

ESTIMATION OF BIOMASS AND CARBON POOL IN BARKOT FOREST RANGE, UK USING GEOSPATIAL TOOLS

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ABSTRACT:

The forest ecosystem is an important carbon sink and source containing majority of the aboveground terrestrial organic carbon. Carbon management in forests is the global concern to mitigate the increased concentration of green house gases in the atmosphere. The present study estimated vegetation carbon pool and biophysical spectral modelling to correlate biomass with reflectance/ derivatives in Barkot Forest Range, Uttarakhand. The study was carried out using Cartosat-1, IRS-P6 LISS-IV MX, IRS LISS-III, Landsat 7 ETM satellite data and ground data collected from stratified random sampling. Forest type and forest crown density was mapped using resolution merged Cartosat-1 and LISS-IV imagery. Growing stock, biomass and carbon was calculated for the individual sample plots using inventory-based biomass assessment technique. Field-inventoried data was correlated with the surface reflectance and derivatives of it. Among the four vegetation types, viz. *Shorea robusta*, *S. robusta* mixed, *S. robusta Tectona grandis* mixed, *T. grandis* plantation, mixed plantation, Grassland and Agriculture/ orchard, the *S. robusta* was found to be the dominant vegetation in the area, covering 55.86 km² of the total area. The study revealed that the *S. robusta* with high density had the highest aboveground biomass (AGB) (t/ha) was found in *S. robusta* > 70 % (530 t ha⁻¹), followed by *S. robusta* 40 – 70 % (486 t ha⁻¹) and minimum was found in mixed plantation <10% (101 t ha⁻¹). The general trend showed the decrease in AGB with decrease of forest density in each forest type category. The average AGB of *S. robusta T. grandis* forest was found (308 t ha⁻¹-458 t ha⁻¹) due to the dominancy of *S. robusta* trees. The study highlighted the invaluable role of geospatial technology and field inventory for growing stock, biomass and carbon assessment.

1. INTRODUCTION

Forests play an important role in stabilizing the atmospheric concentration of CO₂ as they can be both sinks and sources of carbon depending upon the succession, disturbances and management practices. It is estimated that 2-4 Gt C of atmospheric carbon can be sequestered by forests annually (Lu et al. 2010; Qureshi et al. 2012). Forests contain about 50% of the world's terrestrial organic carbon stocks, and forest biomass constitutes about 80% of terrestrial biomass. Forests also contribute over two thirds of global terrestrial net primary production. Each year, forests lock up 335-365 Gt of carbon making them a viable solution to climate change mitigation (MEA, 2005). Tropical forests store roughly 475 Bt of carbon (Pan et al. 2011). Retaining this carbon through conservation and increasing its stock through management activities, promote forest growth that will play a major role in curbing the CO₂ concentration in atmosphere (Valentin B. and Sebastiaan L., 2015).

Increasing temperatures, longer dry seasons and increasing CO₂ concentrations in the atmosphere in the long term, are expected to reduce the capacity of forests to store and sequester carbon, possibly converting forests from carbon sinks to carbon sources (Whitehead, D., 2011; Ollinger et al. 2008). The potential impacts of climate on forests vary according to geographical region and local topography and land uses, but with only a few exceptions, temperature is expected to increase (FAO, 2012). Remote sensing has opened an effective way to estimate forest biomass and carbon (Liviu et al. 2017, Galidaki et al. 2016). According to

the IPCC GPG (Intergovernmental Panel on Climate Change, Good Practice Guidance), remote sensing methods are especially suitable for verifying the national LULUCF (Land Use, Land-Use Change, and Forestry) carbon pool estimates-particularly the aboveground biomass (IPCC, 2007). Remote sensing and GIS technologies have become essential for forest planning and management. Major contributions of these technologies in forestry sector in India are: forest cover mapping, growing stock/timber volume assessment, encroachment detection and forest development planning, wildlife habitat evaluation, grassland mapping, and environmental impact assessment (Kushwaha, 2005, Nandy et al. 2017).

Over the past 25 years global carbon stocks in forest biomass have decreased by almost 11 gigatonnes (Gt). This reduction has been mainly driven by conversion to other land uses and to a lesser extent by forest degradation (FRA, 2015). In 2010, the total biomass (aboveground and belowground) contained in the world's forests amounted to 600 Gt, the total carbon stock in the biomass of the world's forests is estimated at 289 Gt and total carbon stock in dead wood and litter in 2010, amounted to 72 Bt or 17.8 tha⁻¹ (FAO, 2010). The total growing stock of India's forest and trees outside forests is estimated as 5,822.37 million cum (FSI, 2017).

Some of the commonly employed techniques to estimate forest biomass are (i) the harvest of average size trees either for the stand or within given size classes, (ii) the harvest of all materials in an unit area, and (iii) the harvest of individuals over a wide range in size and establishing the relationship between biomass and easily measurable plant parameters such as diameter and/or height. The height-

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diameter at breast height (dbh) relationship to biomass in forest stand is well formulated (Kira and Ogawa, 1971). Kushwaha et al. (2003) have found that the satellite image-based inventory using stratified random sampling was found to have about 90 % correspondence with the inventory done by the Forest Department in Lachchhiwala Forest Range, Uttarakhand. Remote sensing technology provides an important approach for estimating aboveground biomass (AGB) at large spatial scales (Pedro et al. 2017; Dube et al. 2016). Fern et al. (2018) evaluated the suitability of the normalized difference vegetation index (NDVI) and Optimized Soil Adjusted Vegetation Index (OSAVI) as potential estimators of green and vegetative coverage in a semi-arid rangeland. John et al. (2018) found that the vegetation indices calculated from wavelengths located in the red edge are good estimators of grassland biomass. Growing stock and biomass of woody vegetation in Asola-Bhati Wildlife Sanctuary estimated with high accuracy using optical remote sensing data (Kushwaha et al. 2014). Growing stock estimated leads to quantification of biomass, which in turn is essential to assess the amount of carbon stored in the forests. The allometric equation for above-ground live tree biomass (AGB) by combining field-based, combination of field data observation and technology (WV-3 and light detection and ranging (lidar)) and by using only technology derivation (Mohd Zaki et al. 2018). The estimation of growing stock has, therefore, assumed significance existing climate change scenario. The present study attempts to couple ground based vegetation quantification with the satellite remote sensing

2. STUDY AREA

Barkot Forest Range (30°03'52"- 30°10'43" N and 78°09'49" - 78°17'09" E) lies about 40 km away from Dehradun, on the Dehradun-Rishikesh road (Fig.1). It consists of two adjacent forest ranges of Barkot and Rishikesh, covering an area of 84.96 km². Forest type is Sal Mixed Moist Deciduous Forest. The forest is bounded in the north by Thano Forest Range, in the south by Motichur Forest Range, in the west by Lachchhiwala Forest Range and Song River and in the east by the river Ganga. The main nearby township are Doiwala, Bhaniawala and Rishikesh.

The whole area possesses the relatively flat, gentle and undulating topography. The altitude ranges between 340 m to 560 m above mean sea level. The study area lies in the Doon Valley. The soil is fine Loamy Thermic Haplustalf occurs on gentle slopy terrain of study area (Working Plan of Dehradun Forest Division, 2009). The climatic condition of the study area is more temperate and humid than that of the adjoining districts. The temperature varies from 2°C in January to about 42°C in June. Frost is common in winter, especially becomes severe from mid-December to mid-February, causing damage to young *S. robusta* regeneration.

The major portion of the forests in Dehradun Forest division comprise of Sal, classified under the three sub-types viz; Moist Shiwalik Sal Forest, Moist Bhabhar Dun Sal Forest and Dry Shiwalik Sal Forest. The study area Brakot Forest range lies within Sub-Group 3C North Indian Tropical Moist Deciduous Forests. Forest type is 3C/C2b Moist Bhabhar Dun Sal Forest. Sal (*Shorea robusta*) is the dominant species,

forming nearly pure stands. Its typical associates are sain (*Terminalia tomentosa*) and dhauri (*Lagerstroemia parviflora*). Other important associates are bahera (*Terminalia belerica*) and jamun (*Syzygium cumini*) in varying proportions.

The underwood is generally light and consists of rohini (*Mallotus philippensis*), chamror (*Ehretia laevis*) and amaltas (*Cassia fistula*). The undergrowth consists of karaunda (*Carissa opaca*), bindu (*Colebrookia oppositifolia*), gandhela (*Murraya koenigii*), *Ageratum cynzoids* etc. The common grasses are pula (*Imperata cylindrica*) and baib (*Eucaliopsis-binata*). *T. grandis* of Verbenaceae was introduced on trial basis in 1955 but it was raised as commercial plantations since 1962 in Dehradun Forest Division. Most of the *T. grandis* plantations were raised by under planting in *S. robusta* areas of Barkot, Lachchhiwala and Rishikesh ranges where, *S. robusta* is in predominant stage.

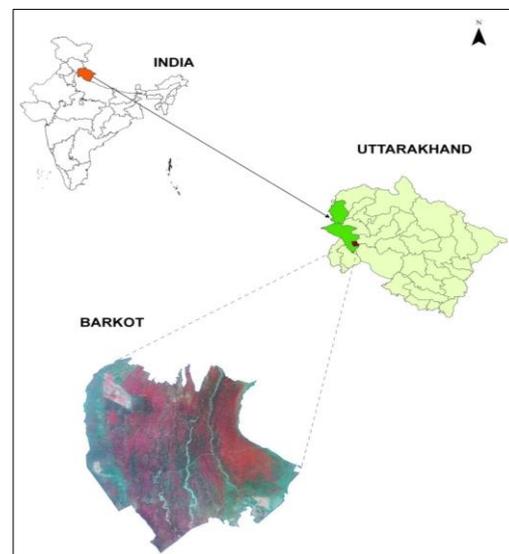


Fig. 1 Location of Barkot Forest Range in India

3. MATERIALS AND METHODS

The IRS-P6 LISS-IV MX (dated 16th March 2010), IRS-P6 LISS III (dated 22nd Jan. 2011) and Cartosat-1 PAN (dated 6th March 2010) satellite imagery, with spatial resolution of 5.8, 23.5 and 2.5 m respectively, were used in the study. Radiometric correction and haze in satellite data was minimized using dark pixel subtraction technique (Lillesand et al. 2007), followed by geo-referencing using Landsat TM ortho-rectified image as reference image (Fig. 2). LISS-IV and Cartosat-1 datasets were merged using High Pass Filtering (HPF) resolution merge technique to obtain 2.5 m resolution false colour composite (FCC) of the study area (Fig. 3a). Preliminary interpretation of resolution merged Cartosat-1 and LISS-IV MX imagery was done for forest cover/landuse mapping of the study area by visual interpretation method. The normalized difference vegetation index (NDVI) image was used for forest canopy density stratification.

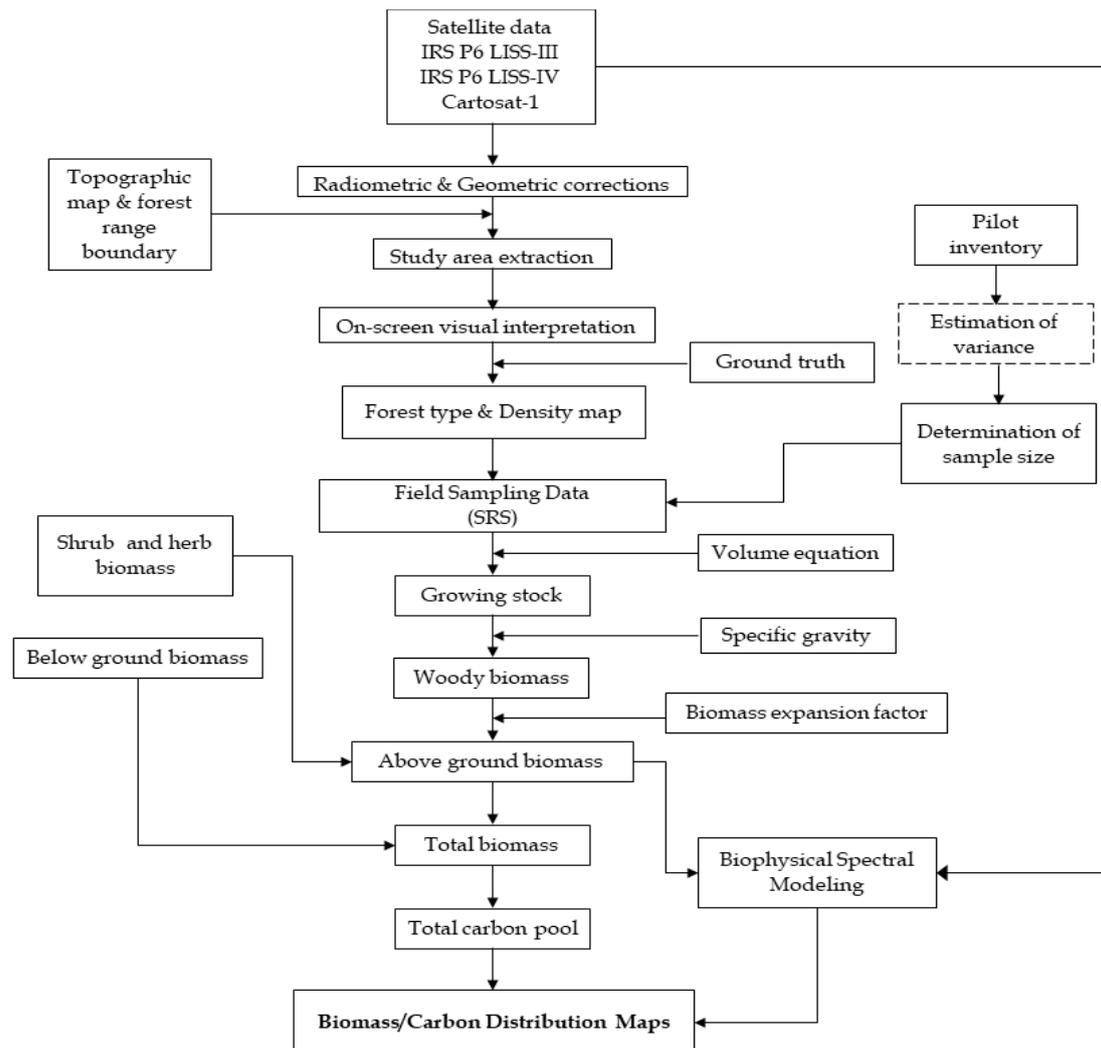


Fig. 2 The methodology

Both forest type and canopy density maps were validated in the field. A total of 125 ground truth points were used for interpretation. Forest type and canopy density maps were intersected to generate the type-density map and 187 points were used for accuracy assessment of the forest type-density map. The following formula (Chako, 1965) was used for calculating the number of plots required for sampling:

$$n = \frac{(t^2) \times (CV)^2}{(SE\%)^2} \quad (1)$$

Where n is the number of sample plots, t is the statistical value at 95% significance level, CV is the coefficient of variation and $SE\%$ is the standard error percentage. By using the above formula, a total of 43 plots of dimension 31.62 m x 31.62 m (0.1 ha) were laid for inventory of trees. Two plots of dimension 5 m x 5 m were laid within each 0.1 ha plot in two opposite corners for shrub sample collection and four sample plots of dimension 1 m x 1 m were laid within each 0.1 ha plot in each corner for litter collection. The sample plots were proportionally allocated to various strata following Cochran (1963):

$$n_h = \frac{N_h}{N} \times n \quad (2)$$

Where, n_h is the no. of sample in h stratum, N_h is size of h stratum, N is total population size and n is total no. of samples. The following formula was used for determining sampling intensity (Cochran (1963) :

$$\text{Sampling intensity (\%)} = \frac{\text{plot size} \times \text{sampling size}}{\text{total population size}} \times 100 \quad (3)$$

Field inventory was carried out for recording of all details regarding coordinates of sample plot, altitude, tonal characteristics on FCC, forest type, top canopy species, ground cover, soil type, terrain, local names of trees, circumference at breast height (cbh) at 1.37 m above ground etc. and the database in the prescribed format was systematically generated. GARMIN Juno SB GPS was used for recording coordinates in the middle of all the sampled plots. Shrub and herbaceous layer were clipped from sample plot and oven dried in laboratory to estimate total above-ground biomass. The litter was collected and fresh weight was taken and representative portion oven dried in laboratory for dry weight analysis. Volume of each tree was calculated using volumetric equations developed and compiled by FSI (1996). The sum of tree, shrub, herb, litter and humus layer biomass (t/ha) was taken as total AGB of the plot and strata-wise. The BGB of trees was estimated by

indirect method using root/shoot ratio available from existing studies. The R/S ratio of 0.30 for *S. robusta* trees (Negi, 1984) and 0.26 for other tree species (Cairns et al. 1997) were used. No estimates for shrubs and herbs layer for BGB were made due to non-availability of root/shoot ratio. The multiplication of biomass with the conversion factor of 0.47 represents the average carbon content in biomass (Westlake, 1963). Ground data was correlated with the surface reflectance and derivatives of multi-resolution data. The best correlation of aboveground biomass with NDVI was used for mapping aboveground biomass and carbon.

4. RESULTS AND DISCUSSION

The total forest area was accounted to 94% (79.54 km²) of the total area (Table 1). *S. robusta* was found dominant in the area followed by mixed plantation, *T. grandis* and *S. robusta* mixed. *S. robusta* covers maximum area of 55.86 km², followed by mixed plantations (13.15 km²), *T. grandis* plantation (5.32 km²), *S. robusta T. grandis* mixed (1.87 km²) and *S. robusta* mixed forest type (3.34 km²). In some areas, *S. robusta* is mixed with natural local forest species like *Lagerstroemia parviflora*, *Syzygium cumini*, *Diospyros malabarica*, *Pterospermum acerifolium*, *Terminalia bellerica*, *Mallotus philippinensis*, *Cassia fistula*, *Ehretia laevis* and *Murraya koenigii*. Fig. 3b & 3c shows forest land use and forest canopy density map of the study area. Among forest categories, dense forest dominates (39%) the study area. Fig. 3d shows the forest type-density map of the study area, depicting fourteen forest type-density categories of *S. robusta*, *T. grandis* and mixed plantation.

The average AGB ranged from 101 t ha⁻¹ (mixed plantation) to 530 t ha⁻¹ (*S. robusta*). Sal forest had highest biomass due to higher value of specific gravity (0.72). Negi (1984) reported that the root biomass of sal trees increased with increasing AGB, but the percentage contribution of BGB decreased from 38% to 22% with increasing diameter and AGB. Similar results were also reported by Misra (1969) for *S. robusta* trees. In the present study, the mean R/S (0.30) for *S. robusta* tree was taken as per findings of Negi (1984) while, 0.26 was considered for other tree species.

The very high density of *S. robusta* forest had the highest mean volume i.e. 626.67 m³/ha, while open density of mixed plantation the least (104.72 m³/ha). The *S. robusta* forest with very high density contained maximum mean total biomass, i.e. 530.08 t ha⁻¹, and mixed plantation with open density had the lowest, i.e. 101.34 t/ha. The trend of total vegetation C in different forest strata was similar to tree layer, being the major contribution of tree layer in total vegetation carbon. The vegetation C-density (249.14 t ha⁻¹) of *S. robusta* (>70%), was found highest among all strata (Table 2). The present results support to the earlier studies by Negi and Chauhan (2002) on the total vegetation in *S. robusta* forest of Doon valley.

The reported C-density in total biomass varied from 72 t ha⁻¹ to 320 t ha⁻¹, depending upon density of different forest type classes. Based on the data on growing stock and total area of *S. robusta* forest in India, Lal and Singh (2003) reported 430.51 t ha⁻¹ average above ground biomass of tree layer. Similar results have been reported by Negi and Chauhan (2002), Dadhwal et al. (2006) and Srivastava (2009). The above ground biomass of *S. robusta* forests reported with density classes are 136.2 t ha⁻¹ for 0-40 % class, 247.7 t ha⁻¹ for 40 – 70 % class and 351.5 t ha⁻¹ for >70 % class density (Dadhwal et al. 2006). Srivastava (2009) also reported similar results in Barkot Forest range same of the present study area. Similar results have been reported by Pandey et al. (2010), Singh S. (2010) and Anonymous (2009). The above ground biomass of *S. robusta* forests was reported within the range of 116 t ha⁻¹ to 520 t ha⁻¹, *S. robusta* mixed (230 t ha⁻¹-519 t ha⁻¹), mixed forest (45-228 t ha⁻¹), and *T. grandis* plantation (63-410 t ha⁻¹) under different density classes (Pandey et al. 2010). Singh (2010) also reported 138.21 t ha⁻¹ to 461.33 t ha⁻¹ AGB in *S. robusta* forest, 221 t ha⁻¹ to 261 t ha⁻¹ in *S. robusta T. grandis* mixed under different density classes.

Table 1 Area under forest type-density strata.

Sr. No.	Forest type-density class	Area (km ²)	Area (%)
1.	<i>S.robusta</i> (>70%)	25.11	31.56
2.	<i>S.robusta</i> (40-70%)	20.36	25.60
3.	<i>S.robusta</i> (10-40%)	9.47	11.91
4.	<i>S.robusta</i> (<10%)	0.96	1.21
5.	<i>S.robusta</i> mixed (40-70%)	3.33	4.19
6.	<i>S.robusta T. grandis</i> (>70%)	0.10	0.13
7.	<i>S.robusta T. grandis</i> (40-70%)	1.70	2.14
8.	<i>S.robusta T. grandis</i> (10-40%)	0.06	0.08
9.	<i>T. grandis</i> (40-70%)	2.42	3.05
10.	<i>T. grandis</i> (10-40%)	2.04	2.57
11.	<i>T. grandis</i> (<10%)	0.84	1.06
12.	Mixed plantation (40-70%)	4.03	5.07
13.	Mixed plantation (10-40%)	4.87	6.13
14.	Mixed plantation (<10%)	4.23	5.32
	Total	79.54	100.00

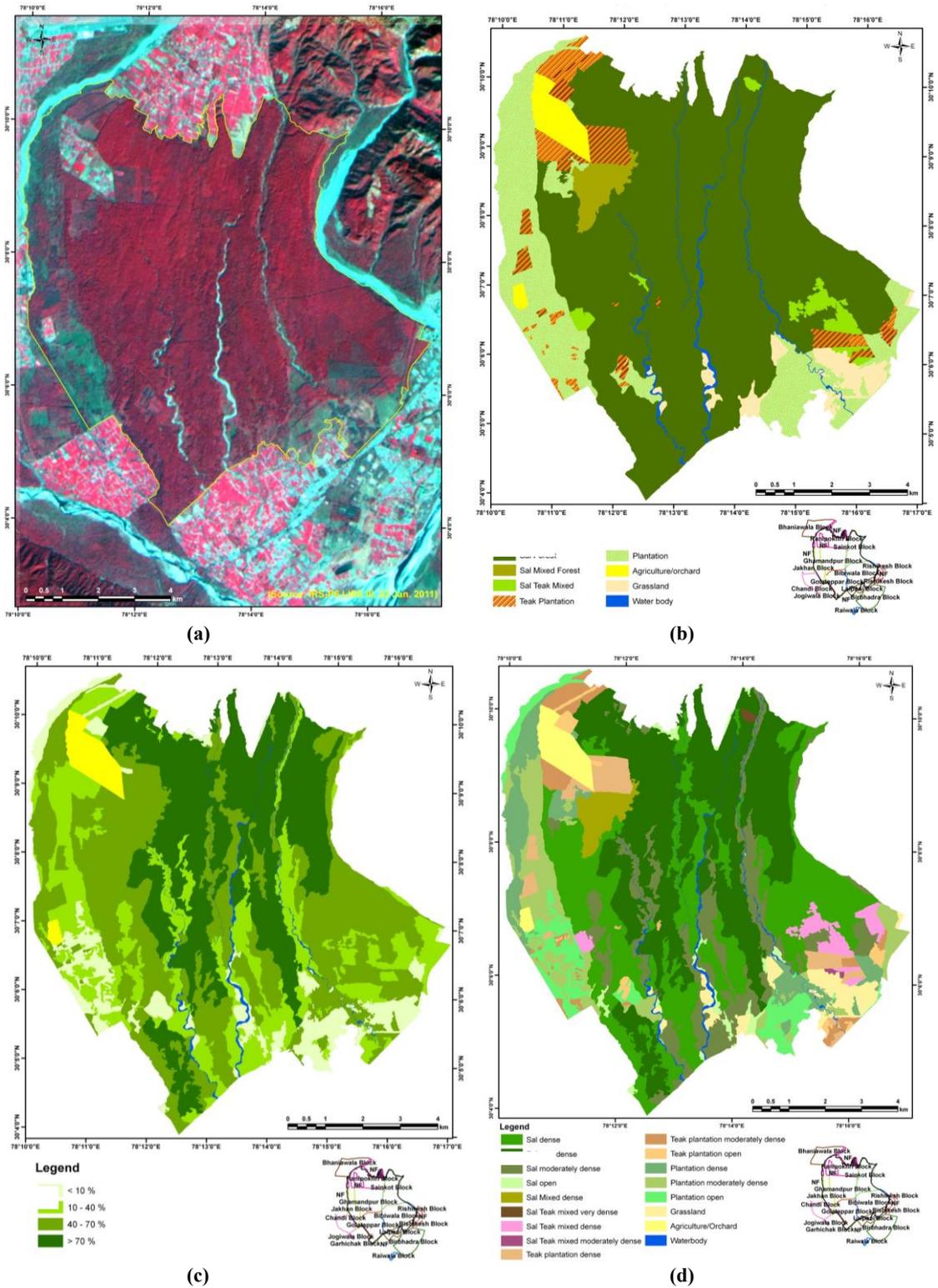


Fig. 3 (a). FCC of study area, **(b).** Forest/land use map, **(c).** Crown density map and, **(d).** Forest type-density strata map

Table 2. Growing stock, biomass and carbon in different forest stratum.

S. No.	Stratum	Mean volume (m ³ /ha)	Total GS (m ³ *10 ³)	Mean biomass (t/ha)	Total biomass (t*10 ³)	Mean carbon (t/ha)	Total carbon (t*10 ³)
1	<i>S.robusta</i> (>70%)	626.67	1573.26	530.08	1330.79	249.14	625.47
2	<i>S.robusta</i> (40-70%)	583.01	1187.03	486.54	990.61	228.67	465.59
3	<i>S.robusta</i> (10-40%)	511.46	484.33	393.00	372.15	184.71	174.91
4	<i>S.robusta</i> (<10%)	231.75	22.27	199.90	19.21	93.97	9.03
5	<i>S.robusta</i> mixed (40-70%)	506.97	168.99	372.99	124.33	175.32	58.44
6	<i>S.robusta</i> <i>T. grandis</i> (>70%)	575.42	5.76	486.51	4.87	228.77	2.29
7	<i>S.robusta</i> <i>T. grandis</i> (40-70%)	527.65	89.79	435.15	74.05	204.50	34.80
8	<i>S.robusta</i> <i>T. grandis</i> (10-40%)	352.98	2.12	314.68	1.89	148.18	0.89
9	<i>T. grandis</i> (40-70%)	410.00	99.32	359.60	87.11	169.00	40.94
10	<i>T. grandis</i> (10-40%)	311.94	63.70	272.27	55.60	127.96	26.13
11	<i>T. grandis</i> (<10%)	126.90	10.67	200.87	16.89	94.43	7.94
12	Mixed Plantation (40-70%)	299.65	120.88	248.96	100.43	117.00	47.20
13	Mixed Plantation (10-40%)	253.83	123.74	214.49	104.56	100.80	49.14
14	Mixed Plantation (<10%)	104.72	44.34	101.34	42.91	47.64	20.17

Different regression models were established between estimated AGB obtained from ground observations and corresponding NDVI values and with different spectral bands. Strong correlation, with R^2 value of 0.71 was noticed between NDVI and biomass. The regression model, so generated, was used for computation of biomass and carbon for the entire study area (Fig. 4a). The field-estimated and predicted values for biomass showed 77% agreement at 96% confidence level (N=30) (Fig. 4b), which indicates that NDVI can be used for estimation of the biomass. The maximum above ground carbon density was found in Sal with very high density and minimum in low

density class. The maximum AGB was found in sal > 70 % (530 t ha⁻¹), followed by sal 40 – 70 % (486 t ha⁻¹) and minimum was found in mixed plantation <10% (101 t ha⁻¹). As expected, the tree layer of total above ground carbon has the major contribution among all components, varies from 97% to 99% of the total above ground carbon. The carbon density in tree layer showed decreasing trend with decrease of forest density classes similar to total above ground and tree layer was most adversely affected by forest degradation. Below ground carbon was estimated only for tree layer based on root/shoot ratio and therefore the results were also similar to tree layer.

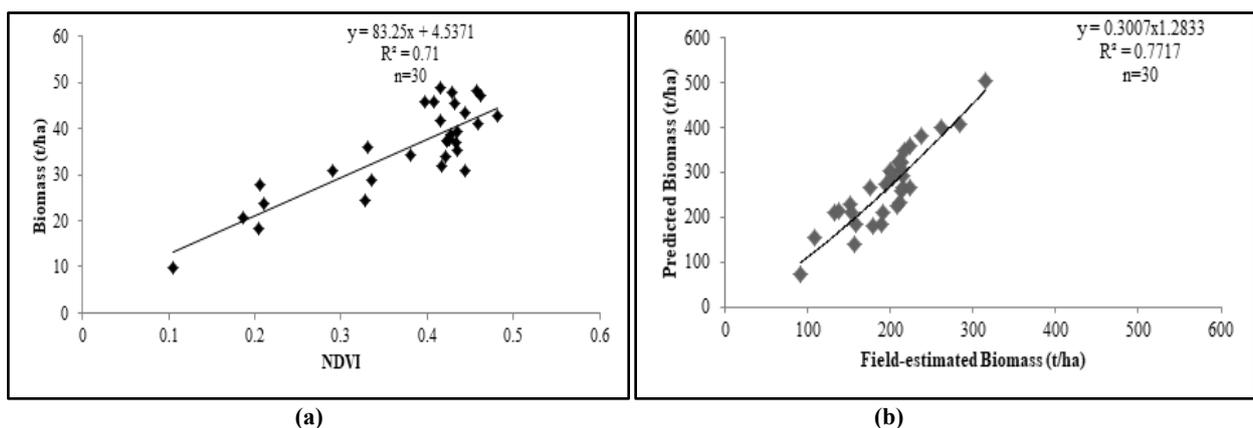


Fig. 4. Correlation between (a). NDVI and biomass and (b). predicted and field estimated biomass

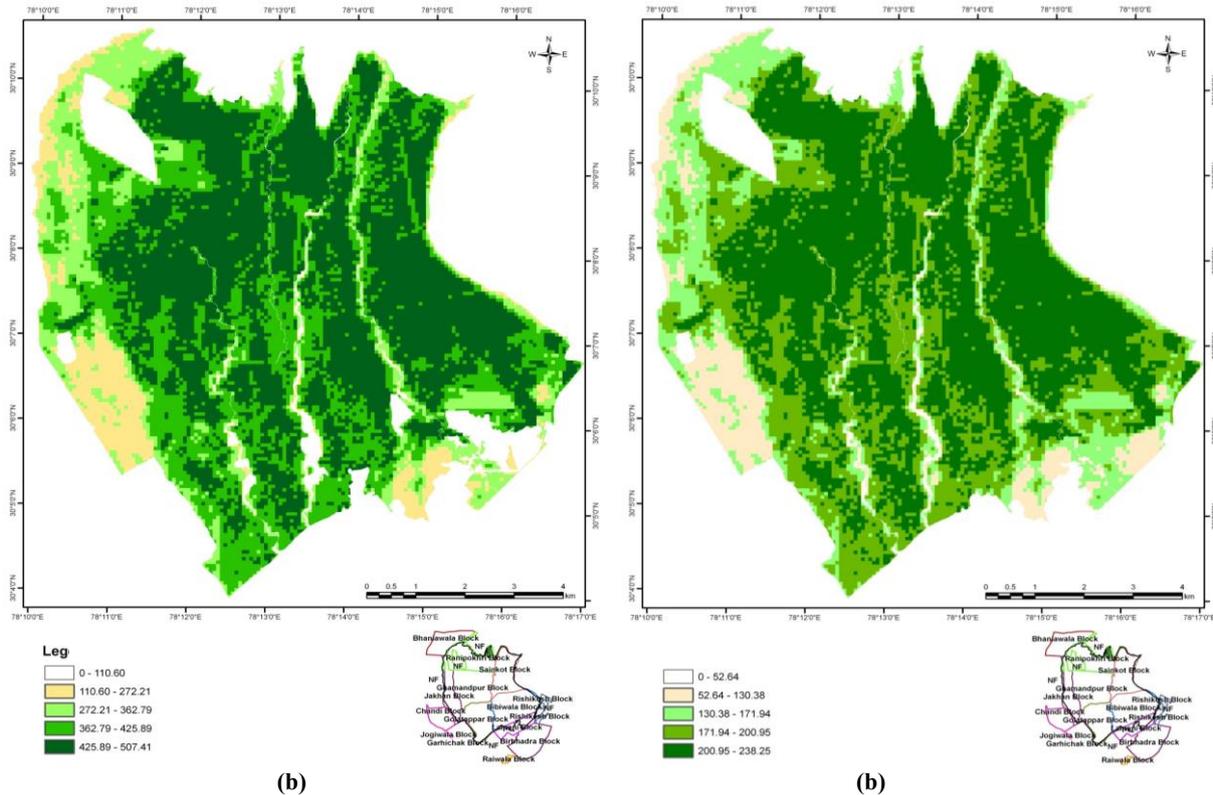


Fig. 5a Biomass and b Carbon in Barkot Forest Range

5. Conclusion

The highest potential carbon density was assessed for pure Sal followed by Sal mixed, Sal teak and teak plantation, indicating that pure Sal forests are better in carbon sequestration in the present study area. The best fit regression correlation of estimated aboveground biomass carbon was found with NDVI values of linear function. The results of above ground biomass and carbon mapping was validated which indicates good prediction with the model developed. It may be concluded from the present study that pure Sal forest is better in C-sequestration. The present data can be used as baseline information for further temporal studies to ascertain the status of carbon sequestration in Sal forest and planning of forest management plan to address the problem of forest degradation to enrich the carbon sequestration and long term carbon stock as mitigation

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measures of global warming. The use of alternative imaging technology (SAR, LiDAR, or high resolution imagery) be considered and methods to better capture the horizontal (spatial) and vertical (height) characteristics of the forest should be further studied.

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