Comparative Assessment of the Relationship of Satellite Data with the Above Ground Biomass of Sal Trees (*Shorea robusta*) Determined from Phenologically Different Time Periods

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Abstract The Above Ground Biomass (AGB) estimates of vegetation comprise both the bole biomass determined through a volumetric equation and litter biomass collected from the ground. For mature trees, the AGB estimated in phenologically different time periods is directly affected by the litter biomass since the Diameter at Breast Height (DBH) and height (H) of such trees that are used in the estimation of bole biomass would remain unchanged over a reasonable time period. In the present study, we have determined the AGB of Sal trees (*Shorea robusta*) in two contrasting seasons: the peak green period in October being devoid of litter on the ground and the leaf shedding period in February with abundant amount of litter present on the ground. Estimation of AGB for the month of February included the litter biomass. In contrast, the AGB for October represented only the bole biomass. AGB was estimated for ten different plots selected in the study area. The AGB estimated from ten sampling plots for each time period was regressed with the individual tree parameters such as the average DBH and height of trees measured from the corresponding plots. The regression analysis exhibited a significantly stronger relationship between the AGB and DBH for the month of October as compared to February. Furthermore, the correlation between the remotely sensed derived data and AGB was also found to be significantly higher for the month of October than February. This observation indicates that inclusion of the litter biomass in AGB will tend to decrease the regression relationship between AGB and DBH and also between the remotely sensed data and AGB. Therefore, these conclusions invite careful consideration while estimating AGB from satellite data in phenologically different time periods.

Keywords above ground biomass; bole biomass; diameter at breast height; litter biomass; remotely sensed data

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Introduction

Vegetation plays a great role in our ecosystem. It is one of the biotic components which is autotrophic in nature and governs the environmental factors of any ecosystem. Forests in particular, play a key role in the carbon cycle and in maintaining climatic balance. Plant biomass sequesters carbon produced during photosynthesis. Biomass is defined as organic material above-ground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. [1] Above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Below-ground biomass consists of all living roots excluding fine roots (less than 2 mm in diameter). The assessment of biomass is mainly required as the primary inventory...
data to understand carbon pool changes and forest productivity. In addition to understanding carbon pool changes, biomass estimates are important for a broad range of applications such as determining the condition of the health of vegetation, biodiversity assessment, habitat suitability analysis, fire impact modeling and other disturbances. Biomass assessment enables monitoring of forest management activities including plantation, rehabilitation and improvement, as well as modeling of the environmental and economic consequences of energy production from biomass.

In forest biomass studies, two biomass units are used: fresh weight and dry weight. Many biomass assessment studies conducted are focused on the above-ground forest biomass because it accounts for the majority of the total accumulated forest ecosystem biomass. There are mainly two basic methods employed by researchers to estimate the Above Ground Biomass (AGB) from the field: harvesting and non-harvesting.

Collection of different tree parts is essential in the harvesting method and it is also known as the destructive method. The destructive method requires felling the sample tree and weighing it. Direct weighing can only be done for small trees, but for larger trees, partitioning is necessary so that the partitions can fit into the weighing scale. In cases where the tree is large, the volume of the stem is measured. Sub-samples are collected, and its fresh weight, dry weight, and volume are measured. The dry weight of the tree (biomass) is calculated from the ratio of fresh weight (or volume) to the dry weight. The demerit of this method is that it causes the loss of biodiversity in the ecosystem since harvesting is the primary requirement. Therefore, the harvesting method is not applicable to the higher plant kingdom except when the forest felling period is in progress.

The non-destructive method on the other hand does not require the trees to be felled. Measurements can be done by measuring the various plant parts and computing the total volume. Tree density or specific gravity, which can be found from literature, is used to convert the measured volume into biomass estimates. This procedure is even more time consuming and costly to perform than the destructive methods. It is more applicable however to natural, protected or conserved forest ecosystems. This method uses various formulas and models to estimate the biomass without harvesting, so its advantage is that it does not cause loss of biodiversity. But the demerit is reduced measurement accuracy.

There are different factors that affect the AGB estimation through the non-harvesting method such as a person’s or surveyor’s perception, sample numbers and size, sample selection, accessibility, topography, instrumentation, season and time of sampling, and the formulas adopted for volume estimation of trees.

In the present study, we have performed a comparative assessment of the relationship between the remotely sensed parameters and the AGB of the Sal (Shorea robusta C. F. Gaertn) determined in two phenologically different time periods: the peak green stage prevailing in the month of October 2008 and the leaf shedding stage in the month of February 2009. The AGB of the Sal trees was estimated through a volumetric equation substituting the desired tree parameters such as tree height and DBH measured in the field. Since the Sal trees in the study area are mature, their height and DBH remained unchanged over a period of five months i.e. from October 2008 to February 2009. In the study area, it was observed that the month of October is devoid of litter while during the leaf shedding stage in February the ground is almost completely covered with litter. Therefore, in the estimation of AGB for the month of February litter biomass was added to the bole biomass whereas for the month of October, only the biomass measured from the volumetric equation was considered. We have employed a linear regression analysis to determine the relationship between the remotely sensed parameters and the AGB determined for the two time periods considered in the present study.

Aims and objectives are listed as follows:
- To determine the AGB for two phenologically different seasons: October (without litter) and February (with litter).
- To determine the regression coefficient ($R^2$) between the field-estimated AGB and different tree parameters such as DBH, height of trees and number of trees for the two different phenological periods and further, to delineate a comparison between the two periods.
To determine the relationship between the remotely sensed derived parameters and the AGB for the two different phenological periods and subsequently, to delineate comparisons between the two periods.

1 Study area

The study area selected for the present research covers the campus of the Birla Institute of Technology, Mesra, Ranchi located within Ranchi City, the capital of Jharkhand, India (Fig. 1). The study area is representative of a natural and protected open type forest with Sal as the dominant species. There are three main seasons prevailing in the region: summer (15 March-15 June) when the climate is extreme with a maximum temperature of 42°C and a minimum of 21°C, rainy season (June-October) with an annual rainfall of about 1530 mm, and winter (November-February) with temperatures ranging between 2°C and 22°C. The vegetation remains green during the rainy and winter seasons while the summer season is characterized by both leaf shedding and leaf emerging processes. The soil type within the study area is mainly lateritic. [11]

Fig. 1 Study area showing the location of sampling plots

2 Materials and methods

2.1 Materials used

To perform the present investigation, the survey of India toposheet No. 73E/7 on a 1:50000 scale was used for visual interpretation of the study area and as a guide to reach the different study locations. A Leica Handheld Global Positioning System was used to determine the exact geographic coordinates of the different sampling plots selected within the study area. A hypsometer was used to measure the height of the trees within the plots. To determine the total area of a sampling plot in terms of its dimension (100 m×100 m), the Girth at Breast Height (GBH) of trees and the observer’s distance from the tree base at the time of measuring the height of the trees were measured using a measuring tape. Small plastic bags were used to store the collected litter from the ground and also to transport it to the laboratory. The linear regression analyses between the AGB and the other governing tree parameters such as DBH, height and number of trees within each plot were performed using the SPSS 17.0 software. MS-Excel software was used for generation of plots between the AGB and the various tree parameters as mentioned above.

2.2 Methods used

The task of biomass estimation of the Sal trees through the non-harvesting technique, the determination of the regression relationship between the field-estimated AGB and the various tree parameters, as well as the determination of the correlation between the remotely sensed parameters and field-estimated AGB involved the following steps and are discussed below.

(1) Methods used for field data collection and AGB estimation.

(2) Linear regression analyses between the field-estimated biomass and different tree parameters such as the number of trees, tree height and DBH.

(3) Determination of correlation coefficient values between the remotely sensed derived parameters and field-estimated AGB.

2.2.1 Methods used for field data collection and AGB estimation

The collection of various field data pertaining to the Sal trees and subsequently, estimation of their AGB was carried out using the following steps (Fig. 2).

- Ten representative sampling plots were selected, taking into consideration the extent of the
study area and the variation in the canopy density of the Sal trees within the study area.

- The size of each sampling plot was taken as 1 hectare that approximately corresponds to an area covering 4 pixel by 4 pixel of LISS III data of the Indian Remote Sensing Satellite. Exact geographic coordinates of these plots in the field were determined using GPS (Leica Handheld Global Positioning System).
- Total number of trees existing within each sampling plot was counted.
- The GBH of the individual trees occurring within each plot was measured using a measuring tape and was later converted to DBH (diameter at breast height) by dividing the GBH values by \( \pi \) (0.318).
- An important parameter for the volume estimation of trees through volumetric equation is the height of tree. The measurement of the tree height was carried out through an indirect approach. First, using a hypsometer, the viewing angle between the observer and position at the first forking of the tree was measured and then the distance between the observer and the base of the tree was determined using a measuring tape. The height of the tree was determined using the following formula:

\[
\tan \theta = \frac{h}{s}
\]  

(1)

where \( \theta \) denotes the viewing angle; \( h \) denotes height of the tree; \( s \) denotes distance from tree.

The volume of each tree was determined using the following formula\(^{12} \):

\[
V = 0.118 + 0.257 D^2 H
\]  

(2)

where, \( V \) denotes volume of Sal trees; \( D \) denotes diameter at breast height and \( H \) denotes height at the first forking.

- The total AGB of a plot is calculated as the sum of the total bole biomass of all the trees occurring within the plot and the litter biomass contained in the plot. The bole biomass represents the dry weight of the standing tree whereas the litter biomass indicates the dry weight of the leaves lying on the ground. The bole biomass of each tree was determined by multiplying the volume of the tree with its specific gravity. For Sal trees the specific gravity has been determined as 0.726.\(^{12}\) The litter biomass within each plot was determined using the following procedure: The litter lying within a few small sampling subplots with a size of 1 m×1 m selected at different locations within the main plot were collected from the ground and then their dry weight was measured in the laboratory and averaged to obtain the litter biomass of a 1×1 m plot. The total litter biomass of the main plot was determined by multiplying the average litter biomass corresponding to a 1×1 m plot with the area of the main plot. Then the total bole biomass and total litter biomass estimated for each main plot was summed up to determine the total AGB within each main plot.

![Fig. 2 Strategy of vegetation inventory in field data collection](image)

In the above figure, the region, site and plot represents the extent of the study area, area covered by the forest and sampling plot of 100 m×100 m respectively. The subplots of 1 m×1 m were selected within the sampling plot from where litter was collected.

2.2.2 Linear regression analysis between the field-estimated biomass and different tree parameters used in the present study

Linear regression analysis was performed between the mean AGB value of each plot and mean values of the individual tree parameters such as DBH, height and number of trees of the corresponding plot for the entire study area for both time periods (October 2008 and February 2009) through SPSS 17.0 software.

Finally, comparative analysis was carried out among the results obtained from the linear regression analysis performed for the data of both the time periods in order to determine the tree parameter that yielded maximum regression coefficient with the field-estimated AGB.
2.2.3 Determination of correlation coefficient values between the remotely sensed derived parameters and field-estimated AGB

From each of the ten sampling plots, the average reflectance value of the 16 pixels in the most reflective band (near infrared or NIR) and the most absorptive band (red) of the IRS LISS III data for vegetation was determined for the two time periods, October 2008 and February 2009 respectively. In addition, the average values of the Normalized Difference Vegetation Index (NDVI) were also determined for the individual sampling plots. Correlation coefficient values were estimated between the AGB of the different plots and the corresponding average red, average near infrared and average NDVI values for the two time periods respectively in order to determine in which time period the AGB correlates better with the various remotely sensed parameters.

3 Results

The results of the present research comprise: (1) the regression coefficient \( R^2 \) values derived from the linear regression analysis performed between the AGB of Sal trees estimated through the volumetric equation for ten sampling plots and the corresponding individual tree parameters such as DBH, height and number of trees for two phenologically different time periods, one representing the peak green phase having no litter on the ground (October 2008) and the other the leaf shedding season with litter on ground (February 2009) (Table 1) and (2) the correlation coefficient values between the remotely sensed parameters and the AGB for the two time periods (Table 2). The various tree parameters remained the same during the two time periods considered in this investigation. Comparative analysis of the regression coefficient values \( R^2 \) given in Table 1 indicates that February 2009 (with litter) has the highest \( R^2 \) value of 0.90 between the field-estimated AGB with DBH (Fig. 3) followed in decreasing order by the number of trees \( (R^2 = 0.68) \) (Fig. 4) and height of trees \( (R^2 = 0.48) \) (Fig. 5). Whereas in October 2008 (without litter), a still better regression relationship of the AGB with the DBH (Fig. 6) and the number of trees (Fig. 7) occurs with \( R^2 \) values of 0.94 and 0.73 respectively, while the height of the trees shows a much lower \( R^2 \) value of 0.33 (Fig. 8) as compared to February 2009. This observation indicates that the contribution of the litter biomass to the AGB tends to decrease the regression relationship between the AGB and each of the DBH and number of trees in the study area. Furthermore, there were significantly higher values of correlation coefficients between the AGB estimated for the green period (October 2008, without litter) and the reflectance values in the red band (Figs. 9(a) and (b)), near infrared band (Figs. 10(a) and (b)) and NDVI (Figs. 11(a) and (b)) respectively as compared to the leaf shedding period (February 2009, with litter).

| Tree Parameters | Regression coefficient \( (R^2) \) |
|-----------------|---------------------------------|
|                 | February \((\text{with litter})\) | October \((\text{without litter})\) |
| DBH             | 0.90                            | 0.94                              |
| Height of trees | 0.48                            | 0.33                              |
| No. of trees    | 0.68                            | 0.73                              |

| October, 2008 \((\text{without litter})\) | February, 2009 \((\text{with litter})\) |
|-------------------------------------------|----------------------------------------|
| RED band                                  | 0.62                                   | 0.57                                 |
| NIR band                                  | 0.65                                   | 0.57                                 |
| NDVI                                      | 0.81                                   | 0.70                                 |

Fig. 3 Relationship between AGB and DBH (February)

Fig. 4 Relationship between AGB and No. of trees (February)
Fig. 5  Relationship between AGB and height of trees (February)

Fig. 7  Relationship between AGB and number of trees (October)

Fig. 6  Relationship between AGB and DBH (October)

Fig. 8  Relationship between AGB and height of trees (October)

Fig. 9  Relationship between AGB and Red band

Fig. 10  Relationship between AGB and NIR band

Fig. 11  Relationship between AGB and scaled NDVI values
4 Conclusion

It can be inferred from the investigations carried out in the present study that there occurs a stronger relationship between the various remotely sensed parameters and the AGB estimated for the green period that excludes the litter biomass than the leaf shedding period as ascertained by the occurrence of higher correlation coefficient values. Furthermore, as expected, the AGB is better correlated with the individual tree parameters vis a vis DBH and the number of trees in the peak green season as compared to the leaf shedding season. This observation signifies that the inclusion of the litter biomass in the total AGB tends to reduce the magnitude of correlation with the various remotely sensed parameters. Therefore, it is highly significant to consider the phenological stage of vegetation when determining the AGB of the vegetation through the remotely sensed data.

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