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Geospatial Analysis of Biomass in Lake Region of Kumaun Himalaya, Uttarakhand

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Abstract

The present study includes vegetation and forest biomass mapping in the lake region of Kumaun, Uttarakhand, using IRS1C LISSIII satellite data. A total of 11 forest types including forest plantation were mapped, among various forest types analyzed, maximum area exhibited by Banj oak followed by Pine forest. Mean total above-ground biomass values were ranged between 52.1 and 402 t/ha. Mean crown cover and biomass values were computed for selected sites. Biomass values were related to crown cover through allometric equation. The biomass estimated through remote sensing in the present study has shown to be in close agreement with that estimated through conventional methods.

Keywords: *Forest biomass, crown cover, Banj oak, allometric equation, vegetation mapping*

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INTRODUCTION

Lake Region of Kumaun has been chosen for the study as within past few years the natural ecosystem of this region is gradually being disturbed by several factors such as land use changes in the form of deforestation for the sake of expansion of agriculture and extraction of fossil fuel for the purpose of burning. This is imposing a negative impact on the atmosphere in the form of disturbance in the carbon cycle and other life activities of the biotic organisms as it is very much closely related with the terrestrial ecosystem. Satellite remote sensing and GIS techniques have been found as an indispensable tool for understanding the structural and functional processes of different land-cover types. These techniques have been used for the characterization of land use and vegetation in Kumaun Himalaya [1]. Use of satellite remote sensing for biomass mapping in India started during mid-1980s using aerial photographs [2, 3] and through visual interpretation of satellite images [4]. Digital image processing of satellite data has been used for biomass mapping [2, 5]. These studies generated total biomass maps. However, no attempt has been made for mapping biomass in various components of the forests. In the present study, an attempt has been made to map biomass in major components of forest vegetation, viz., bole, branch, twig and leaf, in the lake region of Nainital District, Uttarakhand.

STUDY AREA

The study was carried out in the lake region of Kumaun Himalaya lying between 79°24′15.48″ to 79°39′ 28.53″ longitude and 29°14′ to 29°24′ 54.12″N latitude (Figure 1). The region falls within administrative boundary of district Nainital. The area includes catchment area and surroundings of major lakes of Kumaun region, viz., Khurpatal, Nainital, Bhimtal, Sattal and Naukuchiatal. The area includes part of Siwalik Hills and Kumaun Lesser Himalaya. Annual rainfall varies from about 1500 to 2250 mm. The amount of rainfall depends on altitude and aspect of the slope. Total geographical area is about 14347 ha.

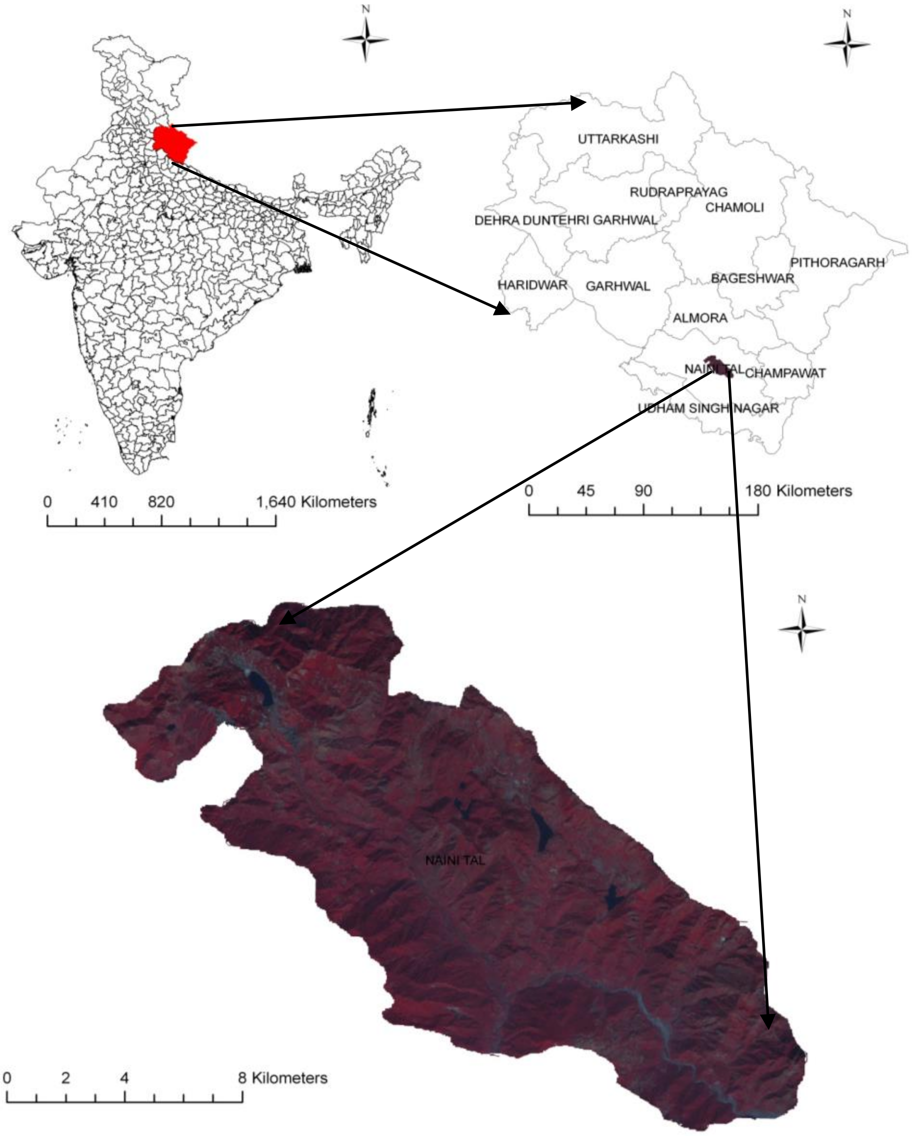

Fig. 1: *Location Map of the Study Area.*

MATERIALS AND METHODS

In the present study, IRS 1C LISS III data of November 2001 and February 2002 were used. A thorough field survey was carried out using forest compartment maps, topographic sheets and satellite images (FCC). Digital image processing was carried out using ERDAS image processing software at Regional Remote Sensing Service Centre, Dehradun(RRSSC-D).

A hybrid digital classification approach was adopted in the present study, which involves supervised and unsupervised or both and is aimed at improving the accuracy or efficiency of the classification process [6]. Unsupervised classification of the area was carried out in the first step for finding out automatic spectrally separable classes using clustering algorithm iterative self-organizing data analysis technique (ISODATA) [7–9]. The unsupervised classified output was then taken to field for ground verification. The geographic location of the reference test sites was determined using global positioning system (GPS).

The vegetation information obtained during ground truthing was utilized for the generation of signature file. During generation of signature file, ten homogenous training sets were selected for each class. Spectral statistics were generated for all the classes. Spectral separability between different classes was examined using inter-class transformed divergence. Maximum likelihood supervised classification algorithm was used in the present study, which involves considerable computational effort because it calculates a very large amount of information on the class membership characteristics of each pixel [10].

The crown cover was estimated for each forest type and classified based on the normalized difference vegetation index (NDVI) of November 2001 data. The crown cover was grouped into four distinct classes of 20% interval. In order to calibrate the remote sensing-based crown cover, it was measured on ground for each classified crown cover range, using the line intercept method [11–13]. Mean ground measured crown cover for various classes is given in Table 1.

A forest-type-cum-crown-cover map was generated through integration of the vegetation and crown-cover map. Forest-type-cum-crown-cover map was the major base for forest biomass mapping. A total of 45 sites representing all crown-cover classes of various forest types were selected randomly from classified output. In each site 8–12 quadrates, each 10 × 10 m in size were laid down; CBH of each individual tree was measured.

Table 1: Mean Ground Measured Crown Cover in Different Crown Cover Classes.

Forest type	Crown cover			
	< 20	20–40	40–60	> 60
Sal	17	34	56	69
Mixed Sal	16	39	54	76
Pine	15	32	47	67
Pine-mixed broadleaved	0	0	56	75
Banj Oak	18	29	53	72
Low altitude mixed Oak	0	32	49	75
High altitude mixed Oak	17	34	56	74
Kharsu Oak	0	0	52	69
Surai	0	33	0	0
Teak	N/A	0	0	0
Degraded forest	16	0	0	0

In each site, crown cover was measured through a line-intercept method. A stand biomass for each site was computed using mean CBH, density and allometric equations [14–16]. For a few species, fresh equations were generated using nondestructive method [17]. Biomass was computed for different components of above-ground vegetation, i.e., bole, branch, twig and foliage. Sum of biomass of all components yielded total above-ground biomass. Biomass values were related to crown cover using allometric equation of the form:

$$\log_{10} Y = a + b \log_{10} X$$

where, Y is biomass (tons per ha) and X is crown cover (%). Intercept (a), Slope (b), and r^2 values of above relationship are presented in Table 2.

Mean biomass for various crown-cover classes of different forest types was computed using mean crown cover and the above equation. Component-wise and total above-ground biomass values were regrouped into discrete intervals. All classes falling within similar ranges were regrouped through a computer model to generate biomass maps. The schematic diagram depicting methodology has been presented in Figure 2.

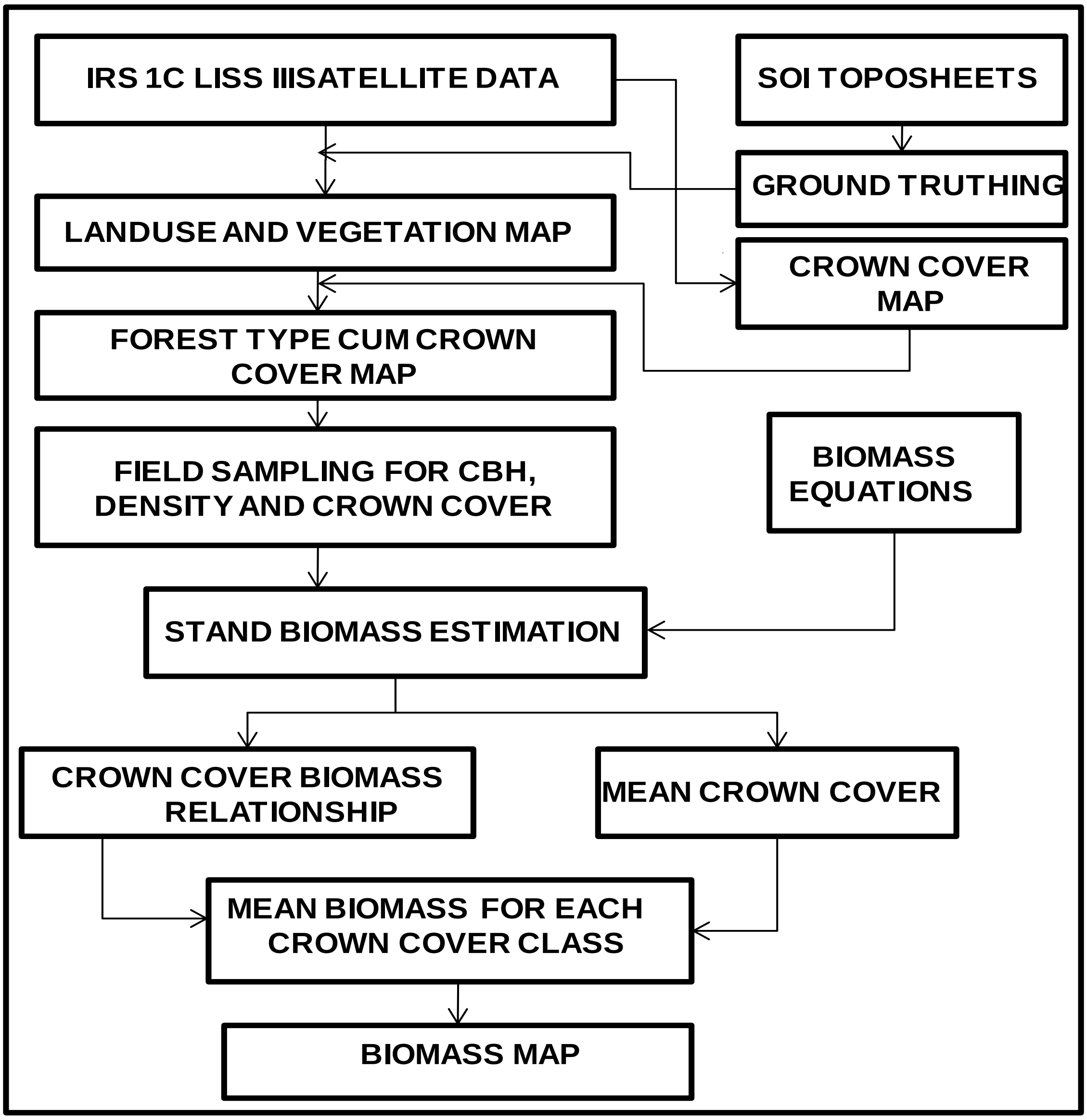

Fig. 2: *Schematic Representation of Methodology for Biomass Mapping.*

RESULTS AND DISCUSSION

A Total of 14,347 ha area was analyzed, which showed about 17% of the geographical area under non-forest use. Among non-forest categories, agriculture was the most predominant land use occupying 8.31% of total area. Other non-forest land use categories were scrub land, grassland, town/built-up area, barren land, eroding land, water bodies and roads. About 82% of the total study area was shown by forest. Maximum area was exhibited by Banj oak followed by Chir pine. Area under different vegetation and land use classes is presented in Figure 3. Integrated forest-type-cum-crown-cover map is presented in Figure 4. Different forest types encountered in the study area are described below:

Sal forest occurred in the southern part of the study area and covered a total of 1940 ha of total study area. Dominant species with maximum importance value index (IVI) 200 was *Shorea robusta*. Associated species were *Mallotus philippensis*, *Terminalia tomentosa*, *Terminalia belerica* and *Syzygium cumini*. Forest appeared in four crown-cover classes with mean crown cover of 17, 34, 56 and 69%, respectively.

Table 2: *Allometric Equations between Crown Cover (X, %) and Biomass (Y, t ha^{-1}) according to* $Log_{10}\,Y = a + b\,Log_{10}X$.

Forest type/component	Intercept (a)	Slope (b)	(r^2)
Sal			
Bole	0.05368	1.21308	0.914
Branch	0.08214	0.97835	0.893
Twig	0.39617	0.64296	0.859
Foliage	−0.44110	1.05040	0.922
Mixed Sal			
Bole	0.10186	1.17548	0.985
Branch	0.16045	0.98278	0.893
Twig	0.48769	0.63763	0.893
Foliage	−0.27701	0.99379	0.832
Pine			
Bole	0.40281	0.98626	0.985
Branch	−0.29705	0.95409	0.984
Twig	−0.65660	1.11486	0.988
Foliage	−0.53803	1.00296	0.985
Pine-mixed broadleaved			
Bole	0.11557	1.19779	0.051
Branch	0.17788	0.93287	0.988
Twig	0.44112	0.63763	0.918
Foliage	−0.32359	0.99379	0.979
Banj Oak			
Bole	0.65100	0.90713	0.942
Branch	0.52043	0.79350	0.842
Twig	−0.30117	1.06690	0.884
Foliage	−0.43017	1.08650	0.831
Low-altitude mixed Oak			
Bole	0.30254	1.04980	0.902
Branch	0.27683	0.85959	0.922
Twig	−0.38171	1.00392	0.941
Foliage	−0.36493	1.01370	0.961
High-altitude mixed Oak			
Bole	0.38110	0.99820	0.831
Branch	0.29499	0.84140	0.881
Twig	−0.85621	1.11270	0.860
Foliage	−0.73391	1.10109	0.849
Kharsu Oak			
Bole	0.49767	1.9401	0.900
Branch	0.33985	0.80570	0.915
Twig	−1.30720	1.32426	0.880
Foliage	−1.20910	1.39308	0.784
Surai			
Bole	0.29427	1.12412	0.949
Branch	0.74285	0.31816	0.900
Twig	-0.75005	0.96649	0.851
Foliage	-0.48959	0.91168	0.802

Mixed Sal forest extended over a total area of 352 ha. Dominant species continued to be *S. robusta* but its IVI reduced to the range of 100. Important associated species were *Terminalia tomentosa, S. cumini, Cedrela ciliata, Lannea grandis, M. philippensis* and *Cassia fistula*. Forest was represented by all the crown cover classes.

Pine forest dominated by *Pinus roxburghii* (IVI 250–300) with the total occupied area of 2402 ha. Associated species were *Lyonia ovalifolia, Myrica esculanta* and *Rhododendron arboreum*. About 75% forest had crown cover < 60%.

Pine mixed broadleaved forest exhibited a mixed composition of *Pinus roxburghii* and various broadleaved species. Important associated species were *L. ovalifolia, M. esculanta, R. arboreum, Quercus leuchotrichophora, Coronus oblonga* and *Cedella ciliata*. This forest was spread over an area of 56 ha, 75% of this forest under crown cover > 60%.

In Banj oak forest, *Q. leuchotrichophora* was the dominant species with an IVI about 200. Important associated species were *L. ovalifolia, M. esculanta, R. arboreum, Ilex dipyrina, Persea odoratissima,* and *Pyrus pashia*. This forest occupied 21.17% of total study area. About 68% of this forest exhibited crown cover < 40%.

Low-altitude mixed forest found over 366 ha area below 2000 m altitude. In this forest, IVI of *Q. leuchotrichophora* was between 100 and 150. Important associated species were *L. ovalifolia, M. esculanta, R. arboreum, Q. leuchotrichophora, Coronus oblonga, Eurya japonica, Pyrus pashia* and *Vibernum cotonfolium.* About 70% of this forest had < 40% crown cover.

High-altitude mixed oak forest occupied an area of 700 ha, about 75% of which had > 40% crown cover. The forest had high-altitude oak species such as *Q. semicarpifolia* and *Q. floribunda*. Associated species were *M. esculanta, R. arboreum, Litsea umbrosa, Fraxinus micrantha, Ilex dipyrirena* and *Alnus nepalensis*.

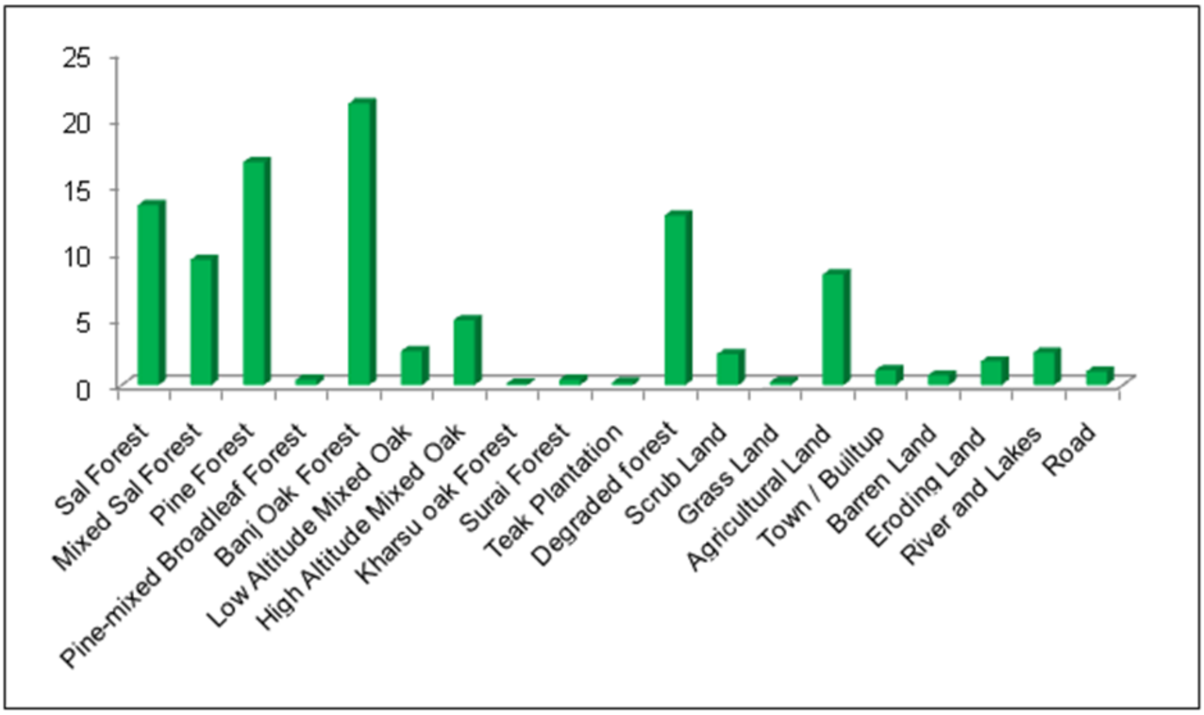

Fig. 3: *Percentage Area Occupied by Different Landuse and Vegetation Classes.*

Kharsu oak forest found in association with high-altitude mixed oak forest, not well separable from other oaks, was classified through contextual refinements. This forest was found in an area of 16 ha. About 99% of this forest had a crown cover of 40–60%.

Surai forest occupied 56 ha land, mainly found with crown cover of 20–40%. Teak plantation was found near Ranibagh, in an area of 24 ha. Degraded forest with very-low crown cover and degraded trees was found. This forest occupied a total area of 1830 ha.

Biomass was computed in different components of trees. Mean biomass values for different crown cover classes of various forest types are presented in Table 3. Mean bole biomass ranged between 18.6 t/ha (degraded forest) to 229.9 t/ha (Pine mixed broadleaved forest). Pine forest exhibited a high proportion (70%) of total above-ground biomass in bole. However, within this forest the allocation to bole was slightly higher in lower-crown-cover classes (40% crown cover) than that of higher-crown-cover classes. Among different forest types, allocation to bole biomass ranged between 33% (degraded forest) and 78% (Kharsu oak forest with > 60% crown cover).

The percentage allocation of total above-ground biomass to branches ranged between 10 (Kharsu oak forest > 60% crown cover) and 31% (High-altitude mixed-oak forest with < 20% crown cover). Twig biomass contributed 4% (Kharsu oak forest with 40–60% crown cover) to 34% (degraded forest) to total above-ground biomass.

In general, the foliage contributed about 6% (high-altitude mixed-oak forest with < 20% crown cover) to 18% (degraded forest) to total above-ground biomass.

Table 3: *Mean Biomass (t/ha) in Various Crown Cover Classes of different Forest Types.*

Forest type	**Crown cover class**			
	< 20%	**20–40%**	**40–60%**	**> 60%**
Sal				
Bole	35.2	81.6	149.4	192.5
Branch	19.3	38.1	62.0	76.1
Twig	15.4	24.0	33.1	37.9
Foliage	7.1	14.7	24.8	30.9
Total	77.0	158.4	269.4	337.3
Mixed Sal				
Bole	32.9	93.8	137.5	205.5
Branch	22.1	53.0	72.9	102.1
Twig	18.0	31.8	39.1	48.6
Foliage	8.3	20.1	27.8	39.1
Total	81.3	198.7	277.4	395.3
Pine				
Bole	36.5	77.1	112.7	159.9
Branch	6.7	13.8	19.9	27.9
Twig	4.5	10.5	16.1	23.9
Foliage	4.4	9.4	13.8	19.7
Total	52.1	110.8	162.5	231.4
Pine-mixed broadleaved				
Bole			162.0	229.9
Branch			64.4	84.5
Twig			36.0	43.3
Foliage			25.9	34.7
Total			288.3	392.4
Banj Oak				
Bole	61.6	95.0	164.1	216.7
Branch	32.8	48.0	77.4	98.7
Twig	10.9	18.2	34.6	47.9
Foliage	8.6	14.4	27.7	38.7
Total	114.0	175.5	303.8	402.0
Low altitude mixed Oak				
Bole		76.3	119.4	186.6
Branch		37.2	53.7	77.4

Twig		13.5	20.7	31.7
Foliage		14.5	22.3	34.3
Total		141.5	216.0	330.0
High altitude mixed Oak				
Bole	40.7	81.3	133.7	176.6
Branch	21.4	38.3	58.3	73.8
Twig	3.3	7.0	12.3	16.7
Foliage	4.2	9.0	15.5	21.1
Total	69.5	135.6	219.8	288.2
Kharsu Oak				
Bole			163.6	217.0
Branch			24.5	27.0
Twig			9.2	13.4
Foliage			15.2	22.5
Total			212.5	279.9
Surai				
Bole		135.0		
Branch		18.3		
Twig		6.7		
Foliage		10.0		
Total		170.1		
Teak				
Bole		98.6		
Branch		46.5		
Twig		8.5		
Foliage		10.9		
Total		164.5		
Degraded forest				
Bole	18.6			
Branch	8.4			
Twig	18.7			
Foliage	9.9			
Total	55.5			

Maps showing bole, branch, twig, foliage and total above-ground biomass are presented in Figure 5. Mean total above-ground biomass values were minimum (52.1 t/ha) for Pine forest with < 20% crown cover. The Banj oak forest with > 60% crown cover exhibited highest total above ground biomass (402 t/ha).

Mean biomass values when multiplied with respective geographical area, yielded total biomass. Study area exhibited a total above-ground biomass of 21.88×10^5 t, out of which 56% was contributed by bole, 23% by branch, 12% and 9% twig and foliage, respectively (Figure 6).

Out of total biomass of 21.88×10^5 t in the area 30% was contributed by oak forest. Kharsu, Surai and Teak cumulatively contributed 1% of total biomass of the area. About 18% of total biomass was contributed by Pine forest (Figure 7).

Average biomass density was obtained by dividing total biomass of the area with aerial extent of the vegetation type. Density of total above ground biomass ranged from 55 t/ha (degraded forest) to 267 t/ha (mixed Sal forest).

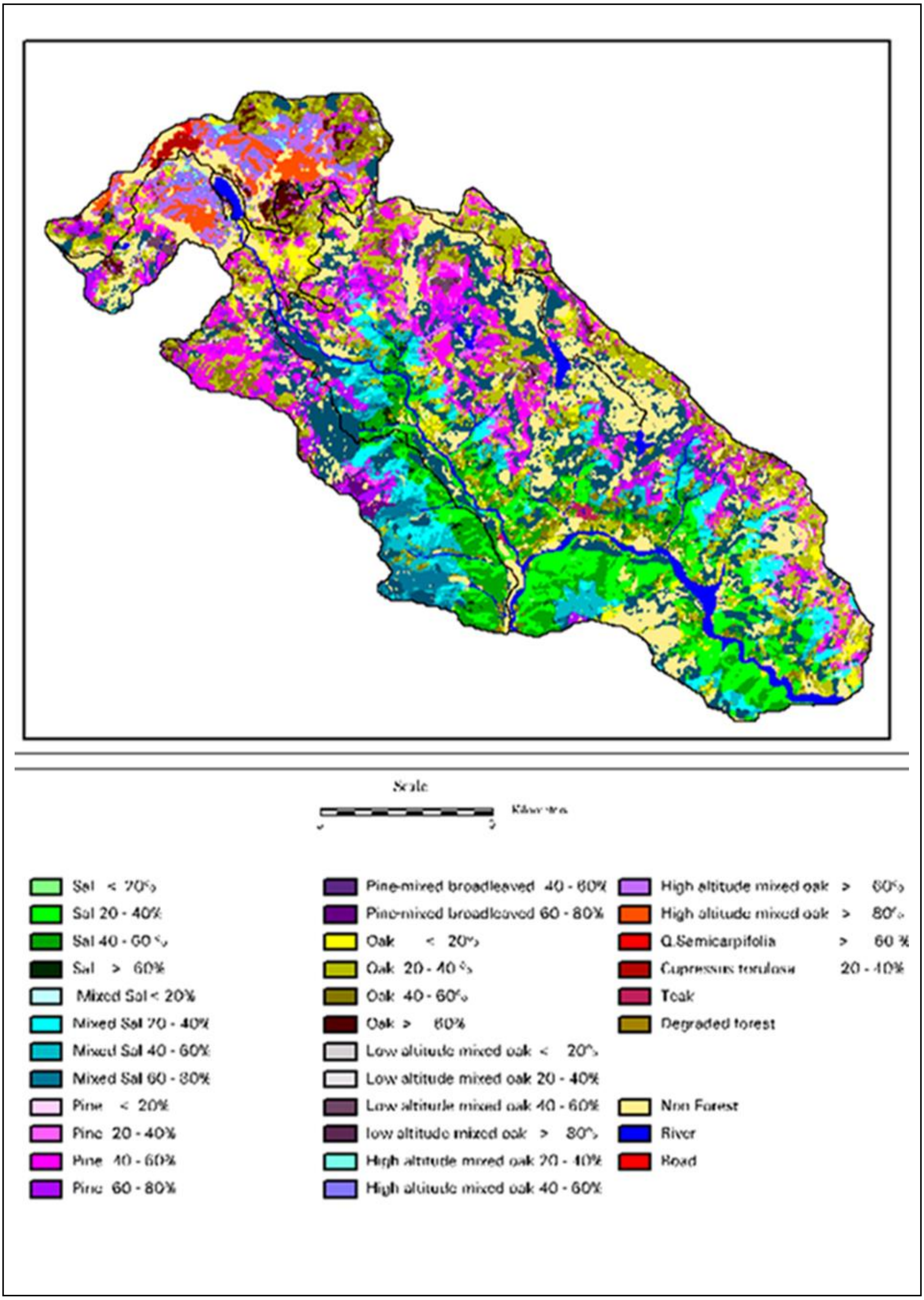

Fig. 4: *Integrated Forest-Type-cum-Crown-Cover Map.*

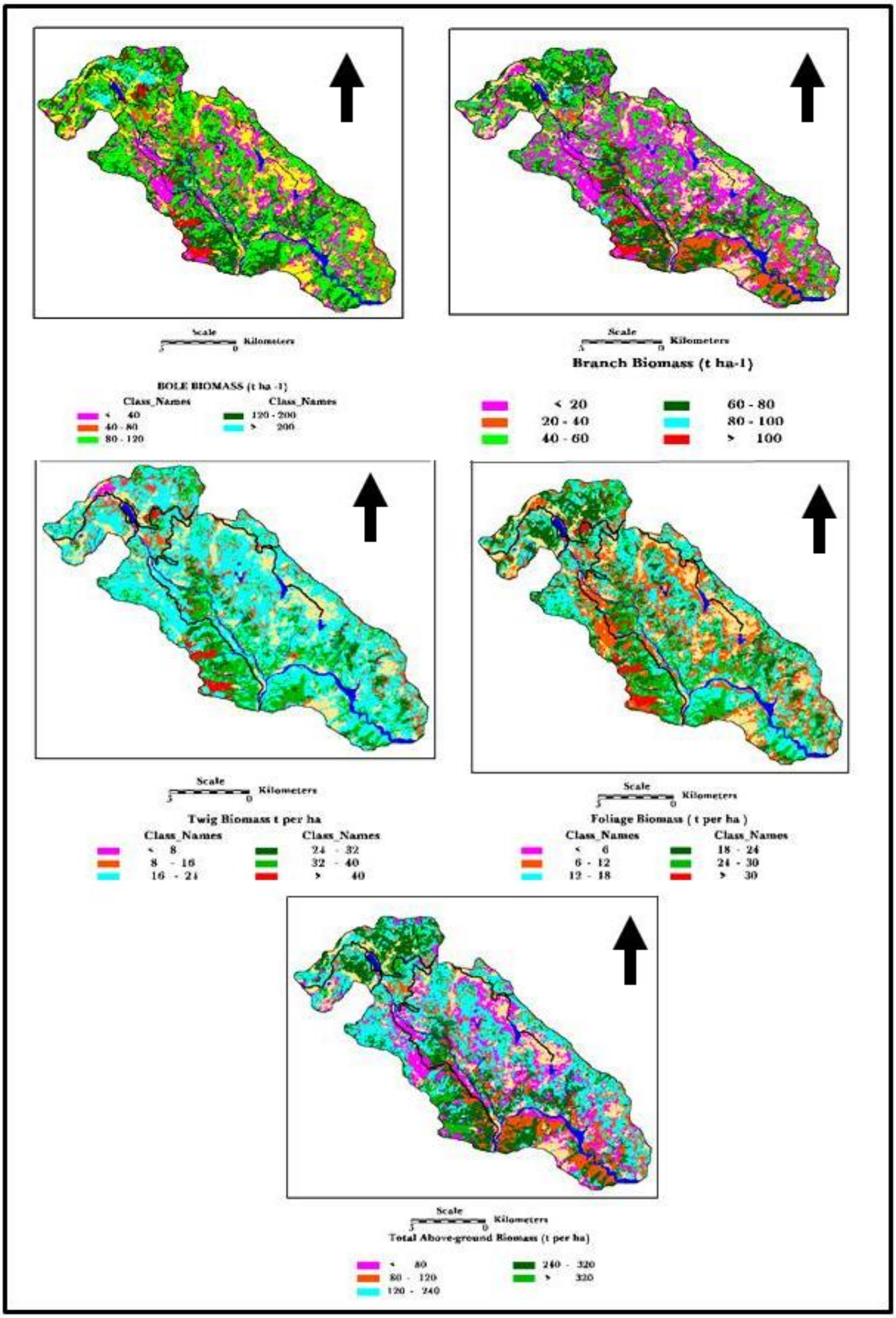

Fig. 5: *Component Wise and Total above-Ground Biomass Maps of Study Area.*

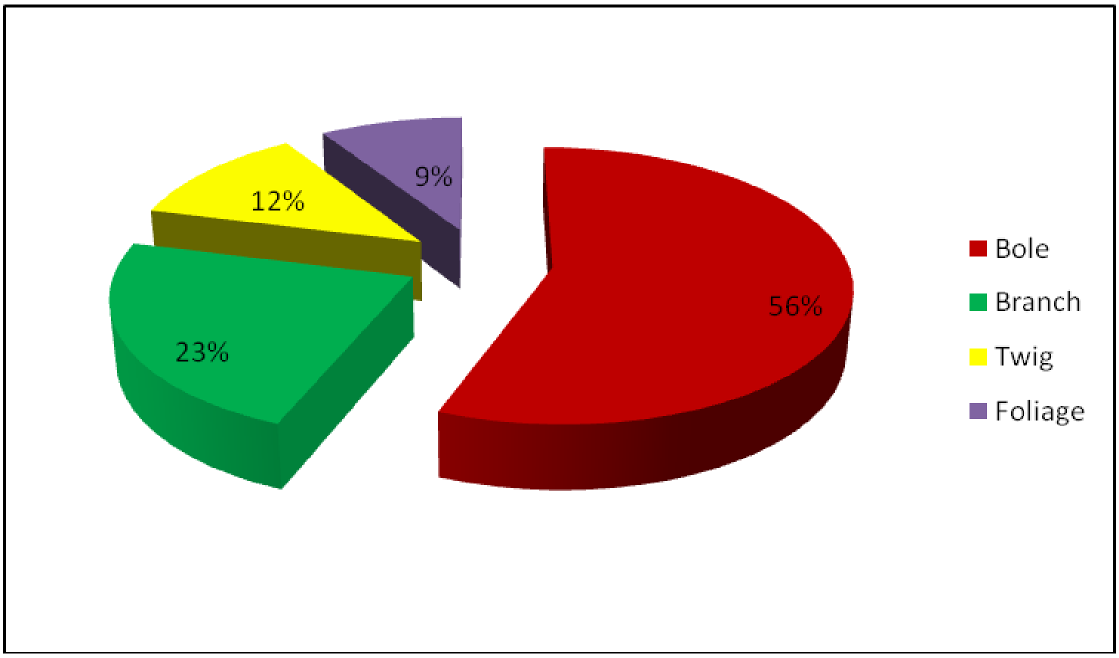

Fig. 6: *Contribution of Different Components to Total above-Ground Biomass of the Study Area.*

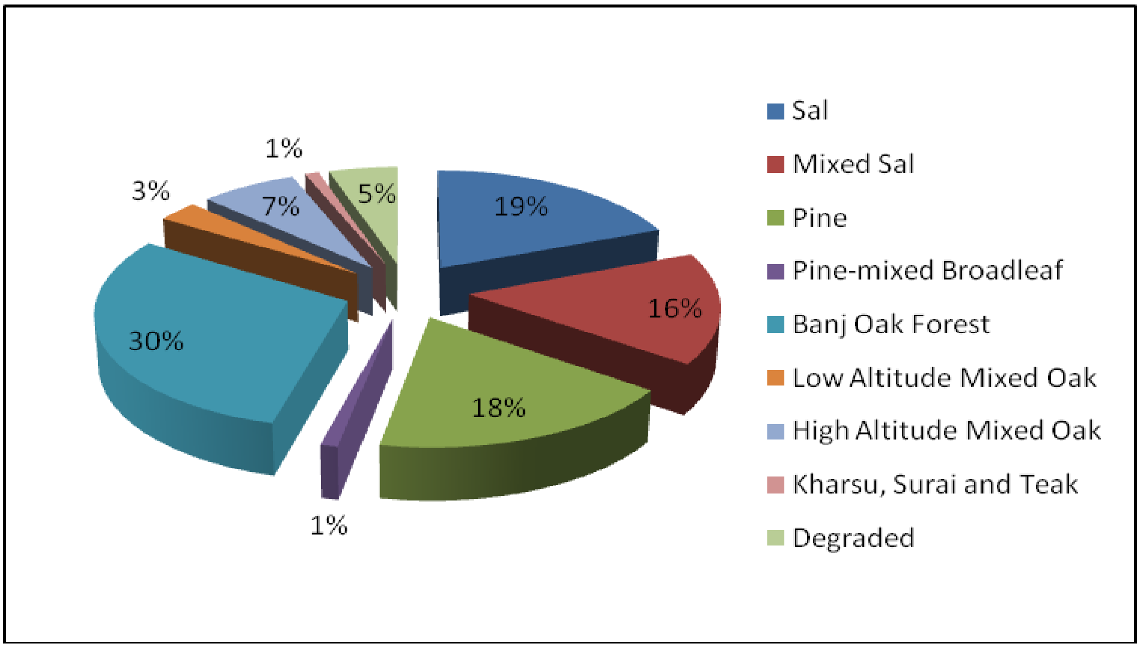

Fig. 7: *Contribution of Different Forest Types to Total above-Ground Biomass of Study Area.*

Biomass is an important parameter to assess the atmospheric carbon that is harvested by trees. In recent times, biomass-related studies have become significant due to growing awareness of carbon credit system the world over. The estimates presented in this study are of tremendous use in analyzing carbon budget of forests. Based on the existing field and laboratory data on net primary productivity, litter fall, litter decomposition and biomass coefficients can be generated to relate biomass with carbon flux rates

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