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**Research Articles**

# CARBON STOCKS IN *Shorea robusta* AND *Pinus roxburghii* FORESTS IN MAKAWANPUR DISTRICT OF NEPAL

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## ABSTRACT

Forests are natural carbon sink, and play an important role in sequestrating the atmospheric carbon into biomass and soil. As both carbon sources and sinks, they have the potential to form important components to combat global climate change. The study was carried out in *Shorea robusta* forest in tropical region and *Pinus roxburghii* forest in sub-tropical region of Makawanpur district, Nepal. The inventory for estimating above and below ground biomass of forest was carried out using stratified random sampling. Forest biomass was calculated using standard allometric models. Soil samples were taken from soil profile up to 60 cm depth at the interval of 20 cm. Walkey and Black method (1934) was used for measuring soil organic carbon. Total biomass carbon in *Shorea robusta* and *Pinus roxburghii* forest was 170.75t/ha and 144.96 t/ha, respectively. Soil carbon sequestration in *Shorea robusta* and *Pinus roxburghii* forest was 58.82 and 43.94 t/ha, respectively. Total carbon sequestration in *Shorea robusta* forest was 1.21 times higher than in the *Pinus roxburghii* forest. *Shorea robusta* and *Pinus roxburghii* forests have found potentiality in contributing to the global goal of climate change mitigation through storage of carbon, hence wise use and sustainable management of forest resources are recommended.

**Key words**: Carbon stock, forest, Nepal, climate change.

## INTRODUCTION

Carbon sequestration is the reduction of atmospheric carbon by removing carbon from the atmosphere and storing in the soil or biomass (IPCC, 2006). Forest plays a vital role in the global carbon cycle, as it sequestrates a large amount of atmospheric carbon stock. Carbon storage in the forest ecosystems involves numerous components including biomass carbon and soil carbon (Brown & Pearce, 1994). They can be both sources and sinks of carbon, depending on the specific management regime and activities (IPCC, 2006). Carbon (C) sequestration by growing forests has been found to be a cost-effective option for mitigation of global climate change (Brown et al., 1996). It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown et al., 1996). Forests of Nepal are important in this regard and quantification of carbon stocks in different forest types will contribute to management planning for global climate change mitigation.

The carbon sequestration in forest vegetation varies according to geographical location, plant species and age of the stand (Van Noordwijk et al., 1997). Estimates of the biomass contained within forests are critical aspects of determination of the carbon loss associated with a wide range of land use and land-cover change processes (FRA, 2005). Decomposition of dead organic matter, respiration, burning fossils fuels, disturbance such as fire, harvesting, tillage, volcanic eruptions, etc. also release carbon back to the atmosphere and act as the source of $CO_2$. In order to assess the impact of deforestation and re-growth rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for different forest types. The $CO_2$ emissions from the deforestation account for about a quarter of global emissions (Skutch, 2005). The total area of the world's forest is about 3.952 million ha (FRA, 2005), and it is estimated that it stores 283 Gt of carbon in their biomass alone and 638 Gt of carbon as whole including dead, wood, litter, and soil upto 30cm depths. In Nepal's context, the forest covers nearly 44.74% of the total land area of the country and stores 1054.97 million t of carbon stock (DFRS, 2015).

Atmospheric $CO_2$ including other Green House Gases (GHGs) are increasing day by day and are causing global warming, making difficult to sustain human life. One approach to manage this is to expand biological sinks of atmospheric carbon in forests (IPCC, 2001). Community forestry has been widely acclaimed as a successful participatory approach for forest protection and management in Nepal. During the last 35 years of community forestry implementation, more than 30% of the national forest area is being handed

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over to more than 19 thousand community forest user groups (DoF, 2017). Community forest users groups are protecting community forests for decades, but the knowledge on role of these forests in climate change mitigation is limited, particularly for different forests in Makawanpur district of Nepal. It is therefore necessary to estimate the carbon stocks in order to understand the potential role of forests in carbon sequestration. The main objective of this study was to provide the baseline information for the carbon sequestration potentiality of two community managed forests from two different ecological regions of Makawanpur, Nepal.

## MATERIALS AND METHODS

### Study area

This study was carried out in two different community managed forests a) Banaskhandi community forest (CF), and b) Okhe community forest of Makawanpur district of Nepal in 2015. Makawanpur district lies between $27^0$21' to $27^0$40' N latitude and $84^0$41' to $84^0$35'E longitude, and is 34 km south of Kathmandu (DDC, 2016).

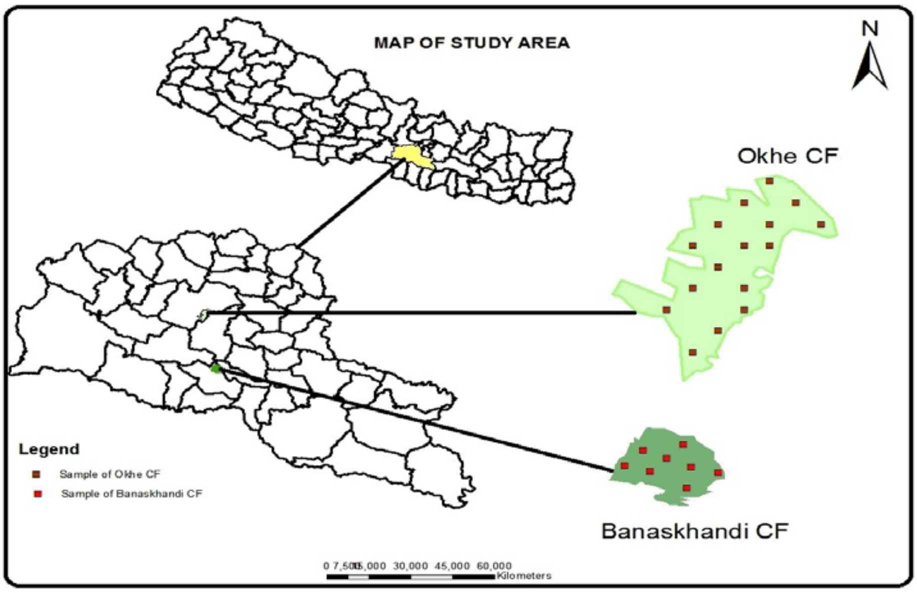


Figure 1: Map of the study area

The district's terrain lies in the Siwalik and Mahabharata. Banaskhandi CF is natural *Shorea robusta* which covers an area of 98.83 ha at 460-550 msl. Okhe CF is a natural *Pinus roxburghii* forest which covers an area of 266.13 ha at 900-1600 msl. The management practices implemented in these community forests are weeding, cleaning, pruning, thinning and fire control as prescribed in the operational plan.

### Sampling design

Stratified random sampling was used to layout the plots for surveys of soil and vegetation. Eight and sixteen sample plots were taken in *Shorea robusta* forest and *Pinus roxburghii* forest respectively with the sampling intensity of 0.5, the details of sampling for each forest types were taken as per the recommendation by Community Forestry Inventory Guideline of Government of Nepal (DoF, 2004). The quadrat size was 20 m x 25 m for trees (>30 cm dbh):- nested quadrat size was 10 m x 10 m for poles (10-29.9 cm dbh), 5m x 5m for sapling (>5 cm dbh) and 1m x1m for regeneration, grass and herb were laid out.

### Biophysical measurements

Diameter at breast height (dbh) of each tree was measured within 8 plots of *Shorea robusta* forest and 16 in *Pinus roxburghii* forest using diameter tape and height of each tree was estimated using Abney's level. All under storey bushes, grasses and herbaceous plants with in 1m x1m plots were clipped and the fresh weight of those materials (samples) were determined and representative sub sample of 500g was taken to laboratory for oven dry (72 hours at $60^0$C). Similarly, leaf litter and twigs, were also collected and taken to the laboratory for carbon stock analysis.

**Soil sampling**

Soil profile was dug at center part of the each plot (8 for *Shorea robusta* forest and 16 for *Pinus roxburghii* forest) up to 60 cm depth of 3 different intervals (0-20 cm, 20-40cm and 40-60 cm) with W-type shape for proper representation of both forests. Two separate samples were taken for analyzing organic carbon and bulk density from each depth. A core ring sampler (10 cm diameter and 5.5 cm length) was used to take samples of soil for bulk density estimation.

**Data Analysis**

**Biomass estimation**

Biomass includes all parts such as stem, branch, root, leaves, and undergrowth biomass. The above ground biomass was estimated using the following equation:

**Aboveground biomass**

Above ground biomass include above ground tree parts such as stem, branches, and leaves. The volume was estimated by the already established model with the help of DBH and height. The logarithmic transformation of the algometric formula was used to estimate above ground volume and biomass. The total stem volume of each tree was calculated using the relationship developed by Sharma and Pukkala (1990):

$$\text{In}(V) = a + b^{*}\ \text{In}(d) + c^{*}\ \text{In}(h)$$

Where,
V= total stem volume with bark, d= diameter at breast height (cm), h= tree height (m), and a, b & c are species specific constants shown in the table 1.

**Table 1. Parameter a, b, and c and $R^2$ for major tree species**

| SN. | Species | A | B | C | $R^2$ |
|---|---|---|---|---|---|
| 1. | *Shorea robusta* | -2.4554 | 1.9026 | 0.8352 | 98.3 |
| 2 | *Pinus roxburghii* | -2.9770 | 1.9235 | 1.0019 | 99.2 |
| 3. | Miscellaneous in Hills | -2.3204 | 1.8507 | 0.8223 | 97.7 |
| 4. | Miscellaneous in Terai | -2.3993 | 1.7836 | 0.9546 | 98.3 |

(Source: Sharma and Pukkala, 1990)

To determine the above ground biomass, the obtained above ground volume of the tree was multiplied by the dry density of the wood of the species (Chaturvedi & Khanna, 1982). The biomass of branches and leaves were estimated using 45% and 11 % of the stem biomass respectively (Sharma, 2003).

**Under-Growth Biomass**

All the under storey bushes, grasses and herbaceous layers belong to the under growth category, which were harvested at ground level. They were clipped and weighted in the field. In addition, leaf litters and twigs with in the quadrate 1m x 1mwere also collected and air dried. Sample were oven dried for 72 hours at 60$^{o}$ C. Oven dry weight was recorded and biomass of under growth, grasses, bushes and leaf litter was calculated using the following formula (Lasco et al., 2005):

$$\text{ODW (t)} = \text{TFW} - \frac{\text{TFW x (SFW-SODW)}}{\text{SFW}}$$

Where,
ODW = Total oven dry weight, TFW = Total fresh weight
SFW = Sample fresh weight, SODW = Sample oven dry weight

**Belowground Biomass**

Below ground biomass includes the roots of trees below the ground. Below ground (root) biomass was estimated using root-shoot ratio value of 1:5; (i.e**.** 20% of above ground biomass), as reported by MacDicken (1997).

**Estimation of Net Carbon Stock**

The biomass carbon was calculated using stock method. The carbon content is assumed to be 47% of dry biomass (IPCC, 2006). This value is a typical value of C content in the forest species investigated. The following formula was used for computing total above and below ground biomass organic carbon:

Total above ground biomass organic carbon= (Total above ground biomass of tree + total under storey biomass + total leaf litter and twigs biomass) x 47% and,
Total belowground biomass organic carbon= (Total root biomass of tree) x 47% + total soil organic carbon.

**Bulk Density**

The soil bulk density is the dry weight of soil per unit volume of soil. Oven dry weights of soil samples weredetermined for moisture correction. The dried (for 24 hours at constant temperature of 105$^{o}$C) soil was then passed through a 2 mm sieve to differentiate stones. The sieved soil was weighed and volume of stones was recorded for stone correction. Bulk density was determined by the following formula:

Bulk density (gm/cm$^3$) = (Oven dry weight of soil in gm)/ (Volume of the soil in cm$^3$)
Where,
Volume of the soil= Volume of core – Volume of the stone

**Soil Organic Carbon (SOC)**

The Walkey-Black method was applied for measuring the percentage of soil organic carbon (McLean, 1982). The SOC % was measured in the Regional Soil Test Laboratory, Hetauda, Governmentof Nepal. Total soil organic carbon was calculated using the following formula (Chabra et al., 2003):
SOC= Organic carbon content % x soil bulk density (gm/cm$^3$) x thickness of horizon (cm)

## RESULTS AND DISCUSSION

**Properties of *Shorea robusta* and *Pinus roxburghii* forest stand**

The mean diameter (32.97cm), mean height (18.76m) and total number of trees per hectare (111) of the *Shorea robusta* forest stand was higher than the *Pinus roxburghii* forest stand (30.84cm, 17.85m and 107, respectively) (Table 2). This shows that *Shorea robusta* forest was denser than *Pinus roxburghii* forest. *Shorea robusta* forest was also found denser in sapling and regeneration than *Pinus roxburghii* forest.

**Table 2. Descriptive statistics of measured samples of two forests**

| Types of forest | Density/ ha | Diameter (cm) | | | Height (m) | | |
|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Mean | Min. | Max. | Mean |
| *Shorea robusta* forest | 111 | 12.00 | 68.00 | 32.97 | 8.00 | 33.00 | 18.76 |
| *Pinus roxburghii* forest | 107 | 10.00 | 84.00 | 30.84 | 6.00 | 35.00 | 17.85 |

**Aboveground biomass estimation**

Aboveground tree biomass was higher in *Shorea robusta*forest (302.79 t/ha) than in*Pinus roxburghii* forest (257.09 t/ha) (Table 3). Undergrowth biomass was also higher in *Shorea robusta* forest (13.98 t/ha) and lower in the *Pinus roxburghii* forest (11.12 t/ha).

**Table 3. Distribution of aboveground biomass in two forests**

| Types of Forest | Above ground biomass tree (t/ha) | | Undergrowth biomass (t/ha ) | | Total biomass (t/ha) | No. of plots | p-value (t test) |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | |
| *Shorearobusta* forest | 288.81 | 37.21 | 13.98 | 2.41 | **302.79** | 8 | 0.007* |
| *Pinusroxburghii* forest | 245.97 | 23.65 | 11.12 | 1.72 | **257.09** | 16 | 0.007* |

* $p < 0.05$ is considered as statistically significant.

The mean above ground biomass tree (t/ha) and undergrowth biomass (t/ha) is significantly different for both the forest types with *p* value 0.007 ($p<0.05$) and 0.007 ($p<0.05$) respectively (t-test).

**Aboveground carbon sequestration**

Total aboveground carbon sequestration was higher in *Shorea robusta* forest than in *Pinus roxburghii* forest (Table 4). Pandey and Bhusal (2016) reported that the total carbon stock density of the forest vegetation including carbon in the trees, saplings, leaf litters, herbs and grass together with the dead wood and stumps was found to be 123.15 t/ha and 384.20 t/ha in the *Shorea robusta* forests of the Hills and the Terai, respectively. Though the value for *Shorea robusta* forest of the hills is closer to our findings, the variation in values could be due to other factors such as stand density. The tree density and tree size (dbh and height) were higher in *Shorea forest* compared to *Pinus roxburghii* forest (Table 2). Baral et al., (2009) as the authors reported that tropical forests of Nepal had higher level of above ground carbon stock than sub-tropical forests. Above ground biomass carbon stock is directly impacted by the condition of the forest (Goetz et al., 2009).

**Table 4. Aboveground carbon sequestration in two forests**

| Types of Forest | Carbon Sequestration (t/ha) by | | | | Total above ground carbon Sequestration (t/ha) | p-value (t test) |
|---|---|---|---|---|---|---|
| | Stem | Branch | Leaf | Undergrowth | | |
| *Shorearobusta* forest | 87.01 | 39.15 | 9.56 | 6.57 | 142.29 | 0.010* |
| *Pinusroxburghii* forest | 74.10 | 33.34 | 8.14 | 5.22 | 120.80 | 0.010* |

* $p < 0.05$ is considered as statistically significant.

The total above ground carbon sequestration (t/ha) is significantly different for both the forest types with *p* value 0.010 ($p$<0.05) (t-test).

**Root biomass and carbon sequestration**

Root biomass was higher in *Shorea robusta*forest than in *Pinus roxburghii* forest. Similarly, root carbon sequestration was also found higher in *Shorea robusta* forest than in *Pinusroxburghii* forest, but not significantly different (Table 5).

**Table 5. Root biomass and carbon sequestration in two forests**

| Types of Forest | Root biomass (t/ha) | Root carbon sequestration (t/ha ) | No. of plots | p-value (t test) |
|---|---|---|---|---|
| *Shorearobusta* forest | 60.55 | 28.46 | 8 | 0.08 |
| *Pinusroxburghii* forest | 51.41 | 24.16 | 16 | |

* $p < 0.05$ is considered as statistically significant.

**Soil carbon sequestration**

**Bulk density**

There was a distinct variation in the bulk density (BD) with respect to depth in both forest soils. Indeed there was a gradual increment in the BD with the increase in soil depth in both forests. The range of bulk density in two different forests based on the entire profile (0-60 cm) depths has been presented in Table (6). Accordingly the lowest BD was found at the top soil (0-20 cm) in the case of *Pinus roxburghii* forest whereas highest BD was recorded at the depth of 40-60 cm in *Shorea robusta* forest (Table 6).

**Table 6. Bulk density in *Shorea robusta* and *Pinus roxburghii* forests**

| Soil depth (cm) | *Shorea robusta* forest | | *Pinus roxburghii* forest | |
|---|---|---|---|---|
| | Mean (g/cm$^3$) | SD | Mean (g/cm$^3$) | SD |
| 0-20 | 1.10 | 0.063 | 0.99 | 0.115 |
| 20-40 | 1.19 | 0.061 | 1.11 | 0.116 |
| 40-60 | 1.23 | 0.065 | 1.18 | 0.093 |

**Soil organic carbon (SOC)**

The SOC was higher at the upper layers that gradually decreased in the soil depth. Table 7 presents the depth-wise distribution of SOC stock in two forests. Accordingly the maximum SOC was found at the top soil (0-20 cm) in *Shorea robusta* forest whereas the minimum SOC was reported at the depth of 40-60 cm in the case of *Shorea robusta* forest (Table 7). The total SOC was also higher in *Shorea robusta* forest than in the case of *Pinus roxburghii* forest (Table 7). SOC diminishes with the depth of the profile (Trujillo et al., 1997). The higher organic carbon percentage in the top layer may be due to rapid decomposition of forest litter in a favorable environment. Pandey and Bhusal (2016) reported that the SOC decreased with the increase in soil-depth in *Shorea robusta* forests of hills and terai regions of Nepal.

The total soil organic carbon stock was also higher in *Shorea robusta* forest than in the case of *Pinus roxburghii* forest (Table 7). Kafle (2014) reported that 51.27 t/ha in a *Pinus roxburghii* forest in Daman hills of Makawanpur district of Nepal, our findings are closer to this value. Soil organic carbon stocks in forest soils fluctuate from 50 to more than 200 $Mgha^{-1}$, depending on climate and soil conditions, the age and type of the tree stand, and management practices (Ostrowska et al., 2010). A soil carbon study in Garhwal Himalayan Region of India revealed 46.07 t/ha and 85.67 t/ha organic carbon in *P. roxburghii* and *P. wallichiana* forest in 0-30 cm soil layer (Gupta &Sharma, 2011). Leaf litter and root inputs play major role in forest carbon dynamics (Shrestha &Singh, 2008). Higher amount of SOC in *Shorea robusta* forest as found in the study could be also due to the higher density of saplings and regenerations and its organic residues.

**Table 7. Soil organic carbon (t/ha)in *Shorea robusta* and *Pinus roxburghii* forests**

| Soil depth (cm) | *Shorea robusta* forest | | | *Pinus roxburghii* forest | | | p-value (t test) |
|---|---|---|---|---|---|---|---|
| | N | Mean | SD | N | Mean | SD | |
| 0-20 | 8 | 24.44 | 2.98 | 16 | 18.39 | 2.94 | |
| 20-40 | 8 | 18.43 | 2.61 | 16 | 13.67 | 1.81 | 0.001* |
| 40-60 | 8 | 15.95 | 1.84 | 16 | 11.88 | 2.43 | |
| **Total** | | **58.82** | | | **43.94** | | |

* $p < 0.05$ is considered as statistically significant.
N= Number of samples
Total soil organic carbon stock for two forests types is significantly different with *p* value 0.001 ($p<0.05$) (t-test).

**Total Carbon Sequestration**

Total carbon sequestration was higher in *Shorea robusta* forest than in *Pinus roxburghii* forest (Table 8). Total carbon sequestration in *Shorea robusta* forest was composed of found 62% for above ground, 26% by the soil and 12% by the root (Table 8). Similarly, Carbon sequestration in *Pinus roxburghii* forest was contributed to 64% by above ground, 23% by the soil; and 13% by the root. Nepal (2006) reported that the carbon stock density in a *Shorea robusta* forest in a community forest of Palpa district to be 186.95 t/ha. Shrestha (2008) found 235.95 t/ha carbon stock density in a *Shorea robusta* forest of the hilly region. The values are closer and the variation in values could be due to other factors such as stand density. The values of carbon stock density in *Shorea robusta* forest in this study was found higher than the average carbon stock in Nepalese forest (161.1 t ha-1) estimated by the Global Forest Resource Assessment Report of FAO (2006). FAO used the projected Forest Inventory data of 1994 in its report that might be the reason for this. Baral et al. (2009) also reported that total carbon stock of *Shorea robusta* forest was higher than that of pine forest. The rate of carbon sequestration by different forest types depended on the growing nature of the forest stands. Moreover temperature and moisture, which vary with altitude, are major climatic factors responsible for determining the decomposition rate of organic carbon (Amundson, 2001). Litter fall and root turnover are critical components of ecosystem nutrient cycling and carbon sequestration (Gill & Jackson, 2000). Total carbon sequestration was sum of aboveground carbon, root carbon and soil organic carbon.Chhabra et al., (2003) reported found 70 $Mg\ ha^{-1}$ soil organic carbon stocks (1 m depth) in tropical deciduous forest, and 162 $Mgha^{-1}$ in montane temperate forest in India. Shrestha and Singh (2008) also reported higher carbon stocks of vegetation and soil in *Shorea robusta* than in the pine forest. The total carbon stock in Nepal's forest has been estimated as 1,054.97 million t (176.95 t/ha). Out of this, tree component (live, dead standing, dead wood and below-ground biomass), forest soils, and litter and debris constitute 61.53%, 37.80 %, and 0.67%, respectively (DFRS, 2016). *Shorea robusta* and *Pinus roxburghii* forest types have contributed in such way to global climate change mitigation.

**Table 8: Total carbon sequestration in *Shorea robusta* and *Pinus roxburghii* forests**

| Carbon Sequestration | Carbon Stock (t/ha) in | | p-value (t test) |
|---|---|---|---|
| | ***Shorea robusta* forest** | ***Pinus roxburghii* forest** | |
| Aboveground Carbon | 142.29 | 120.80 | 0.009* |
| Root Carbon | 28.46 | 24.16 | |
| Soil Carbon | 58.82 | 43.94 | |
| Total | **229.57** | **188.90** | |

* $p < 0.05$ is considered as statistically significant.

## CONCLUSION

The total carbon stock as revealed form this study was higher in the tropical *Shorea robusta* forest (229.57 t/ha) than in the sub-tropical *Pinus roxburghii* forest (188.90 t/ha). Likewise soil organic carbon (SOC) decreased with the increase in soil-depth in both the forests. The SOC contributed 26% of the total carbon pool in the *Shorea robusta* forest whereas in the case of the *Pinus roxburghii* forest it accounted for 23%. Likewise, the total carbon stock density was significantly higher in the *Shorea robusta* forest (229.75 t/ha) than in the *Pinus roxburghii* forest (188.90 t/ha). Total carbon stock of *Shorea robusta* forest was 1.21 times higher than that of *Pinus roxburghii* forest. It can be thus concluded that forest representing the tropical region of Nepal had higher amount of total carbon stock per hectare compared to sub-tropical region. Both *Shorea robusta* and *Pinus roxburghii* forests are important for sinking carbon, hence contributing to climate change mitigation. Wise use and sustainable management of both forest types are recommended.

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