>
<td>7</td>
<td>67%</td>
<td>0.52</td>
</tr>
<tr>
<td>Nibuwatara</td>
<td>5</td>
<td>75%</td>
<td>0.69</td>
</tr>
<tr>
<td>Janprogati B</td>
<td>2</td>
<td>86%</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Higher no of species classified, lower the accuracy obtained
## Results: Correlation among CPA, height and carbon stock

What is the relationship between CPA, height and carbon stock of dominant tree species?

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Variables</th>
<th>df (n-2)</th>
<th>t-statistic</th>
<th>r</th>
<th>R Square</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Shorea robusta</em></td>
<td>CPA and carbon</td>
<td>60</td>
<td>6.89</td>
<td>0.70</td>
<td>0.49</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Height and carbon</td>
<td>60</td>
<td>8.58</td>
<td>0.77</td>
<td>0.60</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>CPA and height</td>
<td>60</td>
<td>6.56</td>
<td>0.68</td>
<td>0.47</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><em>Lagerstroemia parviflora</em></td>
<td>CPA and carbon</td>
<td>29</td>
<td>5.46</td>
<td>0.62</td>
<td>0.38</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Height and carbon</td>
<td>29</td>
<td>7.97</td>
<td>0.75</td>
<td>0.56</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>CPA and height</td>
<td>29</td>
<td>5.70</td>
<td>0.63</td>
<td>0.40</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><em>Terminalia tomentosa</em></td>
<td>CPA and carbon</td>
<td>16</td>
<td>9.16</td>
<td>0.79</td>
<td>0.63</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Height and carbon</td>
<td>16</td>
<td>11.90</td>
<td>0.86</td>
<td>0.74</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>CPA and height</td>
<td>16</td>
<td>6.47</td>
<td>0.68</td>
<td>0.46</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><em>Schima wallichii</em></td>
<td>CPA and carbon</td>
<td>23</td>
<td>10.75</td>
<td>0.84</td>
<td>0.70</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Height and carbon</td>
<td>23</td>
<td>6.83</td>
<td>0.70</td>
<td>0.49</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>CPA and height</td>
<td>23</td>
<td>5.51</td>
<td>0.62</td>
<td>0.38</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><em>Others</em></td>
<td>CPA and carbon</td>
<td>49</td>
<td>6.64</td>
<td>0.69</td>
<td>0.47</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Height and carbon</td>
<td>49</td>
<td>7.33</td>
<td>0.72</td>
<td>0.52</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>CPA and height</td>
<td>49</td>
<td>4.66</td>
<td>0.55</td>
<td>0.31</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
Results: Model calibration

\[ \text{Ln Carbon} = \beta_0 + \beta_1 \times \text{Ln (CPA)} + \beta_2 \times \text{Ln (Height)} \]

Where,

- \( \text{Ln} \) is natural logarithm to the base 2.71828
- \( \text{Carbon} \) is above ground carbon stock per tree in Kg
- \( \beta_0 \) is intercept
- \( \beta_1 \) is coefficient of CPA
- \( \beta_2 \) is coefficient of Lidar derived tree height

<table>
<thead>
<tr>
<th>Species</th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( R \text{ Square} )</th>
<th>Adjusted ( R \text{ Square} )</th>
<th>Standard error</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorea robusta</td>
<td>-0.877</td>
<td>0.597</td>
<td>1.873</td>
<td>0.66</td>
<td>0.65</td>
<td>0.90</td>
<td>62</td>
</tr>
<tr>
<td>Lagerstroemia parviflora</td>
<td>0.205</td>
<td>0.370</td>
<td>1.494</td>
<td>0.60</td>
<td>0.57</td>
<td>0.58</td>
<td>31</td>
</tr>
<tr>
<td>Terminalia tomentosa</td>
<td>-0.126</td>
<td>0.458</td>
<td>1.848</td>
<td>0.82</td>
<td>0.80</td>
<td>0.37</td>
<td>18</td>
</tr>
<tr>
<td>Schima wallichii</td>
<td>-0.144</td>
<td>1.124</td>
<td>0.883</td>
<td>0.75</td>
<td>0.73</td>
<td>0.61</td>
<td>25</td>
</tr>
<tr>
<td>Others</td>
<td>0.044</td>
<td>0.616</td>
<td>1.396</td>
<td>0.64</td>
<td>0.63</td>
<td>0.57</td>
<td>51</td>
</tr>
</tbody>
</table>
Results: Model Validation

- **Shorea robusta**
  - $R^2 = 0.94$
  - RMSE% = 24.85

- **Lagersroemia parviflora**
  - $R^2 = 0.78$
  - RMSE% = 27.77

- **Terminalia tomentosa**
  - $R^2 = 0.76$
  - RMSE% = 33.80

- **Schima wallichii**
  - $R^2 = 0.84$
  - RMSE% = 37.96

- **Others**
  - $R^2 = 0.78$
  - RMSE% = 49.75
Results: Carbon stock mapping
Results: Carbon stock estimation (species and CF wise)

How much carbon is stored by each major type of tree species in the study area?

Total carbon stock in study area: 188485 Mg
Carbon stock per ha: 216.38 Mg
Conclusions

- Lidar derived tree height was able to explain 76% of field measured tree height with RMSE of 3.84 m
- WorldView-2 satellite image is reasonably accurate in differentiating the tree species on the basis of spectral signature separability
- Combination of VHR satellite image and airborne Lidar data is reasonably accurate in segmenting individual tree crown
- Relationship among CPA, Lidar derived tree height and carbon measured from field data was found to be significant
- Species wise multiple regression models using CPA and height can accurately estimate the carbon stock of forest
Future Work

- Up-scaling
- Use medium resolution
- Affordable
- Practical
- REDD MRV

Acknowledgement: