Pak. J. Bot., 48(6): 2351-2357, 2016.

CARBON STOCKS ASSESSMENT IN SUBTROPICAL FOREST TYPES OF KASHMIR HIMALAYAS

HAMAYUN SHAHEEN*, RAJA WAQAR AHMAD KHAN, KARAMIT HUSSAIN, TARIQ SAIFF ULLAH, MUHAMMAD NASIR AND ANSAR MEHMOOD

Department of Botany, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan
**Corresponding author's email: hamayunmaldial@yahoo.com*

Abstract

Estimation of carbon sequestration in forest ecosystem is necessary to mitigate impacts of climate change. Current research project was focused to assess the Carbon contents in standing trees and soil of different subtropical forest sites in Kashmir. Tree biomass was estimated by using allometric equations whereas Soil carbon was calculated by Walkey-Black titration method. Total carbon stock was computed as 186.27 t/ha with highest value of 326 t/ha recorded from *Pinus roxburghii* forest whereas lowest of 75.86 t/ha at mixed forest. Average biomass carbon was found to be 151.38 t/ha with a maximum value of 294.7 t/ha and minimum of 43.4 t/ha. *Pinus roxburghii* was the most significant species having biomass value of 191.8 t/ha, followed by *Olea cuspidata* (68.9 t/ha), *Acacia modesta* (12.71 t/ha), *Dalbergia sissoo* (12.01 t/ha), *Broussonetia papyrifera* (5.93 t/ha), *Punica granatum* (2.27 t/ha), *Mallotus philippensis* (2.2 t/ha), *Albizia lebbeck* (1.8t/ha), *Ficus palmata* (1.51 t/ha), *Acacia arabica* (1.4 t/ha), *Melia azedarach*, (1.14 t/ha) and *Ficus carica* (1.07 t/ha) respectively. Recorded value of tree density was 492/ha; average DBH was 87.27 cm; tree height was 13.3m; and regeneration value was 83 seedlings/ha. Soil carbon stocks were found to be 34.89 t/ha whereas agricultural soil carbon was calculated as 27.18 t/ha. Intense deforestation was represented by a stump density of 147.4/ha. The results of Principal Component Analysis (PCA) revealed the distinct species clusters on the basis of location, biomass and Carbon stock values. *Pinus roxburghii* and *Olea cuspidata* were found to be the major contributors of carbon stock having maximum vector lengths in the PCA Biplot. Forest in the area needs to be managed in a sustainable manner to increase its carbon sequestration potential.

Key words: Carbon sequestration, Forest biomass, Allometry, Himalayas, Subtropical.

Introduction

Carbon sequestration is the long term capture and storage of atmospheric carbon in different carbon sinks including vegetation and soils (Gibbs *et al.*, 2007). Carbon sequestration studies include different allometric models and species assemblage patterns determined by a mosaic of structural attributes and environmental conditions, making it a complicated process (Chave *et al.*, 2003). Approximately three times more carbon is stored in vegetation and soils than total atmospheric carbon (Houghton, 2007). Importance of forest ecosystem in regulating the global carbon cycle emphasizes the need to accurately estimate the carbon stocks of different forest types (Körner, 2007). Estimation of forest biomass is helpful to assess forest productivity, structural attributes, carbon sequestration potential as well as carbon stock values (Chave *et al.*, 2005). Forest biomass and Carbon stocks are found to be varying with species and forest stands (Bora *et al.*, 2013). Factors influencing forest biomass and Carbon stocks in include ecological differences, geographical features, climatic conditions, species and soil composition, sampling strategies and seasonal variations in forest structure, tree density and forest regeneration status (Melkania, 2009); DBH, height and wood density values, forest age, disturbance frequencies and use of generalized allometric models for biomass estimation (Franklin *et al.*, 2002; Rosenfield & Souza, 2013).

The forests of Himalayas are facing severe degradation due to rapid socio-economic transformations and economic developments (Upadhyay *et al.*, 2005; Blaikie & Sadeque, 2000). Deforestation is considered as 2nd highest GHGs emissions source quantified to release an estimated 2 Giga tons of Carbon (GtC) yearly over the last few years (Kindermann *et al.*, 2006; Eggleston *et al.*, 2006). Study area is located in lesser Himalayan foothills characterized by subtropical mixed forest types dominated by Chir Pine. Local population is heavily dependent on the forest resources to fulfill their needs of timber, fuelwood, fodder, medicinal plants and pastures. Due to poor socio-economic status, climatic severity and absence of alternate energy resources people are forced to rely on local forests resources (Schild, 2011). Kashmir has lost >25 % of its vegetation cover since 1990 to 2005 (Butt, 2006). The study sites lie in Muzaffarabad district, Azad Jammu and Kashmir at 34º 21' 0" N Latitude and 73º 28' 48" E Longitude in an altitudinal range of 800m in South to 1300 in East (GOAJK, 2014). Climate is subtropical monsoon type with a mean annual precipitation of 1511 mm and a relative humidity fluctuating between 58% and 84% (Pak-Met, 2012). The rationale of the C-Sequestration study project was to undertake research to improve understanding of Carbon sequestration in local forest ecosystems. The objectives were to measure biomass and soil Carbon stocks in the selected area and to quantify which type of forest has better carbon sequestration potential.

Materials and Methods

Five forest sites with subtropical mixed forests (Site 1 and 2) *Olea cuspidata* forest (Site 3) and *Pinus roxburghii* forest (Site 4 and 5) were selected for the estimation of carbon stocks in the area (Fig. 1). At each site, 20 plots (20 m x 20 m) were established for trees and soil sampling. Tree DBH and height were measured by following standard sampling techniques (Ahmed & Shaukat, 2012). Soil samples (0-30 cm depth) were taken by using a metallic soil sampler. Four soil samples from the corner and one from the center of each plot were taken. Five soil samples (0-30 cm depth) were taken from the agricultural land near every site. Parameters investigated at each selected site included altitude, tree density, DBH, regeneration capacity. Anthropogenic pressure in terms of grazing, erosion, deforestation Intensity, and distance from Settlements was also recorded.

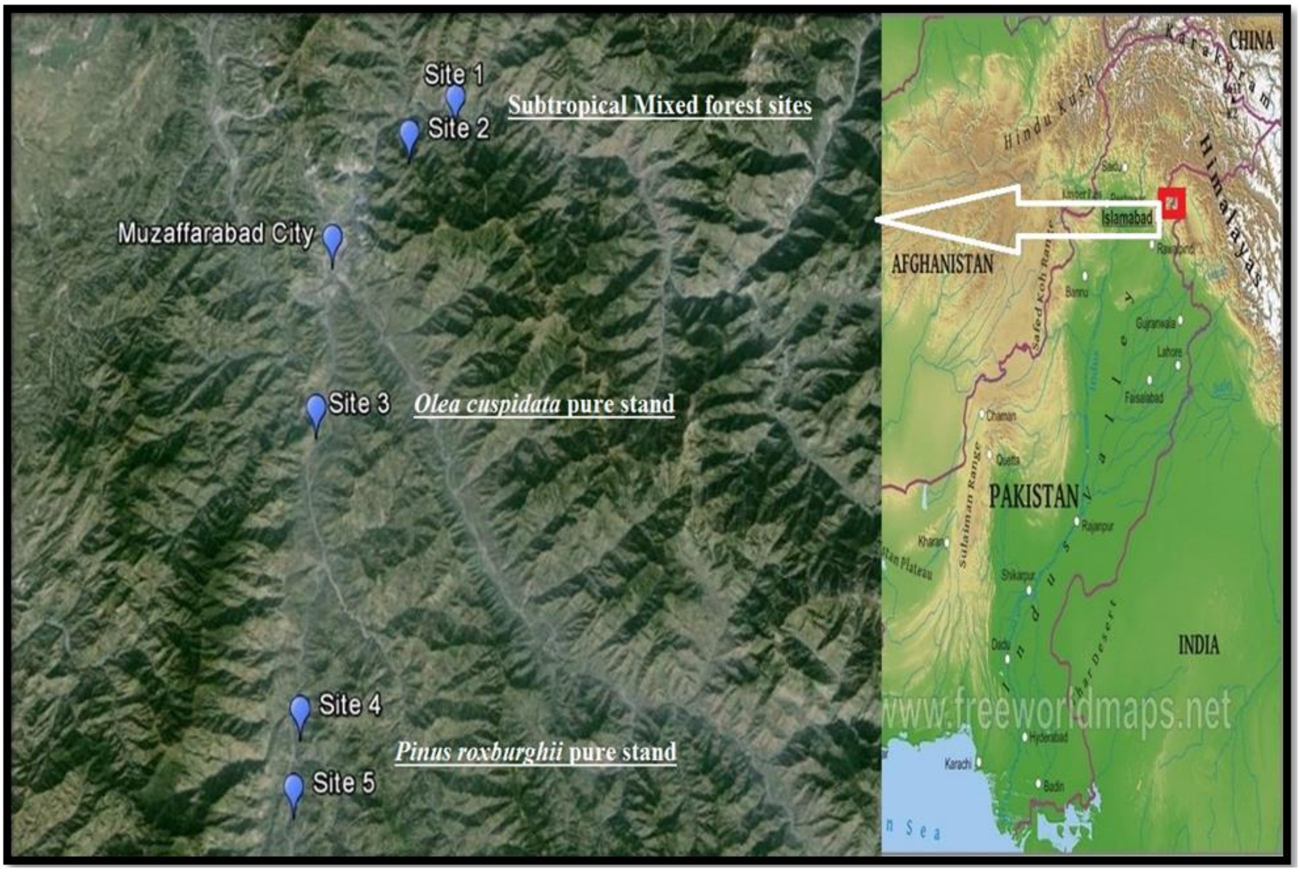

Fig. 1. Map of the study area (Right) and Location of the sites (Left).

Above ground tree biomass (AGTB) was calculated by using allometric equations developed on the basis of forest types, species and ecological conditions. The literature survey was carried out for the selection of species specific as well as general allometric models. Biomass carbon contents of each species differ from others due to specific wood density and properties. Allometric equations given below were constructed for individual species based on their wood properties for the accurate and precise estimation of the biomass and carbon contents for the respective species sampled from the study sites.

Acacia spp.	0.071+0.0818*DBH^ (2)*H (Nizami *et al.*, , 2009).
Broussonetia papyrifera	$0.776*(\rho D^2H)^{0.940}$(Chave *et al.*, 2005).
Dalbergia sissoo	0.667*DBH^ (1.832) (Chave *et al.*, 2005).
Ficus spp.	0.0421*(DBH^ (2)*H) ^ (0.9440) (Gibbs *et al.*, 2007)
Mallotus philippensis	0.0547*(DBH^ (2.1148))*(H^ (0.6131)) (Gibbs *et al.*, 2007)
Pinus roxburghii	$0.0509* \rho D^2 H$ (Chave *et al.*, 2003)

D = diameter of a tree at breast height (in cm),

H = height of a tree (in m) and ρ = wood density value (g cm $^{-3}$).

Biomass of *Albizia lebbeck, Melia azedarach, Olea cuspidata* and *Punica granatum* was calculated by multiplying the tree volume by the wood density of tree species.

Biomass (kg) = Volume $^{(m3)}$ × Wood density $^{(kg \cdot m-3)}$

where Volume = πr^2H and $r = D/2\pi$

D = diameter, H = Height of a tree (Hangarge *et al.*, 2012). The specie wise AGTB was calculated by summing up all the tree biomass values (in kg) estimated from every plot and converting to tons per hectare (t/ha).

General formula based on 1:5 for root to shoot value was applied for estimation of below ground biomass (BGTB) estimation, as BGTB is generally considered 20% of AGTB (MacDicken, 1997). Carbon stocks were calculated from biomass values by multiplying total biomass of a stand with 0.5, as Carbon stock is generally considered 50% of biomass. Soil samples were brought to the laboratory and were mixed very well to make a composite accordingly. Walkley-Black method of chromic acid wet oxidation was followed to determine the Carbon concentration in the forest and agricultural soils.

The soil bulk density was also calculated after (Nizami *et al.*, 2009) as Soil bulk density=Oven dried weight of soil ÷ Volume of cylinder. Amount of Carbon (%) obtained was transformed into Soil organic Carbon (SOC). Soil Carbon pool was calculated after multiplying the SOC with bulk density and depth of soil (de M *et al.,* 2001).

SOC (t /ha) = OC (Mg / kg) × bulk density (g / cm3) × depth (cm).

Results

An average Carbon stock value of 186.27 t/ha was determined for the study area. Highest Carbon stock value of 326 t/ha was recorded from *Pinus roxburghii* forest at site 4 whereas the lowest value of 75.86 t/ha Carbon stock recorded at mixed forest site 2. Average biomass value was found to be 151.38 t/ha for the whole area. Average value of Soil Carbon was 34.89 t/ha. Maximum soil Carbon value of 43.76 t/ha was recorded from *Pinus* forest site 5 whereas minimum soil Carbon value of 25.64 t/ha was recorded from mixed forest site 1. Average biomass calculated for the forests was 302.74 t/ha. The maximum biomass value of 589.4 t/ha was estimated from *Pinus roxburghii* site 4 whereas minimum of 86.8 t/ha from mixed forest site 2. Average above ground tree biomass (AGTB) was recorded as 252.28 t/ha with highest value of 491 t/ha at *Pinus roxburghii* forest site 4 whereas the lowest of 72.3 t/ha at mixed forest site 2. Average value of BGB was calculated as 50.46 t/ha (Table 1).

Pinus roxburghii was the most significant species in terms of net primary productivity containing an average biomass value of 191.8 t/ha, having 63.35% share in estimated biomass followed by *Olea cuspidata* 68.9 t/ha (22.67%), *Acacia modesta*12.71 t/ha (4.19%), *Dalbergia sissoo*12.01 t/ha (3.96%), *Broussonetia papyrifera* 5.93 t/ha (1.95%), *Punica granatum*2.27 t/ha (0.74%), *Mallotus philippinensis*2.2 t/ha (0.73%), *Albizia lebbeck* 1.8t/ha (0.59%), *Ficus palmata* 1.51 t/ha (0.5%), *Acacia arabica* 1.4 t/ha (0.46%), *Melia azedarach*, 1.14 t/ha (0.4%) and *Ficus carica* 1.07 t/ha (0.3%) respectively (Table 2).

Forest stands showed an average tree density of 492/ha with a maximum of 625/ha at mixed forest site 2 whereas the minimum of 220 trees/ha at *Pinus roxburghii* site 5. Average DBH value were found to be 87.27 cm with maximum of 150.78 cm in *Pinus roxburghii* forest site 4 whereas minimum of 43.63 cm at mixed forest site 2. Average tree height for the forest stands was 13.3m with a maximum of 21.8m at *Pinus roxburghii* site 4 was whereas minimum of 5.95 m at mixed forest site 2. Deforestation intensity was represented by an average stump density of 147.4/ha with highest of 251.5/ha recorded at *Olea cuspidata* site 3 whereas the lowest of 77.5/ha at *Pinus roxburghii* site 4. Forests showed an average regeneration capacity of 83 seedlings/ha with a maximum of 180 at mixed forest site 1 whereas zero regeneration at *Olea cuspidata* site 3 (Table 1).

Table 1. Mean biomass and soil carbon stocks at investigated sites.

Site No.	Tree density/ha	Stumps /ha	Seedlings /ha	AGTB (t/ha)	BGTB (t/ha)	Total biomass (t/ha)	Biomass carbon stock (t/ha)	Soil organic carbon (t/ha)	Total carbon (t/ha)
1	620	83.07	180	137.5	27.5	165	82.5	25.64	108.14
2	625	195	75	72.3	14.5	86.8	43.4	32.46	75.86
3	620	251.5	0	252.4	50.5	302.9	151.5	40.99	192.49
4	275	77.5	50	491.2	98.2	589.4	294.7	31.62	326.32
5	320	130	110	308.0	61.6	369.6	184.8	43.76	228.56
Average	492	147.4	83	252.2	50.46	302.74	151.38	34.89	186.27

Table 2. Biomass and Carbon stock values of tree species at investigated sites.

No.	Species	Site 1	Site 2	Site 3	Site 4	Site 5	Biomass t/ha	Carbon stock (t/ha)	% Contribution
1.	*Acacia arabica* Linn.	7.0	0	0	0	0	1.4	0.7	0.46
2.	*Acacia modesta* Wall.	15.8	47.75	0	0	0	12.71	6.36	4.19
3.	*Albizia lebbeck* L.	5.34	3.6	0	0	0	1.8	0.9	0.59
4.	*Broussonetia papyrifera* L.	17.98	11.71	0	0	0	5.93	2.97	1.95
5.	*Dalbergia sissoo* Roxb.	44.38	15.71	0	0	0	12.01	6.01	3.96
6.	*Ficus carica* L.	5.38	0	0	0	0	1.07	0.53	0.40
7.	*Ficus palmata* Forssk.	7.56	0	0	0	0	1.51	0.75	0.50
8.	*Mallotus philippensis* Muell.	4.8	6.21	0	0	0	2.20	1.1	0.73
9.	*Melia azedarach* L.	3.9	1.82	0	0	0	1.14	0.57	0.37
10.	*Olea cuspidata* Wall. ex G. Don	41.48	0	302.9	0	0	68.9	34.45	22.76
11.	*Pinus roxburghii* Sarg.	0	0	0	589.4	369.6	191.8	95.9	63.35
12.	*Punica granatum* L.	11.38	0	0	0	0	2.27	1.14	0.74
	Total	**165**	**86.8**	**302.9**	**589.4**	**369.6**	**302.74**	**151.38**	**100**

Principal component analysis explained more than 90% of variance along the 1st and 2nd axis, indicating the statistical strength of the test. *Olea cuspidata* showed significant correlation with forest site 3 on X-axis whereas *Pinus roxburghii* was placed closed to sites 4 and 5 on Y axis. This strong correlation between dominant species with the respective sites showed strong dominance of these species having maximum biomass and carbon shares. The most prominent cluster is formed along X-axis though not significant statistically. Here all the species found at mixed forest sites 1 and 2 are shown in overlapping form with small vectors for carbon stock values showing their minimum share (Fig. 2, Table 2). Cluster analysis was performed based on Euclidean distance Neighborhood clustering. It showed distinct grouping of species in clearly segregated clusters based on location, biomass and Carbon stock values. *Olea cuspidata* (Site 3) and *Pinus roxburghii* (site 4 & 5) were grouped separately on the extreme left of the dendrogram forming individual branches with minimum similarity being in pure stands (Fig. 3). Rests of the species were clustered in 3 distinct groups based on species coexistence at sites 1 and 2 (mixed forest) closely related in geographical occurrence. *Ficus carica, F. palmata, Punica* and *Acacia arabica* formed a cluster with maximum similarity at cut level 1.0. This was because of their presence at only site 1 mixed forest site which significantly separated these from the rest at maximum similarity. Whereas *Abizia, Mallotus, Dalbergia, Brossonetia* and *Acacia modesta* being present at both site 1 and 2 formed another cluster at cut level 0.8 with significant similarity (Fig. 3, Table 2).

Discussion

The quantitative assessment of Carbon stocks in subtropical forests is of great importance since they refer to estimates obtained in a very poorly studied vegetation type as compared to other forests (Rosenfield & Souza, 2013). Current study revealed an average Carbon stock value of 186.27 t/ha in subtropical forest of District Muzaffarabad. This value is lower than the reported Carbon stocks values of 250 t/ha in forests of Southeast Asia (Houghton & Hackler, 1999); 285.0 t/ha in rain forests (Malhi *et al.*, 1998); 250-300 t/ha in central Himalayan forests (Singh & Singh, 1987; Rawat & Singh, 1988); 173.7 to 262.6 t/ha in Chir pine and Banj oak forests of Kumaun Himalaya (Jina *et al.*, 2009). The results are also lower than the estimates of 219.86-490.33 t/ha in Oak- pine forest of Garhwal Himalaya (Joshi *et al.*, 2013); 203.9 t/ha in broadleaved forest of China (Zhang *et al.*, 2012); and 274 to 194 t/ha in subtropical forests of Vietnam (Zemek, 2009). This decrease in values can be attributed to the fact that the forest sites had relatively lower biomass yield (Segura & Kanninen, 2005). Present study revealed that our average biomass value of 302.74 t/ha is lower than 1157-827 t/ha and 790.47 t/ha (Sharma *et al.*, 2014) for Himalayan region.

Forest Biomass is highly effected by anthropogenic activities through changes in land-use and forest management activities, and thus changing the natural greenhouse gases cycle (Bhadwal & Singh, 2002). Stump density of 147.4/ha reflected the deforestation intensity and pressure on the local forest reserves. Population are dependent on forests for livelihood; and economic growth puts additional demands on forests for construction and industrial development (Wani *et al.,* , 2010). Sites and species with lower tree density are characterized by low Carbon stocks values (Kindermann *et al*., 2006). Average tree density of 492/ha recorded in the study area is less than 534-620/ha in lesser Himalayas (Ahmed *et al.*, 2006); 1158/ha in western Himalayas (Sundriyal *et al.,* , 1994); 530-940/ha in Kumaun Himalayas (Kharkwal, 2009; Hussain *et al.*, 2008). The reasons for low tree density include fuel and timber wood extraction, high grazing pressure and unmanaged use of forest products (Czegledi & Radacsi, 2005).

Grazing directly affects soil Carbon by removing vegetation biomass and forest regeneration capacity. Regeneration capacity of the forests was 83 seedlings/ha which is lower than the reported value of 5474 seedlings/ha in Sikkim Himalaya(Sundriyal *et al*., 1994); 1400 seedlings/ha in central Himalaya (Thadani & Ashton, 1995); 520 to 1240 seedlings/ha in Garhwal Himalaya (Ballabha *et al.,* , 2013); 361 to 833 seedlings /ha in Northwest Himalayas(Kumar & Sharma, 2014) and 212 seedlings/ha in lesser Himalaya (Shaheen *et al*., 2011). Improper grazing management is reported to decrease Carbon storage in forest ecosystems by removing biomass and altering species composition (Ingram *et al.*, 2008; Sun & Guan, 2014).

Tree characteristics like DBH and height directly influence biomass production. Lower values of DBH and height results into lower biomass and Carbon stocks (Feldpausch *et al.*, 2012). DBH value of 87.27 cm recorded in our study is lower than the reported values of 123 cm in Terai and Mahabharat Foothills region of Nepal (Baral *et al.,* , 2009); 200 cm in Central Himalayas (Nautiyal & Singh, 2013) and 250 cm in US forests (Jenkins *et al.*, 2003). Similarly, average height of 13.3 m in this study is also lower as compared to reported value of 26.85 to 30.05 m in the forests of Nepal (Shrestha *et al.*, 2013) and 18.8 to 35.1 in Indian subtropical forest (Mishra *et al.*, 2009). Natural and anthropogenic disturbances limit tree growth and reduce total forest biomass ultimately decreasing Carbon assimilation in forest ecosystem (Rossi *et al.*, 2007).

There is considerable variation in Carbon sequestration in subtropical forests according to forest types and geographical location. This fact is also supported by the ordination tests including PCA and cluster analyses which showed distinct species segregation on the basis of variations in the carbon stock levels (Figs. 2, 3). The highest Carbon stock value of 326.32 t/ha was recorded in the *Pinus roxburghii* forest sites having highest DBH (150.78 cm) and Height (21.82 m) values. Low pressure in terms of grazing and tree felling synchronized with better environmental conditions resulted in a better growth of the forest biomass (Semmartin *et al.*, 2010). Soil Carbon values were higher in *Pinus roxburghii* sites also because of higher rates of needles and grasses decomposition. Mixed forest sites showed lower Carbon values attributed to low DBH, height, retarded regeneration high deforestation and grazing. *Pinus roxburghii* was the most dominant species participating 95.9 t/ha (63.35 percent) in average biomass Carbon stocks because of better ecological and geographical conditions, greater density, DBH and height values. A difference in Carbon stock values is observed along altitudinal gradient. Subtropical mixed forests in lower altitudinal range (>1000m) collectively show lower Carbon stocks as compared to *Pinus* sites at relatively higher altitude (Tang, 2006).

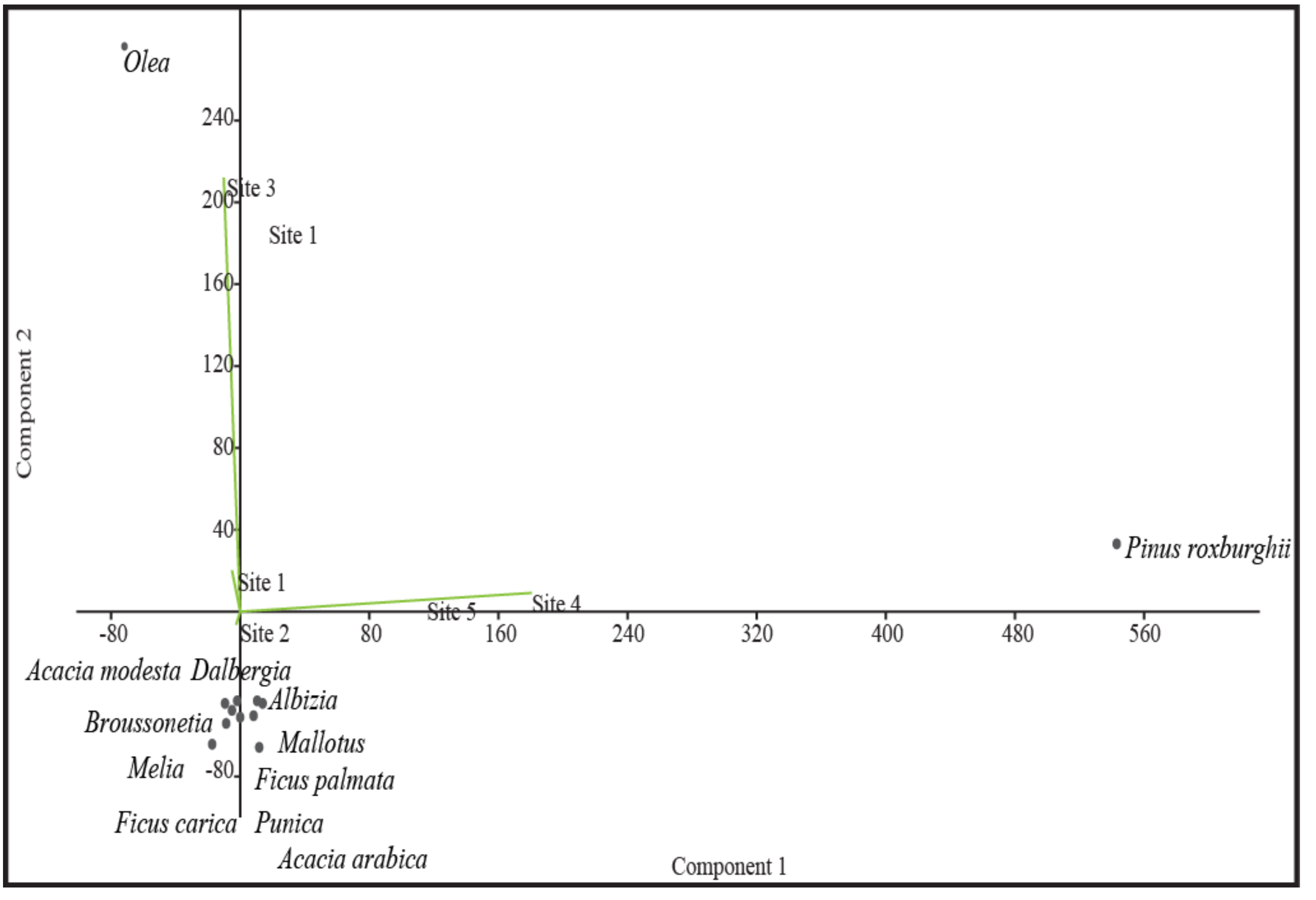

Fig. 2. Principal Component Alayses (PCA) biplot of investigated sites and tree species.

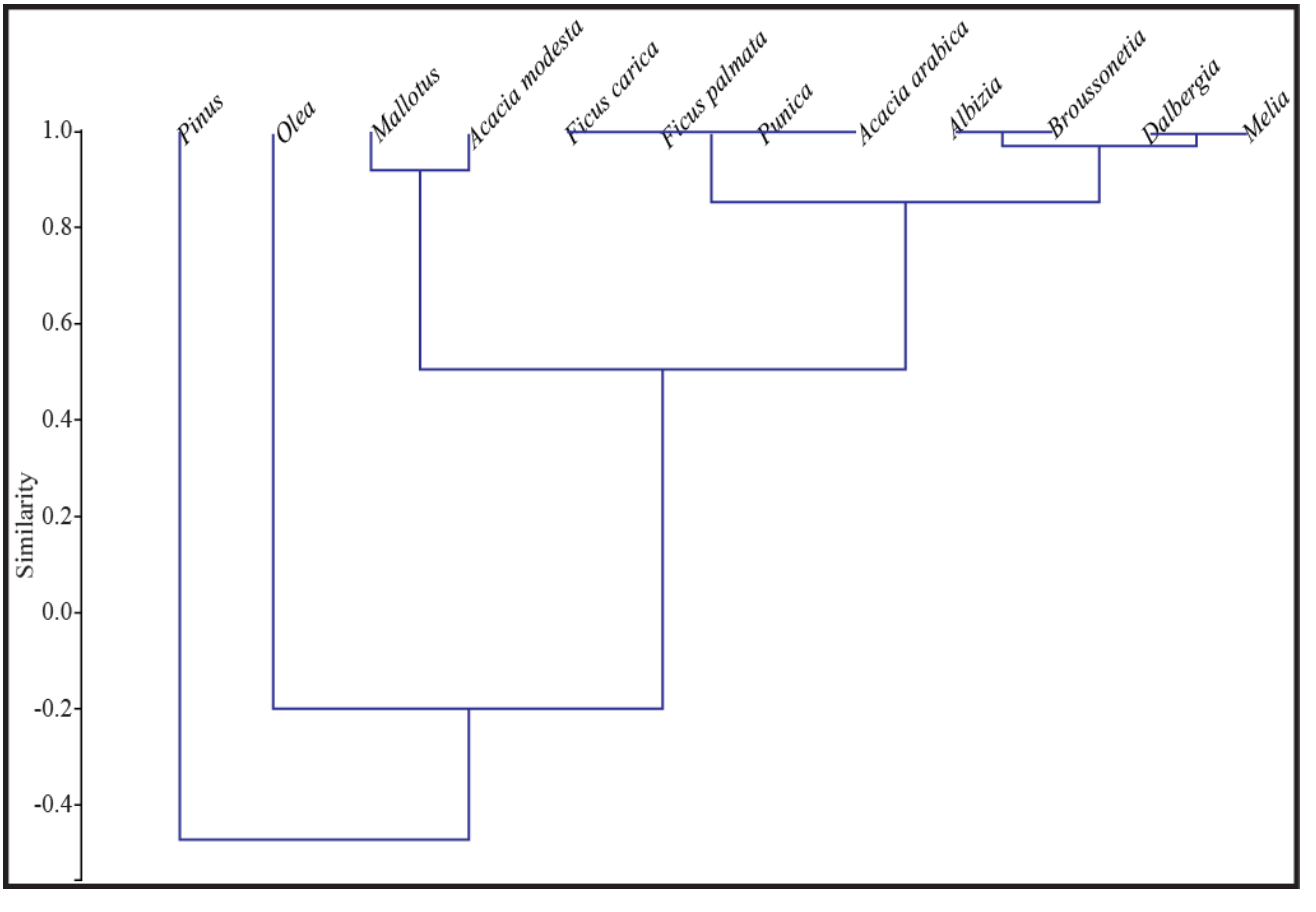

Fig. 3. Cluster Analyses Dendrogram of investigated tree species based on Euclidean Ditance.

Soil is a vast Carbon pool and contains large quantities of sequestered Carbon that could potentially reduce global warming. Average value of Soil Carbon stocks in the study area was 34.89 t/ha. Higher values of 185.6 t/ha and 124.8 t/ha soil Carbon stocks were reported for the subtropical and temperate forests of Garhwal Himalaya (Sheikh *et al.*, 2009); 63.9 to 83.8 t/ha, 57.5 to 60.1 t/ha, and 55.5 to 59.7 t/ha in different soil depths in central Himalayan forest (Arora *et al.*, 2014); 83 to 156 t/ha in different Canadian soils (Banfield *et al.*, 2002) and 105.73 t/ha in lower subtropical broadleaved evergreen forest of China (Sun & Guan, 2014)**.** The Himalayan region is susceptible to high rates of soil erosion due to a number of factors like steep slopes, present and past glaciation, high rainfall intensities due to aerographic effects, and disturbed vegetation cover (Myers, 2001). Besides high erosion rates, the downstream effects of mountain erosion are perceived to be severe (Thapa & Weber, 1995). Agricultural soil Carbon stocks was found to be 27.18 t/ha. Higher values of 78.3 t/ha agricultural Carbon stocks were reported in France; 72.9 t/ha in Slovakia; 69.6 t/ha in Poland; 65.0 t/ha in Bulgaria; 58.7 t/ha in Italy; 58.5 t/ha in Denmark and 150.6 t/ha in Netherlands (Lugato *et al.*, 2014) and 42.35 to 35.26 t/ha in India (Ravindranath & Ostwald, 2007). Soils have lost as much as 20 to 80 tons Carbon per hectare due to conversion of forest to agricultural ecosystems that severely causes depletion of the SOC (Lal, 2004; Soto-Pinto *et al.*, 2010). Poor cultivation management, negative balance of nutrients in cropland, removal of residue, soil degradation through accelerated soil erosion and salinization deplete SOC stock in upland soils (Bhat *et al.*, 2012).

Conclusion

Forest and soil Carbon stocks showed variations in response to combination of natural and anthropogenic variables. *Pinus roxburghii* forest showed maximum carbon values having highest DBH, tree height, density and cover whereas mixed forest sites showed lower values of carbon stocks. There is further need to develop methodologies for biomass estimation in different forest types in order to strengthen the policies for forest conservation and climate change mitigation.

References

Ahmed, M., T. Husain, A. Sheikh, S. Hussain and M. Siddiqui. 2006. Phytosociology and structure of Himalayan forests from different climatic zones of Pakistan. *Pak. J. Bot*., 38(2):361.

Ahmed, M. and S. Shaukat. 2012. *A Text book of Vegetation Ecology.* Abrar Sons, Near New Urdu Bazar Karachi, Pakistan.

Arora, G., S. Chaturvedi, R. Kaushal, A. Nain, S. Tewari, N.M. Alam and O.P. Chaturvedi. 2014. Growth, biomass, carbon stocks, and sequestration in an age series of Populus deltoides plantations in Tarai region of central Himalaya. *Turk. J. Agric. & Forestry*, 38(4):550-560.

Ballabha, R., J. Tiwari and P. Tiwari. 2013. Regeneration of tree species in the sub-tropical forest of Alaknanda Valley, Garhwal Himalaya, India. *Forest Sci. & Practice*, 15(2):89-97.

Banfield, G., J. Bhatti, H. Jiang and M. Apps. 2002. Variability in regional scale estimates of carbon stocks in boreal forest ecosystems: results from West-Central Alberta. *Forest Ecol. & Manag*., 169(1):15-27.

Baral, S., R. Malla and S. Ranabhat. 2009. Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari* 19(2):10-14.

Bhadwal, S. and R. Singh. 2002. Carbon sequestration estimates for forestry options under different land-use scenarios in India. *Curr. Sci*., 83(11):1380-1386.

Bhat, J.A., M. Kumar, A.K. Negi, N.A. Pala and N.P. Todaria. 2012. Soil organic carbon stock and sink potential in high mountain temperate Himalayan forests of India. *Int. J. Cur. Res.,* 4(12): 206-209.

Blaikie, P.M. and S.Z. Sadeque. 2000. *Policy in high places: environment and development in the Himalayan region*: ICIMOD.

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. & Envir. Sci.,* 39(2):97-106.

Butt, T.M. 2006. Sustainable forest management: A case study on machiara national park In district muzaffarabad, state of Azad jammu and kashmir, Pakistan, Department of Geography Norwegian University of science and technology.

Chave, J., C. Andalo, S. Brown, M. Cairns, J. Chambers, D. Eamus, H. Fölster, F. Fromard, N. Higuchi and T. Kira. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145(1):87-99.

Chave, J., R. Condit, S. Lao, J.P. Caspersen, R.B. Foster and S.P. Hubbell. 2003. Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama. *J. Ecol*., 91(2):240-252.

Czegledi, L. and A. Radacsi. 2005. Overutilization of pastures by livestock. *Acta pascuorum (Grassland studies)* 3: 29-36.

de M.S., C.C. Cerri, W.A. Dick, R. Lal, P.V. Solismar Filho, M.C. Piccolo and B.E. Feigl. 2001. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. *Soil Sci. Soc. Amer. J.,* 65(5): 1486-1499.

Eggleston, H., L. Buendia, K. Miwa, T. Ngara and K. Tanabe. 2006. IPCC guidelines for national greenhouse gas inventories. *Institute for Global Environmental Strategies, Hayama, Japan*.

Feldpausch, T.R., J. Lloyd, S.L. Lewis, R.J. Brienen, M. Gloor, A. Monteagudo Mendoza, G. Lopez-Gonzalez, L. Banin, K. Abu Salim and K. Affum-Baffoe. 2012. Tree height integrated into pantropical forest biomass estimates. *Biogeosciences*, 3381-3403.

Franklin, J.F., T.A. Spies, R. Van Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, D.B. Lindenmayer, M.E. Harmon, W.S. Keeton and D.C. Shaw. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecol. & Manag.,* 155(1):399-423.

Gibbs, H.K., S. Brown, J.O. Niles and J.A. Foley. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Envir. Res. Letters*, 2(4):045023.

GOAJK. 2014. Planning and Development department. Government of Azad Jammu and Kashmir. . In *Government of Azad JAmmu and Kashmir*. Muzaffarabad, Pakistan.

Hangarge, L., D. Kulkarni, V. Gaikwad, D. Mahajan and N. Chaudhari. 2012. Carbon Sequestration potential of tree species in Somjaichi Rai (Sacred grove) at Nandghur village, in Bhor region of Pune District, Maharashtra State, India. *Annals of Biol. Res.,* 3 (7): 3426-3429.

Houghton, R. 2007. Balancing the global carbon budget. *Annu. Rev. Earth Planet. Sci*., 35: 313-347.

Houghton, R. and J. Hackler. 1999. Emissions of carbon from forestry and land‐use change in tropical Asia. *Global Change Biology*, 5(4): 481-492.

Hussain, M.S., A. Sultana, J.A. Khan and A. Khan. 2008. Species composition and community structure of forest stands in Kumaon Himalaya, Uttarakhand, India. *Tropical Ecology*, 49(2):167.

Ingram, L., P. Stahl, G. Schuman, J. Buyer, G. Vance, G. Ganjegunte, J. Welker and J. Derner. 2008. Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. *Soil Sci. Soc. Amer. J.*, 72(4):939-948.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath and R.A. Birdsey. 2003. National-scale biomass estimators for United States tree species. *Forest Science*, 49(1): 12-35.

Jina, B., P. Sah, M. Bhatt and Y. Rawat. 2009. Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of Oak and Pine forest of Kumaun Central Himalaya. *Ecoprint: An Int. J. Ecol*., 15: 75-81.

Joshi, N.R., A. Tewari and D.B. Chand. 2013. Impacts of forest fire and aspects on phytosociology, tree biomass and carbon stock in oak and pine mixed forests of Kumaun central Himalaya, India: Researcher.

Kharkwal, G. 2009. Qualitative analysis of tree species in evergreen forests of Kumaun Himalaya, Uttarakhand, India. *Afr. J. Pl. Sci*., 3(3):49-52.

Kindermann, G.E., M. Obersteiner, E. Rametsteiner and I. McCallum. 2006. Predicting the deforestation-trend under different carbon-prices. *Carbon Balance & Manag.*, 1(1): 15.

Körner, C. 2007. The use of 'altitude'in ecological research. *Trends in Ecol. & Evol*., 22(11):569-574.

Kumar, S. and S. Sharma. 2014. Diversity, disturbance and regeneration status of forests along an altitudinal gradient in Paddar Valley, Northwest Himalayas. *Indian Forester*, 140(4):348-353.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*, 304(5677): 1623-1627.

Lugato, E., P. Panagos, F. Bampa, A. Jones and L. Montanarella. 2014. A new baseline of organic carbon stock in European agricultural soils using a modelling approach. *Global Change Biology*, 20(1): 313-326.

MacDicken, K.G. 1997. *A guide to monitoring carbon storage in forestry and agroforestry projects*: Winrock International Institute for Agricultural Development USA.

Malhi, Y., A.D. Nobre, J. Grace, B. Kruijt, M.G. Pereira, A. Culf and S. Scott. 1998. Carbon dioxide transfer over a Central Amazonian rain forest. *Journal of Geophysical Research: Atmospheres (1984–2012)* 103 (D24): 31593-31612.

Melkania, N. 2009. Carbon sequestration in Indian natural and planted forests. *Indian Forester*, 135(3): 380.

Mishra, A., S. Nautiyal and D. Nautiyal. 2009. Growth characteristics of some indigenous fuelwood and fodder tree species of sub-tropical Garhwal Himalayas. *Indian Forester*, 135(3): 373.

Myers, N. 2001. Hotspots *Encyclopedia of Biodiversity*, 3: 371-381.

Nautiyal, N. and V. Singh. 2013. Carbon Stock Potential of Oak and Pine Forests in Garhwal Region in Indian Central Himalayas. *J. Pharm. & Phytoch*., 2(1): 34-38.

Nizami, S.M., S.N. Mirza, S. Livesley, S. Arndt, J.C. Fox, I.A. Khan and T. Mahmood. 2009. Estimating carbon stocks in sub-tropical pine (Pinus roxburghii) forests of Pakistan. *Pak. J. Agri. Sci*., 46(4): 266-270.

Pak-Met. 2012. The Normals of Climatic Data of Azad Jammu & Kashmir: Pakistan Mateorological Department.

Ravindranath, N.H. and M. Ostwald. 2007. *Carbon inventory methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects*. Vol. 29: Springer Science & Business Media.

Rawat, Y. and J. Singh. 1988. Structure and function of oak forests in central Himalaya. I. Dry matter dynamics. *Annals of Bot.*, 62(4): 397-411.

Rosenfield, M.F. and A.F. Souza. 2013. Biomass and carbon in subtropical forests: Overview of determinants, quantification methods and estimates. *Neotro. Biol. & Conser.*, 8(2): 103-110.

Rossi, S., A. Deslauriers, T. Anfodillo and V. Carraro. 2007. Evidence of threshold temperatures for xylogenesis in conifers at high altitudes. *Oecologia*, 152(1): 1-12.

Schild, A. 2011. The Himalayas as the providers of essential ecosystem services–Opportunities and challenges.

Segura, M. and M. Kanninen. 2005. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica1. *Biotropica*, 37(1): 2-8.

Semmartin, M., C. Di Bella and I.G. de Salamone. 2010. Grazing-induced changes in plant species composition affect plant and soil properties of grassland mesocosms. *Plant and Soil*, 328(1-2): 471-481.

Shaheen, H., R. Qureshi and Z. Shinwari. 2011a. Structural diversity, vegetation dynamics and anthropogenic impact on lesser Himalayan sub-tropical forests of Bagh district, Kashmir. *Pak. J. Bot*., 43(4):1861-1866.

Sharma, V., S. Hussain, K. Sharma and V.M. Arya. 2014. Labile carbon pools and soil organic carbon stocks in the foothill Himalayas under different land use systems. *Geoderma*, 232: 81-87.

Sheikh, M.A., M. Kumar and R.W. Bussmann. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance & Manag*., 4(6): 1-6.

Shrestha, S., B.S. Karky, A. Gurung, R. Bista and O.R. Vetaas. 2013. Assessment of carbon balance in Community Forests in Dolakha, Nepal. *Small-Scale Forestry*, 12(4): 507-517.

Singh, J. and S. Singh. 1987. Forest vegetation of the Himalaya. *The Botanical Review*, 53(1): 80-192.

Soto-Pinto, L., M. Anzueto, J. Mendoza, G.J. Ferrer and B. de Jong. 2010. Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. *Agroforestry Syst.*, 78(1): 39-51.

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.*, 249-258.

Sundriyal, R., E. Sharma, L. Rai and S. Rai. 1994. Tree structure, regeneration and woody biomass removal in a sub-tropical forest of Mamlay watershed in the Sikkim Himalaya. *Vegetatio*, 113(1): 53-63.

Tang, C. 2006. Evergreen sclerophyllous Quercus forests in northwestern Yunnan, China as compared to the Mediterranean evergreen Quercus forests in California, USA and northeastern Spain. *Web Ecology*, 6(1): 88-101.

Thadani, R. and P. Ashton. 1995. Regeneration of banj oak (Quercus leucotrichophora A. Camus) in the central Himalaya. *Forest Ecol. & Manag*., 78(1): 217-224.

Thapa, G.B. and K.E. Weber. 1995. Status and management of watersheds in the Upper Pokhara valley, Nepal. *Envir. Manag.*, 19(4): 497-513.

Upadhyay, T., P.L. Sankhayan and B. Solberg. 2005. A review of carbon sequestration dynamics in the Himalayan region as a function of land-use change and forest/soil degradation with special reference to Nepal. *Agric. Eco. & Envir.*,105(3): 449-465.

Wani, N., A. Velmurugan and V. Dadhwal. 2010. Assessment of agricultural crop and soil carbon pools in Madhya Pradesh, India. *Tropical Ecology*, 51(1): 11-19.

Zemek, O.J. 2009. Biomass and carbon stocks inventory of perennial vegetation in the Chieng Khoi Watershed, NW Vietnam, MSc thesis, University of Hohenheim, Stuttgart.

Zhang, H., D. Guan and M. Song. 2012. Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China. *Forest Ecol. & Manag*., 277: 90-97.

(Received for publication 22 October 2015)