International Journal of Applied Earth Observation and Geoinformation 10 (2008) 211–219

INTERNATIONAL JOURNAL OF APPLIED EARTH OBSERVATION AND GEOINFORMATION

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Estimation of LAI and above-ground biomass in deciduous forests: Western Ghats of Karnataka, India

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Received 1 June 2007; accepted 26 November 2007

Abstract

This study demonstrates the potentials of IRS P6 LISS-IV high-resolution multispectral sensor (IGFOV ~ 6 m)-based estimation of biomass in the deciduous forests in the Western Ghats of Karnataka, India. Regression equations describing the relationship between IRS P6 LISS-IV data-based vegetation index (NDVI) and field measured leaf area index (ELAI) and estimated above-ground biomass (EAGB) were derived. Remote sensing (RS) data-based leaf area index (PLAI) image is generated using regression equation based on NDVI and ELAI ($r^2 = 0.68, p \leq 0.05$). RS-based above-ground biomass (PAGB) image was generated based on regression equation developed between PLAI and EAGB ($r^2 = 0.63, p \leq 0.05$). The mean value of estimated above-ground biomass and RS-based above-ground biomass in the study area are 280(±72.5) and 297.6(±55.2) Mg ha^{-1}, respectively. The regression models generated in the study between NDVI and LAI; LAI and biomass can also help in generating spatial biomass map using RS data alone. LISS-IV-based estimation of biophysical parameters can also be used for the validation of various coarse resolution satellite products derived from the ground-based measurements alone.

JEL classification: Multispectral imagery; Classification; Image interpretation; Mapping

Keywords: Deciduous forest; Leaf area index; IRS LISS-IV; Above-ground biomass

1. Introduction

Remote sensing data applications have evolved as very useful tool in the characterization of the state of the biosphere at regional and global scales. Indian remote sensing satellite P6 (IRS P6) offers a unique opportunity of simultaneous acquisition of data at multiple spectral resolutions of 56, 23.5 and 5.8 m from AWiFS, LISS-III and LISS-IV sensors respectively in similar spectral bands from a common platform. Although spectral characterizations of on-board IRS P6 are quite similar to each other and to the corresponding channels in earlier IRS instruments, their detailed spectral response functions are not identical. It is important for the resource planners to evaluate the capabilities of any sensor to fully understand its potential and the level of application feasibility due to strong relationship between spatial and spectral resolution of the imagery and level of application. The understanding of the effects of varying spectral responses are useful in the quantification and retrieval of bio-geographical parameters such as reflectance, vegetation indices, LAI, forest density, above-ground biomass, etc.

Biomass estimation for tropical forests has received much attention in recent years because the change of biomass regionally is associated with important components of climate change (Brown et al., 1997). Biomass is also a prime substitute for quantifying forest

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doi:10.1016/j.jag.2007.11.004

resources, including timber, fuel and fodder, and represents a key indicator of biodiversity and forest structure. Biomass is a function of density of stems, height of the trees and basal area of the trees in a given location. The contribution of these parameters to above-ground biomass differs with sites, successional stage of the forest, disturbance levels, species composition, etc. (Whitmore, 1984). Strong relation of biomass with basal area was found in many studies (Rai and Proctor, 1986). Therefore, accurate biomass estimation is necessary for better understanding deforestation impacts on carbon release, global warming and environmental degradation. In India, especially in Southern Western Ghats having very high biodiversity, very few biomass studies have been carried out, e.g., biomass estimation using destructive method (Rai, 1984) and using non-destructive method (Tiwari, 1992). A non-destructive method is mainly based on regression equations which are derived from measurable tree parameters like diameter at breast height (*dbh*), basal area, and tree height (Brown et al., 1991; Murali et al., 2005).

Remotely sensed data, of late, is considered to be the most reliable means for spatial biomass estimation in the tropical region over large areas (Roy and Ravan, 1996). Several studies (Franklin and Hiernaux, 1991; Nelson et al., 2000; Steininger, 2000) have estimated the biophysical parameters using the coarse resolution sensors and thus were not able to account for the local variabilities and also suffer from uncertainties. The use of relatively high-resolution data IRS P6 LISS-IV enhances the spatial information content as it is an important factor in improving spatial biomass estimation accuracy.

The primary objective of our study is to demonstrate the potentials of Resourcesat-1 (IRS P6) LISS-IV sensor for the above-ground biomass estimation.

2. Materials and methods

2.1. Study area

The study area is located in parts of Haliyal and Yellapur Forest divisions, Western Ghats of Karnataka, India (Fig. 1). It is located between geographical positions 15°01′15″ to 15°06′30″N latitude and 74°42′34″ to 74°45′34″E longitude. Geographically, it is a transitional zone between the younger rocks of

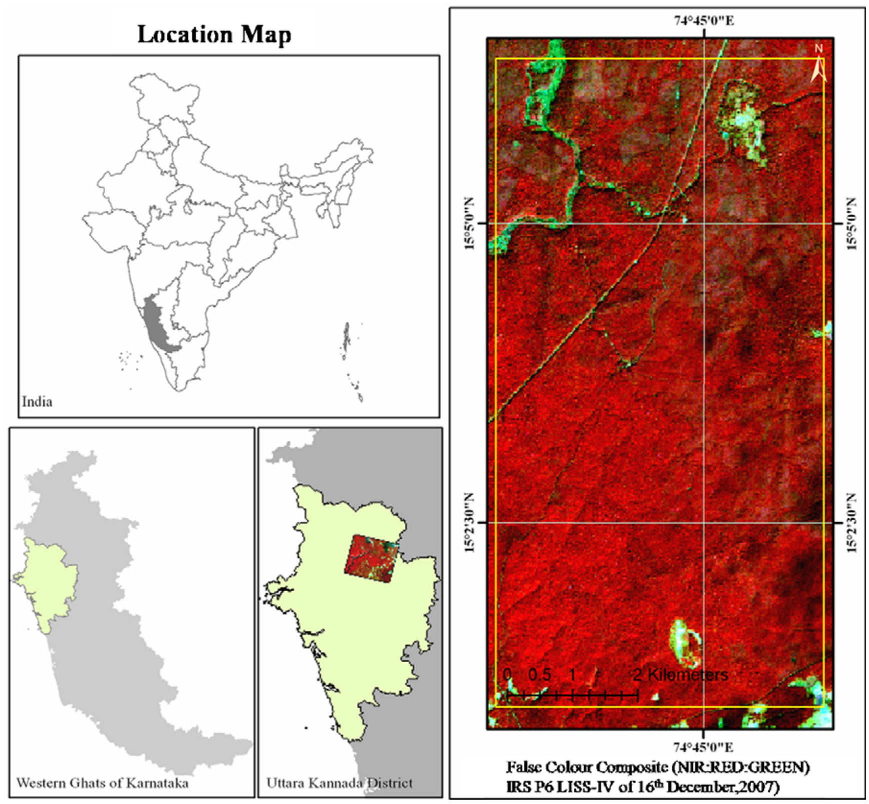

Fig. 1. Location map of study area, Yellapur and Haliyal Forest areas, Western Ghats of Karnataka, India.

Deccan trap formation and the older crystalline rocks of Archean shield of the Indian Peninsula. The soil on the exposed slopes and broad valleys is loamy laterites with pH ranging from 5 to 5.8. The area experiences southwest monsoon largely restricted to the months of mid-June and mid-October and mean annual rainfall is about 2500 mm. The mean monthly temperature ranges from 25 to 33 °C. Native vegetation is evergreen/semi-evergreen type and has a continuum to secondary/moist deciduous types in lower rainfall tracts to the east (Pascal, 1986). Champion and Seth (1968) have described tropical wet semi-evergreen and tropical moist and dry deciduous forest types in the study area. *Tectona grandis*, *Xylia xylocarpa*, *Lagerstroemia lanceolata*, *Terminalia alata*, *Terminalia paniculata*, *Dillenia pentagyna* are the dominant tree species and understory is represented by *Psychotria dalzelli*, *Eupatorium odoratum*, *Wagatea spicata* and *Ziziphus* spp.

2.2. Forest inventory data

Intensive fieldwork was carried out between May and October 2005. Based on the experiences from the previous inventory research work in the study area (Anonymous, 2002), the sampling intensity of 0.02% has been found to be optimum to account for the variability of the biomass ranges. As the present study area is mainly dominated by one major forest type, i.e., moist deciduous forest and thus the sampling intensity of around 0.02% of the total study area of 50 km^2 was considered to be sufficient. The field crew inventoried 30 plots of 20 m × 20 m size. These thirty plots were distributed in the study area using the randomizer function of ERDAS Imagine software (ERDAS field guide, 2005) and were located in the field using a mobile GPS unit (Trimble, 2005). IRS P6 LISS-IV classified image was used as primary stratification base. In each plot, all adult individual trees were measured for GBH (Appendix A).

Field measured LAI (ELAI) measurements on the ground were done using Plant Canopy Analyzer (PCA)-2000 (LICOR, 1992). On every measurement location, one above canopy and five below-canopy readings were taken to compute a single LAI value. Above and below-canopy measurements were made with a "fisheye" optical sensor with 148° angle of view. Below-canopy measurements were made just above the shrub layer (understory) and respective geo-locations were collected with the help of Handheld Global Positioning System (Trimble Recon GPS Reciever-CE00F).

2.3. Field estimated above-ground biomass (EAGB)

Basal area is calculated using field measured GBH using Eq. (1). Allometric regression model (Eq. (2)) of Murali et al. (2005) was used in EAGB estimation of each individual and was extrapolated to per hectare basis (Brown et al., 1997):

$$\text{Basal area} = \frac{\text{GBH}^2}{4\Pi} \tag{1}$$

$$\text{EAGB} = [-73.55 + (10.73\text{Basal area})] \quad (r^2 = 0.82) \tag{2}$$

2.4. IRS P6 LISS-IV image processing

Cloud free IRS P6 LISS-IV (Appendix B) multi-spectral images were acquired for Yellapur study site (16 December 2005; path 202, row 122) from NRSA Data Centre, NRSA, Hyderabad, India. The images were geometrically rectified and then atmospherically corrected. Digital numbers (DN) of image pixels were converted to at-sensor radiance (*L*) using IRS P6 L4 calibrated constants. The values of '*L*' thus obtained were converted to reflectance using top-of-atmosphere irradiance (Pandya et al., 2002) and DOS (dark object subtraction) techniques. The reflectance data is used to calculate NDVI using ERDAS Imagine 9.0 software. Preliminary image feature space analysis is done and NDVI image layer was generated from various ranges of spectral reflectance between NIR and Red bands.

2.5. Delineation of forest types

Feature space image (fsp) is generated between NIR and Red bands (Fig. 2). All the eight vegetation classes prevalent in the study area are delineated based on their spectral signature based on the image/ground observation. In the present study, the boundaries between the vegetation types were quite sharp due to higher spatial resolution of LISS-IV sensor. Using acquired ground truth data, training sets were generated and the image was classified using supervised classification method into a land use/land cover image. The classes are as follows: (1) moist deciduous forest as major component and (2) semi-evergreen forest, (3) dry deciduous forest, (4) teak mixed, (5) teak plantation, (6) bamboo mixed, (7) bamboo and (8) areca plantation. The built-up areas, roads and the linear features were also very clearly delineated.

Table 1
Stand structure parameters of study area in part of Western Ghats of Karnataka, India

Item	Density (trees ha^{-1})	Leaf area index (ELAI)	GBH (cm)	Basal area (m^2 ha^{-1})	Above-ground biomass (EAGB) (Mg ha^{-1})
Range	210–372	2.5–7.0	30–280	26–42	145–350
Mean	–	4.4(±1.0)	190(±42.16)	31.56(±6.65)	280(±72.5)

2.6. Integration of estimated above-ground biomass (EAGB) and RS-based leaf area index (PLAI)

Pearson's correlation coefficient is used to analyse the relationships between vegetation index (NDVI), and ELAI and generated PLAI layer from obtained regression equation (Eq. (3)) using ERDAS Imagine 9.1. EAGB and PLAI values are regressed and obtained a regression model (Eq. (4)) for the prediction of RS-based above-ground biomass (PAGB). PLAI layer is used as input and thus generated RS-based PAGB layer:

$$\text{PLAI} = a_1 \ln(\text{NDVI}) + b_1 \quad (r^2 = 0.68, \quad p \leq 0.05) \qquad (3)$$

$$\text{PAGB} = a_2\,\text{PLAI} - b_2 \qquad (r^2 = 0.63, \quad p \leq 0.05) \qquad (4)$$

where a_1, a_2 and b_1, b_2 are the constants.

Thus RS-based leaf area index image layer was generated from NDVI data using the regression coefficients obtained and the PLAI pixel values were compared with field measured LAI.

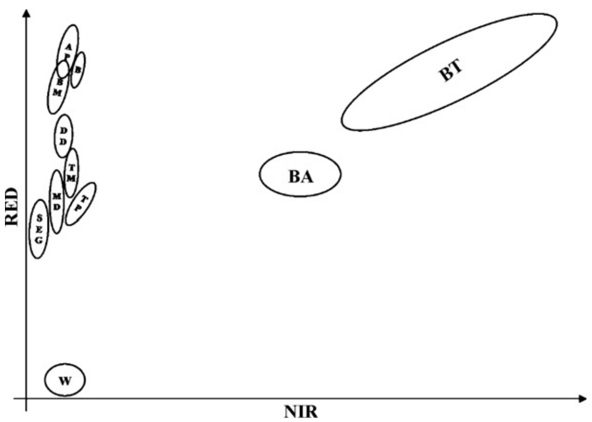

Fig. 2. Feature space image (fsp) analyses in delineation of land use/ land cover classes between NIR and Red channels of IRS P6 LISS-IV sensor. W, waterbody; SEG, semi-evergreen; MD, moist deciduous; DD, dry deciduous; TP, teak plantations; TM, teak mixed; B, bamboo; BM, bamboo mixed; AP, areca plantations; BA, barren area; BT, built-up area.

3. Results and discussions

Remotely sensed reflectance data are comprehensive responses of species composition, density and vegetation stand structure. Different forest types express different magnitudes of reflectance and have variable textural patterns in different wavelengths. Information extracted from LISS-IV data has facilitated the generation of maps on 1:12 000 scale with better planimetric fidelity (Fig. 3). Vegetation types viz. teak mixed, bamboo mixed teak and areca plantations are discriminated in the study area. The delineation of the closely related vegetation types (belonging to one major type) could be achieved due to the high-spatial resolution and better spectral reflectance response of plant canopies in the LISS-IV sensor.

3.1. Field data analysis and estimated above-ground biomass (EAGB)

Study area contains large and fragmented patches with various crown densities of deciduous forest patches with 42 species of trees and shrubs. Out of the total, 25 tree spp. are overstory tree species. The tree density in the study area ranged between 256 and 319 individuals per hectare. For each inventory plot, basal area was computed from collected ground data which is summarized in Table 1. Study area is dominated by mature tree stands (GBH < 200 cm), which may have a majority of their canopy materials in the top portion of the canopy with varied GBH values (30–280 cm).

The EAGB values ranged from 145 to 350 Mg ha^{-1} with an average of 280(±72.54) Mg ha^{-1} which is similar to studies carried out in the tropics (Table 2). Ground-based LAI and EAGB showed significant

Table 2
Comparison of biomass range in the study area with reference to reported values in literature

S. No.	Biomass (Mg ha^{-1})	Reference
1	220–260	Brown et al. (1997)
2	210–324.5	Clark et al. (2001)
3	281 ± 20	Chave et al. (2003)
4	311.70	Liu et al. (2006)
5	261.08	Soumit and Malaya (2006)
6	280 ± 72.54	Present study

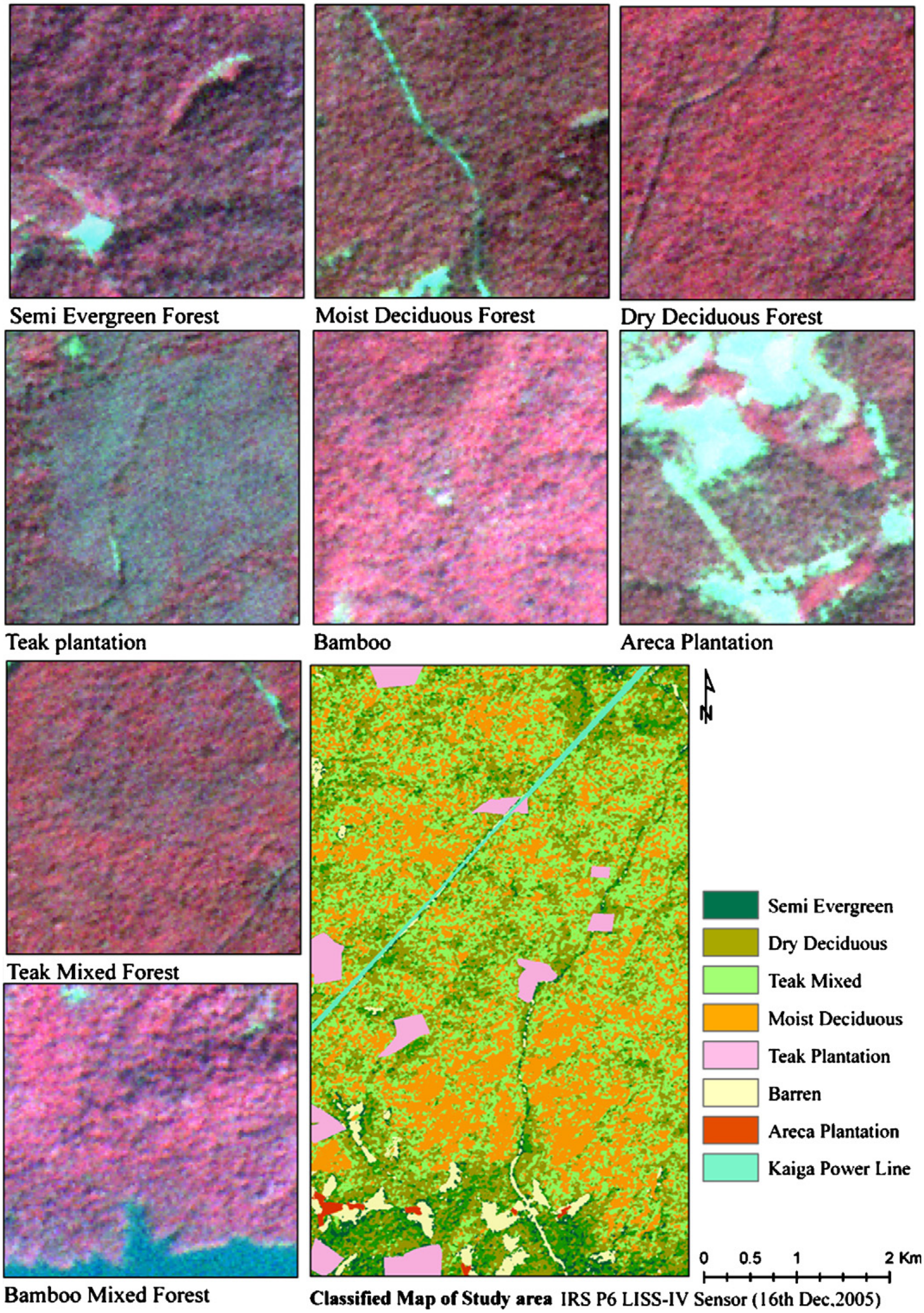

Fig. 3. Classified map of land use/land cover classes (Yellapur and Haliyal Forest area, Karnataka).

correlation ($r^2 = 0.62$, $p \leq 0.05$). ELAI values ranged from 2.5 to 7 with mean of 4.4($\pm$1.0). It is observed that as the leaf area (LAI) increases, there is proportionate increase in the estimated biomass.

3.2. Field measured LAI (ELAI) and NDVI

In conjunction with ground experience, regression analysis is done between ELAI and NDVI (Fig. 4).

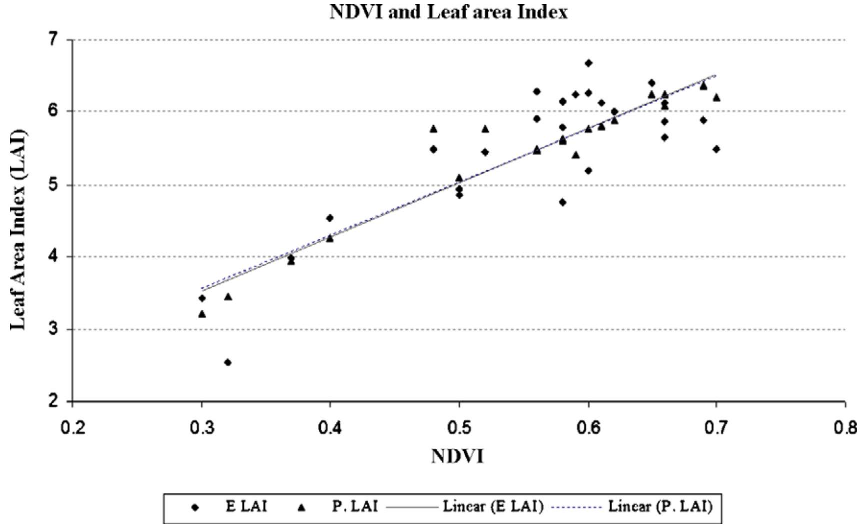

Fig. 4. Scatter plot describing the correlation between NDVI and field measured LAI and remote sensing image-based LAI in deciduous forests of Yellapur and Haliyal Forest areas, Western Ghats of Karnataka, India.

NDVI values ranged from 0.2 to 0.8 with a mean of 0.5. Positive correlation was observed between ELAI and NDVI ($r^2 = 0.68$, $p \leq 0.05$). As the ELAI value increases, a proportionate increase of NDVI values is observed. It shows that NDVI levels are good indicators of LAI values (Kawabata et al., 2001).

Chen and Cihlar (1996) found that the simple NIR/Red ratio and NDVI were correlated with LAI (up to $r^2 \sim 0.52$). Leaf optical properties are most directly expressed at the canopy level in the NIR spectral region when leaf area (LAI) is very high. The major limitation of using vegetation indices particularly NDVI is that they asymptotically approach a saturation level after a certain LAI 7.0 is reached (Thenkabali et al., 2000).

3.3. Remote sensing-based leaf area index (PLAI) and above-ground biomass (PAGB)

The observed mean values for PLAI and PAGB are 5.24(±0.84) and 297.6(±55.23) Mg ha^{-1}, respectively. Scatter plot (Fig. 5) with linear fit between PLAI and PAGB variables showed positive relationship ($r^2 = 0.75$,

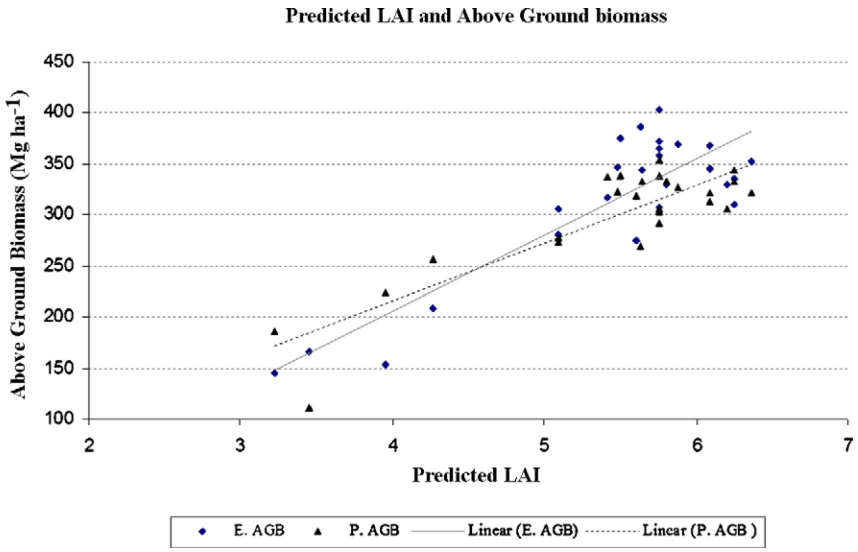

Fig. 5. Scatter plot describing the correlation between remote sensing image-based LAI and above-ground biomass (EAGB and PAGB) in deciduous forests of Yellapur and Haliyal Forest areas, Western Ghats of Karnataka, India.

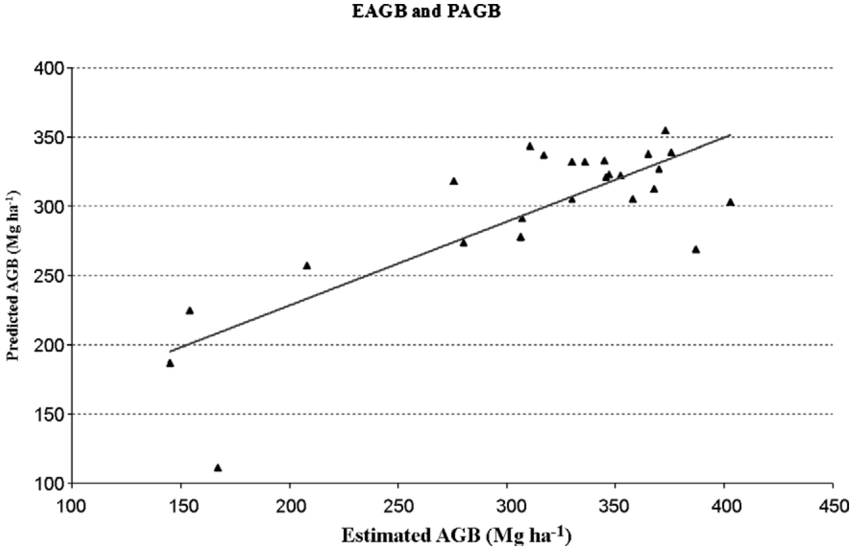

Fig. 6. Scatter plot describing the correlation between estimated above-ground biomass and remote sensing image-based AGB in deciduous forests of Yellapur and Haliyal Forest areas, Western Ghats of Karnataka, India.

$p \leq 0.001$). In a recent study, the relationships between above-ground biomass and spectral vegetation indices were compared and it was observed that overstory component of tree biomass has significant relationship with LAI and NDVI (Riedel et al., 2005).

Variation in PLAI resulted due to the interaction of electromagnetic radiation with vegetation canopies (Goel and Strebel, 1983), complex structure and amount of light availability of sparse vegetation. However, other limiting factors also influence the LAI such as water and nutrients availability, stand age and climatic factors.

3.4. Field estimated AGB (EAGB) and RS-based AGB (PAGB)

A significant 'r^2' of 0.63 ($p \leq 0.05$) exists between the estimated and predicted AGB (Fig. 6). The mean values of estimated and predicted AGB are 280(±72.54)

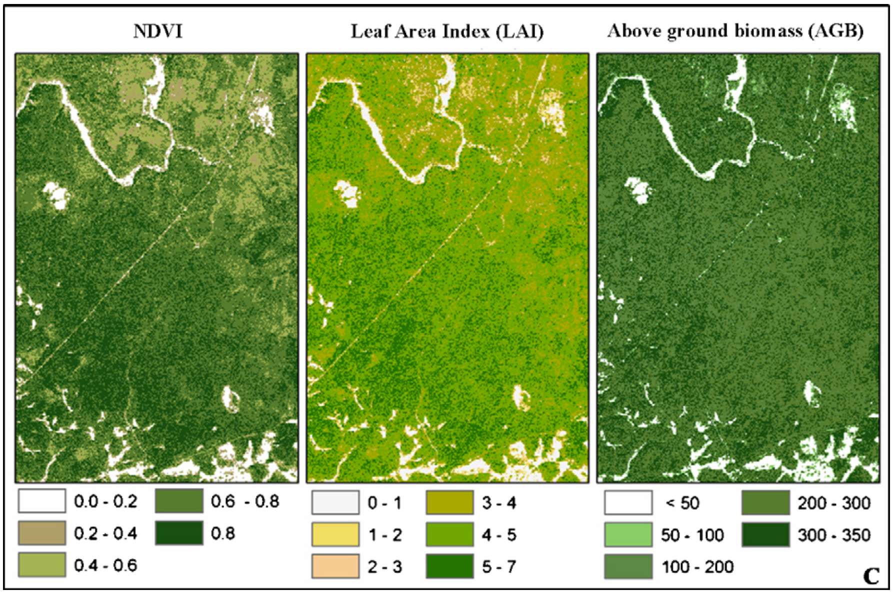

Fig. 7. Normalized differential vegetation index (A), leaf area index (B) and above-ground biomass (AGB) (C) layers of Yellapur and Haliyal Forest area, Western Ghats of Karnataka, India.

and 297.6(±55.23) Mg ha^{-1}, respectively. They are approximately in the same range.

The attempt made in this study showed strong possibility of using spectral response-based models for biomass estimation (Fig. 7). However it is noteworthy that remote sensing-based AGB estimation is a complex procedure in which many factors such as atmospheric conditions, mixed pixels, data saturation, complex biophysical environments, insufficient sample data, extracted remote sensing variables, and the selected algorithms, may interactively affect AGB estimation (Luther et al., 2006).

The increase in reflectance of the NIR provides a remarkable capability for distinguishing vegetation from almost any other surface material, especially soil and water. Thus, this contrast is the basis for the application of vegetation indices in the estimation vegetation parameters. Studies have established relationships between the LAI of the canopy and vegetation indices from the signal reflected from the top of the canopy in the NIR and Red regions of the spectrum. The LISS-IV data could be successfully used for forest patch level estimation with better accuracy.

4. Conclusions

Broad leaf tropical forests exhibit unique structural and environmental responses in the spectral domain. The increase in biomass levels results in the increase of reflectance values. NDVI, LAI and biomass are significantly correlated with ground estimated biophysical parameters. The regression models developed in this study can also help in generating spatial biomass map using RS data alone with better precision and less effort for tropics where spectral biomass maps are either unavailable or have large uncertainties because of coarse resolution.

The future research should focus on the integration of multi-source data, which involves the effective integration using remotely sensed data. A model that incorporates remotely sensed data and associated ancillary data has the potential to improve model performance and is more applicable to a large study area. Such a model is best developed through integration of geographic information system (GIS) and remote-sensing techniques, and should be especially valuable if the required ancillary data can be captured.

Acknowledgements

The authors are grateful to the Director, Deputy Director (RS/GIS-AA), Group Director, LRG and Head, Forestry and Ecology Division, NRSA for providing the facilities to carry out the studies and thanks are due to Indian Space Research Organization (ISRO-GBP) for financial support. Authors also thank Dr. K.M.M. Rao, Deputy Director (DP), NRSA for the important suggestions in the manuscript preparation. Thanks are due to Divisional Conservator of Forests and the field staff of Yellapur and Haliyal Divisions, Karnataka Forest Department for assistance in field data collection. Authors also thank to colleagues of Forestry and Ecology Division for their cooperation.

Appendix A. Abbreviations used in the study

Abbreviation	Explanation
GBH	Girth at breast height
EAGB	Ground-based estimates of above-ground biomass
PAGB	Remote sensing-based estimates of above-ground biomass
ELAI	Ground measured leaf area index using Plant Canopy Analyzer-2000
PLAI	Spectral-based estimated leaf area index
NDVI	Normalized differential vegetation index

Appendix B. IRS P6 LISS-IV sensor specifications

IGFOV (across track)	5.8 m
Ground sampling distance	5.8 m
Spectral bands	B2, B3, B4
Swath	23.9 km (multispectral mode)
Saturation radiance (mw/(cm^2 sr μm))	B2–55 (0.52–0.59 μm; Green) B3–47 (0.62–0.68 μm; Red) B4–31.5 (0.76–0.86 μm; NIR)

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