Spatial Distribution of Forest Biomass Using Remote Sensing and Regression Models in Northern Haryana, India

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ABSTRACT
This study aims to estimate aboveground biomass and carbon stock in forests of northern Haryana covering Siwalik ranges, the foothills of the western Himalaya, in northern India. Spectral modeling of aboveground biomass was done on the basis of field data collected from 92 sampling plots of 0.1 ha across different forest types and forest densities. The field sampling, spectral responses of different bands and indices of MODIS 250m spatial resolution surface reflectance (SR) satellite data of 4 different months were used for assessing the aboveground forest biomass. Based on the relative forest area within the MODIS pixel, weighted-area biomass has been estimated to extrapolate the aboveground biomass (AGB). For geospatial distribution of the aboveground biomass, the best regression model \( r^2 = 0.774 \) between MODIS SR (250m) satellite data and the AGB was with December month red band with power function. The relationship between observed biomass and predicted biomass was highly significant \( r^2 = 0.722 \). The mean aboveground biomass varied from 30.46 Mg ha\(^{-1}\) to 310.10 Mg ha\(^{-1}\) on plot basis across forest types. The predicted AGB based on MODIS data ranged from <30 Mg ha\(^{-1}\) to 346 Mg ha\(^{-1}\). For regional level AGB representation, the mean AGB within the grids of 5×5 km was 32 to 210 Mg. The total AGB was 26.99 Tg accounting for a total carbon stock 12.96 Tg in the forests ecosystems of northern Haryana.

Key Words: Carbon Stock, Siwaliks, Aboveground Biomass (AGB), Spectral Modeling, Weighted-area Biomass, Biomass Carbon

INTRODUCTION
Forests are precious biological resources which provide provisioning, regulatory, cultural and economic services and are source of timber, fuel wood, food and the various kinds of raw materials and social benefits (FAO 2006). Forests contain about 80% of global terrestrial aboveground carbon stock, and play an important role in the global carbon cycle (Houghton 2005). Tropical forests are also critical to the global carbon cycle because half of the world’s biomass carbon is stocked in the forests and 14% of the world soil carbon is located in the soil of tropical forests (IPCC 2001, FAO 2006). The carbon stocks based on carbon density of vegetation and soils has been reported (Atjay et al. 1979, Saugier et al. 2001). For forest carbon studies, there is need to develop specific biomass models for each on regional basis and forest types (Brown 1997). The carbon stocks in the Indian forests have been estimated on the basis of growing stock volume data of forest inventories and using appropriate conversion factor to both biomass and carbon (Rabindranath 1997, Lal and Singh 2000, Chhabra et al. 2002, Dadhwal et al. 2009, Patil et al. 2010).

Many non-destructive or least destructive approaches of easily measurable plant parameters, such as diameter/girth and height and their relationship with plot or point volume/biomass have been used for assessing forest biomass (Brown 1997, Laurance et al. 1999, Kale et al. 2004, Laumonier et al. 2010). Remote-sensing techniques may represent a viable alternative for monitoring forest biomass due to their synoptic and repetitive nature, along with spectral, spatial and temporal resolution (Shugart et al. 2000, Baccini et al.
The studies have shown that remote sensing data collected from different sensors at various scales (e.g. from 1 m IKONOS to 1 km Moderate Resolution Imaging Spectroradiometer MODIS) can be directly or indirectly applied for estimating aboveground forest biomass (Hurtt et al. 2003, Lefsky et al. 2005, Zheng et al. 2008).

Remote sensing methods are especially suitable for independent verification of the land use, land-use change, and forestry carbon pool estimates, particularly aboveground biomass (IPCC 2001). It is important to analyze aboveground biomass because it comprises 75 to 85% of the carbon stocks in different types of forests (Jackson et al. 1996). Remote sensing has been successfully applied to analyze forest structure and aboveground biomass over large areas (Roy and Shirish 1996, Houghton 2007, Lu 2006, Zheng et al. 2008). Remotely sensed spectral reflectance measurements have been found to be useful predictors of biomass (Shugart et al. 2000, Baccini et al. 2008). The moderate resolution imaging spectroradiometer (MODIS) data have been used to map woody aboveground biomass across tropical Africa (Baccini et al. 2008).

The aim of this study is to develop an empirical model for aboveground biomass estimation in forests of northern Haryana on the basis of the spectral responses of different bands and indices of MODIS 250m spatial resolution surface reflectance (SR) satellite data of different months and the forest plot biomass data. The present study is a part of Indian Space Research Organisation-Geosphere-Biosphere Programme (ISRO-GBP) National Carbon Project-Vegetation Carbon Project (NCP-VCP) undertaken at the national level.

**STUDY SITE**

The study area covers Yamunanagar and Panchkula Forest Division of northern Haryana in the Siwalik ranges, the foot hills of western Himalaya. The Kalesar Reserved Forest at Yamunanagar Forest Division is located between 30° 00' 00” to 30° 30' 00” N latitude and 70° 00' 00” to 77° 00' 45” E longitudes. The Panchkula forest division is situated between 76° 46’ 40” E to 77° 0’ 33” E longitudes and 30° 40’50” N to 30° 54’ 40” N latitudes (Figure 1). The altitude in the Siwalik ranges of the study area varies from 300 m to 650 m above mean sea level at Kalesar reserved forest in Yamunanagar forest division. The elevation above mean sea level varies from 370 m near Bir Shikargah to about 1100 m at Morni hills in the Panchkula forest division. The Siwaliks are composed of alluvial detritus of the solidified and upheaval detritus of the great Himalayan range (Wadia 1961) in northern India.

The total forest area in Yamunanagar is 193 km² which forms 10.92% of the total geographical area of the district (FSI 2009). The forests are mainly composed of dry Siwalik Shorea robusta forest, dry plain Shorea robusta forest, mixed dry deciduous forests, dry deciduous scrub, dry tropical riverine forests, and the plantation forests (Champion and Seth 1968). The total forest area in Panchkula forest division is 400 km² which forms 30.55% of total geographical area of the district (FSI 2009). According to Champion and Seth (1968), the forests in Panchkula forest division are northern dry mixed deciduous forests, dry deciduous scrub, and subtropical pine.

**Climate**

The climate of the study area is subtropical and monsoonal with distinct winter, summer and rainy seasons. The annual rainfall varies from 716 to 1897 mm. About 84% of the total rainfall occurs during the monsoon months from June to September. The summer months from March to June are hot and dry. The winter season from October to February is cold and dry.

**Soil**

In Siwalik ranges of the study area, the soil is clay-loam and underlying rocks are soft sandstone and conglomerates. The Kalesar reserved forest in the Yamunanagar district is mostly covered by alluvium and other younger tertiary groups of rocks including Siwalik formation. The soils in the Siwalik belt consist of sandstone and conglomerates; the bands of clay are inter-bedded with these sandstone and conglomerates to provide cohesion to the soil. The soils of the Lal dhang formation at Kalesar in Yamunanagar district is red clay which owes its origin from the red sandstone. The soil of the plains has been formed by alluvial deposition of the river Yamuna and its tributaries. The alluvium consists of variable proportions of clay, sand and silt in different forests. The soils show a marked variation from sandy to clayey. The soils in the Panchkula forest division are recently formed, shallow, and generally red, brown and black with high base status.
Figure 1. Location of the study area. A) Panchkula Forest Division; B) Yamuna Nagar Forest Division in northern Haryana, India.
Table 1. Site characterization of the sampling plots (n=92) in different forest types in northern Haryana, India.

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Density trees ha(^{-1})</th>
<th>DBH m</th>
<th>Basal area m(^2) ha(^{-1})</th>
<th>Tree volume m(^3) ha(^{-1})</th>
<th>Biomass Mg ha(^{-1})</th>
<th>Number of plots</th>
<th>Vegetation composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical dry deciduous</td>
<td>973.5</td>
<td>0.49</td>
<td>41.09</td>
<td>425.18</td>
<td>310.10</td>
<td>32</td>
<td><em>Shorea robusta</em> Gaertn. f., (Importance Value Index, IVI = 128), <em>Mallotus philippensis</em> (Lamk.) (IVI = 75), <em>Ehretia laevis</em> Roxb. (IVI = 50). The under-storey is composed of 11 tree species with IVI ranging from 1.77 to 19.18. The forest floor has good growth of tree saplings and shrubs. 71.07% canopy cover with canopy height up to 28.5 m, shrubs present.</td>
</tr>
<tr>
<td><em>Shorea robusta</em> forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Siwaliks tropical deciduous</td>
<td>803.0</td>
<td>0.16</td>
<td>29.67</td>
<td>357.82</td>
<td>195.20</td>
<td>12</td>
<td><em>Shorea robusta</em> (IVI = 77), <em>Mallotus philippensis</em> (IVI = 85), <em>Ehretia laevis</em> (IVI = 41). The understorey is represented by 15 tree species (IVI = 1.17 to 12.80).</td>
</tr>
<tr>
<td><em>Shorea robusta</em> forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry deciduous mixed forest</td>
<td>413.3</td>
<td>0.28</td>
<td>11.06</td>
<td>204.65</td>
<td>127.75</td>
<td>24</td>
<td><em>Diospyros tomentosa</em> Roxb. (IVI = 61.11), <em>Lannea coromandelica</em> Merr. (IVI = 29.92), <em>Anogeissus latifolia</em> (Roxb. ex DC.) Wall. ex Guill. &amp; Perr. (IVI = 29.87). For the remaining 27 tree species in the forest, the IVI ranged from 1.22 to 19.94. 67.70% canopy cover with canopy height up to 19.5m, shrubs present, located on steep slopes.</td>
</tr>
<tr>
<td>Sub-tropical Pine forest</td>
<td>315.0</td>
<td>0.34</td>
<td>03.44</td>
<td>270.39</td>
<td>101.46</td>
<td>08</td>
<td>Sub- tropical pine forest occurring at an altitude of about 1200 m in the Siwaliks, dominated by <em>Pinus roxburghii</em> (IVI = 193.41), and the IVI of seven other tree species ranged from 4.85 to 26.29. 68.91% canopy cover with height up to 24.5m.</td>
</tr>
<tr>
<td>Plantation forests</td>
<td>442.5</td>
<td>0.38</td>
<td>03.86</td>
<td>235.04</td>
<td>123.70</td>
<td>08</td>
<td><em>Acacia catechu</em> (L.f.) (IVI = 83.48) <em>Eucalyptus tereticornis</em> Haines,Willd (IVI = 74.7), and <em>Tectona grandis</em> L. (IVI = 74.3) in Bir Shikargah sanctuary.</td>
</tr>
<tr>
<td><em>Acacia catechu</em> forest</td>
<td>474.7</td>
<td>0.40</td>
<td>0.72</td>
<td>40.78</td>
<td>30.46</td>
<td>08</td>
<td><em>Acacia catechu</em> (L.f.) (IVI = 86.43) in Nawanagar protected forest on moderate to steep slopes, abundant shrub cover</td>
</tr>
</tbody>
</table>
METHODS

Field Sampling

Sampling design for field inventory is based on the approaches followed in ISRO-GBP/NCP-VCP. The sites characteristics of the selected forest types for analysing spatial distribution of the aboveground biomass (AGB) are given in Table 1. The forest inventory was carried out in the Kalesar Reserved forest, Yamunananagar forest division, and Panchkula forest division during April 2009 to December 2009. Four sample plots of 0.1 ha were laid at each site of 250x250 m which is equivalent to the size of MODIS SR pixel with 250 m spatial resolution. A total of 92 plots, at 23 sites, were laid for tree enumeration. Co-ordinates of all the plot centers as well as site centers were taken using GPS. The numbers of sites were well distributed considering the probability proportion to its size of the forest type and density.

All individuals of the trees ≥10 cm CBH were measured in different forest ecosystems selected for the study. Aboveground biomass for each survey plot (0.1 ha) was derived as a function of the total number of trees <10 cm and >10 cm diameter classes, using allometric regression for the regional tropical forest trees. Site-wise sample plot field data for the plant species with diameter >10 cm and >3 to <10 cm were organized in spreadsheet. The aboveground biomass (obtained using volume equation and specific gravity) was estimated for each forest cover type (Figure 2).

Figure 2. Flowchart for estimating aboveground biomass of trees (Patil et al. 2009)
Image Data Acquisition and Processing

Six scenes of eight day composite image of MODIS Surface reflectance (SR product MOD09, Path/Row 24(h) 05 (v), of 2009) belonging to the February, May, October and December 2009 were downloaded from GLCF site http://glcf.umiacs.umd.edu/data.modis/). Spatial resolution of MODIS SR for Band 1 and Band 2 is 250, which is a daylight data only LISS III (Spatial resolution 23.5 m and bands were green, red, infrared and Short-wave infrared) data of dry and wet seasons were co-registered with the help of geotiff images of Landsat ETM+. Satellite image was georeferenced and the data were processed in ERDAS Imagine 9.1 software and ArcGIS 9.1, ESRI 2002, for creating the database. The ground control points were well and evenly distributed and RMS error achieved was less than half pixel (Patil et al. 2009). Forest cover density map was procured from Forest Survey of India (FSI 2003) and used for sampling design. Forest cover type and density, NDVI of Landsat images and accessibility were used for site identification. MODIS data of 250×250m Spectral resolution and a 16-day composite temporal resolution was used.

Aboveground Biomass Estimation

To minimize the effects of sub pixel variability and errors due to mismatches in resolution between field data and satellite observation, the field plots were overlaid on the MODIS imagery. Then average aboveground biomass for only those 250×250 m pixels having four field plots were computed by using weighted area approach by using forest type and forest density map. Using this approach, a total of 23 Pixel locations containing four field plot inventories were identified.

The aboveground biomass predictions for the Yamunanagar and Panchkula districts were generated by correlating field biomass with reflectance value of different bands and indices of MODIS satellite data to develop the combined regression models. Using regression models for aboveground forest biomass estimation, the forest biomass map of Yamunanagar and Panchkula districts were generated.

Weighted Area Biomass Estimation

MODIS SR 250 m data have been used to create vector-boxes around the 23 sampling sites in Arc GIS, whose coordinates were taken using a GPS during the field data collection. These vector-boxes of 250×250 m were then overlaid on LISS III satellite data. Visual interpretation on high resolution satellite data within each vector-box for mapping of forest cover type/land use and forest cover density maps was carried out. Forest type and density maps were intersected in GIS domain to obtain density-wise forest cover type map. The area of each forest type was multiplied by respective aboveground biomass to obtain total aboveground biomass for forest type and density within the vector-box. Proportionate area of each land use/land cover class occurring within the vector boundary was obtained by taking the ratio between the area occupied by the respective class within the pixel and total area of the MODIS pixel i.e. 6.25 ha. The classes such as water body and settlement were not considered. Subsequently, area weights based on per cent area occupied in the MODIS pixel by each forest type and density class was multiplied with the corresponding aboveground biomass to obtain the total biomass in the vector-box. Area weighted aboveground biomass was obtained for each sample site (Patil et al. 2009, Anonymous 2010).

Spectral Modeling

The spectral modeling to correlate aboveground biomass with reflectance of multi-season MODIS data and to extrapolate the aboveground biomass in non-sampled areas was done. Four regression functions such as linear, logarithmic, exponential and power were tried to find the best model with data-sets such as red, infrared bands and NDVI (Table 2) with weighted area biomass based on clustered sampling as well as biomass of individual plots. Correlation coefficients of best fit models thus obtained were used to model biomass for the entire area/region for forest divisions in northern Haryana covering the Siwaliks.

RESULTS AND DISCUSSION

Aboveground Biomass

The biomass has been estimated based on two approaches: the first one is based on the biomass of 92 individual plots, i.e., point observation on the ground, and the second one is based on determination of the mean site biomass of clustered plots. The observed aboveground biomass in 92 individual plots varied from 16.86 to 850.59 Mg ha⁻¹. The observed mean above-
ground biomass of the 92 sampling plots varied from 30.46 to 310 Mg ha\(^{-1}\) (Table 1), if considered clustered sampling at 23 sites (4 diagonally laid plot at each site). However, site-wise biomass after assigning area based weights in 6.25ha grid (MODIS pixel area), the averaged biomass ranged from 37.11 Mg ha\(^{-1}\) to 415.50 Mg ha\(^{-1}\).

The wide variation in the observed aboveground biomass (16.859 Mg ha\(^{-1}\) to 850.59 Mg ha\(^{-1}\)) on plot basis across forest types are because of marked variations in species composition, tree density (282 to 1092 trees ha\(^{-1}\)), and basal area of trees (0.52 to 73.72 m\(^2\) ha\(^{-1}\)). Most of the high values of the biomass were found concentrated in the Kalesar National Park, which is comprised of northern tropical dry deciduous Shorea robusta forest and northern mixed dry deciduous forest as per the classification of Champion and Seth (1968).

The aboveground tree biomass of the region varied from <10 to 350 Mg ha\(^{-1}\) at 250×250m spectral resolution in northern Haryana. The aboveground forest biomass of the moderately dense forests as in mixed dry deciduous forests and sub-tropical pines, at Kalesar Wildlife Sanctuary, Khol Hai Raitan Sanctuary and Balaghat protected forest varied from 52 to 96.6 Mg ha\(^{-1}\). The lowest values of biomass <10 to 51.9 Mg ha\(^{-1}\) are generally associated with the open and degraded forests in the outer Siwaliks, and the riverine forests at Kalesar. The aboveground forest biomass distribution is shown in phytomaps in Figure 4.

Model Results

The linear regression model between basal area and aboveground tree biomass of trees for the Yamunanagar forest division and the Panchkula forest division for estimation of biomass for >3 to <10 cm DBH trees by reverse application of models on basal area of plots are as follows:

\[
\hat{Y} = 8.7765 \times X - 62.205 \quad (d.f. \ 51; \ r^2 = 0.9304; \ P<0.01)
\]

\[
\hat{Y} = 5.4572 \times X - 29.558 \quad (d.f. \ 39; \ r^2 = 0.9271; \ P<0.01)
\]

where, \( \hat{Y} = \) Biomass (Mg ha\(^{-1}\))

\( X = \) Basal area (m\(^2\) ha\(^{-1}\))

Regional Aboveground biomass Modeling

The regression analysis of the observed biomass in 92 plots and the weighted area biomass of 23 sites have been evaluated with multi-season MODIS SR data using linear, power, exponential and logarithmic functions. The results of the regression analysis of all the models with the four functions with weighted area biomass are summarized in Table 2. The result of best model with N=92 and N=23 are given in the Figure 3.

### Table 2. Coefficient of determination (r\(^2\)) of spectral reflectance of Red band, Infrared band and NDVI with aboveground biomass (AGB) using the different regression models.

<table>
<thead>
<tr>
<th>Regression</th>
<th>February</th>
<th>May</th>
<th>October</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral reflectance of Red band vs AGB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>0.3294</td>
<td>0.4095</td>
<td>0.2668</td>
<td>0.4258</td>
</tr>
<tr>
<td>Logrithum</td>
<td>0.3601</td>
<td>0.456</td>
<td>0.3787</td>
<td>0.5263</td>
</tr>
<tr>
<td>Power</td>
<td>0.3685</td>
<td>0.4583</td>
<td>0.4224</td>
<td>0.7742</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.3314</td>
<td>0.4206</td>
<td>0.2972</td>
<td>0.5325</td>
</tr>
<tr>
<td><strong>Spectral reflectance of IR band vs AGB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>0.0003</td>
<td>0.1904</td>
<td>0.3677</td>
<td>0.0023</td>
</tr>
<tr>
<td>Logrithum</td>
<td>0.00E-05</td>
<td>0.1723</td>
<td>0.3757</td>
<td>0.0083</td>
</tr>
<tr>
<td>Power</td>
<td>0.0024</td>
<td>0.1346</td>
<td>0.4776</td>
<td>0.0009</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.0056</td>
<td>0.1516</td>
<td>0.4743</td>
<td>0.0001</td>
</tr>
<tr>
<td><strong>Spectral reflectance of NDVI vs AGB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>0.3352</td>
<td>0.4374</td>
<td>0.1897</td>
<td>0.4359</td>
</tr>
<tr>
<td>Logrithum</td>
<td>0.2930</td>
<td>0.4004</td>
<td>0.1732</td>
<td>0.3831</td>
</tr>
<tr>
<td>Power</td>
<td>0.2735</td>
<td>0.3891</td>
<td>0.1846</td>
<td>0.4389</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.3174</td>
<td>0.4196</td>
<td>0.2019</td>
<td>0.4944</td>
</tr>
</tbody>
</table>

Using plot-wise biomass and spectral responses of different bands and indices a significant correlation was found between reflectance values of December 2009 red band (MODIS) and per pixel biomass (Figure 3), the best fit model derived is:

\[
\hat{Y} = 162046 \times X^{-1.2506} \\
(r^2 = 0.774; \text{ S.D.} = 17.447; \text{ SQRT} = 4.7958; \text{ S.E.} = 36.3807; \text{ N=23})
\]

The best correlation with determination of coefficient (r\(^2=0.774\)) explaining 77% of variability in aboveground biomass was with red band data of December with power function followed by December NDVI (r\(^2=0.494\)) with the variability of 49% with exponential function,
Figure 4. Aboveground biomass map of YamunaNagar Forest Division and Panchkula forest division (A) & (B) at 250×250 m; (C) & (D) at 5×5 km spatial resolution
and followed by that of October IR band with power function \((r^2 = 0.4776)\). The best model of red band data of December with power function yielded a model of \(Y = 162046X^{1.2506}\) with \(r^2 = 0.774\) with standard deviation and standard error of 17.45 and 36.38, respectively. This model was used for modeling of biomass for 23 forest sites. For regional level AGB representation, mean AGB was assessed within 5×5 km grids and was found to range from 32 to 210 Mg. The mean forest biomass amounted to 83.62 Mg.

Figure 3. Correlation between biomass based on clustered data and MODIS red band (October) data with power function (N=23).

The predicted aboveground biomass in the forests of northern Haryana calculated from the mean site biomass of clustered plots was comparable to that of earlier estimates for Indian forest ecosystems (Shrestha et al. 2000, Behera and Misra 2006, Baishya et al. 2009). For central Himalayan Shorea robusta dominated forest, Shrestha et al. (2000) reported aboveground biomass in the range of 337 to 698 Mg ha\(^{-1}\). Behera and Misra (2006) reported aboveground biomass of 261 Mg ha\(^{-1}\) for the 10 year old tropical Shorea robusta forest of Eastern Ghats in India. Baishya et al. (2009) have reported 406 Mg ha\(^{-1}\) of aboveground biomass for the Shorea robusta plantation forest of Nongkyllem wildlife sanctuary in Meghalaya in north-eastern India. Thus, from the results of this study, it is concluded that cluster sampling approach for calculating mean site biomass of the forest ecosystems is better than that of the individual plot biomass determination sampling method.

The aboveground biomass carbon stock was calculated by assuming that the carbon content is 48% of the total aboveground biomass (Brown and Lugo 1982, Ravindranath et al. 1997). The carbon density in the forests of northern Haryana was assessed to be 12.96 Tg.

**Correlation between Predicted and Estimated Biomass**

An assessment has been made to find the relationship between the estimated biomass on the basis of actual forest sampling and the predicted biomass obtained through spectral modeling after obtaining area weighted biomass (Figure 5). The relationship between the observed and the estimated biomass was highly significant \((r^2 = 0.722)\) explaining 72% variability at 90%
confidence level (Figure 6). The differences in the biomass values of the predicted and estimated aboveground biomass could be attributed due to difference in the tree density and phenology and vegetation composition at the time of satellite data acquisition. Earlier studies have indicated that remote sensing data are sensitive to season, tree phenological characteristics, and degree of crown closure (Lu 2006, Houghton 2007, Zheng et al. 2008). The variability in biomass is also dependent on general or regional volume equations and the tree specific gravity.

CONCLUSIONS

The MODIS data set combined with forest density map and vegetation type map used in the regression model captured the amount and spatial distribution of aboveground biomass in different forest ecosystems of Yamunanager and Panchkula forest divisions. Predictive modeling of the above-ground biomass and the spectral data under investigation showed significant linear relationship. This study clearly indicated that clustered sampling along with spectral modeling using satellite data is a better alternative approach to reduce the uncertainties in aboveground biomass estimation. Integrating remote sensing and field inventory data is a useful approach obtaining consistent, reliable and comparable spatial analysis across landscapes for improved forest aboveground biomass estimates. The combination of remote sensing and forest inventory data is a practical and effective technique for mapping the aboveground biomass distribution that are necessary for regional carbon stock assessment. Forest biomass maps were created through spectral responses of pixel biomass and observed biomass. Regional aboveground biomass maps give explicit information of spatial- variation of the aboveground biomass at moderate spectral resolution. This study provides a baseline for monitoring and modeling of carbon exchange in the dry deciduous forest ecosystems of tropical and sub tropical regions on regional basis.

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