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Quantitative assessment of aboveground carbon dynamics in temperate forest of Shimla district

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Abstract: The carbon pool of the tropical and temperate forests in India is largely affected by land use change and deforestation. The land use changes directly influence the amount of carbon stored in vegetation and soil releasing carbon dioxide in the atmosphere. In order to understand and analyze the carbon sequestration rate in relation to land use change, an assessment of above ground carbon and its variation with time is important. Aboveground biomass of tree species has been considered as a very good proxy for carbon assessment but only few attempts have been made in this regard. The present study aims to estimate the change in the above ground biomass and carbon stock for a period of 10 years for three major forest types (Deodar, Oak, and Pine) in Shimla district as a consequence to landuse dynamics using NDVI-based approach. Non-destructive sampling techniques have been used for preparing the forest inventory for two time periods (2003 and 2013). The correlation between carbon stock and NDVI values was found to be significant (r = 84 % for 2003 and 80 % for 2013) and was used for the spatial interpolation of carbon values in order to generate carbon map for the two time periods and the results of the analyses are presented.

Key words: Above ground biomass (AGB), biomass extension factor, carbon cycle, carbon sequestration, deforestation, landuse/landcover (LULC) dynamics.

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Introduction

Environmental issue related to climate change and carbon management is one of the major global concerns. Forests sequester a large amount of carbon-dioxide (CO_2) through the process of photosynthesis and play a significant role in controlling earth's climate. Post industrialization era has witnessed an unprecedented growth in population, urbanization, technological and scientific innovation that have triggered a drastic change in land use/land cover. The ever increasing human demands for natural resources have resulted in extensive deforestation throughout the world (Richard & Flint 1994). This has resulted in release of CO_2 into the atmosphere which in turn

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is responsible for the increase in greenhouse gasses. Deforestation is estimated to have released 1-2 billion tonnes of carbon per year during the 1990s (Gibbs *et al*. 2007; Laurance 2007; Malhi *et al*. 2000). Prior to the industrial revolution carbon concentration was around 270 ppm, but increased to 401.52 ppm in 2013 (NOAA 2013). It has been observed that if the atmospheric carbon keeps on increasing at this pace and no attempts are made to reduce it, the carbon level in the atmosphere would rise up to 936 ppm by the end of the year 2100 (IPCC 2013; Cramer *et al*. 2001; USGCRP 2009), which will adversely influence the habitation on Earth (Whipps 1990). In response to this global concern of rising greenhouse gases and climate change, environmental scientists and policy makers are in search for new ways to reduce greenhouse gas emission (especially CO_2) in the atmosphere (Asante 2011). Forests are one of the major sources of C sinks in terrestrial ecosystems. The net changes of carbon stock over time provide information about the sequestration efficiency of the sinks (FSI 2011). Various summits starting from the Stockholm (Sweden, 1972), Kyoto protocol (Japan, 1997), Buenos Aires plan of action (Argentina, 1998), COP 5 (Germany, 1999). COP 6 (The Hague, 2000), COP 6 (Bonn, 2001), COP 7 (Marrakech, 2001), COP 8 (New Delhi, 2002), COP 9 to COP 21 have been organized to develop policies for mitigating carbon emission.

Landuse change disrupts the normal functioning of the ecosystem. Climate change is widely believed to be a result of landuse/ landcover changes. Large scale deforestation influences the greenhouse gas concentration of the atmosphere, affecting the climate on earth. Hence, in order to mitigate global climate change, it is required to cut down the rate of greenhouse gas emission either through reducing deforestation or to enhance the carbon sequestration potential of the forests through revegetation and afforestation (Baishya *et al*. 2009). Thus it is crucial to assess the impacts of landuse/landcover change that might increase or decrease the natural sinks. Within a forest, this carbon sequestration capacity varies with species, because photosynthetic efficiency varies for different species (Upadhaya *et al*. 2015). Knowledge on the biomass accumulation rates is important for selection of ideal species for reforestation. As the forest grows with time, atmospheric carbon is absorbed by plants and gets fixed into their biomass and the soils, which is the net primary productivity. Hence, reforestation is a proven and effective approach for carbon sequestration (Joshi *et al*. 2013). Till date considerable studies have been carried out relating biomass increment and carbon sequestration, but so far few attempts were made to estimate the species-wise biomass accumulation and their contribution for sequestration of carbon (Negi *et al*. 2003) using NDVI. Tovar (2011) in his study has identified linkage between various functions of vegetation and NDVI, estimated using satellite images to assess the health of vegetation. In Indian context, Kale (2006), Kale *et al*. (2009) and Kale & Roy (2012) have estimated the species-wise carbon sequestration rates in forested landscapes of central India and Western Ghats. Devi *et al*. (2013) have assessed the biomass production and carbon sequestration potential of eight different plantation ecosystems (*Quercus leucotrichophora, Pinus roxburghii, Acacia catechu, Acacia mollissima, Albizia procera, Alnus nitida, Eucalyptus tereticornis and Ulmus villosa*) in north- western Himalayas.

Forest biomass is an important parameter in the studies of ecosystem productivity, energy and nutrient flows. It plays a significant role in assessing the effect of forest degradation to global carbon cycle. The biomass information is a prerequisite in the planning for ecologically sustainable development of a region (Singh & Singh 1992). It is also a useful measure to compare structural and functional attributes of forest ecosystems over a wide range of environmental conditions (Brown & Schroeder 1999; Baishya *et al*. 2009).

The ISRO- Geosphere Biosphere Programme (IGBP) has undertaken a nationwide landuse/ landcover dynamics project (since 2007), studying the complex interaction between human and environment at river basin level. As a part of the project, an attempt has been made to estimate the change of above ground biomass accumulation and carbon sequestration of the major forest types of Shimla district falling within the Indus river basin in northern India. The study has estimated carbon sequestration potential of three different tree species and how the landuse/landcover changes influence it with time. The results of the study will be useful to analyze the C-sequestration potential of temperate forests in Shimla district, Himachal Pradesh. The study is significant for sustainable land management in India where anthropogenic degradation is one of the main causes of CO_2 release in the atmosphere.

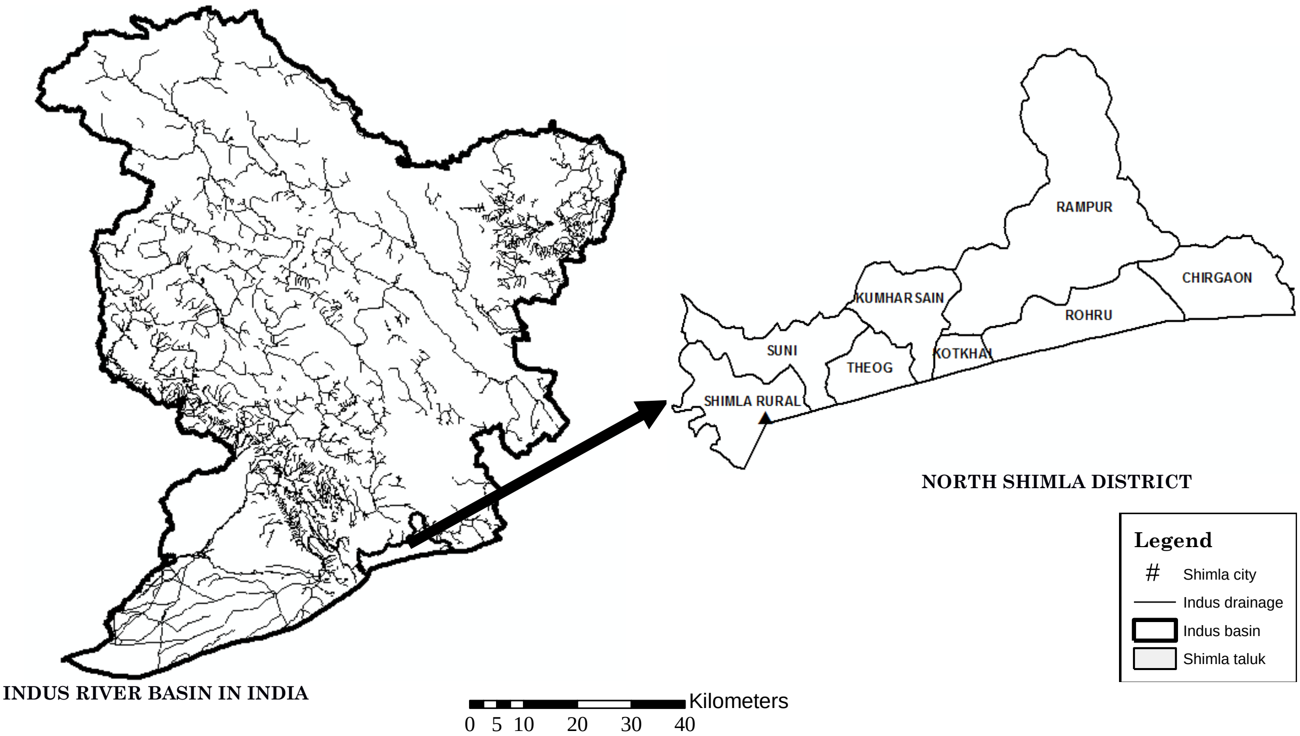


Fig. 1. Location map of study area.

Study Area

The study was carried out in northern part of Shimla district of Himachal Pradesh, India. The part of Shimla district which falls in the Indus river basin, located between 31° 1’ 25.07” N to 31° 43’ 5.61” N latitude and 76° 59’ 41.53” E to 78° 11’ 20.22” E longitude was taken for the study. It covers an area of 2570.8 sq km covering 8 taluks (Fig. 1). The region is drained by three rivers Sutlej, Pabbar and Giri. Shimla is the third most urbanized district of Himachal Pradesh. Deforestation through agricultural expansion, horticulture and urbanization are the major land use change that occurred in this part of Indus valley over last decade (2003-2013). Three major vegetation types were selected *i.e.* Deodar (*Cedrus deodara*), Oak (*Quercus dilatata*) and Pine (*Pinus wallichiana*) to study the change in biomass accumulation with time.

Materials and Methods

The present paper concentrates on the assessment of standing biomass and carbon storage of three vegetation types for two time periods i.e. 2003 and 2013 using satellite remote sensing and field based data merging in GIS domain and subsequently up scaling to the study area. The Landsat TM images (Fig. 2) of both time periods were classified using unsupervised classification technique into various landuse/landcover classes (including vegetation types) to assess the quantitative change in landuse/landcover (LULC) classes for a period of ten years. The output LULC classified images (Fig. 3) were then analyzed to estimate the total area under each vegetation types for both the periods.

An extensive field work was carried out during the mid of April 2013, in the northern part of Shimla district. Stratification based on vegetation type and density was carried out using standard RS and GIS techniques (Kale 2012). Deodar, Oak, and Pine patches were identified in the field survey with the aid of stratified map and GPS for 34 sample plots (20 × 20 m each) for assessing the standing biomass. Sampling intensity of 0.0025 % based on the proportion of area was carried out with 34 plots in different vegetation types. Trees with DBH greater than 5 cm were subjected to biomass inventory. The field inventory data for 2003 was taken from the project DOS DBT (Roy *et al.* 2012). The exactly same 34 plots have been revisited with the help of GPS reading with the accuracy of 5 m. In order to overcome the discrepancies of positional errors of 2003 and 2013, a 3/3

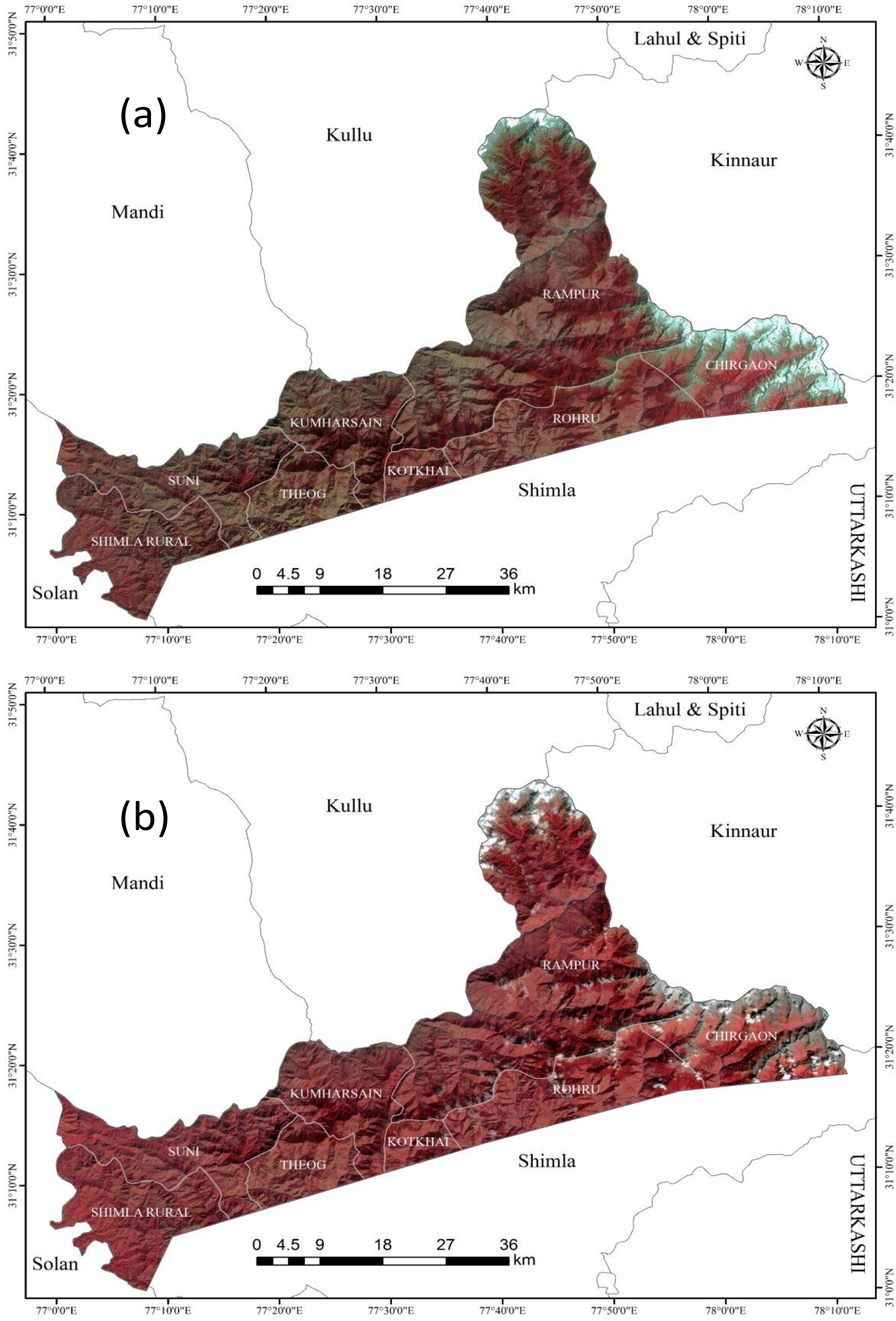


Fig. 2. FCC of the study area (2003 & 2013).

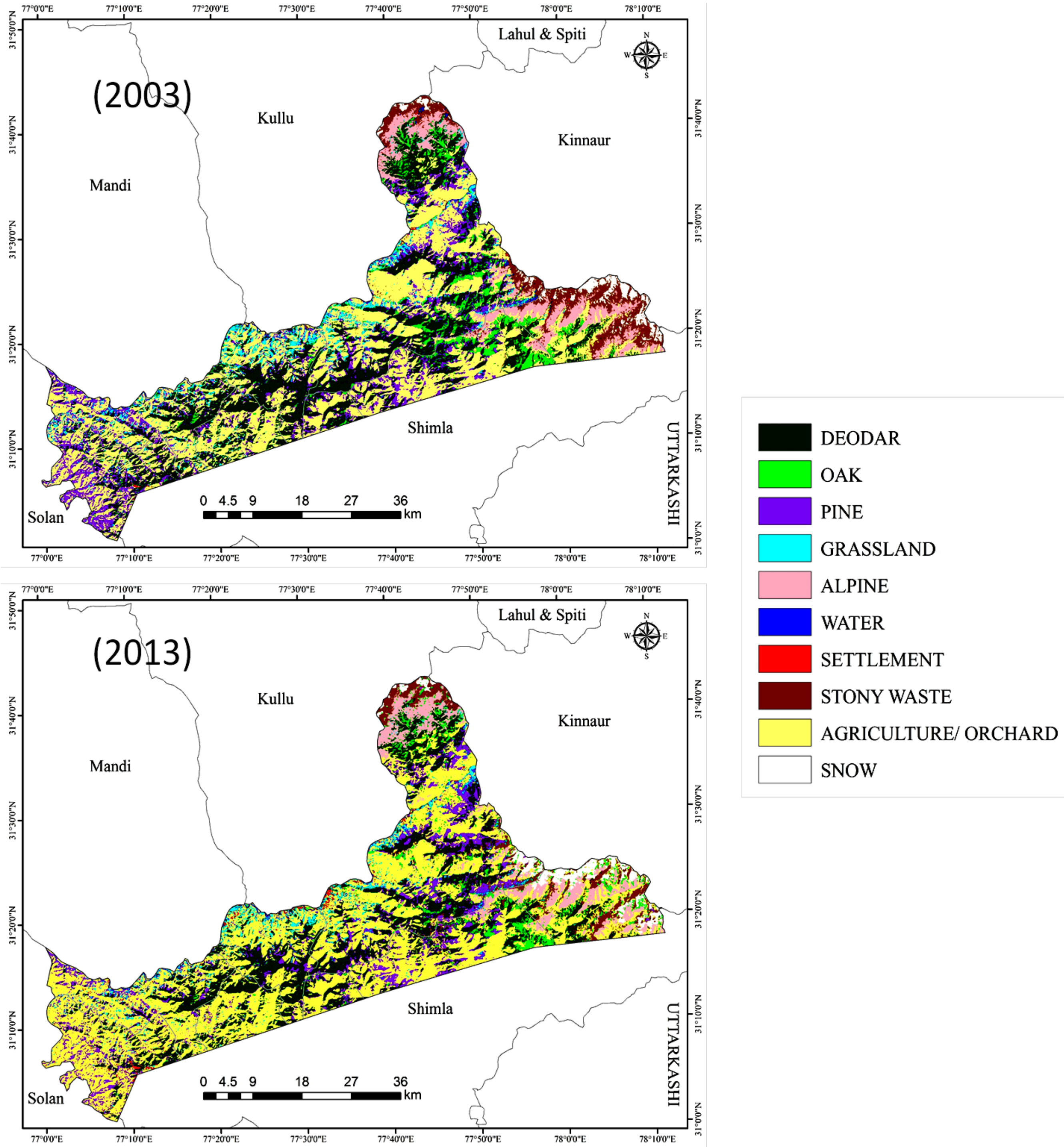
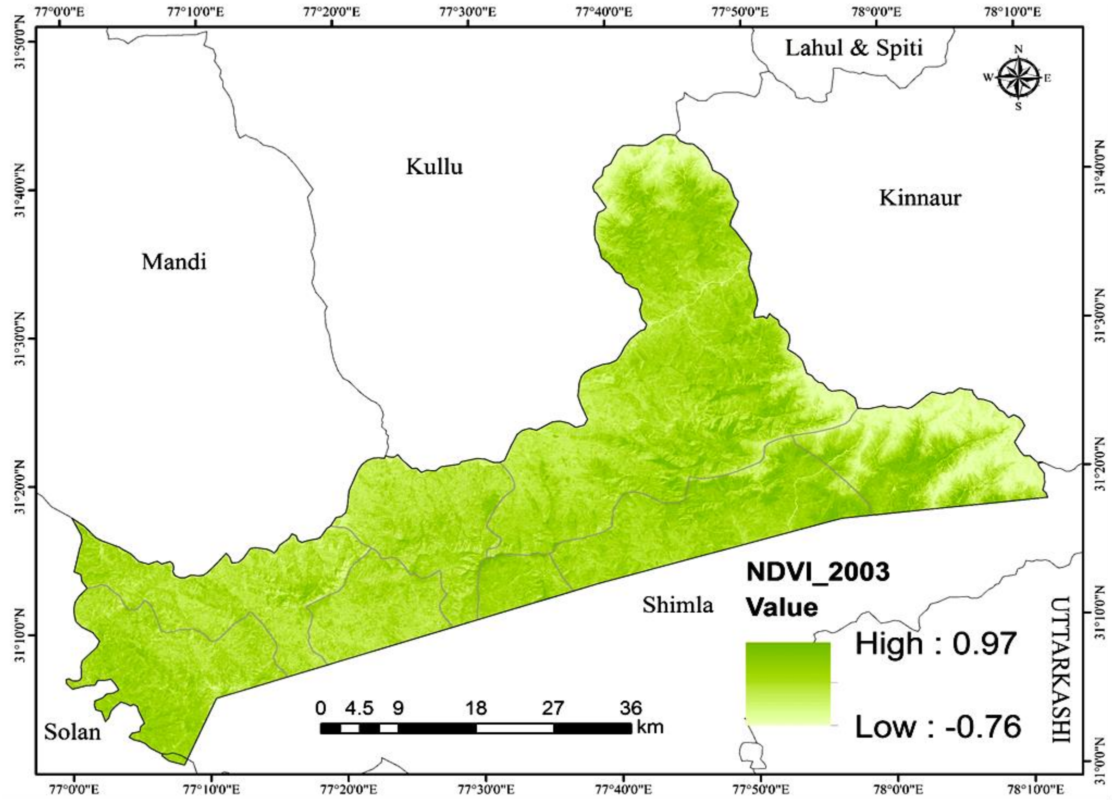


Fig. 3. Landuse/landcover classified image of north Shimla district (2003 & 2013).

kernel was run on both year's database for the most accurate result. Circumference at breast height (CBH, girth) was recorded for all trees using measuring tape to assess the increment of biomass between 2003 and 2013. Hand-held Trimble GPS was used to record the central coordinates of the plots during the field survey.

Sample plot-wise field data with respect to their latitude/longitude, altitude, vegetation type, species name and CBH were organized and processed in a database environment. These databases were used in estimating the wood volume using the local species specific volume equations of FSI (FSI 1996). The equations are as follows:



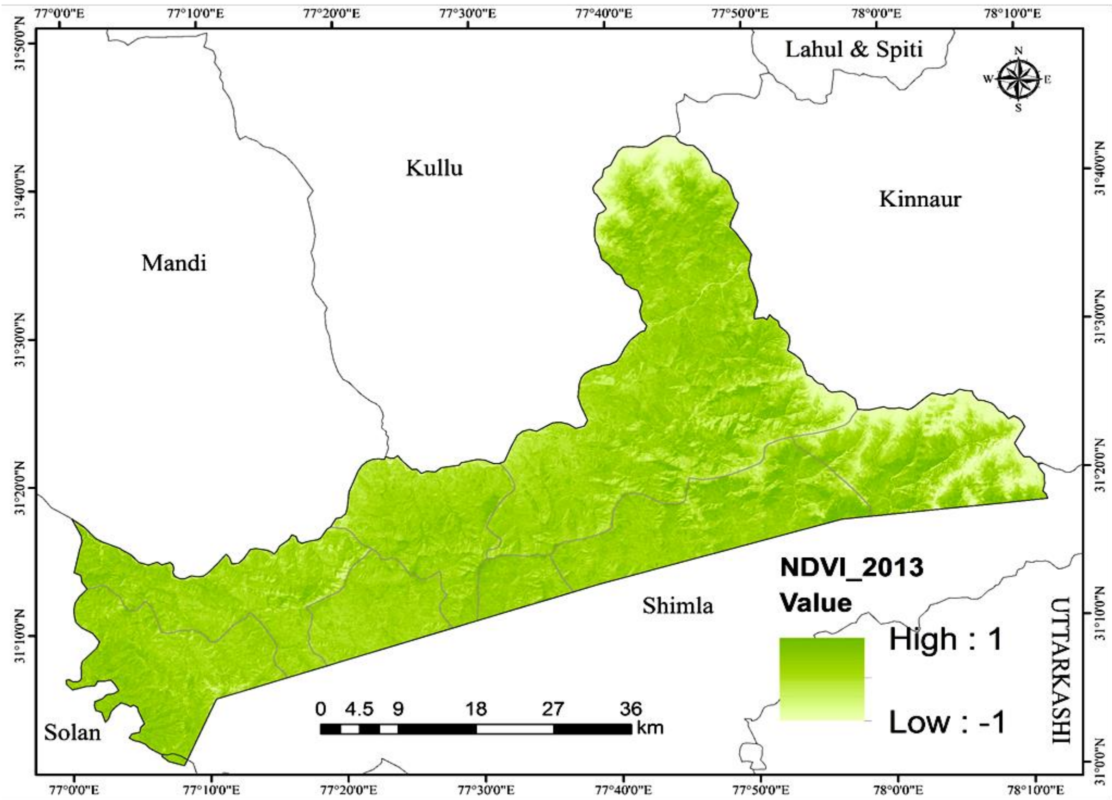


Fig. 4. Vegetation index map.

Table 1. Average carbon stock (t/ha) under different girth categories in Deodar, Oak and Pine forests for the year 2003 and 2013.

Year	Vegetation type	Girth category (cm)						
2003		0-20	20-50	50-100	100-150	150-200	200-250	250-300
	Deodar	1.1	1.2	10.8	26.4	34.3	34.9	0
	Oak	3.5	0	12.5	47.5	127.5	187.5	295
	Pine	3.2	4.5	9.7	13.9	18.0	3	0
2013								
	Deodar	1.0	1.4	13.1	24.4	37.5	27.1	35.2
	Oak	2.6	3.6	8.8	62.5	98.9	144.2	210
	Pine	2.7	4.3	12.8	21	9	10.8	3.2

1. Deodar (*Cedrus deodara*): $V = 0.167174 - 1.735312 \times D + (12.039017 \times D^2)$
2. Oak (*Quercus dilatata*): $V = \left(0.682380 + 5.049937 \times D - \sqrt{2.770924}\right)^2$
3. Pine (*Pinus wallichiana*) $V = 0.251311 - 2.683081 \times D + 13784565 \times D^2$

Where V= volume; D = diameter at breast height.

The above ground biomass was worked out by multiplying the calculated volume with the specific gravity of the tree. Species wise specific gravity (Deodar-0.468, Oak-0.826, Pine- 0.5) (FSI 1996) was used to assess the biomass. Biomass Extension Factor (BEF) of 0.95 (IPCC 1995) was used to calculate the crown, leaf and branch biomass. The total biomass was converted into carbon stock by using carbon fraction of 0.45 (IPCC, 1995) and expressed as tonnes per hectare.

Biomass (B) = Volume (V)* Specific Gravity (SG)

Total Biomass = B + {B* BEF (Biomass Extension Factor, IPCC, 1995)}

Total Carbon = Total Biomass x 0.45

The spectral enhancement tool of Erdas Imagine software was run to generate the vegetation index maps for 2003 and 2013 (Fig. 4). Landsat Thematic Mapper satellite images of 2003 and 2013 (Fig. 2) were used to compute the Normalized Difference Vegetation Index (NDVI) image.

Since NDVI values represent the vigor of vegetation growth and its density, thus it's the ideal remote sensing technique that can identify the state of degradation over a specified zone. This technique is useful for per pixel biomass estimation (Kale 2006 & Roy & Ravan 1996).The assessed NDVI values (2003 and 2013) from satellite imageries were correlated with the biomass value of the year 2003 and 2013 respectively to get the biomass value at the spectral level. The significant positive linear correlation ($r^2 = 0.68$ for 2003 and $r^2 = 0.64$ for 2013) as found in Fig. 5 (a & b), between the NDVI value and the biomass measured at sample plots have been used in the spatial extrapolation of carbon values to produce the per-pixel carbon maps for both the time periods. The change of biomass/carbon between 2003 and 2013 was assessed by subtracting the biomass/carbon value of 2003 from 2013.

Results and Discussion

The growing stock for trees varies with time, and differs for different types of vegetation cover, thus the rate of carbon sequestration also varies among vegetation types. For assessing the role of different types of vegetation in sequestering carbon in a landscape, area under each forest type in North Shimla were evaluated. The landuse/ landcover (LULC) map generated by using satellite images of Landsat TM 2003 and 2013 are shown in Fig. 3. These classified maps were analyzed to estimate the area under each vegetation type in the study area during the two time periods. Landsat TM data were classified into 10 landuse/ landcover (LULC) classes namely Deodar (539 km^2 in 2003 and 494 km^2 in 2013), Oak (113 km^2 in 2003 and 93 km^2 in 2013), Pine (429 km^2 in 2003 and 298 km^2 in 2013), Grassland (106 km^2 in 2003 and 85 km^2 in 2013), Alpine (160 km^2 in 2003 and 157 km^2 in 2013), Waterbody (8 km^2 in 2003 and 8 km^2 in 2013), Settlement (5 km^2 in 2003 and 14 km^2 in 2013), Stony waste (139.5 km^2 in 2003 and 107 km^2 in 2013), Agriculture/ Orchard (1025 km^2 in 2003 and 1252 km^2 in 2013) and Snow (45 km^2 in 2003 and 64 km^2 in 2013). Maximum area was observed to be under agri-

Table 2. Average (avg) growing stock (m^3), biomass and carbon (tonnes) per hectare in different forest types of North Shimla district (2003 & 2013).

	Deodar	Oak	Pine
2003			
Avg. growing stock (m^3 ha^{-1})	539.16	466.10	311.25
Avg. biomass (t ha^{-1})	492.03 ± 48.3	425.36 ± 52.1	287.5 ± 41.2
Avg. carbon (t ha^{-1})	221.4	191.4	129.4
2013			
Avg. growing stock (m^3 ha^{-1})	691	521.1	489.6
Avg. biomass (t ha^{-1})	630.6 ± 37.8	475.5 ± 48.2	452.6 ± 32.7
Avg. carbon (t ha^{-1})	283.8	213.9	203.7

Table 3. Distribution of Area (hectares), total biomass and carbon stock (terra gram) in different forest types of North Shimla district during 2003 & 2013.

	Area (ha)		Total biomass (Tg)*		Total carbon (Tg)*			
Vegetation Type	2003	2013	2003	2013	2003	2013	Decadal change in carbon (Tg)*	Annual change in carbon stock (tonnes / year)
Deodar	53907.4	49374.7	26.52	31.13	11.93	14.01	2.07	207576
Oak	11298.8	9329.17	4.81	4.44	2.16	1.99	-0.17	-16645
Pine	42884.4	29760.9	12.32	13.47	5.55	6.06	0.5	51305

** 1 Tg = 10^6 tonnes.*

culture (1025 km^2 in 2003 and 1252 km^2 in 2013) and minimum area under settlement class (5 km^2) in 2003 and water body class (8 km^2) in 2013. The maximum decadal increase in land cover class was observed in agriculture, an increase of 226 km^2 between 2003 and 2013. Pine forest showed maximum loss in area during the decade (131 km^2 reduced in 2013). For all the vegetation classes *i.e* Deodar, Oak and Pine there is a net loss in area during 2003 to 2013 (45 km^2 reduced for Deodar, 20 km^2 reduced for Oak and 131 km^2 for Pine).

The field inventories of 34 sample plots were used to estimate the volume, biomass and carbon stock for both time period of 2003 and 2013 for the respective vegetation types. The mean carbon in tonnes per hectare under each girth size group and overall mean above ground biomass and carbon stock under each vegetation types (Deodar, Oak, and Pine) was estimated, for both 2003 and 2013 (Table 1 and 2). Both of the average above ground biomass (t ha^{-1}) and carbon stock (t ha^{-1}) (for Deodar, Oak and Pine) showed an increase between 2003 and 2013. It is evident from Table 1 that during the decade, there is an overall increasing trend of carbon assimilation with the rising girth size due to their individual growth as well as the regeneration. Girth size of 100 - 150 cm, 150 -200 cm, and 200 - 250 cm for both the years of 2003 and 2013 shows a higher rate of carbon stock than lower girth size classes of 0 - 50. Therefore mature vegetation seems to contribute more as a potential carbon sink than the young stands, due to variation in C-sequestration potential. For 2003, the mean carbon was estimated to be 221.42 t ha^{-1}, 191.41 t ha^{-1} and 129.38 t ha^{-1} for deodar, oak and pine respectively. For 2013, it was found to be 283.7 t ha^{-1} for Deodar, 213.9 t ha^{-1} for Oak, and 203.6 t ha^{-1} for Pine. This is due to the increase of girth size of the trees (Burrows *et al.* 2002). Therefore, the distribution of total biomass and carbon stock of each forest within the study area is estimated using the simple mathematical multiplication of the homogeneous forest area under each vegetation type (Table 3) by the mean biomass and carbon per hectare (Table 2). The total carbon stock in 2003 was found to be 11.9 Tg for Deodar, 2.2 Tg for Oak and 5.5 Tg for Pine, whereas in 2013, the value of carbon stock was 14 Tg for Deodar, 2 Tg for Oak and 6.1 Tg for Pine (Table 3) in the study area.

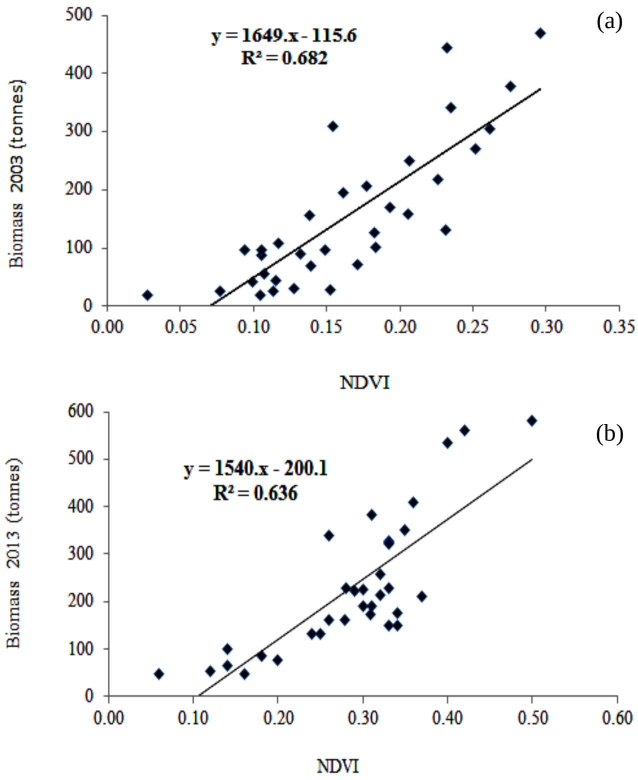
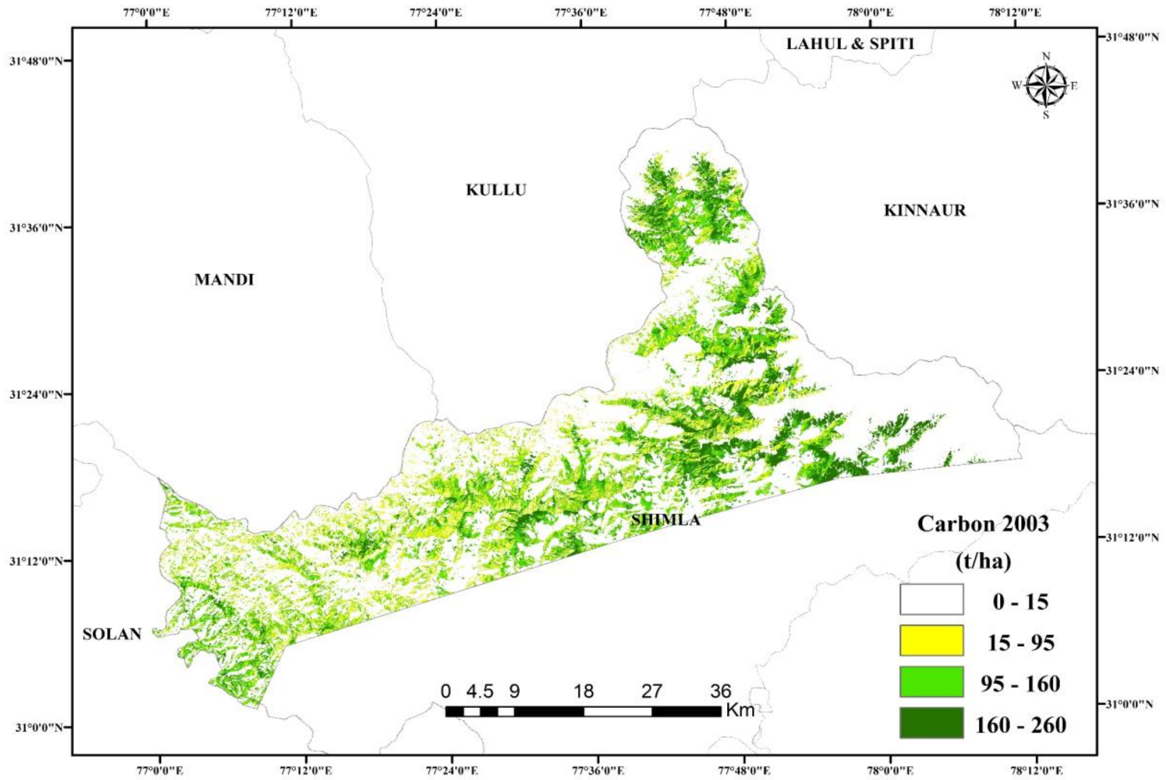


Fig. 5. Relationship between NDVI values and biomass ((a) 2003 and (b) 2013).

The plot-wise carbon values for boththe years of 2003 and 2013 are also extrapolated spatially to generate the carbon stock map of the study area. The NDVI of the study area generated using TM data not only showed a positive correlation with ground based biomass estimate with r^2 value of 0.68 and 0.63 for 2003 and 2013, respectively (Fig. 5a & b), but also represent the carbon density within a vegetation type. The low NDVI values reflect the corresponding areas with disturbed vegetation density, hence reduced carbon content. Statistical regression equation for biomass developed with NDVI was used on the NDVI image to extrapolate the per-pixel biomass/carbon values of Deodar, Oak and Pine forest to generate the landscape level carbon map of the study area for both time periods (Fig. 6).

It is evident from Fig. 7 that Deodar (11.9 Tg in 2003 and 14 Tg in 2013) has the maximum carbon stock followed by Pine (5.6 Tg in 2003 to 6.1 Tg in 2013) and Oak (2.2 Tg in 2003 and 1.9 Tg in 2013) for both 2003 and 2013. There is a significant temporal increase in the mean biomass as well as carbon stock per hectare in all three forest types of the study area in Shimla district (Table 2). In the study area, there is an overall increase in the area under non-forest landuse class from 1490 km^2 to 1686 km^2 (Fig. 3) and a decrease of area under forest class (Table 3) as a consequence of varying anthropogenic influenced landuse changes (agricultural/ horticulture expansion and urbanization) leading to deforestation in the span of ten years. Since Deodar and Pine has a larger coverage in the study area for both the time periods (Table 3) unlike Oak and a higher rate of increase in biomass accumulation per hectare (492 t ha^{-1} in 2003 to 631 t ha^{-1} in 2013 for Deodar and 288 t ha^{-1} in 2003 to 453 t ha^{-1} in 2013 for Pine), thus both Deodar and Pine has a higher carbon sequestration potential (Deodar = 207576 t year^{-1}, Pine = 51306 t year^{-1}) from 2003 to 2013 (Table 3). On the other hand in spite of having a higher biomass accumulation rate (425 t ha^{-1} to 476 t ha^{-1}), Oak forests in the study area has relatively less rate of C-sequestration potential during 2003 to 2013, resulting in net carbon emission of 16645 t year^{-1} (Table 3). This is due to high rate of deforestation and degradation of Oak, resulting in reduction of area under Oak (19.69 km^2 of area reduced under Oak from 2003 to 2013). Furthermore Oak is extensively used as a firewood in the hills resulting in its habitat degradation. A high biomass accumulation in any species is probably due to high energy conversion efficiency as compared to other species (Bohre *et al.* 2012; Devagiri *et al.* 2013). On the contrary, the biomass accumulation rate is considerably lower in case of Pine (288 t ha^{-1} in 2003) as compared to Oak (425 t ha^{-1} in 2003), but it has a higher contribution as a carbon sequester for North Shimla (Fig. 7) because of its greater coverage and increase in total area under Pine. Thus the rate of change in total biomass /carbon content of any habitat depends largely on the growth rate of associated species (affecting the rate of carbon assimilation) or any disturbance influences (affecting area under coverage). Since the forests in North Shimla have around 20 % of its area under Deodar and a mere 4 % of its area under Oak, the overall contribution of Deodar forest in carbon sequestration of North Shimla is more significant than any other forest type. Thus area of coverage is an important parameter influencing the carbon sequestration of trees along with its assimilating capacity.

The observed mean AGB of 408 t ha^{-1} (2003) and 503 t ha^{-1} (2013) in these three forest types of Shimla district was comparable with the findings of Bhatt *et al.* (2013) who reported a value of 402.2 t ha^{-1} of mean AGB for similar temperate forest in Kedarnath wildlife sanctuary. However the present



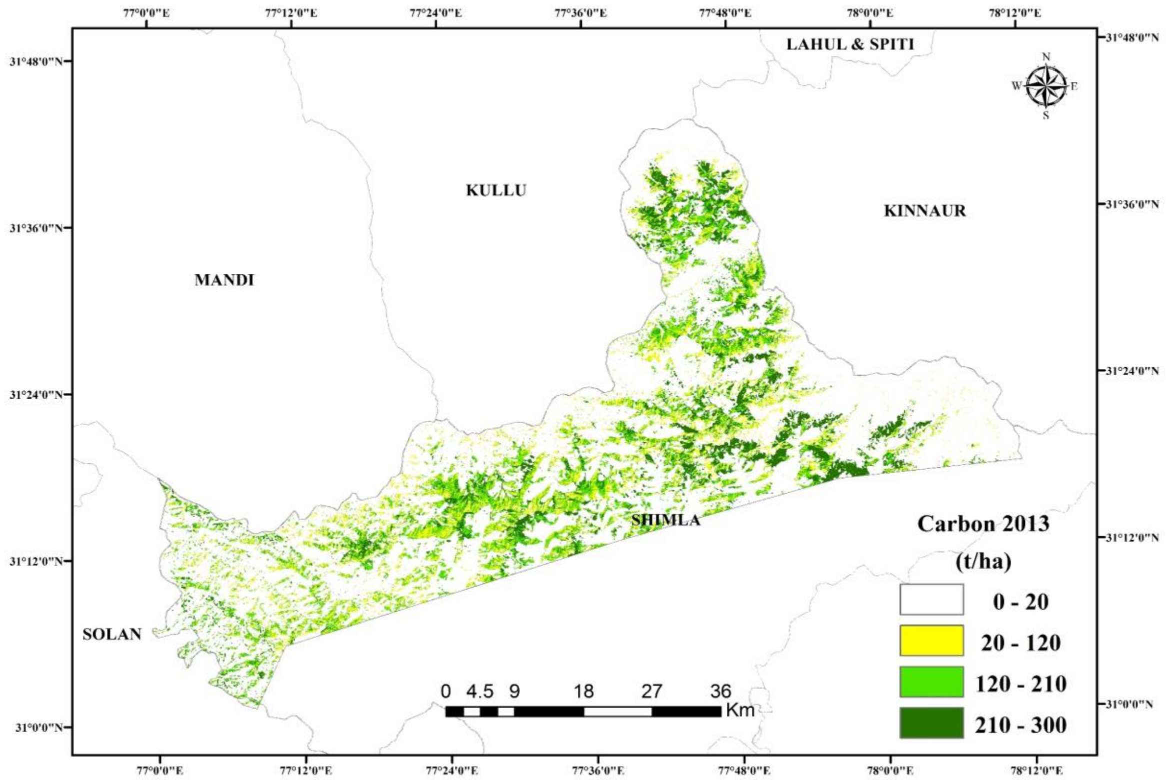


Fig. 6. Carbon maps of north Shimla district (2003 and 2013).

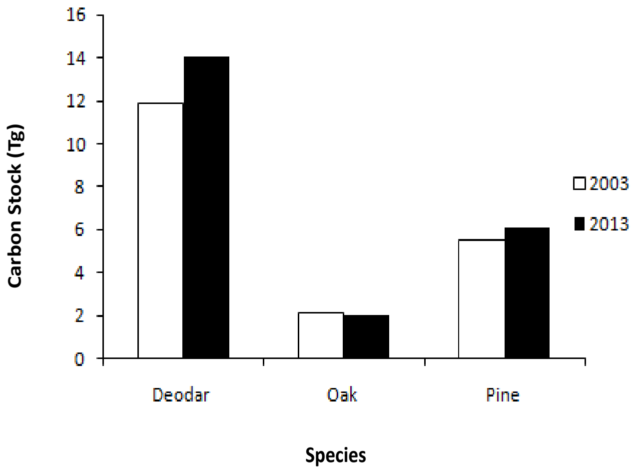


Fig. 7. Changes in carbon stock (2003 and 2013) for the three study species.

values are greater than the mean AGB values of 288.2 t ha^{-1} and 231.8 t ha^{-1} reported for moist temperate slopes and forest of Garhwal Himalaya and Himachal Pradesh by Gairola *et al.* (2011) and Chhabra *et al.* (2002). The AGB value range of 6.7 to 674.5 t ha^{-1} in temperate forest of Kashmir Valley (Singh *et al.* 2012) and 92 to 640 t ha^{-1} in Central Himalayan Biomass study (Singh *et al.* 1994) is lower than the values found in the present study. The amount of carbon stored in the major forest types in the study area (29 to 320 t ha^{-1} in 2003, 52 to 480 t ha^{-1} in 2013) was greater than the temperate forest of Garhwal Himalaya (77 to 291 t ha^{-1}) reported by Sharma *et al.* (2011).

The present study has concentrated on quantifying the change in carbon contribution for the major forest types of the North Shimla region using both field survey and remote sensing tools like NDVI. As evident from the results, the biomass accumulation varies both with time as well as species. Within the same species the carbon stock may differ from time to time due to various local factors like soil nutrients, management practices and availability of light and other environmental factors (Bohre *et al.* 2012). With the increasing importance of carbon sequestration studies all over the world, this kind of research will provide a robust database to assess the change in above ground biomass and carbon stock with time. It can also be used to understand changes in forest structure with time or differentiating between forest types (Cairns *et al.* 2003; Mani & Parthasarathy 2009, Areendran *et al.* 2013, Sahu *et al.* 2015).

Conclusion

In this paper, a study has been presented on how the natural carbon sinks of north Shimla district, are changing with the passage of time as a consequence to various dimensions of human land use change as well as vegetation degradation. In north Shimla district, Deodar is found to have a major role in carbon sequestration for both 2003 and 2013 due to its wider area of coverage. On the contrary, in spite of higher carbon assimilation rate, overall contribution of Oak remains insignificant for both the time periods. It also highlights the contribution of the three major forest types (Deodar, Oak, and Pine) in sequestering carbon from atmosphere depending on their biomass accumulation rate. Since carbon balance is most vital for life on earth by influencing the climate, the changes in carbon dynamics over space and time due to unprecedented anthropogenic intervention, has always been a significant issue in ecological studies. With the rising threat of climate change, accurate forest carbon inventory would result in a robust impact assessment of landuse dynamics on the environment, aiding the future land management and policy decisions (Devi *et al.* 2013).

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