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Research Paper

An assessment of the effect of vegetation size and type, and altitude on above ground plant biomass and carbon

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Abstract. Quantification of vegetation carbon stocks is an important task to evaluate the carbon sequestration potential in the ecosystem. Two community forests (CFs) - Jalbire Mahila CF and Laxmi Mahila CF of Gorkha district, Nepal were selected for the current study to measure carbon stocks. Allometric relationships of diameter and height were used to estimate the biomass of standing trees, poles and saplings, whereas the biomass of grass, herb and litter were determined directly from field measurements. The above ground carbon pools in Jalbire Mahila CF was 131.54 t ha $^{-1}$, while in Laxmi Mahila CF was 52.90 t ha^{-1}. The carbon pool of Jalbire Mahila CF was higher than that of Laxmi Mahila CF due to greater density of the larger sized trees. The species Sal (*Shorea robusta)* sequestrated more carbon pool in both CFs and the larger amount (largest fraction) of carbon pool was found in ‘stem’ among different parts of vegetation (branches, leaves, stem and undergrowth) in all the plant species of both CFs.

Keywords: Carbon sequestration, carbon pool (carbon stock), community forest, biomass.

INTRODUCTION

Carbon sequestration can be identified as the capture of atmospheric CO_2 into green plants, which is stored for long time (Watson et al., 2000). The natural storage of CO_2 by above ground biomass (trees), under storey vegetation and below ground parts (roots and micro-organisms) is one of the effective techniques for mitigating the atmospheric CO_2 levels (Jina et al., 2009). With comparison to atmosphere CO_2 (3000 Gt CO_2), forests accumulate more CO_2 (4500 Gt CO_2) and contributes significantly in global carbon cycle (Griggs and Noguer, 2002). The large quantity of CO_2 is taken up from the atmosphere and converted into plant biomass during the vegetation and plants growing season (Losi et al., 2003; Samalca, 2007; Deo, 2008; Adhikari, 2011).

Gilmour and Fisher (1991) defined community forest (CF) as the control and management of forests by the rural people for their domestic purposes which also became the entire part of their farming systems. In Nepal, CF has been recognized as major source of carbon sink. It is reported that about 20% of the total carbon stock is found in CF (Pokharel and Byrne, 2009). The carbon sequestrated by the government managed forests in Nepal is 596.03 million tons and in CF is 183.40 million tons (Pokharel and Byrne 2009). Carbon stock of CFs depends on climatic conditions, soil type, landscape, altitude, aspect, species, density of stands and forest age (Shrestha and Singh, 2008). Within one elevation, different factors like topography, aspect, slope inclination and soil type results in different forest composition. Zhang et al. (2013) have reported that natural mixed forest has high carbon sequestration capacity in subalpine region of China. They further suggested that the carbon stock could

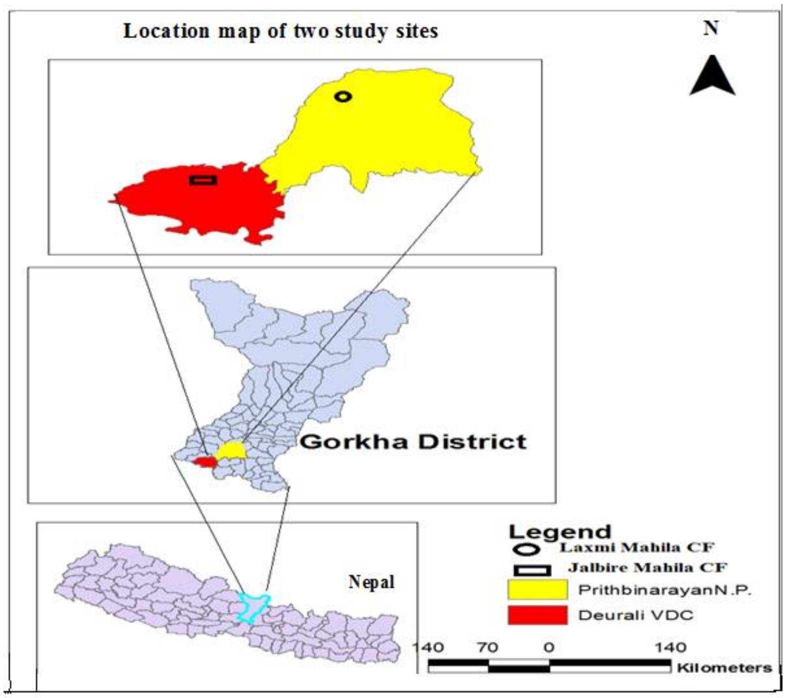

Figure 1. Map of the study area.

be enhanced by minimizing soil disturbance at the time of forest management practices. The variation in age of the forest stands also results in divergence of carbon stocks in different forests (Sun et al., 2004). Besides, some studies have reported that soil organic carbon (SOC) also varies with variation in vegetation types and topographic aspects. The study done in Ethiopia showed that SOC varied significantly among 3 vegetation communities at different topographic aspects (Yimer et al. 2006). Similarly, another study showed wide variation in distribution and stocks of SOC across 4 vegetation types (Fu et al., 2010). Influence of intensity and duration of sunlight affects different aspects of hill slopes (Yadav and Gupta, 2006). Around quarter of Nepalese forests have been handed to more than 1500 community forests users group (CFUG), which represents one third of the total population of the nation (DoF, 2011).

The productive and well-managed CF has an important potential to sequestrate good quantity of carbon, which can contribute mitigating the greenhouse effect. Nepal is one of the potential countries for Reducing Emissions from Deforestation and Degradation Plus (REDD+) program but this program have not expanded in Nepal. The enhancement of carbon stocks through community management might be the basis for potential REDD+ instrument in Nepal. Monitoring of forest cover biomass stock, carbon emission and carbon removal are inadequate in the developing countries like Nepal. Few studies have been carried out on carbon dynamics of community forests. The limited carbon inventory data performed by e.g., (Baral et al., 2009; Khanal et al., 2010; Shrestha, 2009; Shrestha and Singh, 2008) do not represent the whole status carbon stock of CF of Nepal.

So, more studies are needed to determine the particular growth rates in different community managed forests. This study can be helpful in presenting the carbon stocks in the CFs of mid-hills of Nepal. The objective of this study was to quantify and compare the amount and distribution of carbon stocks in the vegetation of two different CFs of Nepal.

MATERIALS AND METHODS

Study area

This study was carried out in two CFs of Gorkha district (Figure 1). Jalbire Mahila CF is situated in Deurali VDC ward no. 5, whereas Laxmi Mahila CF is situated in Prithbi Narayan Municipality ward no. 8. The area of Jalbire Mahila CF is 6.5 ha, while the area of Laxmi Mahila CF is 8.1 ha. These two CFs were handed over to forest users in 1994 and 1998 A.D., respectively. Jalbire Mahila CF is situated 600 m above mean sea level, whereas Laxmi Mahila CF is situated 900 m above mean sea level. Both CFs were situated on moderate to steep slopes ranging from 10 to 40 degrees. The soil type varied from sandy loam to clay loam and had reddish-brown color. The average maximum and minimum temperatures of the Gorkha district is 27°C and 3°C with mean annual rainfall of 1500 mm (LFLP, 2004). The major tree species of Jalbire Mahila CF were Sal (*Shorea* *robusta*), Chilaune (*Schima wallichii*), Sissoo (*Dalbergia sissoo*) and Khayer (*Acacia catechu*), while the major tree species of Laxmi Mahila CF were Sal (*S. robusta*), Chilaune (*S. wallichii*) and Katus (*C. tribuloides*). The crown cover is more than 50% by pole sized trees in both CFs. The major management activities undertaken in both CF were cleaning, thinning, pruning and improvement felling.

Data collection and analysis

Forest sampling and measurement

More than 50% crown coverage by pole size tree (dbh 10 to 29.9 cm) has been reported in CFOPs for these forests (CFOP, 2009, 2011). Based on the crown coverage and size of the trees, 10 m x 10 m sample plot (DoF, 2011) size was used in this study. Generally, larger size of sample plot (e.g. 25 m × 20 m) was used in previous studies (Khanal et al., 2010). But 10 m × 10 m sample plot size was used by Shrestha and Singh (2008). Areas of both CFs were small and therefore smaller sample plot size was used in this study. The total areas of both CFs were already stratified into several blocks: 4 blocks in Jalbire Mahila CF and 5 blocks in Laxmi Mahila CF (CFOP, 2009, 2011). So, the forest sampling was done based on those strata or blocks. But within each block (in both CFs), systematic sampling was performed with fixed interval between plot to plot distance. Species distribution in both forest areas was more or less homogeneous, 5% sampling intensity was used (DoF, 2011). The calculated plot to plot distance was 43 m. The total sample plots measured were 33 and 44 in Jalbire Mahila CF and Laxmi Mahila CF respectively.

In the main plot size 10 m × 10 m, trees (dbh > 30 cm) and poles (dbh = 10 to 30 cm) were measured. Similarly, within this main plot size, nested plot of size 5 m × 5 m were laid out for measuring saplings (dbh = 5 to 10 cm) and another nested plot of size 1 m × 1 m was laid out within 5 m × 5 m plot for measuring weights of regeneration (dbh < 5 cm), grasses, herbs and leaf litters (Khanal et al., 2010). Both the diameter and height were measured and recorded for all the individual stands (tree, pole and saplings, dbh > 5 cm) in each plots of both CFs. However, all the herbaceous and woody vegetations (dbh < 5 cm) inside 1 m × 1 m nested plot were clipped and collected and the representative sub-samples were taken to the Soil laboratory of Institute of Forestry, Pokhara, Nepal. The samples were oven dried at constant temperature 60 to 70°C until the weights of sample became constant (Petsri et al., 2007). Those weights were recorded for further calculation of carbon pool.

Biomass and carbon estimation

Species-specific stem volume was calculated using volume equation, Equation 1 (Sharma and Pukkala, 1990) with data of total height and dbh measured for each individual (tree, pole and sapling), and volume obtained for Equation 1 was multiplied by 1000 as per its application guideline.

$$\ln (V) = a + b^* \ln (dbh) + c^* \ln (ht) \qquad (1)$$

where V = total stem volume with bark (m^3), dbh = diameter at the breast height (cm), ht = total height (m), and *a, b* and *c* are species-specific parameters, and their estimated values are reported in Sharma and Pukkala (1990). Even though this model does not cover some species of my study area such as *Castanopsis tribuloides, Mangifera indica, Engelhardia spicata*, *Mallotus phillippinensis, Ficus nerrifolia, Trichilia connaroides* and *Jacaranda mimosifoia,* models (Sharma and Pukkala, 1990) for miscellaneous hill species or Terai species were applied. This model was also used by other researchers in similar studies (Adhikari, 2011; Karna, 2012; Khanal et al., 2010; Shrestha and Singh, 2008; Shrestha, 2009).

The total species-specific stem volume obtained from Eq. (1) was multiplied with specific-specific dry wood density (Brown 1997; Chaturvedi and Khanna 2000) to get the oven dry weight of stem. The fractions of biomass of branches (0.45) and leaves (0.11) to total tree biomass of *Alnus nepalensis* (Sharma 2003) were used to estimate branch and leaf biomass for all species in the study area. Due to the lack of species-specific conversion factors, this information was used in this study. Other researchers (Adhikari, 2011; Khanal et al., 2010; Shrestha and Singh, 2008; Shrestha, 2009) have also followed Sharma (2003). The samples of undergrowth vegetation (species with dbh < 5 cm, grasses, herbs, leaf litter) were green with higher moisture content. So, they all were oven dried at a constant temperature of 60 to 70°C for about 48 h (Petsri et al., 2007) until the weights of the samples became constant.

Total above ground dry weights for each sample plot were obtained by summing up of dry weights of trees, plots and sapling and undergrowth (grass, herbs, leaf litter). Total biomass of each CF was calculated (Table 2). The total carbon content was assumed to be 43% of the total dry biomass (Negi et al., 2003). This factor was chosen because it was the typical value of carbon content in forest species, which had also been used by many researchers in other studies (Shrestha, 2008; Shrestha, 2009; Shrestha and Singh, 2008; Khanal et al., 2010). But carbon content was calculated as 50% of the total dry biomass in some other studies (Petsri et al., 2007; Terakunpisut et al., 2007; Adhikari, 2011).

Data analysis

The data of individual stands (diameter and height) and undergrowth vegetation were analyzed using statistical

Table 1. Summary statistics of forest inventory.

Characters	Laxmi Mahila CF			Jalbire Mahila CF		
Plot wise	**Mean ± sd**	**Min.**	**Max.**	**Mean ± sd**	**Min.**	**Max.**
Dbh* (tree), cm*	43.45 ± 12.35	30.2	50.6	40.53 ± 8.70	31.1	64.7
Height (tree), m*	19.57 ± 4.98	16.4	27	24.85 ± 2.95	22	33.9
Dbh (pole), cm	13.24 ± 3.10	10	29.9	15.74 ± 4.20	10	29.6
Height (pole), m	11.18 ± 2.68	2.8	19.6	15.55 ± 3.12	8.7	21.9
Dbh (sapling), cm	7.45 ± 1.30	5.1	9.9	8.38 ± 1.32	5.5	9.9
Height (sapling), m	6.91 ± 1.88	2.6	12.6	6.73 ± 1.57	3.1	8.7
Mean no. of trees/plot	0.09			0.75		
Mean no. of poles/plot	9.02			10.54		
Mean no. of saplings/plot	`3.48			0.88		

dbh = diameter at breast height (measured at 1.37 m from the ground); m = meter; cm = centimeter.

Table 2. Vegetation biomass (t ha^{-1}).

SN	CF	Above ground tree	Under-growth (live and dead)	Total
1	Laxmi Mahila	117.213	5.817	123.03
2	Jalbire Mahila	299.615	6.295	305.91

Table 3. Vegetation carbon pool (t ha^{-1}).

SN	CF	Above ground tree	Under-growth (live and dead)	Total
1	Laxmi Mahila	50.401	2.501	52.90
2	Jalbire Mahila	128.834	2.707	131.54

softwares MS excel (versions 2007) and SAS (SAS Institute Inc, 2008). The statistical software SAS was used for biomass estimation and carbon content calculation whereas MS excel was used for processing undergrowth biomass data and for producing graphs and charts.

RESULTS AND DISCUSSION

Carbon pool in above-ground vegetation

The mean above ground biomass in Jalbire Mahila CF was higher than in Laxmi Mahila CF (Table 2). Likewise, under-growth (live and dead) biomass of Jalbire Mahila CF was larger than that of Laxmi Mahila CF (Table 2). The under-growth biomass contributed only about 2.10% of the total above ground biomass in Jalbire Mahila CF, while it equaled about 4.96% of the total above ground biomass in Laxmi Mahila CF.

The above ground carbon pool (both tree and undergrowth) in Jalbire Mahila CF was found to be greatly higher than Laxmi Mahila CF (Table 3). The data showed that the carbon pool of above ground tree biomass in Jalbire Mahila CF was found to be 47.7 times higher than carbon pool in the under-growth biomass, whereas it just 20 times higher in Laxmi Mahila CF.

The biomass of tree and undergrowth vegetation for a particular stand varied with site quality, stand condition, species composition, and many others. The above ground carbon pool in Jalbire Mahila CF was found to be greatly higher than Laxmi Mahila CF (Table 3) due to larger sized trees (greater dbh and height) which have higher biomass values (Table 1). This variation in biomass was seen in different sample plots of same CF and between two CFs due to variation in tree size and density. Similar studies have reported that various factors such as vegetation types, net primary productivity of plants, biomass decomposition, size of trees, age of stands may affect the carbon stock in ecosystem (Shrestha and Singh, 2008). The tree size (both dbh and height) and densities of stands were higher in Jalbire Mahila CF compared to Laxmi Mahila CF (Table 1).

Carbon pool on different parts of vegetation

Proportion of carbon pool was calculated by categorizing the vegetation into four parts: stem, branch, leaf and undergrowth (Figure 2). In both CFs, the carbon pool of ‘stem’ was highest and ‘under growth vegetation’ was lowest. However, there were similarities between two CFs

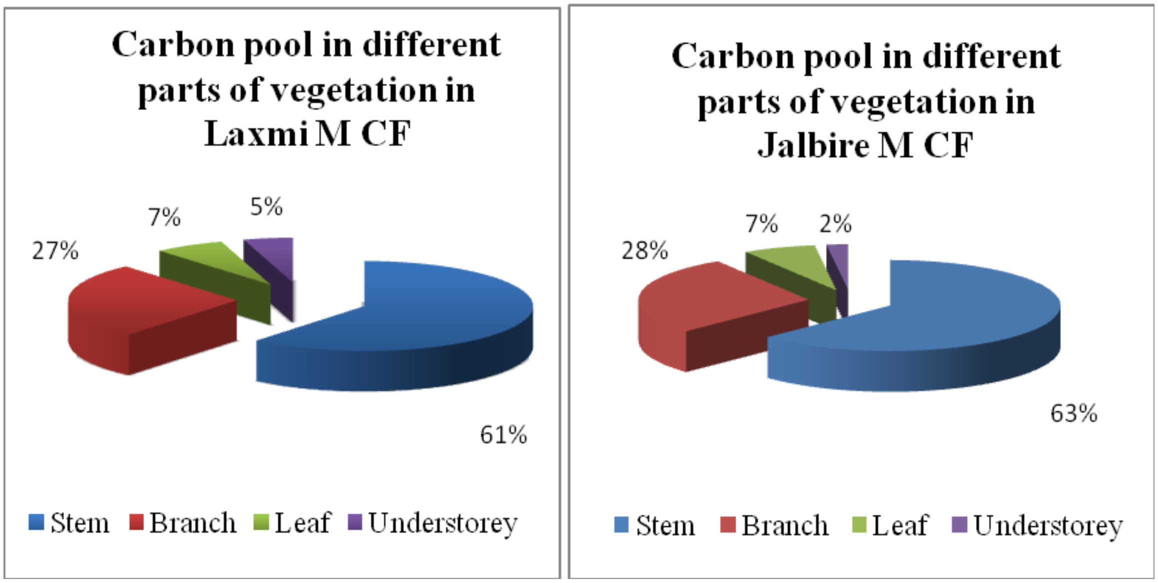

Figure 2. Carbon pool in different parts of vegetation in two CFs.

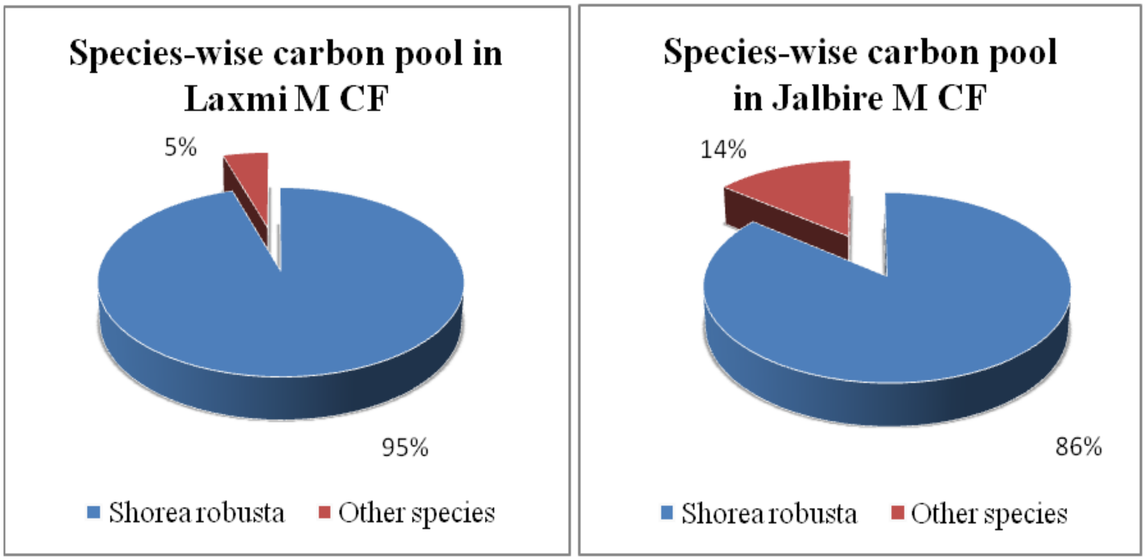

Figure 3. Species-wise carbon pool in two CFs.

regarding proportion of carbon pool in stem, branch, leaf and undergrowth. Some similar characteristics of two CFs such as dominancy of the species 'Sal' and growth of vegetation might be responsible for this result.

Species wise carbon pool on two CFs

Species wise carbon pool by the two CFs is shown in the pie-chart above (Figure 3). Among the species found in both CFs, the carbon pool was highest in species *Shorea robusta* (that is, 48.03 t ha^{-1} in Laxmi Mahila CF and 110.51 t ha^{-1} in Jalbire Mahila CF). Besides, the other species with higher carbon pool was *Dalbergia sissoo* in Jalbire Mahila CF. The lowest carbon pool species were *Largerstromia parvifolia* and *Magnifera indica* in Laxmi Mahila CF and Jalbire Mahila CF respectively.

In both CFs, the major dominant species was *S. robusta*, having more carbon pool (Figure 3). Baral et al. (2009) found that Hill *Shorea* forest sequestrated 97.86 t ha^{-1} C with maximum height of stand 30 m, mean height 12.75 m, maximum dbh of stand 89 cm and mean dbh 19.56 cm. Similarly, Shrestha (2009) noted that *Shorea* forest sequestrated 78.80 t ha^{-1}C with maximum height of stand 15.1 m, mean height 9.75 m and maximum dbh of stand 39 cm, mean dbh 11.11 cm. In contrast to this, Khanal et al. (2010) found that one of CFs of the mid-hill of Nepal sequestrated 40.2 t ha^{-1} C. They also mentioned that the CF had maximum height of stand 22 m, mean height 10.6 m and maximum dbh of stand 50.2 cm and mean dbh 16.22 cm.

By comparing with some previous studies, it was found that the carbon pool of Jalbire Mahila CF seemed to be greater. However, the carbon pool of this study was comparable and realistic with the study of ANSAB (project) done in same district of Nepal (ANSAB, 2011). Both heights and dbh of the stands were greater in Jalbire Mahila CF than the forest of Shrestha (2009). It was the major reason for higher carbon pool in Jalbire Mahila CF. Though the dbh of stand in Jalbire Mahila CF is less than of the dbh of Hill Shorea forest of Baral et al. (2009), but the mean height and maximum height both were larger in Jalbire Mahila CF. So, this might result in greater carbon pool in Jalbire Mahila CF (128.83 t ha^{-1} C > 97.86 t ha^{-1} C). Most of the forests of Gorkha district have more carbon pool than forests of other districts in Nepal (Bhattarai et al., 2012).

Likewise, the result of Khanal et al. (2010) had lower carbon pool because the species composition was different there with dominancy of species *Schima-castonopsis*. The previous studies showed that the carbon pool of Shorea forest was greater than that of *Schima-castonopsis* forest. Shrestha (2009) found that the above ground carbon pool in *Schima-castanopsis* forest was 34.55 t ha^{-1} C, while in shorea forest was 78.80 t ha^{-1} C. However, he found that both mean diameter and height of stand in *Schima-castanopsis* forest were higher than shorea forest (mean dbh, 14.27 cm > 11.11 cm; mean height, 10.03 m > 9.75 m). Similarly, Baral et al. (2009) found that the above ground carbon pool of *Schima-castonopsis* forest was less than that of *S. robusta* forest (34.30 t ha^{-1} C < 97.86 t ha^{-1} C).

CONCLUSION

In comparison to Laxmi Mahila CF (52.90 t ha^{-1}), Jalbire Mahila CF sequestrated more carbon pool (131.54 t ha^{-1}) due to larger sized trees which consequently have greater biomass. The proportion of carbon sequestration was highest in 'stem' among different parts of vegetation in both CFs. In comparison to species-wise carbon pool, the species *S. robusta* sequestrated more carbon pool on both CFs (48.03 t ha^{-1} in Laxmi Mahila CF and 110.51 t ha^{-1} in Jalbire Mahila CF). The species *S. robusta* was dominant and valuable timber species on both study sites.

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