Taiwania 67(1): 47–54, **2022**
DOI: 10.6165/tai.2022.67.47

Biomass carbon stock estimation in lesser Himalayan subtropical broadleaf forests of Kashmir

Raja Waqar Ahmed KHAN, Hamayun SHAHEEN*

Department of Botany, University of Azad Jammu and Kashmir, King Abdullah Campus Muzaffarabad. 13100. Pakistan.
**Corresponding author's email: shaheenecologist@gmail.com; Phone: +92-344-52952552*

(Manuscript received 3 April 2021; Accepted 9 December 2021; Online published 8 January 2022)

ABSTRACT: Carbon stock quantification holds vital significance in evaluating the climate change mitigation potential and carbon management of forest ecosystems. The current study was designed to quantify the biomass carbon stocks in the lesser Himalayan subtropical broadleaf forests of the Kashmir region. Primary data about the structural attributes and species composition of the local forests was collected through quadrat-based sampling followed by the application of allometric equations for the estimation of forest biomass. The biomass carbon stocks were calculated as 135.2 Mg ha^{-1} ranging from a maximum of 226.64 Mg ha^{-1} to a minimum of 11.83 Mg ha^{-1}. The tree layer contributed a biomass carbon content of 134.67 Mg ha^{-1} making up to 99% share in the total forest biomass as compared to the shrub and herb layers with a very low biomass carbon value of 0.37 Mg ha^{-1} and 0.17 Mg ha^{-1} respectively. *Dalbergia sissoo* was recorded as the most dominant tree species with a biomass carbon stock value of 40.70 Mg ha^{-1} followed by *Mallotus philippensis* (30.09 Mg ha^{-1}) and *Ficus palmata* (20.11 Mg ha^{-1}). Principal Component Analysis revealed that the variations in the local carbon stocks were significantly correlated with the distribution pattern of the dominant tree species. Generalized Linear models showed a strong affinity of biomass carbon reserves with the structural attributes of the forest stands. This study generated a standard scientific dataset of the local biomass carbon stocks in the subtropical broadleaf forests with dynamic implications in sustainable forestry and carbon pool management in the region.

KEY WORDS: Biomass, carbon pools, climate, Himalayas, Kashmir, REDD, subtropical forest, vegetation.

INTRODUCTION

Forest biomass constitutes a major terrestrial carbon sink with the ability to sequester atmospheric carbon, enabling the biosphere to mitigate impacts of the global climatic change (Chaudhury and Upadhaya, 2016). The Carbon sequestration potential of the forest ecosystems depends upon a multiplicity of phenomena including species composition, vegetation structure, tree growth attributes like volume and stem density (Ali *et al*., 2014); forest growth stages, the development conditions, nutrients availability, geographic variables, edaphic factors as well as local and regional and climate (Bastida *et al*., 2018).

Lesser Himalayan subtropical broadleaf forests constitute an important vegetation type having immense ecological significance and diverse ecosystem services being a vital regional carbon pool (Khan *et al*., 2013; Pant and Tewari, 2014). The species composition and structure of these forests are primarily governed by a mosaic of climatic conditions and edaphic factors that are echoed in the diverse forest types (Singh *et al*., 2017). The subtropical forests in the lower elevational valley basins in the region with suitable climatic conditions are subjected to intense human development activities like suburbanization and farming which make these areas the most populated in the state of Azad Jammu and Kashmir, Pakistan (Shaheen *et al*., 2021).

Protection and maintenance of the local forest diversity through conservation efforts can play an important role to enhance the carbon sequestration potential of these ecosystems and strengthening their ability to mitigate climate change impacts (Agrawal *et al.,* 2011; Zhou *et al*., 2008). These forests constitute major carbon sinks in the region, dominated by broadleaf tree species including *Acacia modesta, Dalbergia sissoo, Ficus palmata* and *Mallotus philippensis* which hold great ecological significance in the context of "Reducing emissions from deforestation and forest degradation" (REDD+).

Forest cover in the Himalayan region has been subjected to intense anthropogenic disturbances especially land-use conversions and deforestation and soil degradation which has resulted in reduced biomass carbon sequestration (Smith *et al*., 2016; Sun and Guan, 2014). Continued biomass loss through deforestation and forest degradation is expected to undermine the REDD+ goals (Ravindranath and Ostwald, 2008). In this scenario, it becomes vitally important to accurately quantify the biomass carbon reserves in the local Himalayan forest ecosystems (Singh *et al*., 2017). However, these fragile regional forest ecosystems have not been given sufficient consideration for the quantification of their carbon sequestration potential as natural carbon reserves indicating a significant knowledge gap.

The current study was conducted as a part of the carbon stock assessment project in the forest types of the western Himalayan region of Azad Jammu and Kashmir. The study was designed with the aim to quantify the biomass carbon stocks in subtropical broadleaf forest

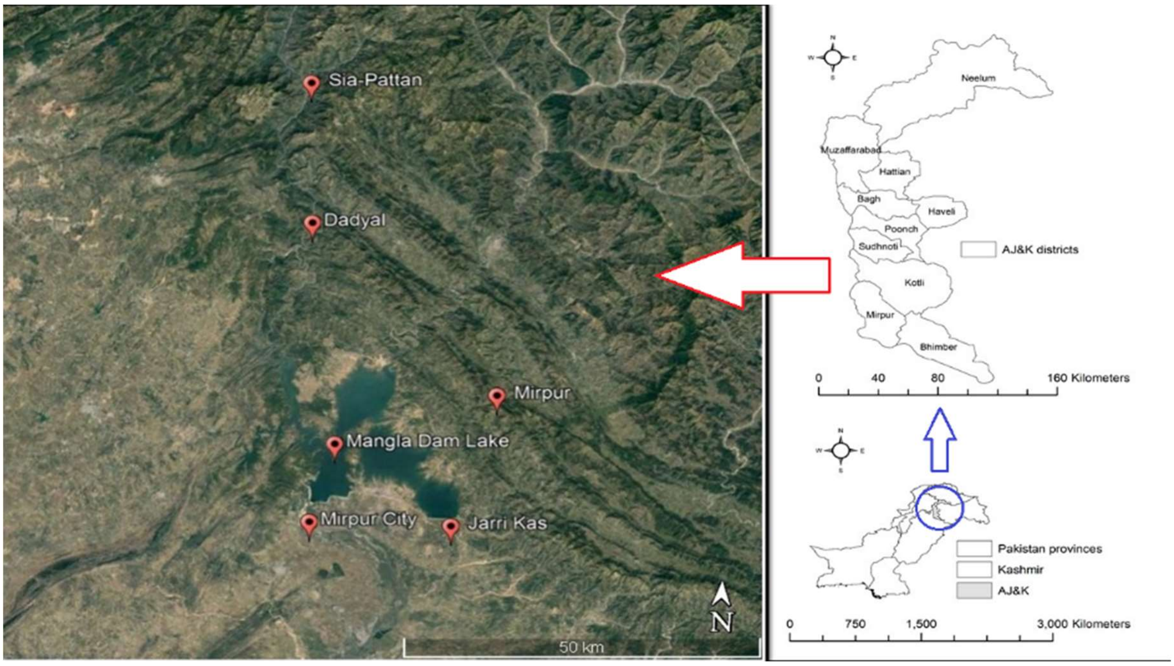

Fig. 1. Map of the study area and satellite imagery of the sampling sites.

types of the region. The specific objectives also included investigating the factors affecting the carbon stocks distribution in the region including the identification of dominant broadleaf species having maximum biomass productivity, and structural attributes of the forest stands including tree density, size and species composition.

MATERIALS AND METHODS

Study area

The study area lye in the Lesser Himalayan foothills in the state of Azad Jammu and Kashmir (AJK), Pakistan. Four major areas were selected in the Sudhnoti, Kotli and Mirpur districts of AJK in an elevation range of 500-900 meters above sea level. The investigated subtropical broadleaf forest sites were selected corresponding to the presence of the maximum number of indicator species and their ecological significance. Study sites included Dadyal (DSF), Jarri Kas (JSF), Mirpur (MSF) and Sia-Pattan (SPSF) forest sites located at 33.06° to 33.43° North Latitudes and 073.51° to 073.36° East Longitudes (Fig. 1).

Topographically the area is rugged terrain mountainous with deep valley basins. The study area is characterized by a subtropical humid climate with hot summers having daytime temperatures around 40 °C whereas the winters are mild. The annual mean temperature records are 27.4 °C in the study area with yearly rainfall remaining about 1100 mm. The maximum rainfall occurs during the Monsoon season (July and August) on the other hand, the dry season prevails from October to January (GoAJK, 2017). The topography of Sudhnoti district includes sub-mountainous valleys, steep slopes covered with vegetation whereas the Mirpur district is mostly Plateau type. The area is inhabited by settlements related to residential, agricultural and infrastructure purposes. Mostly, loamy soils are found with a great susceptibility to erosion due to rains, forest cover loss and increased grazing (Shaheen *et al*., 2021).

Sampling methodology

Detailed field expeditions were carried out in spring 2018–19 to record primary data including species composition as well as the structural attributes of the forest stands at the 4 study sites. A total of fifteen temporary sampling plots of 20 m × 20 m (400 m^2) were established at each of the four sites. Inventory of the tree species constituting the forest structure was built at each site followed by recording the tree structural attributes including tree diameter at breast height (DBH), tree height and stem density following the standard protocols (Sagar and Singh, 2006). Geographical attributes of the sites were recorded using GPS (Garmin-Corp-2000).

Forest Biomass and Carbon Stocks quantification

Regression models were applied on tree growth parameters (tree DBH and height) to quantify the Growing Stock Volume Density (GSVD) (FSI, 1995, 1996, 2001; Hairiah *et al*., 2011; Jain and Sharma, 1978; Misra and Jain, 1984; Tiwari *et al*., 1996). Above-ground biomass in the tree layer was estimated through relevant biomass expansion factors (Brown *et al*., 1999).

$$\text{Above ground biomass}\left(\frac{\text{Mg}}{\text{ha}}\right) = \text{GSVD}\,\frac{\text{m3}}{\text{ha}} \times \text{BEF}\left(\frac{\text{Mg}}{\text{m3}}\right)$$

For hardwood with GSVD ≤ 200 m^3/ha, BEF was calculated as:

$$\text{Biomass expansion factor (BEF)} = \exp[1.91 - 0.34 \times \ln(GSVD)]$$

BEF value of 1 was used for GSVD > 200 m^3/ha, the suggested regression equation (Cairns *et al*., 1997) was applied to calculate the below-ground biomass.

$$\text{Below ground biomass} = \exp[-1.059 + 0.884 \times \ln(\text{AGBD}) + 0.284]$$

Mutually above ground and below-ground biomass reflected the individual tree biomass.

Subplots of 5 m × 5 m (25 m^2) were established within each of the 400 m^2 plots to collect the data for shrub biomass quantification. Biomass in the shrubby flora was estimated after the assessment of shrub cover or basal diameter according to the nature of species growth behaviour in the plots (Jenkins *et al*., 2003; Means *et al*., 1994). Below ground biomass in the shrubs was deliberated as one-fifth (20%) of the total above-ground biomass as recommended by IPCC (MacDicken, 1997).

Shrub biomass = Exp [-3.42620 + 2.5031 *ln* (drc)]
Shrub biomass = Exp [-3.96457 + 1.08631 *ln* (cover)]
Where biomass = total shrub dry weight (Mg ha^{-1}); *ln* (cover) = natural logarithm of shrub cover and *ln* (drc) = basal diameter individual stem near root collar

Herbaceous biomass was clipped from 1m x 1m sub-sub plots established within each 400 m^2 plot. Herb biomass samples were labelled and brought to the laboratory. Similarly, leaf litter was also collected from these micro plots. The extracted herbaceous and litter material from each plot was oven-dried (at 72°C for 48 hours) distinctly and then average biomass was calculated using the digital balance (Magar, 2012). Obtained values of tree, shrub, herbs and leaf litter biomass were summed up to acquire total biomass at the plot and site level. The total biomass carbon was deliberated as half (50%) of the total biomass as suggested by IPCC. (IPCC, 2007).

$$\text{Total Biomass Carbon} = \text{Total Biomass} \times 0.5$$

Data analysis

The numerical data of carbon stock values and tree growth parameters were subjected to Multivariate Ordination Analysis techniques including Principal Component Analysis (PCA) and generalized linear models to explain the variations in the dataset using PAST software version 4.5.

RESULTS

Biomass Carbon Stocks: The average biomass carbon stocks of the investigated subtropical broadleaf forest ecosystems were calculated as 135.2 Mg ha^{-1} ranging between a maximum of 226.64 Mg ha^{-1} to a minimum of 11.83 Mg ha^{-1}. The highest carbon stock value of 226.64 Mg ha^{-1} was recorded from Dadyal followed by 192.46 Mg ha^{-1} at Sia-Pattan and 108.06 Mg ha^{-1} at Mirpur as 108.06 Mg ha^{-1} whereas the lowest value of 11.83 Mgha^{-1} was recorded from Jarri Kas.

The tree layer constituted 99% of the biomass share in the investigated forest sites with a biomass carbon value of 134.67 Mg ha^{-1}. Significant variations were recorded in the tree biomass among the investigated sites ranging from a minimum of 10.97 Mg ha^{-1} at Jarri Kas to a maximum of 228.075 Mg ha^{-1} at Dadyal whereas Mirpur and Sia-Pattan sites exhibited values of 107.58 Mg ha^{-1} and 192.025 Mg ha^{-1} respectively. Shrub biomass contributed >1% in the total forest biomass value having an average value of 0.37 Mg ha^{-1} with a maximum of 0.64 Mg ha^{-1} recorded at Jarri Kas followed by SPSF 0.3 Mg ha^{-1} each at Mirpur and Sia-Pattan Sites. The total herb, leaf litter and deadwood biomass carbon value was calculated as 0.17 Mg ha^{-1} with a maximum value of 0.22 Mg ha^{-1} at Jarri Kas site (Table 1).

Table 1. Total Biomass and carbon pools at the study sites.

Forest Sites	TB	SB	HLDB	TBC	BCS
DSF	456.15	0.45	0.32	456.92	228.46
JSF	21.94	1.27	0.45	23.66	11.83
MSF	215.17	0.59	0.35	216.11	108.06
SAPSD	384.05	0.66	0.20	384.91	192.46
AVG	**269.33**	**0.74**	**0.33**	**270.40**	**135.20**

Key: TB = tree biomass (Mg ha^{-1}), SB = Shrub biomass (Mg ha^{-1}), HLDB = Herb, leaf litter and deadwood biomass (Mg ha^{-1}), TBC = Total biomass count (Mg ha^{-1}), BCS = biomass carbon stocks (Mg ha^{-1}); DSF = Dadyal Subtropical forest, JSF = Jarri Kas Subtropical forest, MSF = Mirpur Subtropical forest, SPSF = Sia-Pattan Subtropical forest, AVG = Average values

Dominant Biomass Producing species: Forest inventory revealed a total of 15 broadleaf tree species that constituted the structure of these subtropical forest stands. *Dalbergia sissoo* was found to be the most dominant biomass producing tree species with the highest biomass carbon value of 40.70 Mg ha^{-1} in the study area followed by *Mallotus philippensis* (30.09 Mg ha^{-1}) and *Ficus palmata* (20.11 Mg ha^{-1}). The codominant species included *Acacia modesta* and *Ziziphus oxyphylla* with biomass carbon values of 10.97 Mg ha^{-1} and 9.43 Mg ha^{-1} respectively whereas the remaining 10 tree species produced relatively lower biomass carbon (<5 Mg ha^{-1}). (Table 2). A total of 8 shrub species were recorded from the studies subtropical forest stands with *Justicia adhatoda* as the highest carbon-producing species with an average biomass carbon value of 0.14 Mg ha^{-1} whereas the remaining shrub species had extremely low (<0.1 Mg ha^{-1}) biomass productivity.

Structural Attributes of the forest stands: The investigated forest stands exhibited large variations in the structural attributes of the broadleaf tree species. Forest ecosystems revealed an average tree density value of 188.7/ha. *Prosopis juliflora* was recorded with the maximum tree density value of 1200/ha, followed by

Table 2. Species wise biomass and carbon Stocks at the study sites.

TREES	Species biomass allocation and carbon stock (Mg ha^{-1})					BCS
	DSF	JKSF	MSF	SPSF	AVG	(Mg ha^{-1})
Acacia modesta Wall.	48.8	0.64	26.0		18.855	9.43
Azadirachta indica A.Juss.			21.0		5.238	2.62
Bombax ceiba L.			1.1		0.275	0.14
Broussonetia papyrifera (L.) L'Hér. ex Vent.			19.0	4.4	5.850	2.93
Carissa sp.	23.0				5.755	2.88
Cassia afrofistula Brenan				36.7	9.175	4.59
Dalbergia sissoo DC.	240.3		41.5	43.8	81.395	40.70
Ficus carica L.	31.6				7.900	3.95
Ficus palmata Forssk.	19.7		93.0	48.2	40.225	20.11
Grewia villosa Willd.	23.8				5.950	2.98
Mallotus philippensis (Lam.) Müll.Arg.				240.7	60.175	30.09
Prosopis juliflora (Sw.) DC.		2.50			0.625	0.31
Punica granatum L.				10.2	2.550	1.28
Toona ciliata M.Roem.			13.7		3.425	1.71
Ziziphus oxyphylla Edgew.	68.9	18.80			21.935	10.97
Total	**456.15**	**21.94**	**215.17**	**384.05**	**269.33**	**134.66**
SHRUBS						
Calotropis procera (Aiton) Dryand.		0.27			0.068	0.03
Carissa spinarum L. (Shrubby form)	0.16	0.44		0.12	0.179	0.09
Colebrookea oppositifolia Sm.				0.29	0.071	0.04
Dodonaea viscosa Jacq.				0.02	0.005	0.00
Jasminum sp.			0.15		0.038	0.02
Justicia adhatoda L.	0.29	0.56		0.24	0.271	0.14
Lantana camara L.			0.24		0.060	0.03
Ricinus communis L.			0.20		0.050	0.02
Total	**0.45**	**1.27**	**0.59**	**0.66**	**0.74**	**0.37**

Key: DSF = Dadyal Subtropical forest, JSF = Jarri Kas Subtropical forest, MSF = Mirpur Subtropical forest, SPSF = Sia-Pattan Subtropical forest, AVG = Average values, BCS = Biomass Carbon Stocks

Table 3. Structural attributes of studied subtropical forests.

TREES	Average		
	DBH (cm)	Height (m)	Density (Trees/ha)
Acacia modesta Wall.	36.4	7.6	433.3
Azadirachta indica A.Juss.	22.5	5.0	20.0
Bombax ceiba L.	20.0	3.5	20.0
Broussonetia papyrifera (L.) L'Hér. ex Vent.	36.2	6.0	110.0
Carissa sp.	22.0	5.0	220.0
Cassia afrofistula Brenan	22.7	3.6	40.0
Dalbergia sissoo DC.	36.7	7.2	200.0
Ficus carica L.	26.0	6.0	80.0
Ficus palmata Forssk.	31.3	5.1	26.7
Grewia villosa Willd.	25.0	4.0	40.0
Mallotus philippensis (Lam.) Müll.Arg.	20.0	3.0	360.0
Prosopis juliflora (Sw.) DC.	14.2	4.6	1200.0
Punica granatum L.	21.0	3.2	20.0
Toona ciliate M.Roem.	24.0	5.0	40.0
Ziziphus oxyphylla Edgew.	27.0	3.7	20.0
Average	**25.7**	**4.8**	**188.7**

Acacia modesta (433/ha), *Mallotus philippensis* (360/ha), *Carissa* sp. (220/ha) and *Dalbergia sissoo* (200/ha) (Table 3). Forest stands revealed an average DBH value of 25.7 cm with the highest value of 36.7 cm exhibited by *Dalbergia sissoo* whereas the lowest of 14.2 cm for *Prosopis juliflora*. An average tree height of 4.8 meters was recorded for the studied forest stands with *Acacia modesta* having the highest tree height of 7.6 m followed by *Dalbergia sissoo* (7.2 m), *Broussonetia papyrifera* and *Ficus carica* (6 m each). (Table 3).

Statistical Analysis: The Generalized Linear Regression models revealed significant correlations among the tree structural attributes and the biomass carbon values. A significant positive relationship (p<0.05) between biomass carbon and tree density values (Fig. 2A). Similarly, the carbon stock values exhibited a linear increasing trend with increasing tree diameter (DBH) values (Fig. 2B).

Species data matrix was subjected to Principal component analysis which significantly identified the major tree species having maximum biomass productivity. *Dalbergia sissoo* was placed distinctly along the x-axis showing its maximum biomass productivity along with co dominant species including *Ziziphus oxyphylla*, *Ficus palmata* and *Mallotus philippensis* correlated to their maximum eigen scores. PCA also identified affinities among the dominant species with sampling sites attributes to the species abundance at specific sites.

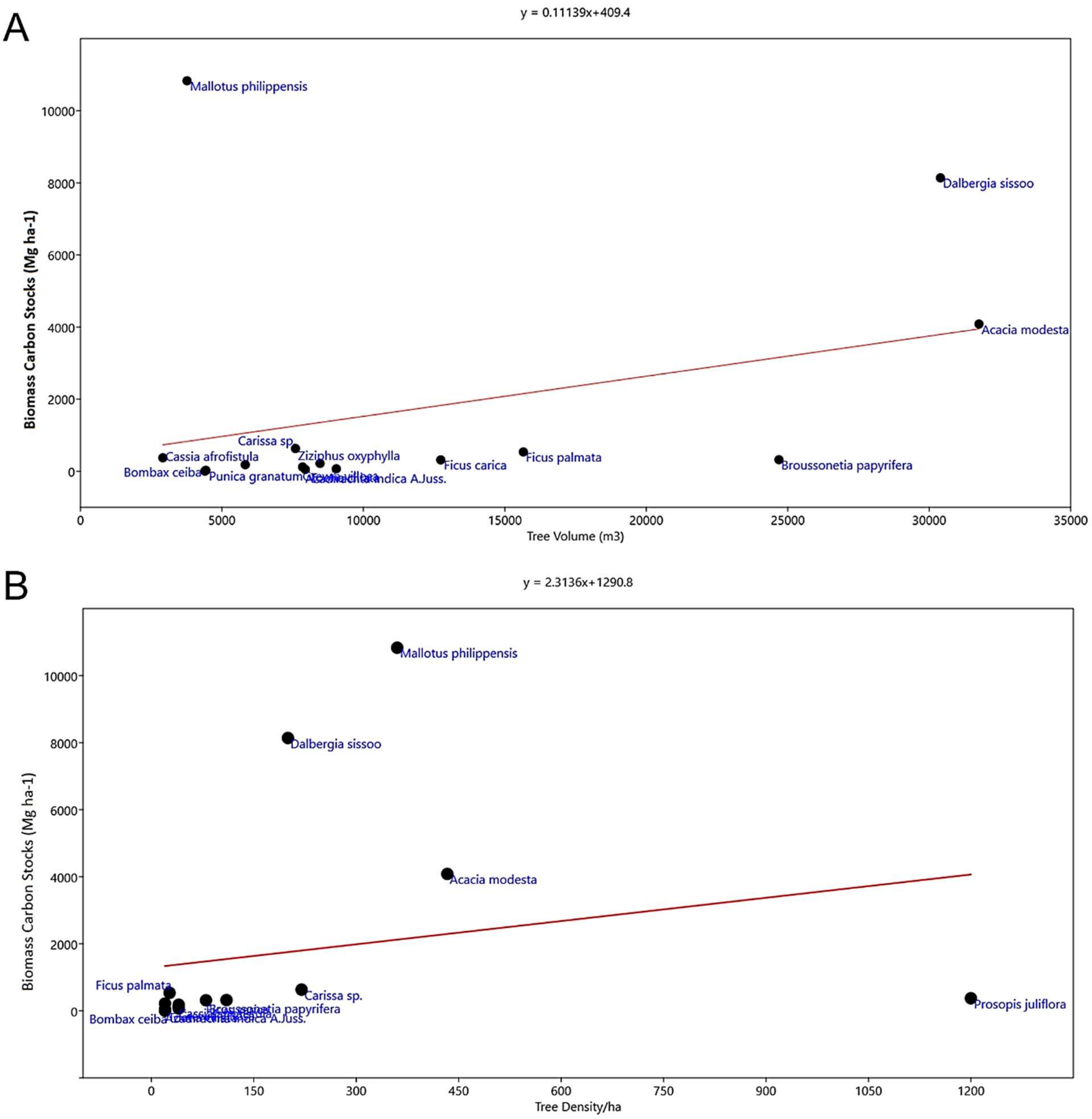

Fig. 2. Generalized linear model-based expression of correlation in biomass carbon stocks with **A**. tree volume and **B**. tree density.

The biplot showed a close affinity of *Ficus palmata* with Mirpur site, *Mallotus* philippensis with Sia-Pattan, and *Ziziphus oxyphylla* with Jarri Kas sites respectively. The remaining species were clustered at the centre indicating their sporadic distribution pattern without a specific site preference as well as lower biomass production. PCA biplot also identified the forest sites having the highest biomass carbon values represented as eigen vectors on the biplot. Dadyal and Mirpur sites exhibited maximum vector lengths along X-axis correlated to their high eigen values identified as major biomass carbon reservoirs whereas Jarri Kas forest deviated along Y-axis due to its low eigen values and lowest biomass value (Fig. 3).

DISCUSSION

Biomass Carbon Stocks: Quantification of biomass carbon stocks in the investigated Subtropical broadleaf forest ecosystems has revealed these forests as a significant regional carbon pool of the Kashmir region (Liu *et al*., 2018). Biomass Carbon Stock values of the investigated forests showed significant variations synchronized with the species composition, structure and growth parameters of the forest stands (Pan *et al*., 2013). Forest inventory showed that the local Forest stands exhibited a diverse structure comprised of 15 broadleaf tree species along with 8 shrub species. It is an established

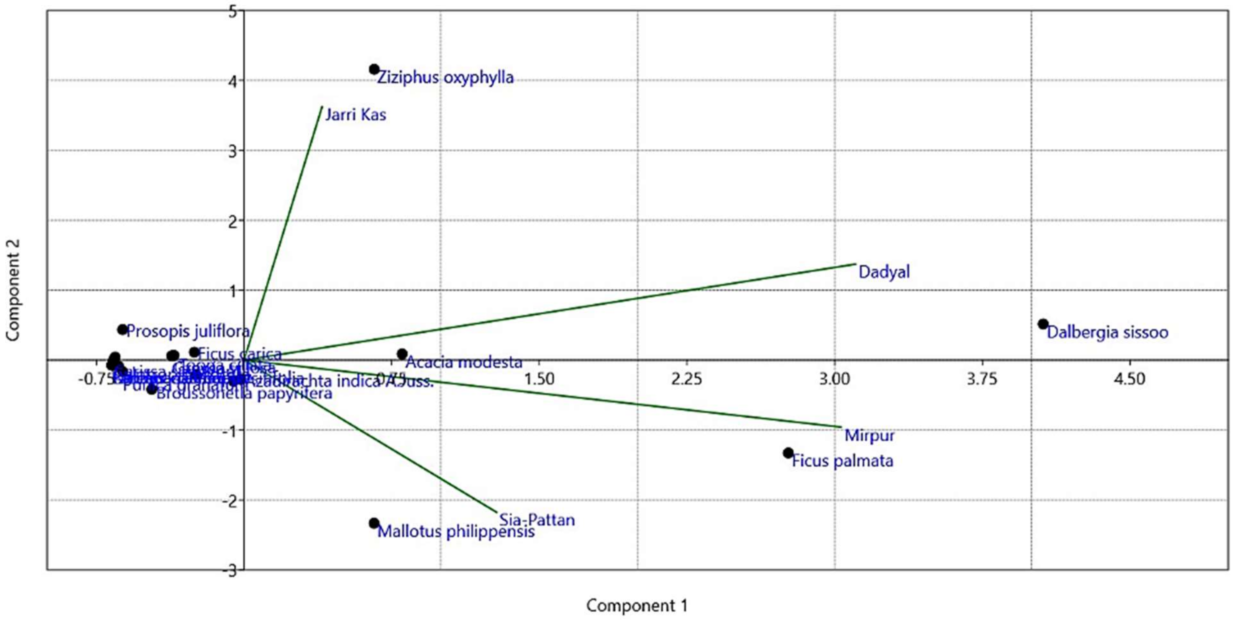

Fig. 3. Principal Component Analysis of the Carbon pools and study sites.

ecological fact that forest ecosystems having higher species diversity yield better biomass production and are better carbon sinks as compared to less diverse forests (Wang *et al*., 2011).

About 99.6% of total biomass carbon content was found captured in the tree layer. Broadleaf tree species are characterized by higher photosynthetic ability and biomass production rates which subsequently enables them to yield relatively higher values of biomass carbon (Bora *et al*., 2013). Studies in adjacent Himalayan areas have also reported biomass carbon stock values ranging from 43.4 to 297 Mg ha^{-1} (Ali *et al*., 2020; Shaheen *et al*., 2016; Siddiq *et al*., 2021). Tree species not only make higher levels of biomass carbon but also increase overall forest carbon storage potential by adding organic carbon into the soil and making carbon reserves as necromass (Vikrant and Chauhan, 2014).

An analysis of the forest structure correlated with carbon stock values revealed that the carbon yielding capacity of the forest ecosystem is strongly correlated with forest structural attributes and tree growth parameters (Ali *et al*., 2020). Tree species having higher DBH and height values produced higher values of biomass carbon to the forest as compared to the smaller sized species. *Acacia modesta, Dalbergia sissoo*, *Ficus palmata* and *F. carica* were identified as the dominant biomass carbon yielding species with greater structural dimensions as which is also verified by the results of PCA (Fig. 2). Linear Regression Models also support our hypothesis and identified strong correlations of biomass carbon values with DBH and Tree height values. Tree density is another important parameter that strongly influences the growing stand volume and biomass production of forest ecosystems (Sun and Guan, 2014). *Acacia modesta, Dalbergia sissoo* and *Mallotus philippensis* were characterized with relatively higher stem densities forming large patches which made them efficient carbon sequestering species. However, *Prosopis juliflora* deviated from this linear trend, and despite having the highest tree density yielded lower biomass carbon values attributed to its low average DBH and height (Fig. 2).

Shrub flora accounted for just 0.27% share in forest biomass carbon with *Justicia adhatoda, and Carissa spinarum* recorded as the dominant biomass producing species (Table 2). Studies in the subtropical forests show that underground flora captures usually low atmospheric carbon due to a reduced rate of photosynthesis, as a result of low light penetration and small size (Chen *et al*., 2015; Zeng *et al*., 2013). Herb layer and necromass contributed a minute fraction of 0.12% to the total forest biomass which is extremely low as compared to the similar studies in the Himalayan region (Dar and Sundarapandian, 2015; Sun and Guan, 2014; Shaheen *et al*., 2016). It is hypothesized that intense anthropogenic disturbances including removal of biomass for burning, impacts of seasonal and man-made fires, animal grazing, browsing and trampling immensely decrease the Carbon sequestration potential of the forest ground flora including the herb and shrub layer in the region (Khan *et al*., 2019).

Subtropical broadleaf forests of the western Himalayan Kashmir region are currently facing intense deforestation due to the increased influx of rapidly expanding human population in valley basins and foothills of the area (Ali *et al*., 2020). Socioeconomic transformations combined with land use changes, agricultural expansions, unsustainable utilization of the forest products like medicinal plants, fuelwood and timber etc. are continuously shrinking the forest cover and ultimately reducing the regional biomass carbon stocks (Aziz *et al*., 2019; Bisht *et al*., 2014; Dlamini *et al*., 2016; Johnson *et al*., 2010).

This study delivers reference records about the regional biomass carbon stocks in the subtropical forest ecosystems and revealed the potential of broadleaf tree species to sequester atmospheric carbon correlated with their structural attributes. Current data provides an insight into the potential of local carbon pools to sequester carbon and mitigate the impact of climate change. The results provide baseline data which can be efficiently utilized to attain the regional REDD+ goals as well as for policy-making, environmental change mitigation and restoration purposes at local and regional levels (Ravindranath and Ostwald, 2008). It is recommended to enhance the carbon storage capacity of these ecologically significant subtropical forests by employing integrated forest conservation strategies along with minimizing the anthropogenic disturbance stimuli in the region. It also invites more intensive and broader research for the forest carbon examination in vegetation types other than subtropical broadleaf forests and better species selection for increased carbon sequestration options in the Himalayan region.

ACKNOWLEDGMENTS

The authors are thankful to the Forest Department of the state of AJK for their support during this study. The authors would also like to express their sincere gratitude to the reviewers.

LITERATURE CITED

Ali, A., W. Ma, X. Yang, B. Sun, Q. Shi and M. Xu 2014. Biomass and carbon stocks in schima superba dominated subtropical forests of eastern China. J. For. Sci. **60(5):** 198–207.

Ali, A., M. I. Ashraf, S. Gulzar and M. Akmal 2020. Estimation of forest carbon stocks in temperate and subtropical mountain systems of Pakistan: Implications for redd+ and climate change mitigation. Environ. Monit. Assess. **192(3):** 1–13.

Agrawal, A., D. Nepstad and A. Chhatre 2011. Reducing emissions from deforestation and forest degradation. Annu. Rev. Environ. Resour. **36(1)**: 373–396.

Aziz, S., F. M. Chughtai, H. Shaheen, R. W. A. Khan and M. E.U.I. Dar 2019. Biomass and soil carbon stocks assessment in western Himalayan Alpine and subalpine vegetation zones of Kashmir. Pak. J. Bot **51(3):** 973–978.

Bastida, F., T. Hernández and C. García 2018. Soil erosion and c losses: Strategies for building soil carbon. The future of soil carbon, 215–238. Elsevier. pp. 215–238.

Bisht, A.S., S. Singh and M. Kumar 2014. Pine needles a source of energy for Himalayan region. Int. J. Sci. Technol. Res. **3:** 161–164.

Bora, N., A.J. Nath and A.K. Das 2013. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar district, Assam, northeast India. Int. J. Ecol. Environ. Sci. **39:** 97–106.

Brown, S.L., P. Schroeder and J.S. Kern 1999. Spatial distribution of biomass in forests of the eastern USA. For. Ecol. Manag. **123(1):** 81–90.

Cairns, M.A., S. Brown, E.H. Helmer and G.A. Baumgardner 1997. Root biomass allocation in the world's upland forests. Oecologia **111(1):** 1–11.

Chaudhury, G. and K. Upadhaya 2016. Biomass and carbon stock in subtropical broad-leaved forest ecosystem of Meghalaya, northeast India. Int. J. Ecol. Environ. Sci. **42:** 125–133.

Chen, Y., Z. Liu, X. Rao, X. Wang, C. Liang, Y. Lin, L. Zhou, X.-A. Cai and S. Fu 2015. Carbon storage and allocation pattern in plant biomass among different forest plantation stands in Guangdong, China. Forests **6(12):** 794–808.

Dar, J. A. and S. Sundarapandian 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environ. Monit. Assess. **187(2):** 55.

Dlamini, P., P. Chivenge and V. Chaplot 2016. Overgrazing decreases soil organic carbon stocks the most under dry climates and low soil pH: A meta-analysis shows. Agric. Ecosyst. Environ. **221:** 258–269.

FSI. 1995. Forest Survey of India, ministry of environment and forests, Government of India. Report on inventory of forest resources of Kodagu district Karnataka. 27 pp.

FSI. 1996. Forest Survey of India, ministry of environment and forests, Government of India. Volume equations for forests of India, Nepal and Bhutan: Forest Survey of India.

FSI. 2001. Forest Survey of India, ministry of environment and forests, Government of India. Carbon stocks in India’s forests.

GoAJK 2017. Disaster & climate resilience improvement project (DCRIP). Planning & Development department, Azad govt of state of Jammu & Kashmir. Mirpur district disaster risk management plan.

Hairiah, K., S. Dewi, F. Agus, S. Velarde and A. Ekadinata 2011. Measuring Carbon Stocks across Land Use Systems: A Manual. Bogor, Indonesia. World Agroforestry Centre. Indonesian Center for Agricultural Land Resources Research and Development (ICRAF) **456:**

IPCC 2007. Intergovernmental panel on climate change. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge university press, Cambridge, United Kingdom and New York, USA, 996 pp.

Jain, R.C. and R.P. Sharma 1978. Standard volume tables for *Dalbergia latifolia* Roxb. Indian Forest Records **1:** 1–8.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath and R.A. Birdsey 2003. National-scale biomass estimators for United States tree species. For. Sci. **49:** 12–35.

Johnson, K., F.N. Scatena and Y. Pan 2010. Short-and long-term responses of total soil organic carbon to harvesting in a northern hardwood forest. For. Ecol. Manag. **259(7):** 1262–1267.

Khan, R.W.A., H. Shaheen, A. Mehmood and S.N. Awan 2019. Grazing intensity impacts on soil carbon stocks of western Himalayan Alpine paddocks. Carbon Manag. **10(6):** 533–540.

Khan, S.M., S. Page, H. Ahmad, Z. Ullah, H. Shaheen, M. Ahmad and D. Harper 2013. Phyto-climatic gradient of vegetation and habitat specificity in the high elevation western Himalayas. Pak. J. Bot **45:** 223–230.

Liu, X., S. Trogisch, J.-S. He, P.A. Niklaus, H. Bruelheide, Z. Tang, A. Erfmeier, M. Scherer-Lorenzen, K.A. Pietsch, B. Yang, P. Kühn, T. Scholten, Y. Huang, C. Wang, M. Staab, K.N. Leppert, C. Wirth, B. Schmid and K. Ma 2018. Tree species richness increases ecosystem carbon storage in subtropical forests. Proc. Royal Soc. B **285(1885):** 20181240.

MacDicken, K.G. 1997. A guide to monitoring carbon storage in forestry and agroforestry projects.

Magar, K.B.T. 2012. Carbon stock in community managed *Shorea robusta* forests of Dhading district, Nepal. MSc, Tribhuvan University, Kathmandu.

Means, J., H. Hansen, G. Koerper, P. Alaback and M. Klopsch 1994. Software for computing plant biomass: Biopak users guide. Forest service general technical report. Forest Service, Portland, OR. Pacific Northwest Research Station, United States.

Misra, N. and R. Jain 1984. Regional volume tables for paper mulberry (*Broussonetia papyrifera*). Indian Forester **110:** 1084–1092.

Pan, Y., R.A. Birdsey, O.L. Phillips and R.B. Jackson 2013. The structure, distribution, and biomass of the world's forests. Annu. Rev. Ecol. Evol. Syst. **44(1):** 593–622.

Pant, H. and A. Tewari 2014. Carbon sequestration in Chir-pine (*Pinus roxburghii* sarg.) forests under various disturbance levels in Kumaun central Himalaya. J. For. Res. **25(2):** 401–405.

Ravindranath, N.H. and M. Ostwald 2008. Carbon inventory methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. Springer Science & Business Media.

Sagar, R. and J. Singh 2006. Tree density, basal area and species diversity in a disturbed dry tropical forest of northern India: Implications for conservation. Environ. Conserv. **33(3):** 256–262.

Shaheen, H., S.N. Awan, R.W. A. Khan, A.R. Khalid, W. Ahmed and F.M. Chughtai 2021. Variations in Soil Organic Carbon Stocks under Different Land-Use Categories in Subtropical Ecosystems of Kashmir. For. Sci. **67(5):** 525–536.

Shaheen, H., R.W.A. Khan, K. Hussain, T.S. Ullah, M. Nasir and A. Mehmood 2016. Carbon stocks assessment in subtropical forest types of Kashmir Himalayas. Pak. J. Bot **48:** 2351–2357.

Siddiq, Z., M.U. Hayyat, A.U. Khan, R. Mahmood, L. Shahzad, R. Ghaffar and K.-F. Cao 2021. Models to estimate the above and below ground carbon stocks from a subtropical scrub forest of Pakistan. Glob. Ecol. Conserv. **27**:e01539.

Singh, G., A. Giri and S. Paul 2017. *Pinus roxburghii* Sarg. (Chir pine): A valuable forest resource of Uttarakhand. Indian Forester **143:** 700–709.

Smith, P., J.I. House, M. Bustamante, J. Sobocká, R. Harper, G. Pan, P.C. West, J.M. Clark, T. Adhya, C. Rumpel, K. Paustian, P. Kuikman, M.F. Cotrufo, J.A. Elliott, R. McDowell, R.I. Griffiths, S. Asakawa, A. Bondeau, A.K. Jain, J. Meersmans, T.A.M. Pugh 2016. Global change pressures on soils from land use and management. Glob. Chang. Biol. **22(3):** 1008–1028.

Sun, L. and D. Guan 2014. Carbon stock of the ecosystem of lower subtropical broadleaved evergreen forests of different ages in Pearl River delta, China. J. Trop. For. Sci. **26(2):** 249–258.

Tiwari, K.P., R.L. Pandey and S.F.R.I.M. Branch 1996. Local volume tables for Teak, Sal, and other species for central circle, Jabalpur (M.P.).

Vikrant, K. and D. Chauhan 2014. Carbon stock estimation in standing tree of Chir pine and Banj Oak pure forest in two van panchayats forest of Garhwal Himalaya. Journal of Earth Science & Climatic Change **5(10):** 240.

Wang, S., L. Zhou, J. Chen, W. Ju, X. Feng and W. Wu 2011. Relationships between net primary productivity and stand age for several forest types and their influence on China’s carbon balance. J. Environ. Manage. **92(6):** 1651–1662.

Zeng, Z.-Q., S.-L. Wang, C.-M. Zhang, C. Gong and Q. Hu 2013. Carbon storage in evergreen broad-leaf forests in mid-subtropical region of China at four succession stages. J. For. Res. **24(4):** 677–682.

Zhou, C., X. Wei, G. Zhou, J. Yan, X. Wang, C. Wang, H. Liu, X. Tang, Q. Zhang 2008. Impacts of a large-scale reforestation program on carbon storage dynamics in Guangdong, China. For. Ecol. Manag. **255(3-4):** 847–854.