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TREE DISTRIBUTION PATTERN, GROWING STOCK CHARACTERISTICS AND CARBON MITIGATION POTENTIAL OF DIFFERENT FORESTS ECOSYSTEMS IN KUMRAT, HINDUKUSH REGION OF NORTHERN PAKISTAN

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Abstract

Using ground inventory and remotely sensed data, this study explored the tree distribution pattern, growing stock characteristics and carbon mitigation potential of different forests of the Hindukush region in Kumrat valley, of northern Pakistan. The results showed that forestland covered an area of 51.13% of the valley. Stem density varied between 243±55 to 585±221 ha^{-1}. Tree height was found in the range of 3 m and 49.85 m among the different forests. The regression analysis between stem density and diameter showed a week correlation in *Cedrus deodara* (CD) and *Abies pindrow* forest (AP), but showed positive correlation in *Pinus wallichiana* (PW), mixed coniferous (MC), and open forest (OF). Tree basal area and stem volume ranged from 343.45±210.68 to 159.64±58.41 m^2 ha^{-1} and 343.45±210.68 to 2160.4±974.91 m^3 ha^{-1} respectively. The range of calculated tree biomass was between 244.06±153.25 and 1499.5±627.74 Mg C ha^{-1}. The carbon values varied between 122.03±76.62 and 749.69±313.85 Mg C ha^{-1}. The results showed that among the different forests, CD had the highest carbon mitigation potential and OF had the lowest carbon mitigation potential. Furthermore, our results showed that the values of stem volume, total tree biomass and carbon in each forest were highly correlated with the basal area. Additionally, our findings provide evidence that basal area is the best predictor of biomass carbon estimation in each forest that suggests the use of the basal area for biomass carbon estimation. This approach could considerably reduce both, financial and physical efforts in carbon inventory regarding the field data collection particularly over the extensive tract of underrepresented carbon forests in Pakistan.

Key words: Kumrat forests, Inventory, Remote sensing, Carbon stock.

Introduction

The increase emissions of greenhouse gases (GHGs) since the industrial revolution significantly influenced the global environment. The growing concern of environmental changes because of climate change the problem of carbon balance, the major GHG, is important. The removal of carbon and their storage in different terrestrial ecosystems for cutting down the increasing level of carbon dioxide is required (Ardö & Olsson, 2004; Wani *et al*., 2017). Forests are the largest carbon sink (Espírito-Santo *et al*., 2014; Coulston *et al*., 2015) and an important component of the global carbon cycle among terrestrial ecosystems (Zhang *et al*., 2013). Forests are extremely important in balancing of the carbon cycle by absorbing 2.9±0.8 Pg C each year (Le Quéré *et al*., 2009; Calfapietra *et al*., 2015). Forests cover over 4 billion ha area of Earth Planet and store 861±66 Pg C (Wani *et al*., 2015). Forestland has the ability to store and sink more carbon; forestland can hold 20 to 50 times more carbon than other land use (Houghton *et al*., 1995). The woody and long living nature of the forest that makes them more attractive tools for the stabilization and reduction of GHGs (Sharma *et al*., 2010).

The measurement of forest biomass carbon is required to understand the dynamics of carbon in a forest for decision making to manage forest resources for climate change (Esser, 1984; Johnson & Kern, 2002; Malhi *et al*., 2004). The quantity of biomass in a forest measure the amount of carbon capture in the forest land, particularly when forests are managed for meeting emission targets (Brown *et al*., 1999). In the recent climate change scenario and their mitigation concerns at the national and international level, carbon management through forest attached greater value (Anon., 2015). To address the challenge of global climate change the IPCC, UNFCC, and the Kyoto Protocol (KP) are working at the regional and international level to coupe the issue of climate change (Wani *et al*., 2012). The KP recognized that different terrestrial ecosystems such as forests, grassland and wetland could potentially store and sequester carbon from the atmosphere and therefore, slow down the increasing concentration of carbon dioxide (Ardö& Olsson, 2004).

Pakistan is a member of the Kyoto Protocol and the UNFCC. The country has diverse ecology and forest types. The northern areas (NA) of Pakistan comprise of Hindu Kush, Karakorum, and Himalaya ranges are the home to the forests. In these forests, major challenges exist with respect to carbon estimation. The lack of resources for research, limited logistical support and week infrastructure in the area are the limitations to carbon inventory. Most of the researchers in this region have only focused their attention on the ecology, regarding the species composition, stand structure and population dynamics (Ahmed *et al*., 2009; Ahmed *et al*., 2011). A number of the studies have only estimated biomass carbon from the available growing stock inventory data in the shape of working plans (Ahmad *et al*., 2014; Ahmad *et al*., 2015).

Although, the available growing stock data can be used in assessing the biomass carbon using IPPC proposed guidelines (Eggleston *et al.*, 2006). However, the minimum diameter of the trees (16 cm) reflecting the dominant interest of commercial volume. In spite of the fact that smaller stems may have less volume than larger, but smaller stems are often occurring relatively more than the larger stems and may share an important proportion of total volume and biomass carbon. Similarly, the available inventory data in working plans only covers trees up to 150 cm in diameter, but trees up to 180 cm have been reported from the Hindukush, Himalaya ranges (Ahamd *et al.*, 2013). Ignoring the smaller trees, as well as the larger trees, in the available inventory data under estimated the biomass carbon of the region. Moreover, no sophisticated information is available regarding the carbon mitigation potential of different forests, the scale, and magnitude of anthropogenic disturbances and their impacts on carbon. Looking into above limitations more accurate data is needed for effective carbon budgeting and to reduce the uncertainties. Taking these considerations in mind, we conducted the present study to evaluate carbon storage and mitigation services of different forest types in the Kumrat valley, of Hindukush Himalaya, range. We used remotely sensed data with the ground survey to identify major land uses and forest types, combined with ground carbon inventory. We measure trees from 6 cm to 180 cm diameter and assessed tree distribution pattern, growing stock characteristics and biomass carbon of different forests types. We compared the carbon mitigation potential of different forests. We furthermore, develop regression models, protocol, and guidelines to study the relationship between stem diameter and tree density, stand basal area and stand volume, stand basal area and biomass carbon, and show that basal area is the best predictor of biomass carbon.

Materials and Methods

Study area: The study was conducted in Kumrat valley, of Khyber Pakhtunkhwa. The valley is located in the northern part of Pakistan. The total area of the valley is 34607.91 ha and lies between latitude 35^0 30' 25" to 35 47' 55"N and longitude 72^0 12' 85 " to 72 022' 58" E. Topographically, the area is characterized by hilly landscape. The elevation of the valley ranges from 2000 m to 6000m. The rocks are mostly igneous and Meta-sedimentary. The area has a temperate type climate. The average precipitation ranges from 1000 – 1200 mm. The area receives maximum precipitation from February-April and July to August. Temperatures varied with a minimum of 0.3^0C in December and a maximum of 25°C in June. The soil has loam or sandy loam textures, porous and rich in humus. The average soil organic matter varied between 2 to 5% and the average organic carbon ranged from 1.16 to 2.90%. The major land use types include agriculture lands, rangelands, water bodies, snow, and glaciers. The major forests in the area include *Cedrus deodara* forest (CD), *Pinus wallichiana* forest (PW), *Abies pindrow* (AP) and mixed coniferous forest (MC). The major tree species of the area includes *Cedrus deodar*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana*, *Taxus bacata*, *Quercus baloot*, *Betula utilis*, *Platanus orientalis*, *Juglans regia*, *Aesculus indica*, *Poplus ciliate* and *Acer caesium.*

Land uses detection and Forest area calculation: The land use map of the study area was generated from multispectral Landsat 8 Oil imagery, 2016 with 30 m resolution in the scale of 1:50,000. The image was obtained from United State geological survey (http:// glovis.usgs.gov).The country topographic map was also used in combination. The map was first scanned and then imported into the processing software. Pre-processing of the image is critical before the classification for establishing a relationship between acquired data and biophysical process (Abd El-Kawy *et al.*, 2011). The geometric correction was performed from the topographic sheet, as well as from the GPS during the field visit. Radiometric, atmospheric, topographic corrections and sub-setting of ROI (region of interest) were performed using Arctic 10.2 and ENVI 5.1. All the satellite data were examined and per-pixel signatures were assigned thus classifying the study area into different classes of dense forest, open forest and rangeland, agricultural land, barren land, water bodies, and snow and glaciers. After that, different colors were assigned to the classes to differentiate them and maximum likelihood algorithm in supervised classification was performed to improve the classification accuracy. The accuracy of the classified image was assessed by Confusion matrix ground truth image. The accuracy was assessed by using 50 points based on ground and visual interpretation. Kappa statistics was also applied to check the accuracy of the classified images. Finally, the land used data generated through satellite imagery was classified into the dense forests (DF), open forests and rangelands (OF, RL) agriculture land (AL), barren land, water bodies, and snow.

Based on the ground survey, dense vegetation of the area was further classified into dense deodar forest (CD), dense Kail forest (PW), dense Fir forest (AP) dense mixed coniferous forest (MC). In the map, (Fig. 1d) open forests (sparse vegetation) and rangelands were assigned combine class. However, based on available literature (Ahmad & Nizami, 2015) rangeland occupied 22% of the sparse vegetation therefore, the area of rangeland was calculated using the equation below.

Area of range land = (Area of sparse vegetation *22)/100

In order to analyze the scale of vegetation coverage, we calculated NDVI (Normalized difference vegetation index) value of the area. The lower value of NDVI indicates low forest cover, while the high value indicates the dense vegetation cover. In this study, we measured the NDVI value from remotely sensed data using band math in ArcGIS 10.2, through the following formula:

NDVI= NIR-RED/NIR+RED, where NIR= near infrared band and RED= Red band

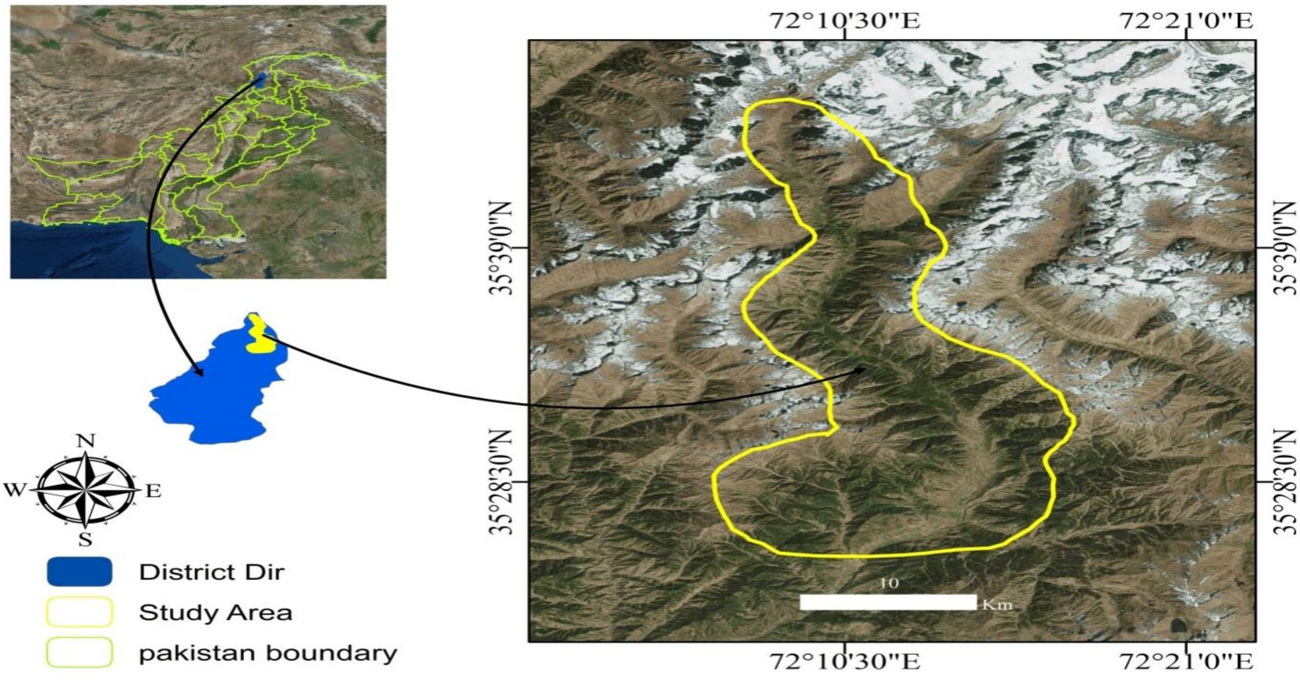


Fig. 1a. Study area image.

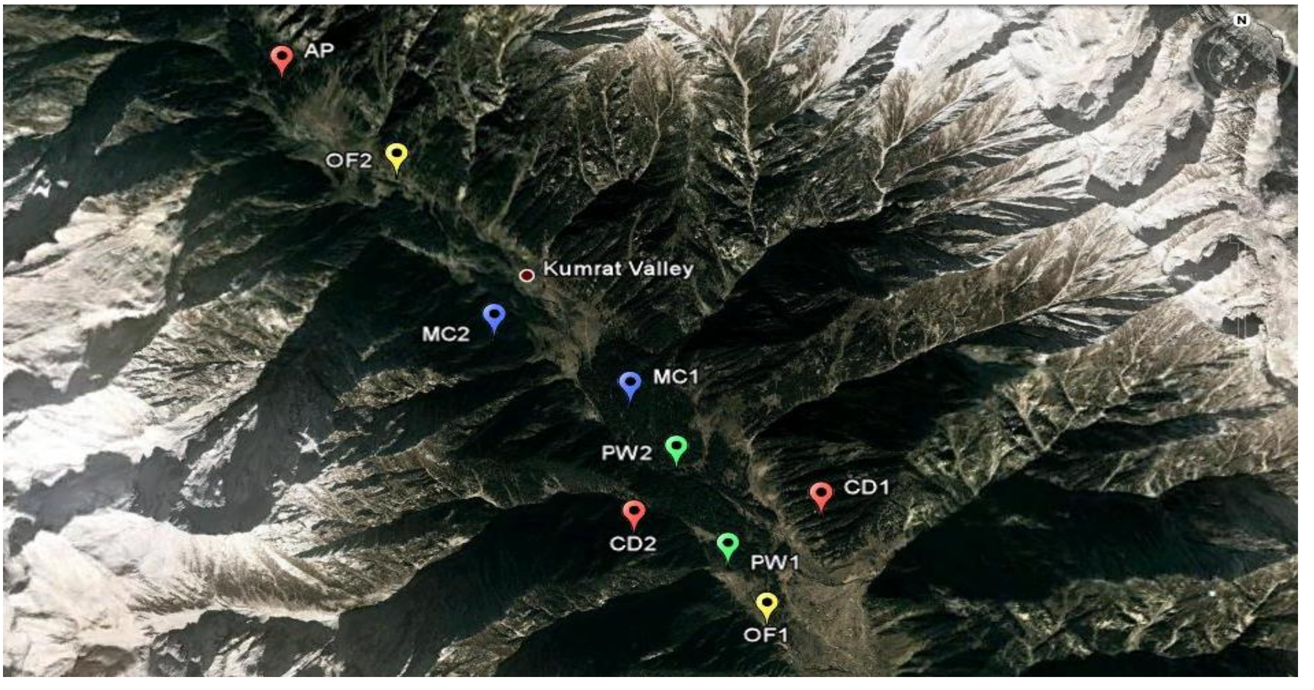


Fig. 1b. Geospatial image of the studied forests (DF1, DF2= Deodar forest sample sites, KF= Kail forest sample site, MF1&MF2= Mix forest sample sites and FF= Fir Forest sample site).

Inventory design and data collection: To determine the topographic nature of the area, tree composition, and distribution a general survey of the area was carried out. The working plan of DirKohistan was also consulted for the ground verification of details. After the survey, the major five forest types were selected for the study. In each forest type, 18 sample plots were laid out randomly. The size of each sample plot was 0.1ha. The shape of the plot was square. All the trees with a diameter larger than 4 cm were measured for dendrometric characteristics, such as tree height (m) and diameter (cm) at breast height (1.3m), in each plot. The trees in each sample plot were counted and stem density was calculated. For measuring tree distribution pattern, all the counted trees in each forest were grouped into diameter classes with a diameter interval of 20 cm (that is, 6-38, 40-58. 60-78, 80-98, 100-118, 120-144, 146-178 cm).

Measurement of growing stock characteristics and biomass carbon: Different growing stock parameters, like stem density (ha^{-1}), tree basal area (m^2 ha^{-1}) and tree volume m^3 ha^{-1}) were measured. Tree volume was measured from the product of tree height (m), tree cross-sectional area (m^2) and form factor following

(Philip, 1994). Stem biomass (Mg C ha^{-1}) was measured from the value of wood density (Kg m^{-3}) of respective tree species and calculated volume following IPPC guidelines (Eggleston *et al*., 2006). The value of wood density was sourced from the available literature of (Haripriya, 2000; Anon., 2006). Total tree biomass (Mg C ha^{-1}) was calculated from the measured value of stem biomass and biomass expansion factor (BEF). The BEF value of each tree species was sourced from (Haripriya, 2000). For assessing the carbon content (Mg C ha^{-1}) in the living tree, we converted the biomass into carbon, using a carbon-measuring fraction (Malhi *et al*., 2004; Houghton, 2005; Nizami, 2012; Zhang *et al*., 2013) using equation below:

$$\text{Carbon (t ha}^{-1}\text{)} = \text{Biomass (t ha}^{-1}\text{)} * \text{Carbon \% (0.5)}$$

Statistical analysis and development of regression models: To test the difference among growing stock parameters and biomass carbon in each forest type, one-way analysis of variance (ANOVA) was used. LSD significant difference test was used to compare the means of each studied parameters (Statistics v.8.1, Analytical software). In each forest type density – diameter regression models were developed to study the relationship between tree diameter (cm) and stem density. Stand specific – height-diameter (H/cm) regression models were also developed for respective trees species. Similarly, models were developed for the relationship between basal area (m^2 ha^{-1}) and stem volume (m^3 ha^{-1}), basal area (m^2 ha^{-1}) and total tree biomass (MgC ha^{-1}) and basal area (m^2 ha^{-1}) and total carbon (Mg C ha^{-1}) in each forest type. Regression models were developed in Sigma Plot (Version 12).

Results

Land use statistics and forest types: The results showed (Table 1, Fig. 1c) that, dense forest covered about 9502.2 ha of the total land area and the area of open forest accounted for 8190.51 ha. Agriculture land, rangeland, and barren land occupied an area of 833.48, 2310.14, and 10179.81 ha respectively. Of the total land area of the valley, about 3610.56 ha is under water bodies, snow, and glaciers. The land uses statistics showed that forest is the dominant land use type, which constitutes about 51.13% of the total land cover. Forests in the area occurred as dense vegetation (dense forests) and sparse vegetation (open forests). The results of satellite imagery (Fig. 1a, 1b, 1c) revealed that dense forests are mainly distributed at higher elevations while open forests at the lower elevations. Similarly, the calculated value of NDVI varied between -0.8 to 0.79 (Fig. 1b). The light green color in the image represents the lower NDVI and the dark green color represents the high NDVI value. It can be seen from the image that, the NDVI value is high at the upper zone and low in the lower zone, which indicates that most of the dense forests occurred at higher elevations and open forests at lower elevations.

Trees DBH-density distribution pattern: The trees distribution pattern highlighted a decreasing trend with respect to increasing diameter in all forest types (Table 2; Fig. 2). In general, among all forests, lower diameter classes held a statistically large number of trees than upper diameter classes. However, In CD and AP, in lower diameter classes, a smaller proportion of trees were counted as compared to PW, MC, and OF, but in upper diameter classes, a larger proportion of trees were counted in CD and AP than the other forests (Table 2). On average, the value of stem density varied between 243±55 ha^{-1} in CD and 585±221 ha^{-1}in PW. Stem density was recorded statistically higher in PW than in other forests. Similarly, the recorded stem density in MC forest was significantly higher from the recorded stem density of CD, AP, and OF. However, the values of stem density were not statistically different among CD, AP, and OF, though the mean density of the OF was found higher from CD and AP. Further correlation analysis (Table 4) between tree diameter (cm) and stem density (ha^{-1}) showed week correlation (R^2=0.31 and 0.39) in CD and AP at 0.05 significant level (p=<0.0001) whereas, statistically positive correlation (Table 4) was observed in PW, MC and OF at 0.05 significant level (p=<0.0001).

Table 1. Land uses statistics of the study area (2016).

Land use type	Total area (ha)	Percentage
Dense Forest	9502.2	27.46
Open forest	8190.515	23.67
Agriculture land	814.68	2.35
Range land	2310.145	6.68
Barren land	10179.81	29.41
Water bodies	1120.23	3.24
Snow and Glaciers	2490.33	7.20
Total	**34607.91**	**100.00**

Growing stock characteristic and biomass: The recorded tree height for respective tree species ranged between 5 and 46.64m at 6 and 178 cm diameter, in CD, while in AP it was 3 and 49.85m at 6 and 144 cm diameter. The range of total tree height in PW and PS was 5.4 and 44.46m at 6, 106 cm diameter, 3.2 and 44.88m at 6 and 110 cm diameter respectively (Fig. 4). The height (m) and diameter (cm) relationship was found strongly positive correlated (R^2= 0.99, alpha=0.05, p<0.0001) (Table 4; Fig. 3) among the all forests. The results of the values of stem volume (m^3 ha^{-1}), basal area (m^2 ha^{-1}), stem biomass (Mg C ha^{-1}), total tree biomass (Mg C ha^{-1}) in various forest types are placed in Table 3. Our presented results in the Table 3 depicted that among the forests, the values of the basal area, stem volume, stem biomass and total tree biomass in CD, were significantly higher from all other forests while significantly lower in OF. Similarly, in AP and PW no significant differences were observed for these values. In addition, in MC basal area, stem volume, stem biomass, and total tree biomass represent a significantly smaller value from AP and PW. Furthermore, the regression analysis (Table 4, Figs. 4-8) showed that the values of stem volume and biomass for all forests were strongly correlated with the basal area.

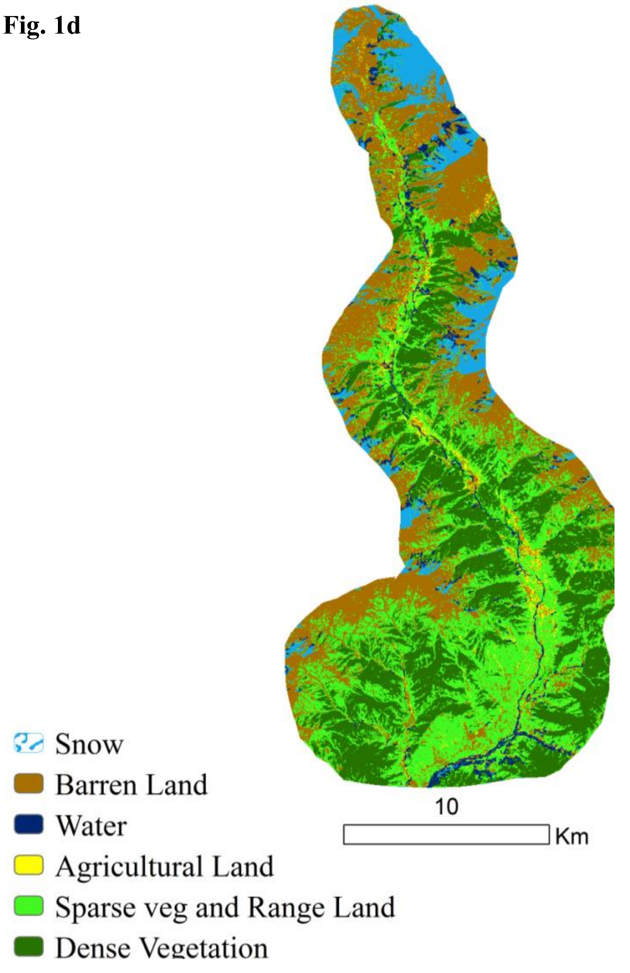


Fig. 1c and 1d. Land uses and NDVI (Normalize difference vegetation index) maps of the area.

Table 2. Tree distribution pattern in different diameter (cm) classes in respective forest types.

Diameter classes (cm)	Density ha^{-1} CD	Density ha^{-1} AP	Density ha^{-1} PW	Density ha^{-1} MC	Density ha^{-1} OF
6-38	47^{b} (19.3%)	74^{b} (27.0%)	273^{a} (46.7%)	247^{a} (52.6%)	230^{a} (71.4%)
40-58	40^{c} (16.5%)	56^{c} (20.4%)	187^{a} (32.0%)	127^{b} (27.1%)	51^{c} (15.7%)
60-78	40^{cd} (16.5%)	48^{bc} (17.5%)	88^{a} (15.0%)	67^{ab} (14.2%)	23^{d} (7.1%)
80-98	33^{ab} (13.6%)	48^{a} (17.5%)	33^{ab} (5.6%)	26^{bc} (5.6%)	10^{c} (3.1%)
100-118	32^{a} (13.2%)	26^{a} (9.5%)	4^{b} (0.7%)	3^{b} (0.7%)	9^{b} (2.7%)
120-144	29^{a} (11.9%)	22^{a} (8.0%)	0^{b}	0^{b}	0^{b}
146-178	22^{a} (9.1%)	0^{b}	0^{b}	0^{b}	0^{b}
Total	**243 ± 55^{c}**	**274 ± 82^{c}**	**585 ± 221^{a}**	**470 ± 159^{b}**	**322 ± 138^{c}**

Different superscripts in each column represent a significant difference (n=90, $p \leq 0.0001$, Alpha=0.05)

Table 3. Stem density (ha^{-1}), Basal area (m^2 ha^{-1}), Stem volume (m3 ha^{-1}), stem biomass (MgC ha^{-1}), total tree biomass (MgC ha^{-1}), and total carbon (MgC ha^{-1}), in respective forest types.

	Basal area	Volume	Stem biomass	Total biomass	Total carbon
DF	159.64 ± 58.41^{A}	2160.4 ± 974.91^{A}	1007.1 ± 407.71^{A}	1499.5 ± 627.74^{A}	749.69 ± 313.85^{A}
FF	113.71 ± 24.05^{B}	1454.5 ± 304.89^{B}	538.87 ± 111.6^{B}	817.01 ± 171.26^{B}	408.51 ± 85.63^{B}
KF	103.74 ± 29.17^{B}	1168.8 ± 437.64^{B}	583.22 ± 218.38^{B}	880.66 ± 329.76^{B}	440.33 ± 164.8^{B}
MF	66.052 ± 31.06^{C}	764.26 ± 232.06^{C}	328.44 ± 99.72^{C}	495.94 ± 150.59^{C}	247.97 ± 75.29^{C}
OF	30.463 ± 18.52^{D}	343.45 ± 210.68^{D}	161.82 ± 101.4^{D}	244.06 ± 153.25^{D}	122.03 ± 76.62^{D}
Mean	94.72 ± 55.83	1178.26 ± 778.1^{2}	523.89 ± 359.6^{3}	787.42 ± 540.21	393.70 ± 270.09

DF= Deodar forest, FF= Fir Forest, KF= Kail Forest, MC= Mix forest, OF= Open forest different superscripts in each column represent significant differences (n=90, $p \leq 0.0001$, Alpha=0.05 (LSD significant difference test)

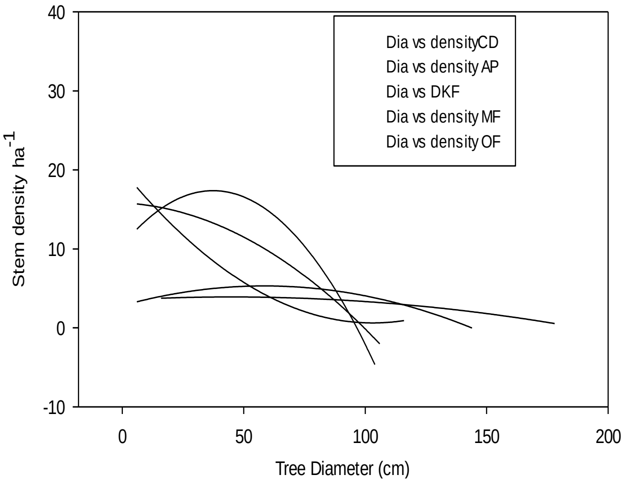


Fig. 2. Relationship between diameter (cm) and tree density (ha-1) in respective forest types.

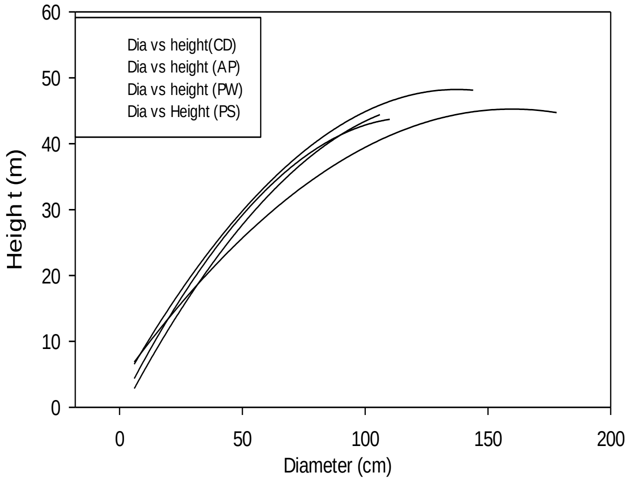
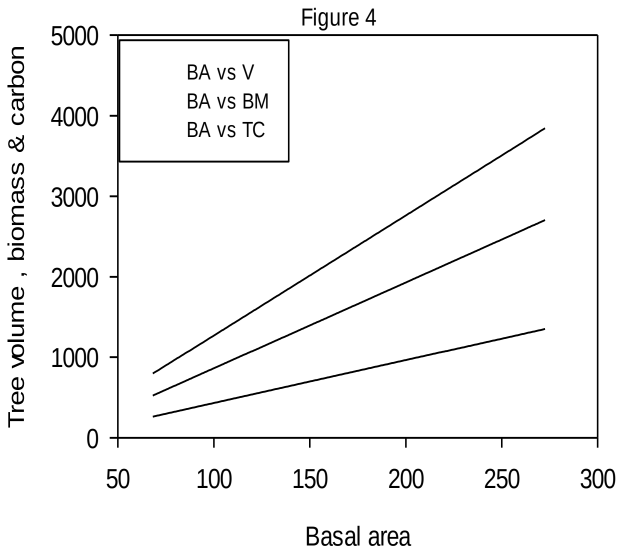
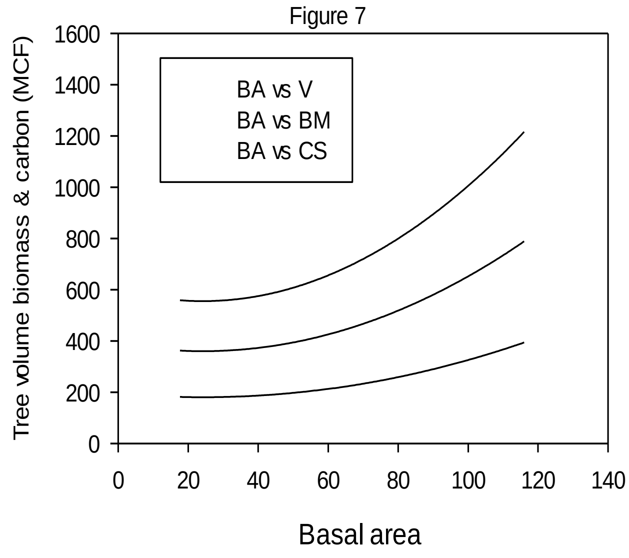


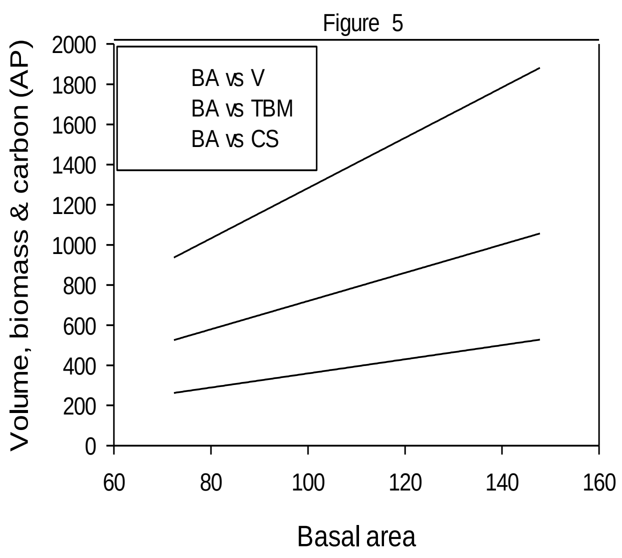
Fig. 3. Relationship between diameter (cm) and tree height (m) in respective forest types.

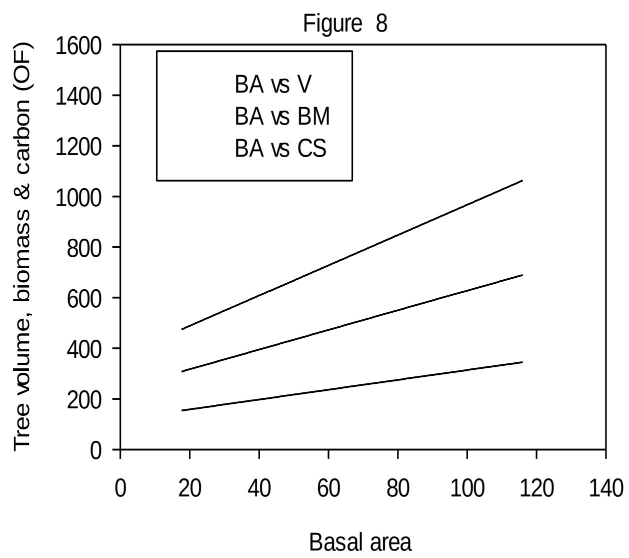
Table 4. Allomatric equations of diameter (cm) and stem density (ha^{-1}), Basal area (m^2 ha^{-1}) and Stem volume (m^3 ha^{-1}), total tree biomass (MgC ha^{-1}), and total carbon (MgC ha^{-1}), in respective forest types.

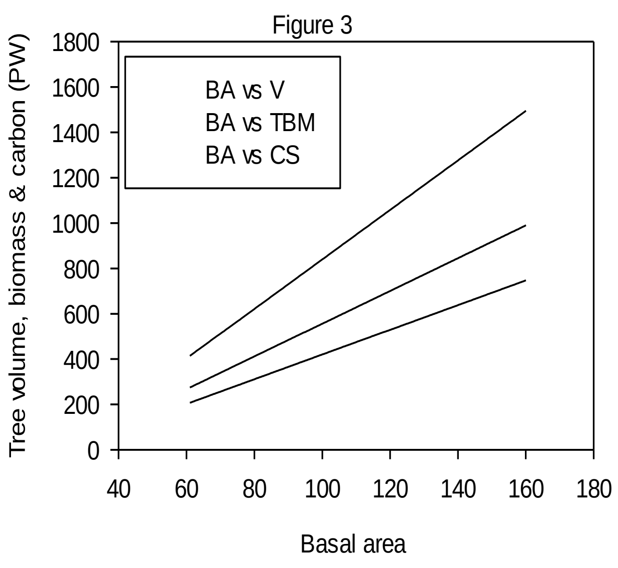
Parameters	R type	Equation	y0	a	B	R^2
Diameter & density (DF)	P. Quadratic	$d = y0+ax+bx^2$	3.5	0.017	-0.0007	0.32
Diameter & Height (CD)	P. Quadratic	$H = y0+ax+bx^2$	3.7	0.5	-0.0016	0.99
Basal area & Volume (DF)	P. Linear	V = y0+ax	-219.4	14.9		0.99
Basal area & biomass (DF)	P. Linear	BM= y0+ax	-203.6	10.6		0.98
Basal area & carbon stock (DF)	P. Linear	CS = y0+ax	-101.8	5.33		0.98
Diameter & density (FF)	P. Quadratic	$d = y0+ax+bx^2$	2.8	0.017	-0.0002	0.40
Diameter & Height (AP)	P. Quadratic	$H = y0+ax+bx^2$	2.6	0.66	-0.0024	0.99
Basal area & Volume (FF)	P. Linear	V = y0+ax	31.37	12.5		0.97
Basal area & biomass (FF)	P. Linear	BM= y0+ax	17.62	7.03		0.97
Basal area & carbon stock (FF)	P. Linear	CS = y0+ax	8.81	3.51		0.97
Diameter & density (KF)	P. Quadratic	$d = y0+ax+bx^2$	10.44	0.37	-0.005	0.64
Diameter & Height (PW)	P. Quadratic	$H = y0+ax+bx^2$	1.3	0.71	-0.0027	0.99
Basal area & Volume (KF)	P. Linear	V = y0+ax	-167.1	7.2		0.93
Basal area & biomass (KF)	P. Linear	BM= y0+ax	-252.3	10.9		0.93
Basal area & carbon stock (KF)	P. Linear	CS = y0+ax	-126.1	5.46		0.93
Diameter & density (MF)	P. Quadratic	$d = y0+ax+bx^2$	15.82	-0.013	-0.0015	0.61
Diameter & Height (PW)	P. Quadratic	$H= y0+ax+bx^2$	0.04	0.37	-0.0031	0.99
Basal area & Volume (MF)	P. Quadratic	$V = y0+ax+bx^2$	601.3	-3.7	0.07	0.73
Basal area & biomass (MF)	P. Quadratic	$BM = y0+ax+bx^2$	390.2	-2.4	0.05	0.73
Basal area & carbon stock (MF)	P. Quadratic	$CS = y0+ax+bx^2$	195.1	-1.2	0.002	0.73
Diameter & density (OF)	P. Quadratic	$d = y0+ax+bx^2$	19.97	-0.37	0.0018	0.81
Basal area & Volume (OF)	P. Linear	V = y0+ax	28.01	10.35		0.82
Basal area & biomass (OF)	P. Linear	BM= y0+ax	10.40	7.6		0.85
Basal area & carbon stock (OF)	P. Linear	CS = y0+ax	5.2	3.8		0.85

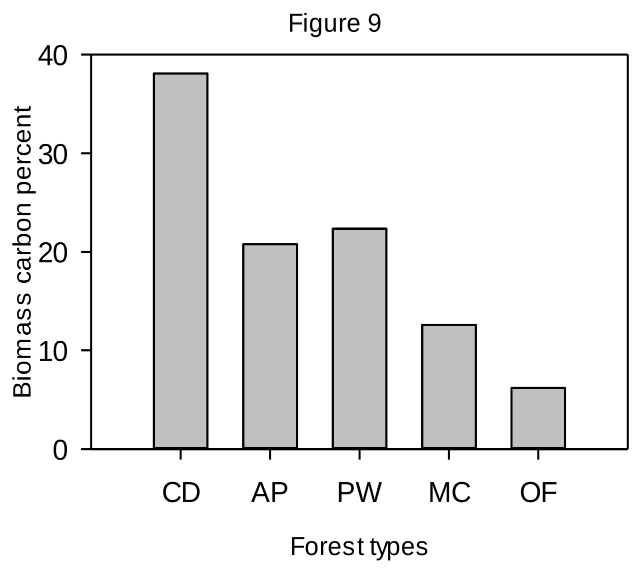












BA= Basal area, V= Volume, TBM= Tree biomass, CS= Carbon stock

Fig. 4 to 8. Relationship between basal area (m^2 ha^{-1}) and stem volume (m^3 ha^{-1}), basal area (m^2 ha^{-1}) and total tree biomass (MgC ha^{-1}), basal area (m^2 ha^{-1}) and total carbon (MgC ha^{-1}) in CD, AP, PW, MC and OF respectively. Fig. 9. Biomass carbon percent of the respective forests.

Biomass carbon mitigation potential: The estimated biomass carbon density ranged between 122.03±76.62 and 749.69±313.85 Mg C. Among the forests types, CD possess the highest carbon stock, followed by PW, AP, MC, and OF (Table 3). The estimated carbon value in different forests permit us to address that, CD stored significantly higher carbon and OF stored significantly lower carbon than the other forests, there is, however, no significant difference in the carbon value of PW and AP. Similarly, MC forest stored statistically lower carbon than AP and PW. Overall, (Fig. 9) CD forest possess the largest percentage carbon (38.08%) followed by PW (22.36%), AP (20.75%), MC (12.59%) and OF (6.19%). Taken together our finding proves that among the forests types, CD has the highest carbon mitigation potential followed by PW, while OF has the lowest carbon mitigation potential.

The basal area of a forest is a good predictor of biomass carbon, therefore, expected highly correlation (Sarmiento *et al*., 2005). In order to study the relationship between basal area and biomass carbon in each forest, we developed regression models (Table 4; Fig. 4-8). The results of our regression analysis showed a strong positive correlation (R^2=0.88-98) between basal area and carbon density in among all forests. The value of R^2 validates the usefulness of basal area in predicting biomass carbon.

Discussions

Tree distribution pattern: Our present study showed that PW had maximum stem density followed by OF and CD had minimum stem density followed by AP. The trees distribution pattern in respective diameter classes shows significant variation among the different forests. In each forest type, the DBH (diameter at breast height) class 6-38 cm showed the highest number of stems (Table 2). Regarding the percentage distribution of trees in different diameter classes, the counted trees in each forest showed a contrasting pattern. In CD and AP, the counted stems were recorded less in 6-38 cm diameter class than in other forests. Compared to, PW, MC and OF, the CD and AP had a relatively larger number of trees in diameter class of 100-118 cm. Moreover, in diameter class 120-144 cm, we only recorded trees in CD and AP, wherein diameter class of 146-178 cm, trees were only recorded in the CD. In general, in all forest types, the stem density decreased with increasing diameter because of natural competition (Palahí *et al*., 2006; Nizami *et al*., 2017), but the results of polynomial quadratic correlation statistics (Table, 4; Fig. 2) between stem density and diameter in CD and AP, showed a week relationship (R^2=31 and 39% respectively). However, in PW, MC and OF we found uniform decreasing trend in stem density with increasing diameter (Table, 4; Fig. 2). We attribute this uneven distribution of trees in CD and AP to the dominance of larger diameter trees. The forests of the area are declared as “Protected forest” and the local people have the rights to collect fuelwood and timber for their uses. In addition, the forests are managed under selection system, in which dead, dry, diseased, mature and over-mature trees are removed. In the study area, CD and AP forests are located at a higher elevation (Fig. 1b), having high conservation value (watershed and wildlife) hence receiving minimum disturbance and removal of trees during management operations, which resulted in the dominance of mature and over-mature trees across the two forests as compared to other forests.

Growing stock characteristics and biomass: The values of tree height in different forest types were in the range of 3 and 49.85 m. The positive correlation between tree diameter and tree height (Fig. 3) showed that the height of a tree increases with increase in tree diameter. The value of R^2 for different tree species in table 4, support the hypothesis that, tree height is the function of diameter (Chave *et al*., 2014; Nizami *et al*., 2017). Our results showed higher values of the basal area, tree volume and total tree biomass in CD forest and lower values in OF than the other forests. The larger value of the basal area, stem volume, and total tree biomass in CD could be related to the presences of larger diameter tree. Forest, having high- volume, contained relatively larger trees (Haripriya, 2000). Forest consisting of small trees, though in a higher number, contained lower volume as compared to those with a higher number of large trees (Pukkala *et al*., 2009). We found similar results in CD forest. Despite the lower stem density from all forests, CD had the highest values of volume and biomass because of the presences of larger diameter trees (up to 178 cm).

Tree volume and biomass have a direct relationship with the basal area and with the increase in basal area, the volume and biomass of a tree also increases. The results (Figs. 4 to 8) showing the functional relationship between basal area and volume/biomass are consistent with (Philip, 1994; Nizami, 2012; Saeed *et al*., 2016). The estimation of timber volume and biomass from the basal area are widely used in the forestry trade (Cannell, 1984; Dagnelie *et al*., 1999; Balderas Torres & Lovett, 2012). Presented models described the best functional relationship between basal area and tree volume/biomass. The higher value of R^2 (0.88-0.98) indicates a strong correlation and suggesting the use of the basal area for tree volume and biomass estimation (Table 4).

Biomass and carbon mitigation potential: The observations of carbon stocks among different forests show significantly higher carbon value in CD forest, whereas it was lower in OF. The higher value of biomass carbon might be related to the presence of larger diameter trees in the CD. The presence of larger diameter trees with old age yielded the highest living tree biomass in CD, because of time-dependent carbon accumulation process. Apart from the presence of more large size trees and high growing stock yield in AP forest, the higher biomass carbon density in PW than AP, reflect the higher wood density of the tree. Our presented results also showed statistical higher carbon in AP and PW forest from MF. This variation in carbon value among the forests might be the results of different forest management operations, accessibility, and topography. Forests such as CD and AP, located at higher altitude (Fig. 1b) are mature, old age and fully stock because of the lake of disturbance, therefore, hold higher carbon. In contrast, forests located at lower elevation (MC, OF) are easily accessible to the local community. Consequently receives more anthropogenic disturbance explaining the low carbon value. The heavy practice of illegal cutting with the traditional felling techniques and the small-scale clearing are the prominent factors for low carbon values in MC and OF.

The relationship between the basal area and biomass carbon density could be used to facilitate the measurement of forest carbon. Basal area is widely used in the assessment of biomass carbon in the tropical forest because it integrates the effect of both the number and size of trees (Whittaker, 1966; Chiba, 1998; Sarmiento *et al*., 2005; Balderas Torres & Lovett, 2012). The relationship between these parameters can also be used in combination with GIS and remote sensing for biomass carbon mapping (O'Grady *et al*., 2000). In this study, the correlation analysis (Figs. 4-8) between basal area and biomass carbon also confirmed that basal area is a good predictor of biomass carbon in a forest. The presented regression models in table 4, showing a highly positive relationship between basal area and biomass carbon (R^2=88-99) thus, clearly implies the use of the basal area for biomass measurement. Nevertheless, the recorded values of R^2 were found different among different forests. The value of R^2 was higher in CD followed by AP, PW, and MC and OF (Table, 4). This variation can be explained by the variation in tree size. The ratio between basal area and carbon value (C/BA) depend on the size of trees, with the increase in the size of the trees (basal area) the carbon value increases (West *et al*., 1999; Zianis & Mencuccini, 2004; Balderas Torres & Lovett, 2012). As the table 2 demonstrates, we can see that among the different forests, more large size trees were recorded in CD followed by AP and thus improve the value of R^2 in these two forests in the models. This improvement in the value of R^2 in the model, with the presences of larger trees and variation in the tree size, are similar to those reported by (Chiba, 1998; Burrows *et al*., 2000; Bi *et al*., 2010).

Conclusion

This paper has investigated trees distribution pattern, growing stock attributes, biomass and carbon mitigation potential of different forests types in Kumrat valley. The findings indicate that CD had the largest carbon mitigation potential because of larger, old age trees, and the absences of anthropogenic disturbances followed by PW and AP. Similarly, OF stored the lowest carbon followed by MC, due the maximum anthropogenic disturbances. These results recommending the protection, conservation and the rehabilitation of the degraded forest based on responsive carbon management approaches for enhancing carbon sequestration in the current climate change context. This will further increase the carbon mitigation ability of the area and can include the area into carbon market under CDM (clean development mechanism) and carbon trading of the Kyoto Protocol. Furthermore, the study explored the use of the basal area in predicting biomass carbon in the context of present carbon gap scenario in Pakistan. Field inventory data are required for the effective monitoring and reporting of forest carbon under the IPPC and Kyoto Protocol. Most of the natural forests in the country are located in highlands of Hindukush, Karakorum and Himalaya ranges. The lake of research facilities and budget, poor infrastructure, logistical support and accessibility and the unavailability of previous data, regarding the carbon stock, are the major limitations to field inventory. In the existing scenario, reducing both the physical and financial efforts in field data collection could be particularly valuable. The present findings have important implication for solving this problem. Developing of biomass carbon table's base on the basal area will be effective for future carbon mapping and monitoring.

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