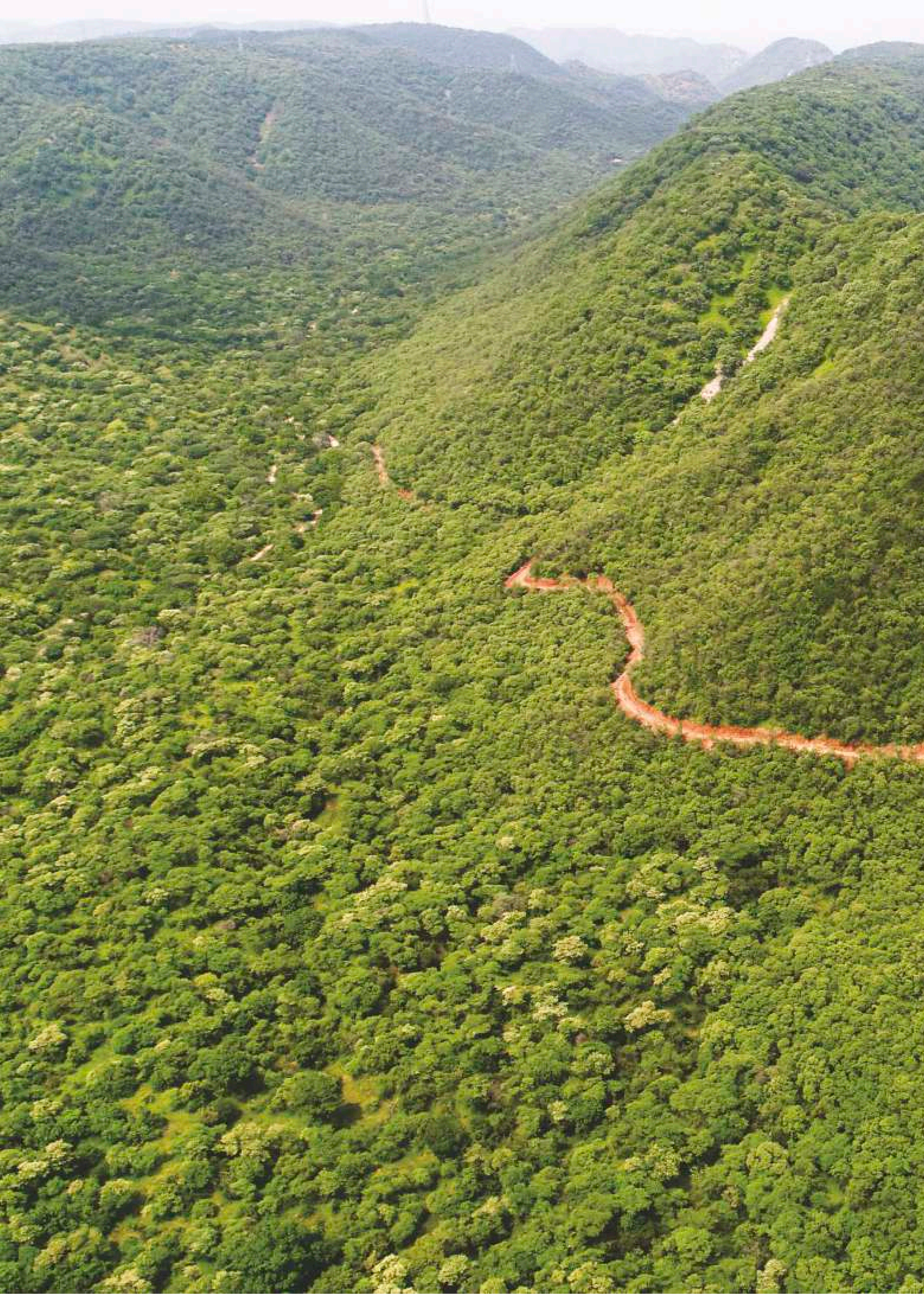
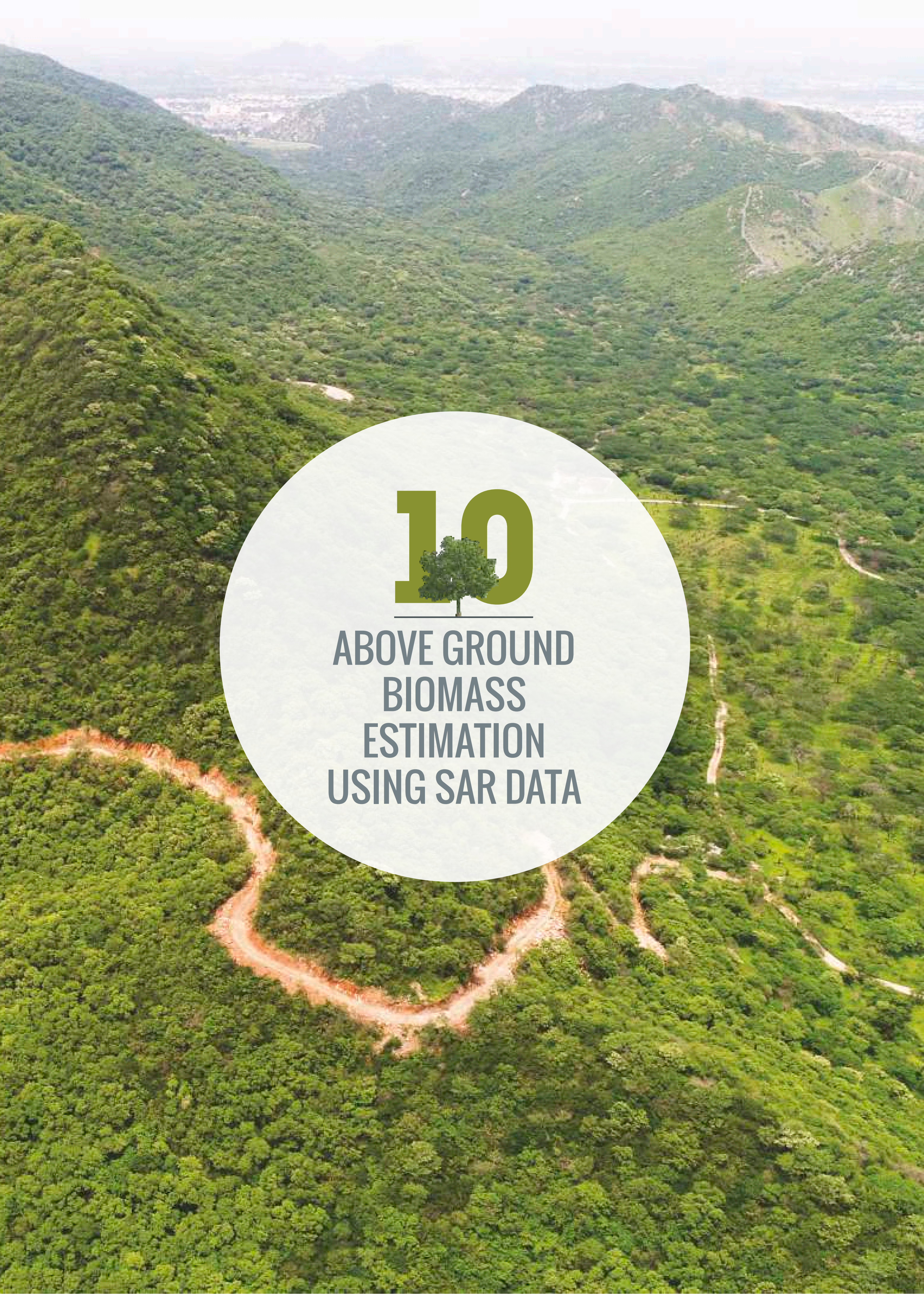




10

ABOVE GROUND BIOMASS ESTIMATION USING SAR DATA

Introduction 10.1

Forests are important constituents of ecosystems worldwide. Forests perform a variety of ecosytem services, one of the most vital ones being absorbing Carbon dioxide from the atmosphere and converting it into biomass. Biomass refers to the mass of the living organism within a tree. Forest biomass comprises nearly 80% of the total biomass on the earth (Reichstein & Carvalhais, 2019)[1] . Estimation of forest biomass helps in enhancing our understanding about the global carbon sink, assessment of carbon stock and the commercial significance of forest through wood production. Mapping and monitoring of forest biomass provides valuable insight into health of forests, carbon stock, carbon sink and sources as well as issues related to Green House Gas (GHG) emissions.

Forest degradation has emerged as a major concern for the global community. World over, strategies are being formulated and implemented to promote sustainable development of the forest and reduction in deforestation/ degradation. Some of these programmes include Reducing Emission from Deforestation & Forest Degradation Plus sustainable forest management and enhancing forest carbon sink (REDD+), Paris Agreement, AICHI targets, Sustainable Development Goals (SDG's) etc.

Forest Survey of India (FSI) has been using field inventory techniques to assess number of trees, growing stock, bamboo estimates, soil carbon, and several other parameters that depict growth & health of forests. Such estimation is based on statistical analysis of field inventory data and provides a larger picture regarding forest biomass. However, data collection from the field is expensive, time consuming, labour intensive, and does not necessarily provide a synoptic coverage of biomass distribution. There are situations when it is not possible to collect data from remote & inaccessible areas. These limitations may be overcome by using remote sensing based tools and techniques.

Information about spatial distribution of the forest biomass and the biomass categories is important for proper management of the forest resources. In 2018 FSI, in collaboration with Space Application Centre (SAC), ISRO, Ahmedabad initiated a special study for estimation of Above Ground Biomass (AGB) at pan-India level using L- band of Synthetic Aperture Radar (SAR) data. The results for the States of Assam and Odisha (as well as AGB maps), were presented in ISFR 2019. The interim results for AGB estimates (and AGB maps) for the entire country are being presented in this chapter. The detailed report will be published on completion of the study.

[1] *M. Reichstein & N. Carvalhais, 2019, Aspects of Forest Biomass in the Earth System: Its Role and Major Unknowns, Surveys in Geophysics volume 40, pages 693-707*

10.1.1 Objectives of the Assessment

The study has been undertaken to achieve the following objectives

- Explore the potential of Synthetic Aperture Radar (SAR) data for understanding forest structure and ultimately biomass within forest.
- Generate estimates of forest biomass at state and country level.
- To prepare AGB map of the country on wall-to-wall basis.
- Synthesize National Forest Inventory data for generation of forest biomass at plot level basis.

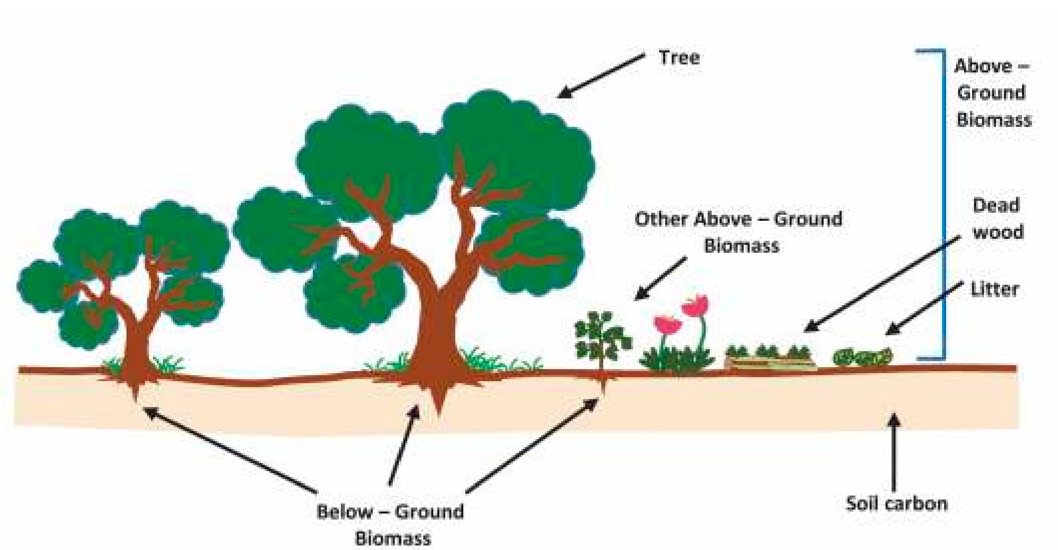
10.2 Forest Biomass

According to IPCC GPG 2003[2] , Forest biomass is an organic product of photosynthesis which is broadly divided into two components:

Above Ground Biomass (AGB) contain the part of vegetation above the ground e.g. stumps, tree, deadwood, litter and foliage.

Below Ground Biomass (BGB) which includes the parts of the tree (roots) which are situated under the ground.

Figure 10.1 Types of Forest Biomass



Source: The IPCC GPG (2003) - Five Carbon Pools

Globally, AGB is a commonly estimated parameter because of its utility in estimation of forest, atmospheric carbon and the GHGs. The present study has focused on the AGB and not ventured into the estimation of the BGB owing to limitation of sensor and non- availability of data for BGB estimates.

[2] *IPCC, 2003. Good Practice Guidance for LULUCF*

Importance of estimating Above Ground Biomass 10.2.1

- Forest biomass serves as an important variable for evaluating carbon sequestration and carbon balance capacity of forest ecosystems.
- Biomass is an important indicator of ecological and management processes in the vegetation[3].
- AGB assessment and monitoring is important for national GHG inventory and activities related to forest ecosystem.
- Provides important inputs for policy formulation related to forestry sector and environment management.
- Provides important information for forest fire risk assessment.
- AGB is the most visible of all the carbon pools, and change in AGB indicates the impact of an intervention on the carbon pool.

Different methods for Above Ground Biomass estimation 10.2.2

With the advancement of technology, techniques for assessment of biomass have changed from the traditional field measurement to the satellite based approaches. Traditionally, biomass has been measured by ground measurement through collection of information on DBH (Diameter at Breast Height), number of tree species, tree height etc. within sample plots. Weighing trees in the field is the most accurate method for estimating tree biomass. Biomass of a tree, till now has been calculated though volumetric or allometric equations in many of the countries.

Remote sensing data provides information based on spatial, spectral and temporal requirements, thereby allowing a synoptic coverage of large area. Optical remote sensing (visible to near infra-red part of the electromagnetic spectrum) is a widely used technology for mapping and monitoring forest resources. These systems use variable spectral response pattern from the visible and near-infrared spectral regions. The optical remote sensing data has been used by researchers to estimate forest biomass. However, due to data saturation beyond 30-50 tonnes/ ha, the estimates for higher biomass regions are not precise enough. Moreover, poor penetration capabilities of this part of the spectrum through forest canopy & cloud, functionality during day light hours only, and its dependence on weather conditions limits its usage for biomass estimation studies.

LiDAR (Light Detection and Ranging) is a laser scanning technique, which works in the near infra-red part of the electromagnetic spectrum (0.75 μm to 1.5 μm). It is a widely used technology for biomass estimation through 3D point cloud data. 3D point cloud data provides detailed information regarding structure and height of trees. However, LiDAR data is limited to small scale studies, as it is not freely available and is expensive when used for estimating biomass. With the advancement in space technology in terms of sensor resolution, data capture and synoptic coverage, Microwave Remote Sensing is currently the preferred technology for biomass estimation. Microwave Remote Sensing offers certain advantages like:

- Deep penetration capability within tree canopy thus allowing more information on tree structure and under the canopy.
- As an active sensor, it can capture data during day and night without any adverse effect due to atmospheric distortions.

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[3] *Principles of Vegetation Measurement & Assessment and Ecological Monitoring & Analysis University of Idaho. https://www.webpages.uidaho.edu/veg_measure/Modules/Lessons/(Biomass&Utilization)*

- Microwave data is weather independent.
- Provides information on surface granularity, dielectric properties and moisture content.
- Imaging the earth surface from different type of polarizations (J.R. Jensen, 2007[4]) serves as a means for better feature extraction.

Of all the available Microwave bands, L-band is widely used for forest biomass estimation due to their longer wavelengths and deep penetration from tree canopy and better interaction in the form of backscatter from branches and tree trunk as illustrated below:

Table 10.1 Different bands of Microwave Data

RADAR Bands	Wavelength (cm)	Frequency (GHz)
Ka	0.75-1.13	26.5-40.0
K	1.13-1.67	18.0-26.5
Ku	1.67-2.4	12.5-18.0
X	2.4-3.75	8.0-12.5
C	3.75-7.5	4.0-8.0
S	7.5-15	2.0-4.0
L	15-30	1.2-2.0
P	30-100	0.3-1.0

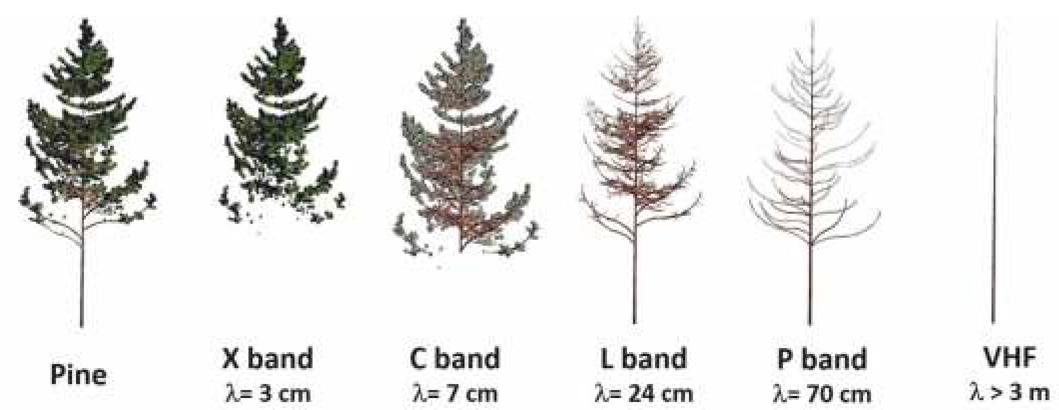


Figure 10.2 Penetration capability of RADAR (Microwave) Data

10.3 Data Used

Following data have been used for estimation of AGB for pan-India.

[4] *John R. Jensen (2007). Remote sensing of the environment: An earth Resource Perspective*

ALOS PALSAR-2 Data 10.3.1

In this study, Phased Array type L-band Synthetic Aperture Radar (PALSAR-2) on -board Advanced Land Observing Satellite (ALOS) Global Mosaic with resolution of 25 m data from Japan Aerospace Exploration Agency (JAXA)[5] has been used. The detailed specification of ALOS PALSAR-2 is given in Table 10.2 and the synoptic coverage is shown in Figure 10.3.

Table 10.2 Detailed specification of ALOS PALSAR-2

Satellite	ALOS PALSAR - 2
Calibration Factor	-83
Band	L-band
Resolution	25 m
Level	2
Polarization	HH+HV

Source: Japan Aerospace Exploration Agency (JAXA)

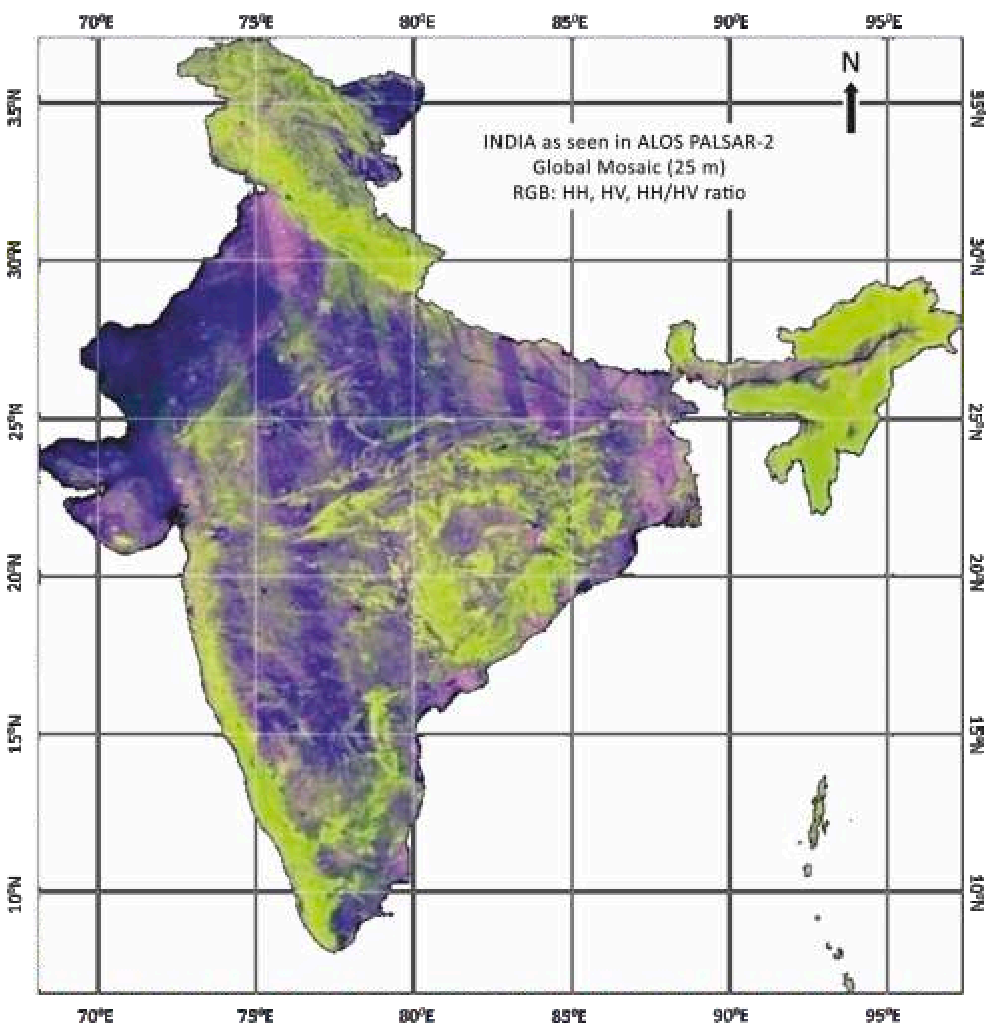


Figure 10.3 ALOS PALSAR-2 False Colour Composite of pan-India

Source: Space Application Centre (SAC)

[5] (http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/data/index.htm)

10.3.2 Field Inventory Data

Forest inventory data collected by field parties of FSI has been synthesized to generate plot-level forest biomass data. This data has been further used to train the biomass models for generation of pan-India biomass estimates. A total of 7,835 plot level data have been used. Prior to processing the information from inventory plots, they have been verified using high resolution Google Earth imagery. Inventoried sample plots with undulating terrain and heterogeneous species have been removed from analysis to minimise errors. Finally, 6,763 plots have been selected for analysis. The zone-wise distribution of sample plots has been carried out on the basis of distribution of inventory data and physiographic zones of India as illustrated in Table 10.3 and Figure 10.4.

Table 10.3 Zone-wise distribution of Inventory data

Zones	States/Union Territories	No. of plots
Zone 1	Jammu & Kashmir, Ladakh, Uttarakhand and Himachal Pradesh	814
Zone 2	Punjab, Haryana, Delhi, Chandigarh and Uttar Pradesh	346
Zone 3	Rajasthan, Gujarat and Daman & Diu	559
Zone 4	Madhya Pradesh	823
Zone 5	Jharkhand, West Bengal and Bihar	548
Zone 6	North-Eastern states and Darjeeling(West Bengal)	1,056
Zone 7	Chhattisgarh and Odisha	1,032
Zone 8	Maharashtra, Dadra & Nagar Haveli and Telangana	904
Zone 9	Goa, Karnataka and Andhra Pradesh	1,030
Zone 10	Kerala, Lakshadweep, Tamil Nadu and Puducherry	671
Zone 11	Andaman & Nicobar Islands	44

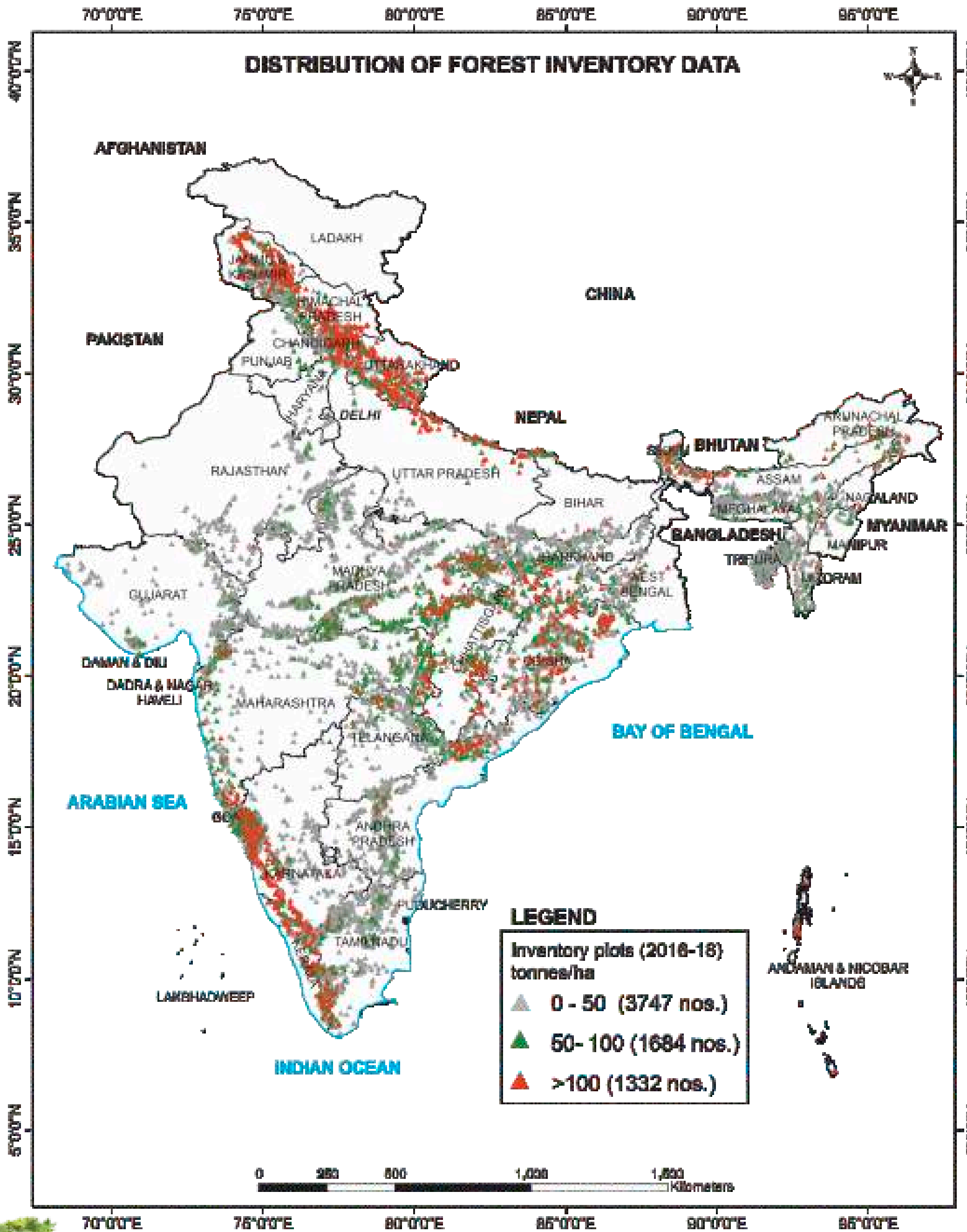


Figure 10.4 Distribution of Inventory Data in India

Forest Cover Map, 2019 10.3.3

Forest Cover map of ISFR 2019 assessment has been used in the study to mask out forest cover for estimation of AGB.

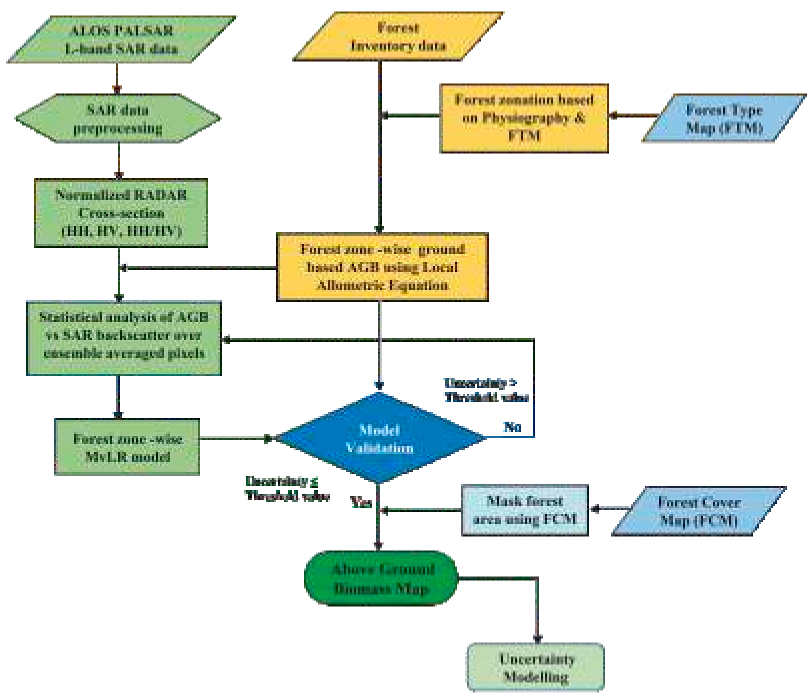
10.3.4 Forest Type Map, 2020

Forest type information has been used from Atlas Forest Types of India 2020 for analysis and validation of AGB maps. Preliminary validation of the generated biomass has been carried out using Forest Type maps. Backscatter (dependent on dielectric constant and surface granularity of the feature) has been found to have a good correlation with the different Forest Type Groups.

10.4 Methodology

The flowchart of the methodology used in the estimation is given in Figure 10.5. National Inventory Data at one hectare plot level have been used for calculation of biomass value in the individual plots.

Figure 10.5 Flowchart of the methodology used for AGB Estimation



10.4.1 Pre-processing of data

The sample biomass plots have been converted as geospatial vector layers to be further overlaid on SAR data to retrieve mean value by averaging of 3 X 3 pixels. ALOS PALSAR-2 data is ortho-rectified using SRTM data. The by-product of Shuttle Radar Topography Mission - Digital Elevation Model [SRTM (DEM)] data, slope and aspect map has been helpful to identify very steep slope areas and shadow region according to the sensor look angle and for topographic correction.

ALOS PALSAR-2 global mosaic data has been radiometrically calibrated to convert the DN value to sigma naught (σ°) in decibel unit (dB) in order to generate backscatter image in different polarization levels (HH, HV, and HH/HV). The calibrated Synthetic Aperture Radar (SAR) data is helpful for information extraction through statistical methods. The following equation has been used for conversion of DN image into backscatter:

$$\sigma^{\circ}(dB) = 10*\log_{10}(DN^{2}) + CF \qquad \dots (1)$$

Where,

σ°(dB) = Backscattering coefficient (Sigma Naught) [unit: dB]

DN = Digital number (or raw pixel value)

CF = Calibration factor

Zonal analysis of biomass has been carried out on the basis of physiographic division of India and distribution of Field Inventory Data.

Source: Japan Aerospace Exploration Agency (JAXA)

Statistical Analysis 10.4.2

Correlation analysis helps to understand the relationship between two or more different variables. Coefficient of correlation (r) shows whether the relation is positive or negative which ranges from -1 to +1 between the variables. The relationship between the reference AGB obtained from field inventory plots (ground measured) and backscatter values of SAR data (HH, HV and HH/HV) has been analysed using scatterplot. The result shows HH and HV have good agreement with ground measured AGB values.

Multi-Linear Regression (MLR) technique 10.4.3

This technique has been used to model the best fitted variables (HH, HV) based on correlation analysis between ground measured AGB and SAR Data. Backscatter values of HH and HV polarised SAR data have been used as an independent variable values and ground measured AGB as dependent variables in the study to generate model coefficient which have been further used to estimate AGB for pan-India.

The biomass equation used in the present study is given below:

$$Y_{\text{Biomass (tonnes/ha)}} = A + (B * \sigma^{\circ}a_{1}) + (c * \sigma^{\circ}a_{2}) \qquad \dots (2)$$

Where,

Y = Predicted Biomass

A, B, C = Model coefficient

a1, a2, .. = Selected Parameters (HH, HV, HH/HV etc.)

Masking of Forest Cover Areas 10.4.4

The Forest Cover map (ISFR, 2019) has been used to mask out the forest and non-forest area from the estimated AGB data. Finally, AGB map has been produced.

10.5 Results & Analysis

The preliminary results of AGB estimation for the country are presented in Table 10.4 and pan-India map (MMU 1 ha) is shown in Figure 10.7. Based on the analysis, the AGB estimates have been divided into six classes (from greater than 0 tonnes/ ha to above 150 tonnes/ ha) with an interval of 30 tonnes/ ha.

Table 10.4 Class-wise distribution of Above Ground Biomass in India

Colour	AGB (tonnes/ ha)	Area (sq.km)	AGB (within forest cover in %)	Total Geographical Area (%)
(yellow)	< 30	2,06,651.61	27.24	6.28
(light green)	30-60	98,525.22	12.99	3.00
(dark green)	60-90	1,23,014.57	16.22	3.74
(blue)	90-120	1,33,226.30	17.56	4.05
(pink)	120-150	1,02,894.01	13.57	3.13
(red)	>150	94,234.19	12.42	2.87

The above classification has been adopted due to sensitivity of SAR backscatter to the soil moisture, terrain properties and sensor parameters which affects SAR backscatter values, although there may be minimum difference in the forest canopy and tree structure. Class-wise distribution of AGB for the entire country has been shown in a pie-chart in Figure 10.6. Based on the analysis of the AGB estimates, it has emerged that the highest percentage of forest cover falls under the class of <30 tonnes/ha, whereas the lowest percentage of forest cover falls under the class of >150 tonnes/ha. The status of AGB estimates in State/UTs of India is presented in Table 10.5.

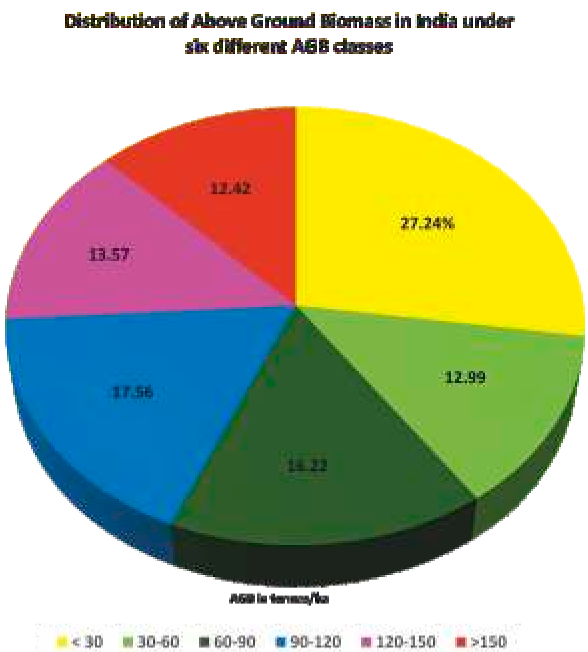
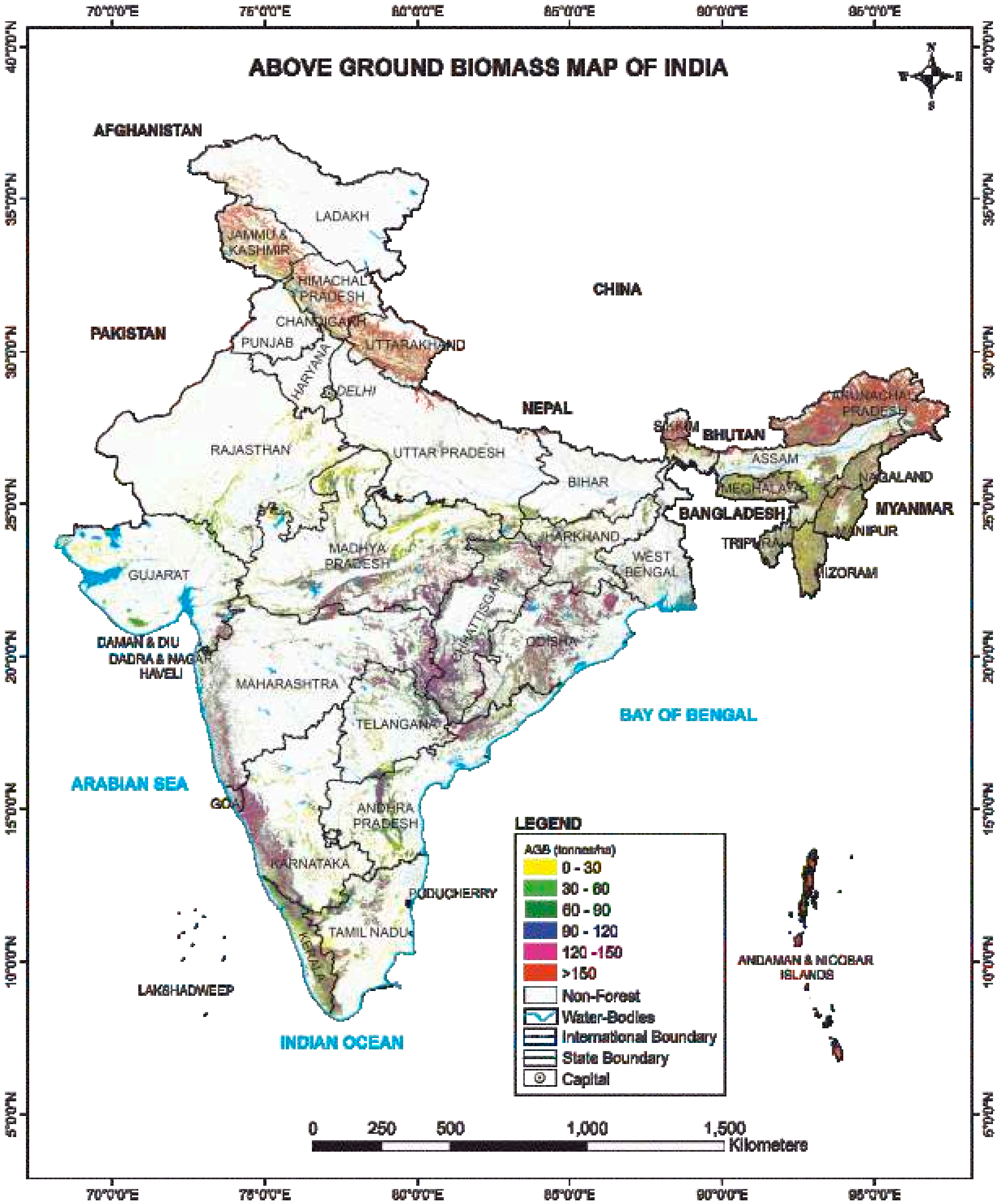


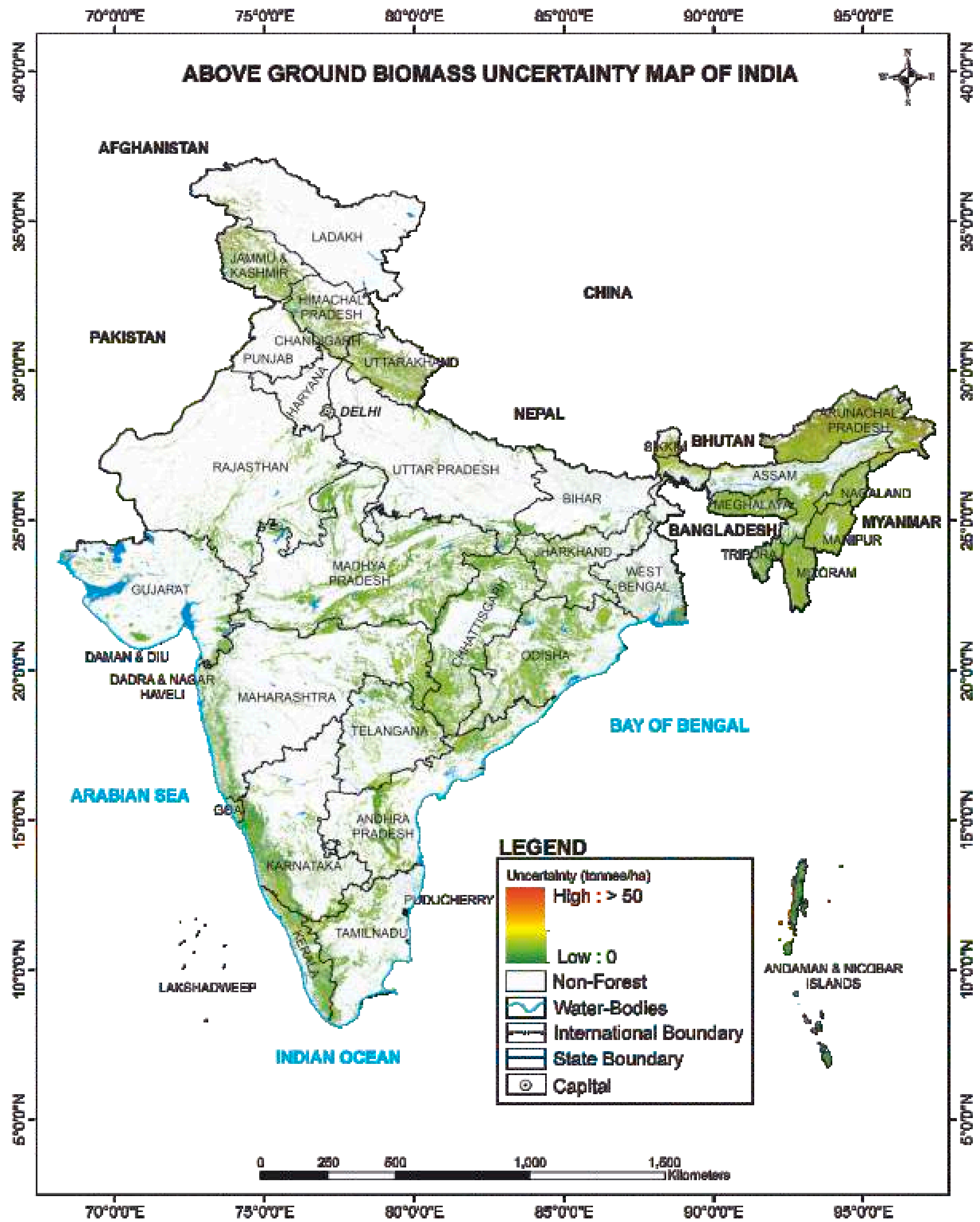
Figure 10.6 Pie-chart showing Class-wise distribution of AGB in India

Figure 10.7 Above Ground Biomass Map of India



** Based on the above method Country level wall to wall Above Ground Biomass map is prepared. However, the detailed observations and the State/UT-wise assessment will be provided in a separate report*

Figure 10.8
Above Ground Biomass Uncertainty Map of India



State wise Area of Above Ground Biomass of India 10.5.1

Table 10.5 Above Ground Biomass in the State/UTs in India (in sq km)

Sl. No	State/UTs		Geo-graphical Area	AGB Classes					
				<30	30-60	60-90	90-120	120-150	>150
1	Andhra Pradesh		1,62,968	11,045.73	6,533.36	7,665.03	6,782.30	3,845.89	1,519.93
2	Arunachal Pradesh		83,743	7,907.54	5,000.40	7,519.47	10,591.51	12,661.69	23,236.64
3	Assam		78,438	10,161.22	4,362.87	4,705.78	4,282.09	3,145.10	1,842.89
4	Bihar		94,163	3,174.26	1,144.08	1,278.21	1,033.61	507.69	418.02
5	Chhattisgarh		1,35,192	8,446.90	6,450.63	11,302.38	15,473.99	11,306.16	3,240.03
6	Delhi		1,483	79.93	83.73	30.62	1.35	0.08	0.03
7	Goa		3,702	167.50	176.47	354.31	551.46	588.81	398.94
8	Gujarat		1,96,244	9,442.12	3,478.48	2,304.38	1,275.47	894.08	456.91
9	Haryana		44,212	1,063.07	276.13	124.53	81.31	64.63	147.05
10	Himachal Pradesh		55,673	3,772.31	1,285.04	1,550.04	1,651.19	1,751.97	5,738.25
11	Jharkhand		79,716	7,921.57	3,670.34	4,508.85	4,355.58	2,823.64	1,019.48
12	Karnataka		1,91,791	9,905.73	5,252.02	7,318.63	9,022.70	7,617.19	3,943.28
13	Kerala		38,852	5,573.32	3,559.87	4,318.11	3,852.45	2,432.63	1,421.29
14	Madhya Pradesh		3,08,252	29,160.26	11,281.86	14,299.41	15,174.22	10,076.77	3,491.88
15	Maharashtra		3,07,713	10,108.10	6,468.74	9,935.12	13,321.43	11,110.95	4,089.71
16	Manipur		22,327	4,983.90	2,798.43	3,176.27	2,956.12	2,149.02	1,964.63
17	Meghalaya		22,429	5,518.72	2,847.36	3,234.68	2,924.61	1,915.56	1,277.69
18	Mizoram		21,081	6,482.97	2,858.25	2,922.33	2,429.45	1,585.20	1,728.21
19	Nagaland		16,579	3,146.40	1,977.08	2,326.78	2,271.34	1,766.55	1,633.74
20	Odisha		1,55,707	8,979.89	7,345.60	11,016.77	13,256.78	10,357.34	4,989.04
21	Punjab		50,362	931.02	219.62	202.72	176.62	137.12	214.46
22	Rajasthan		3,42,239	1,30,31.24	4,270.36	2,369.88	1,121.92	448.90	147.26
23	Sikkim		7,096	393.21	267.16	398.56	551.52	672.51	1,366.18
24	Tamil Nadu		1,30,060	10,400.43	3,715.77	4,509.31	4,207.45	2,857.57	1,388.20
25	Telangana		1,12,077	6,788.74	3,741.18	4,976.14	5,105.80	2,855.77	729.72
26	Tripura		10,486	2,010.01	1,198.77	1,497.10	1,460.24	1,028.16	560.10
27	Uttar Pradesh		2,40,928	6,968.66	1,947.14	1,775.99	1,282.40	676.71	2,741.27
28	Uttarakhand		53,483	5,021.05	1,908.31	2,440.50	2,922.21	3,281.89	9,112.25
29	West Bengal		88,752	6,409.53	2,321.73	2,686.36	2,724.62	1,889.04	1,016.34
30	A & N Islands		8,249	41.80	54.06	64.70	74.12	80.79	6,428.43
31	Chandigarh		114	9.17	2.45	2.83	2.56	1.89	3.23
32	Dadra & Nagar Haveli and Daman & Diu		602	76.71	51.40	49.35	34.62	15.59	5.10
33	Jammu & Kashmir	UT of J&K	53,258*	6,169.31	1,693.72	1,875.92	2,024.70	2,135.37	7,473.12
		UT of Ladakh	1,69,421*	1,305.59	269.20	265.06	245.76	211.05	490.63
		Total	2,22,236	7,474.90	1,962.92	2,140.98	2,270.46	2,346.42	7,963.75
34	Lakshadweep		30	15.95	6.62	3.48	0.95	0.10	0.00
35	Puducherry		490	37.76	7.00	4.98	1.84	0.58	0.25

** Area of shape file provided by Survey of India (December, 2019). Notified geographical area from SOI awaited.*

The generated AGB map shows good correlation with Forest Type Map and Forest Cover Map. The higher values of AGB (>150 tonnes/ha) indicate healthy and Very Dense Forest which is mainly found in hilly areas of Arunachal Pradesh, Uttarakhand and Himachal Pradesh some parts of Western Ghats, part of Central India and Andaman & Nicobar Islands. Most part of Western India contains low biomass values (<60 tonnes/ha) owing to forest density and tree structure.

10.5.2 Comparison of AGB with Forest Cover Map

Comparative analysis has been carried out between predicted AGB (extracted value of AGB using 1,835 random points distributed across the forest cover of the country) for pan-India and Forest Cover Map (ISFR 2019) using line graph shown in Figure 10.9 and Figure 10.10. The line graphs illustrate the trend of forest density classes over each AGB Classes. It can be inferred that the density of forest cover has positive correlation with the increasing biomass.

Figure 10.9 Comparison between Above Ground Biomass and Forest Cover Map

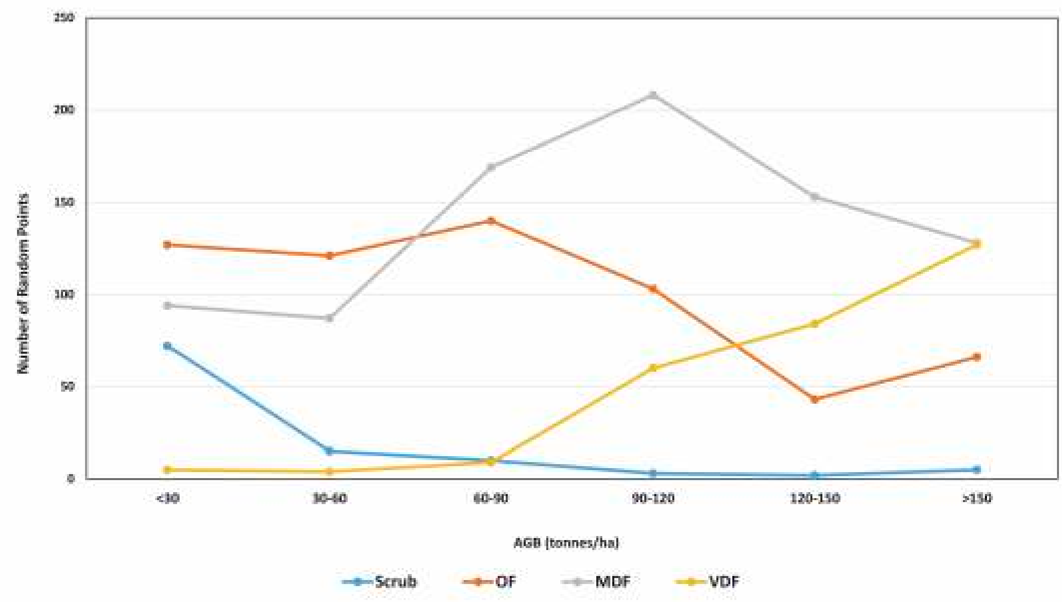
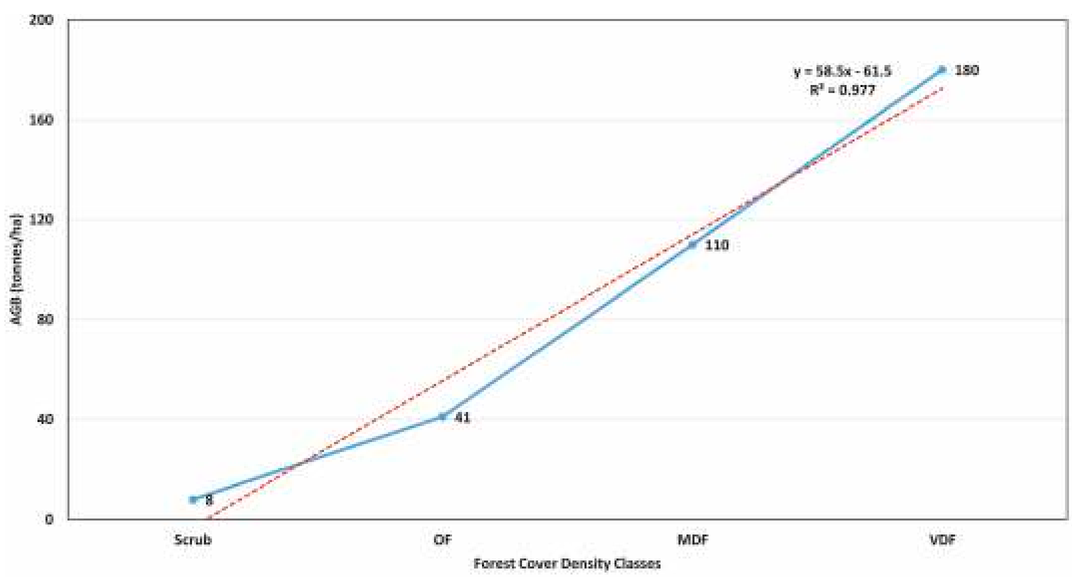


Figure 10.10 Trend of average AGB over each forest cover density classes



The key points are highlighted as given below:

- Average AGB increases with increasing forest density.
- Average AGB for VDF is 180 tonnes/ha, MDF is 110 tonnes/ha, OF is 41 tonnes/ha and Scrub is 8 tonnes/ha.
- AGB estimates have shown good agreement (r^2= 0.977) with forest cover map (ISFR, 2019).

The comparison between reference AGB and estimated AGB under each AGB range is shown in Figure 10.11. From the figure it can be inferred that:

- The estimated biomass is generally higher than the reference AGB under the AGB range of 60-90 tonnes/ha; 90-120 tonnes/ha; and 120-150 tonnes/ha respectively.
- Furthermore, number of observation in reference AGB are higher in rest of the classes under each biomass range (<30 tonnes/ha, 30-60 tonnes/ha, and >150 tonnes/ha) as compared to estimated AGB.

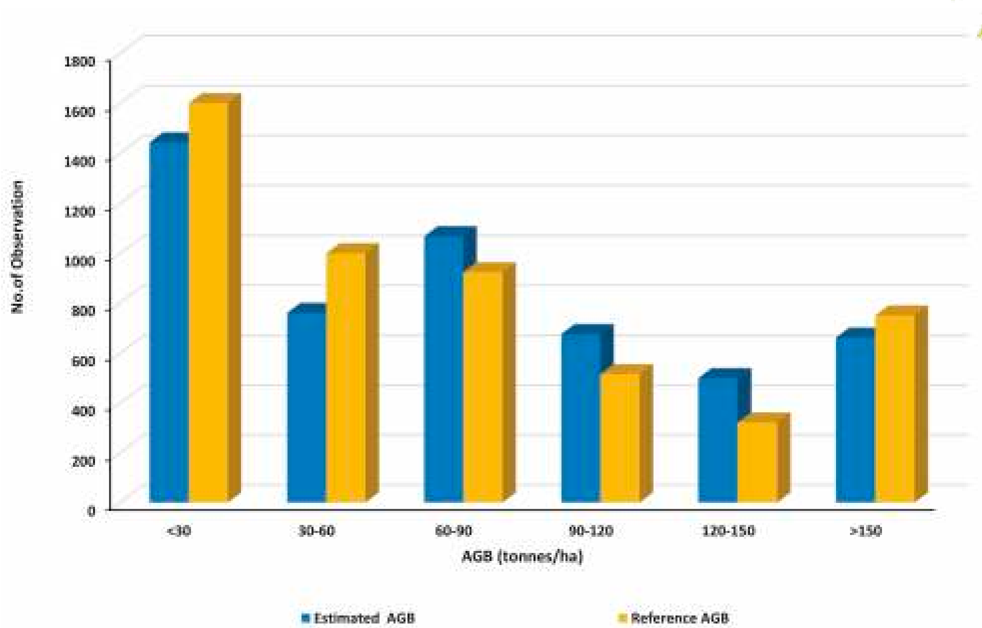


Figure 10.11 Comparison between Reference AGB and Estimated AGB per AGB classes

Key findings of the study 10.5.3

- There is a positive correlation between forest density classes and AGB estimated classes.
- Average biomass values increase with the increase in forest density.
- The highest percentage of forest cover comes under the class of <30 tonnes/ha, whereas the lowest percentage of forest cover comes under the class of >150 tonnes/ha.
- Highest AGB class is observed in the areas having least anthropogenic activity e.g. Andaman & Nicobar Islands, Arunachal Pradesh, Uttarakhand and Himachal Pradesh.
- In the Western part of the country, the majority part of forest cover area shows low biomass values e.g. Rajasthan and Gujarat.
- AGB classes vary with the change in Forest Type Group.
- SAR data has shown promise for biomass estimation at country level.

10.6 Limitations

RADAR data has certain inherent limitations such as data saturation and difficulty in distinguishing forest type, speckle noise, topography effects in undulating terrain such as Speckle, Geometric Distortion (Layover, Foreshortening & Shadow).

Use of other data such as Landsat-8 OLI, Canopy Height Data, FTM and others is being explored for overcoming limitations due to topographical errors of SAR data.

10.7 Conclusion

The correlation analysis between the AGB and the HV, HH, and HV/HH polarised backscatter reveals that the HH, HV polarized backscatter has better correlation as compared to HH/HV polarization. HH, HV polarized backscatter and field biomass values have been used to develop MLR model which have been further used to generate model coefficient for estimation of AGB map. The result suggests that the use of MLR model is quite effective for AGB estimation at country level. The use of ancillary data in combination with SAR data have been effective in improving coefficient of correlation (r) using MLR model. It has been found that biomass estimation have significant constraint over the mountainous areas.