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Vegetation and Soil Carbon Pool in Chirpine (*Pinus roxburghii Sarg.*) Forest of Mahabharat Hill, Nepal

Pramod Ghimire
Faculty of Forestry, Agriculture and Forestry University, Hetauda, Nepal
E-mail: pghimire@afu.edu.np

Abstract: This study analyzed the vegetation and soil carbon stock in natural *Pinus roxburghii* forest in Mahabharat hill of Bagmati Province, Nepal. Systematic random sampling method was applied for forest inventory and forest biomass was estimated by using standard allometric models. Soil samples were taken from soil profile up to 60 cm depth at the interval of 20 cm. Total carbon stock in *Pinus roxburghii* forest was found 193.54 t ha^{-1} and 226.54 t ha^{-1} for Aphnai CF and Okhe CF, respectively. Among the carbon pools carbon stock was found in the order of above ground carbon stock > soil organic carbon stock > below ground carbon stock for both CF. The forest carbon stock showed a positive relationship with biomass, tree diameter, and height but no relationship with tree density. The study concluded that forest vegetation and soil can play vital role on carbon sequestration and subsequently mitigating the problem of global warming.

Keywords: *Pinus roxburghii*, Biomass, Carbon, Soil

Carbon (C) sequestration is the long-term storage of atmospheric C in plants, soils, geologic formations, and the ocean. Forests play an important role in the global C cycle by sequestering, large amounts of atmospheric carbon dioxide (CO_2) in plant biomass and soil (Brown 2001, Acharya et al 2011, Ghimire 2021). The carbon pool in a forest can be categorized into biotic (vegetative carbon) and pedologic (soil carbon) components. Forest vegetation and soils share about 60% of the world's terrestrial carbon (Winjum et al 1992). They are an important carbon sink; store huge amount of ambient C into the growth of woody biomass through the process of carbon dioxide (CO_2) photosynthesis and soil organic carbon (SOC) through plant residues and other organic solids. (Brown et al 1996, Lal 2005, Zhao et al 2019). Therefore, assessing carbon sequestration in existing forest ecosystem is important as it enable us to project carbon sequestration overtime.

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. Response to this concern have focused on reducing emissions of GHGs, particularly CO_2, and on measuring C absorbed by stored in forests, soils and ocean. Carbon sequestration by forest ecosystem is significantly important in mitigating the increasing problem of global warming (IPCC 2001). Carbon sequestration potential of a forest determines its capacity as a sink for sequestrating atmospheric carbon as stand biomass and soil. One important mechanism to manage this is to increase biological sinks of atmospheric carbon in forests (Brown et al 1996, Ostrowska et al 2010, Pandey et al 2016, Chauhan et al 2016, Ghimire 2021). Therefore, there is a high potential for enhancing the carbon sequestration in the vegetation and soils of forest ecosystems through improved conservation of these resources.

Chirpine (*Pinus roxburghii*) pine is the common conifer species found in mid-hill forests of Nepal between 900 m and 1950 m (Jackson 1994). Currently, *Pinus roxburghii* species accounts for almost nine per cent of the total forest area, making *Pinus roxburghii* the third major species of Nepalese forests (DFRS 2015). Among the different terrestrial ecosystems, conifer forests are major carbon reservoirs (Gucinski et al 1995, Pant and Tewari 2014, Ghimire 2021). Their contribution to climate change mitigation is recognized both by their ability to uptake carbon dioxide from the atmosphere through photosynthesis as for the big storing capacity in biotic and abiotic component. Therefore, knowledge of species that can sequester maximum carbon in live biomass is essential. One important approach to sequester atmospheric carbon in expanding biological sinks is forest (Gucinski et al 1995, Oli and Shrestha 2009, Lee et al 2014, Ghimire 2021, Sharma et al 2022). In this context, the current study focuses on analyzing the carbon stock in vegetation and soil layer in *Pinus roxburghii* forest of Mahabharat hill of Nepal. The information will later be useful to planner and policy maker to developed appropriate plan and strategy. It is also anticipated that the study will benefit communities managing the local forest by supporting them to realize the benefits of schemes such as REDD+ and in providing a more information basis for decision-making in management of *Pinus roxburghii* forest in the future.

MATERIAL AND METHODS

Two community forests namely: Aphnai Community Forest (CF) and Okhe Community Forest (CF) dominated by *Pinus roxburghii* were selected for the study (Fig. 1). The study area lies in Bhimphedi Rural Municipality of Makawanpur district, located between 27°21' to 27°40' N to 84°41' to 84°35' E, respectively. The district's terrain varies from valley plain to Mahabharat range and exhibits the subtropical to temperate climate. The maximum temperature rises up to 34 degree Celsius and falls down as low as minus 1.6 degree Celsius. The average annual rainfall, generally, varies from 1900 mm to 2300 mm. Bhimphedi Rural Municipality characterized by upper tropical to temperate climate (DDC 2018).

Both the community forest lies in Mahabharat hill of Makawanpur district in Bagmati Province. Aphnai CF covers an area of 283.67 ha and Okhe CF covers 277.54 ha (Table 1). Natural *Pinus roxburghii* is the major species in both the forest with sparse occurrence of other species like *Shorea robusta* and *Schima wallichii*.

Sampling design: Systematic random sampling technique was used to carryout forest C inventory. Sample plots were laid out following the forest carbon stock measurement guidelines for measuring carbon stocks in community-managed forests as recommended by ANSAB (2011). Concentric circular plots of size 500 m^2, for tree (dbh >30 cm), 100 m^2 for poles (dbh 10 to 29.9 cm) and 1 m^2 for undergrowth (i.e. regeneration, grasses and herbs) was laid out respectively to measure forest biomass. A total of 51 plot i.e. 27 and 24 plots each was laid out in Aphnai CF and Okhe CF, respectively.

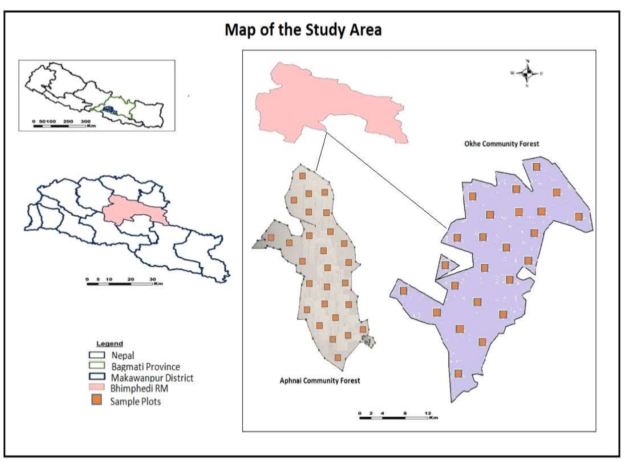

Fig. 1. Map representing the study area

Forest measurement: Diameter at breast height (dbh) and height of each tree was measured within 27 and 24 plots in *Pinus roxburghii* forest of Aphnai CF and Okhe CF, respectively. Diameter tape was used for measuring diameter at breast height (DBH) while height of each tree was estimated using Abney's level. All the under storey regeneration, grasses, and herbs within 1 m^2 plots were clipped and the fresh weight of those samples were recorded and representative sub-sample of 500g was taken to laboratory for carbon stock analysis.

Soil sampling: Soil profile was dug at center part of the each plot up to 60 cm depth of three different intervals (0-20 cm, 21-40 cm and 41-60 cm). A core ring sampler (7 cm diameter and 10 cm length) was used to take samples of soil for bulk density determination. All the samples were bagged, labeled and sent to the laboratory for further analysis.

Aboveground tree-pole biomass and carbon estimation: The logarithmic transformation of the algometric formula was used to estimate above ground biomass. The above-ground tree-pole biomass was calculated using the equations suggested by Chave et al (2005).

$$AGTB = 0.0509 * \rho D^2 H \text{……………..(i)}$$

Where,

AGTB =above ground tree biomass (kg)

ρ = Wood Specific Gravity (g cm^{-3})

D=tree-pole diameter at breast height (cm)

H= tree height (m)

The value of ρ for *Pinus roxburghii*, is taken as 0.650 g cm^{-3} (Jackson 1994).

Biomass stock densiies are converted to carbon stock densiies using the IPCC (2006) default carbon fraction of 0.47.

Undergrowth biomass and carbon estimation: To estimate the undergrowth biomass samples were taken destructively in the field with in the plot size of 1 m^2. Collected sample were oven dried for 72 hours at 60° C and oven dry weight was recorded. Then, the amount of biomass per unit area was calculated by using the formula as prescribed ANSAB (2011).

$$UGB = \frac{W_{field}}{A} * \frac{W_{subsampledry}}{W_{subsamplewet}} * \frac{1}{1000} \text{……………..(ii)}$$

Where,

UGB = biomass of regeneration, herbs, and grasses (t ha^{-1})

W_{field} = weight of the fresh field sample of leaf litters, herbs and grasses, destructively sampled within an area of size A (g)

Table 1. General information of studied community forests

Name of CF/Area (ha)	District/Province	Geographic region/Altitude (m)	Major species
Aphnai CF (283.67)	Makawanpur/Bagmati Province	Mahabharat hill (900-1600)	*Pinus roxburghii*
Okhe CF (277.54)	Makawanpur/Bagmati Province	Mahabharat hill (900-1450)	*Pinus roxburghii*

$W_{subsample dry}$ = weight of oven dry sub sample of leaf litter, herb and grasses taken to the laboratory to determine moisture content (g);

$W_{subsample\ wet}$ = weight of fresh sub sample of leaf litters, herbs and grasses taken to the laboratory to determine moisture content (g); and

A = size of the area in which leaf litter, herb and grass were collected (ha)

The carbon content in undergrowth is calculated by multiplying undergrowth biomass the IPCC (2006) default carbon fraction of 0.47.

Belowground biomass estimation: Below ground biomass includes biomass roots of trees below the ground. Root-shoot ratio method of 1:5 as suggested by MacDicken (1997) was used to estimate the belowground biomass. According to this belowground biomass is 20% of aboveground tree-pole biomass.

Below-ground biomass = Above-ground biomass* 0.20.................(iii)

The carbon content in belowground is calculated by multiplying belowground biomass the IPCC (2006) default carbon fraction of 0.47.

Bulk density analysis: Soil bulk density was determined using core sampling method (Blake and Hartge 1986). Oven dry weights of soil samples were determined for moisture correction. The dried soil (at 105 °C temperature for 24 hours) 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. Then, following formula as suggested by Pearson et al (2005) was used to calculate the bulk density.

Bulk density (($g\ cm^{-3}$)) = (Oven dry weight of soil in gm)/ (Volume of the soil in cm^3)……(iv)

Where,

Volume of the soil= Volume of core – Volume of the stone

Soil organic carbon (SOC) analysis: Walkley-Black wet oxidation method was used to analyze soil organic carbon (SOC) content percent (Walkley and Black 1934). The total SOC was then calculated by using the formula as suggested by Chhabra et al (2003).

SOC = ρ * d * %C……………..(v)

Where,

SOC = Soil organic carbon stock per unit area ($t\ ha^{-1}$)

ρ = soil bulk density ($gm\ cm^{-3}$)

d = thickness of horizon (cm)

%C = Organic carbon content %

Estimation of total carbon stock: The carbon stock density was calculated by summing the carbon stock of the individual carbon pool of forests using the following formula.

Total carbon stock = Aboveground carbon stock + Belowground carbon stock + Soil organic carbon stock……………..(vi)

Furthermore, correlation analysis was performed to access the variation of C stock with stand density, tree dbh, height tree and biomass.

RESULTS AND DISCUSSION

Average DBH and height of *Pinus roxburghii* forests under study: The average number of trees per hectare of *Pinus roxburghii* was found 92 and 95 in Aphnai CF and Okhe CF, respectively. While mean diameter, and mean height of *Pinus roxburghii* forest stand was found 30 cm and 32 cm; 17 m and 19 m for Aphnai CF and Okhe CF, respectively (Table 2). A study conducted in Kathmandu valley revealed mean DBH and height of 35 cm and 24 m in *Pinus roxburghii* forest. Similarly, Ghimire (2021) also reported mean DBH and height of 30 cm and 19 m in pine forest (including *Pinus roxburghii* and *Pinus wallichiana*) in Mahabharat hill of Makawanpur district Nepal. The result of this study is in line with Baral et al (2009) who reported mean DBH and height of 31 cm and 18 m respectively in *Pinus roxburghii* forest of Lalitpur district, Nepalese.

Aboveground biomass and carbon stock: The result found that total aboveground biomass in *Pinus roxburghii* forest was recorded 241.96 $t\ ha^{-1}$ (232.68 $t\ ha^{-1}$ tree-pole biomass and 9.28 $t\ ha^{-1}$ undergrowth biomass) in Aphnai CF and 299.36 $t\ ha^{-1}$ (289 $t\ ha^{-1}$ tree-pole biomass and 10.36 $t\ ha^{-1}$ undergrowth biomass) in Okhe CF respectively (Table 3).

Accordingly, the total aboveground carbon stock was found 113.76 $t\ ha^{-1}$ (109.40 and 4.36 $t\ ha^{-1}$ under above and below ground, respectively) and 140.87 $t\ ha^{-1}$ (136 and 4.87 $t\ ha^{-1}$ under above and below ground, respectively) in Aphnai CF and Okhe CF, respectively (Table 4). Aryal et al (2013) reported 173.3 $t\ ha^{-1}$ of aboveground biomass carbon stock in

Table 2. Properties of *Pinus roxburghii* forest stand of two CF

Name of CF	Density ha^{-1}	DBH (cm)			Height (m)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
Aphnai CF	92	10.00	82.00	30.00	6.00	35.00	17.00
Okhe CF	95	11.00	84.00	32.00	8.00	38.00	19.00

Pinus roxburghii forests in the hill of Lalitpur district, Nepal. Similarly, Ghimire (2021) also found 83.71 t ha^{-1} of aboveground carbon stock in pine forest of Makawanpur district Nepal.

Below ground biomass and carbon stock: Biomass and carbon stock represent the biomass and carbon in the root portion of the forest. In this study belowground biomass were found 46.54 t ha^{-1} and 57.80 t ha^{-1} in Aphnai CF and Okhe CF, respectively. Accordingly, belowground carbon stocks were found 21.88 t ha^{-1} and 27.16 t ha^{-1}, respectively in Aphnai CF and Okhe CF.

Soil Carbon Stock

Bulk density and soil organic carbon content: The range of bulk density (BD) in two community forests based on the soil profile depths (0-60 cm) is presented in Table 4. The study found some variation in BD with respect to depth in both CF. There was a gradual increase in BD with increase in soil depth in both CF. The minimum BD (0.94 gm cm^{-3}) was recorded at top soil layer (0-20 cm) in Okhe CF, whereas, maximum BD (1.25 gm cm^{-3}) at the 41-60 cm soil profile layer in Okhe CF. Furthermore, soil organic carbon content was decrease with increase in soil profile depths (Table 4).

Soil organic carbon (SOC) stock: In this study SOC stock was found to be higher at upper layers that gradually decreased as soil depth increased in both CF. Higher SOC stock (28.20 t ha^{-1}) was found at the top soil layer (0-20 cm) in Okhe CF while lower SOC stock (13.16 t ha^{-1}) was reported at the depth of 41-60 cm in Okhe CF (Table 5). Accordingly, total SOC stock was found 57.85 t ha^{-1} and 58.51 t ha^{-1} in Aphnai CF and Okhe CF respectively. The result is in line with Ghimire (2021) who reported 41.30 t ha^{-1} of SOC stocks in pine forest of Daman hill of Makawanpur district, Nepal. A soil study conducted in Garhwal Himalayan Region of India revealed 46.07 t ha^{-1} of soil organic carbon stock in *Pinus roxburghii* forest in 0-30 cm soil layer (Gupta and Sharma 2011).

Total carbon stock: The Aphnai CF has 193.54 t ha^{-1} of total carbon stock (with 113.76 t ha^{-1} aboveground, 21.88 t ha^{-1} belowground and 57.85 t ha^{-1} soil organic carbon stock), whereas Okhe CF has 226.54 t ha^{-1} total carbon stock (with 140.87 t ha^{-1} aboveground, 27.16 t ha^{-1} belowground and 58.51 t ha^{-1} soil organic carbon stock). Of the total carbon stock more than 50% was found to be accumulated in aboveground pool for both CF. Sharma et al (2020) reported 107.5 t ha^{-1} of total carbon stock (excluding soil carbon stock) in *Pinus roxburghii* forest of hilly area of Kathmandu district, Nepal. A similar finding of biomass carbon stock was also observed by Kafle (2014) and Ghimire (2021) in Daman hill of Makawanpur district, Nepal.

Correlation analysis: The correlation analysis (Table 6) showed that the C stock in *Pinus roxburghii* forest was positively correlated with plant biomass, DBH, and height however, there is no relationship with tree density. A similar finding was also observed by Sharma et al (2020) in *Pinus roxburghii* forest of Kathmandu valley. Similarly, vegetation carbon stock was positively correlated with biomass, DBH,

Table 5. Soil organic carbon stock (t ha^{-1}) in *Pinus roxburghii* forest in two CF

Soil depth (cm)	Aphnai		Okhe CF	
	Mean	SD	Mean	SD
0-20	24.61	2.06	28.20	1.06
21-40	18.30	2.01	17.15	1.09
41-60	14.94	1.82	13.16	1.90
Total	57.85		58.51	

Table 3. Distribution of aboveground biomass (t ha^{-1}) in *Pinus roxburghii* forest stand in two CF

Name of CF	Above ground tree biomass (t ha^{-1})		Undergrowth biomass		Total above ground biomass (t ha^{-1})
	Mean	SD	Mean	SD	
Aphnai CF	232.68	18.75	9.28	1.04	241.96
Okhe CF	289.00	22.00	10.36	1.02	299.36

Table 4. Bulk density and SOC content (%) in *Pinus roxburghii* forest in two CF

Soil depth (cm)	Aphnai CF				Okhe CF			
	Bulk density (gm cm^{-3})		Organic carbon (%)		Bulk density (gm cm^{-3})		Organic carbon (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0-20	0.97	0.90	1.48	0.92	0.94	0.80	1.62	1.02
21-40	1.10	0.80	1.15	1.05	1.08	0.65	0.95	1.07
41-60	1.22	0.60	0.94	0.83	1.25	0.52	0.92	0.70

Table 6. Correlation analysis between carbon stock (t ha^{-1}), biomass (t ha^{-1}), tree density (tree ha^{-1}), diameter (cm) and height (m) in two CF

For Aphnai CF					
Variables	Carbon stock	Biomass	Density	DBH	Height
Carbon stock	1	1*	0.22	0.52*	0.64*
Biomass	1*	1	0.22	0.52*	0.64*
Density	0.22	0.22	1	-0.64*	-0.35
DBH	0.52*	0.52	-0.63*	1	0.70*
Height	0.64*	0.64*	-0.35	0.70*	1
For Okhe CF					
Variables	Carbon stock	Biomass	Density	DBH	Height
Carbon stock	1	1*	0.24	0.55*	0.65*
Biomass	1*	1	0.24	0.55*	0.65*
Density	0.24	0.24	1	-0.60*	-0.40
DBH	0.55*	0.55*	-0.60*	1	0.72*
Height	0.65*	0.65*	-0.40	0.72*	1

* $p< 0.05$ is considered as statistically significant

and height. Tree density was negatively correlated which is in accordance with Thapa-Magar and Shrestha (2015) and Shaheen et al (2016). Therefore, tree DBH, height, and biomass are the determinant variable for forest C.

CONCLUSIONS

The study was focused in only one species i.e. *Pinus roxburghii*. *Pinus roxburghii* forest has 193.54 t ha^{-1} and 226.54 t ha^{-1} total carbon stocks in Aphnai CF and Okhe CF, respectively. Carbon stocks in different pool of *Pinus roxburghii* forest was found in the order of above ground carbon stock > soil organic carbon stock > below ground carbon stock for both CF. The result showed that the tree DBH, height, and biomass were the determining factors for forest C, which positively affected the forest C stock, while tree density has no effect on forest C stock.

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