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Carbon Sequestration Potentiality of *Pinus roxburghii* Forest in Makawanpur District of Nepal

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Abstract: Estimation of total carbon stock in any forest is very important as it provides ecological as well as economic benefits through various environmental services. The study was carried out to quantify the vegetation and soil carbon stock of natural Chirpine (*Pinus roxburghii*) forest of in sub-tropical region of Makawanpur district, Nepal. The inventory of estimating above and below ground biomass of forest was carried out using stratified random sampling method Forest biomass was calculated using standard allometric models. Soil samples were taken from soil profile up to 40 cm depth at the interval of 20 cm. Walkey and Black method (1934) was used for measuring soil organic carbon. Total amount of carbon stock in *Pinus roxburghii* forest was 213.05 t/ha with above ground carbon stock 140. 56 t/ha, below ground carbon stock 27.14 t/ha and soil organic carbon 45.35 t/ha respectively. Total carbon stock in *Pinus roxburghii* forest was composed of 66% for above ground, 21% by the soil and 13% by below ground. The study concluded that forest types and soil play an important role on total carbon sequestration. Hence, 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 ecosystem.

Keywords: Carbon Sequestration, Biomass, Forest, Soil

1. Introduction

Carbon stock is the quantity of carbon contained in a carbon pool which has the capacity to accumulate or release carbon. Carbon sequestration is known as the removal of carbon from the atmosphere by storing it in the biosphere [1]. Forests play a vital role in global carbon cycle as they sequester 20 to 100 times more carbon per unit area than croplands [2]. Carbon storage in the forest ecosystems involves numerous components including biomass carbon and soil carbon. Hence, vegetation and soils play profound role of viable sinks of atmospheric carbon and may significantly contribute mitigation of global climate change [3, 4].

Forests acts as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial aboveground, and 40% of terrestrial belowground carbon storage [5]. Biological sequestration of CO_2 by forest has numerous benefits to other emission reduction technologies. Firstly, it is considered to be more effective than other carbon sequestration methods [6], and secondly, managing forests sustainably will greatly reduce carbon emissions as it is estimated that global deforestation alone accounts for about 17.4% of the global greenhouse gases emissions [7]. Hence, there is a high potential for enhancing the carbon sequestration in the vegetation and soils of the hilly region through improved management of degraded lands [8].

Soils are a potentially viable sink for atmospheric carbon [4]. Soil organic carbon (SOC) stocks display a high spatial variability carbon depending upon land use and soil management [9]. SOC is an important index of soil quality because of its relationship to plant productivity [10]. In this context, SOC sequestration has numerous ecological as well as economic implications in terms of carbon credits, improving quality of soil and water resources, and achieving global food security. Thus, soils play a vital role in maintaining a balanced global carbon cycle.

Carbon accumulation by terrestrial forest ecosystem is potentially important in mitigating the increasing problem of global warming. 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 ecosystem [11]. *Pinus roxburghii* is the common conifer species found in Nepal between 900m and 1950m. Among the different terrestrial ecosystems, conifer forests are major carbon reservoirs [12, 13]. 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 [13]. Hence, the intended to quantify the vegetation and soil carbon stock in the *Pinus roxburghii* forest of subtropical region and their role in maintaining carbon balance.

2. Materials and Methods

2.1. Study Area

The study was carried out in the Okhe community forest of Kailash Rural Municipality Makawanpur district covering an area of 266.133ha. 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. The district's terrain lies in the Siwalik and Mahabharata. Okhe community forest 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, thinning pruning, and fire control as prescribed in the operational plan.

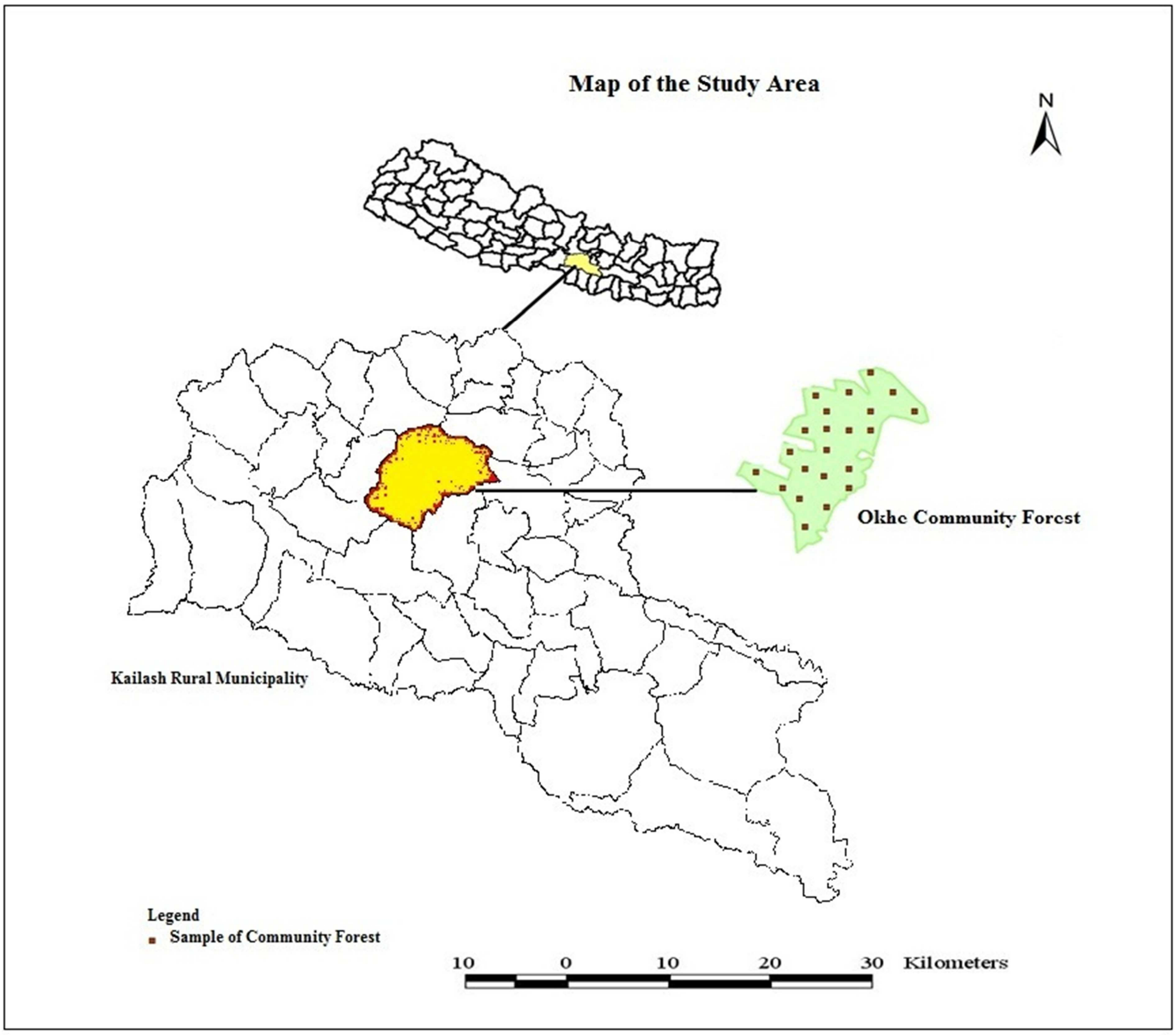

Figure 1. *Map of the study area.*

2.2. Sampling Design

Stratified random sampling was adopted for the study. Biophysical measurement and soil samples were major data collection. Twenty four sample plots were taken with the sampling intensity of 0.5 as per the recommendation by Community Forestry Inventory Guideline of Government of Nepal [13]. Concentric circular plots of size 500 m^2, 100 m^2 and 1 m^2 were laid out for trees (dbh >30 cm), poles (dbh 10 to 29.9 cm) and leaf litters, herbs and grasses respectively to measure forest biomass.

2.2.1. Biophysical Measurements

Diameter at breast height (dbh) of each tree was measured within 24 plots of *Pinus roxburghii* forest using diameter tape and height of each tree was estimated using Abney's level. All under storey grasses, leaf litters and herbaceous plants with in 1 m^2 plots were clipped and the fresh weight of those samples were determined and representative sub sample of 500g was taken to laboratory for oven dry (72 hours at 60°C) for carbon stock analysis.

2.2.2. Soil Sampling

Soil profile was dug at center part of the each plot up to 40 cm depth of 2 different intervals (0-20 cm, and 20-40 cm). Two separate samples were taken for analyzing organic carbon and bulk density from each depth. In each sampling site, a pit of 30 cm by 50 cm pit was dug and undisturbed soil core samples were taken by a cylindrical core sampler (7 cm diameter and 10 cm length) from 0-20cm and 20-40cm soil depths for the determination of bulk density. The bulk soil samples were oven dried, sieved through a 2mm sieve and carefully stored before basic considerations.

2.3. Data Analysis

2.3.1. Biomass Estimation

The biomass of tree includes two layers as above ground biomass and below ground biomass. Biomass was estimated by using the following equation:

i. Above Ground Biomass (AGB)

Above ground biomass include above ground tree parts such as stem, branches, and leaves. The logarithmic transformation of the algometric formula was used to estimate above ground biomass with the help of DBH and height. The allometric formula suggested by Chave et al [15]; was used to estimate the aboveground tree and pole biomass;

$$AGTB = 0.0509 * Þ\ D^2\ H$$

Where,

AGTB =above ground tree, pole biomass (kg)

Þ= Wood Specific Gravity (g/cm^3)

D=tree diameter at breast height (cm)

H= tree height (m)

The value of Þ for Pinus roxburghii is 0.650 (g/cm^3) [16].

ii. Leaf litters, Herbs and Grasses (LHG) Biomass

To determine the biomass of leaf litters, herbs and grasses, samples were taken destructively in the field with in the plot size of $1m^2$. The amount of LHG biomass per unit area was estimated by the following formula [17]. For forest floor the amount of biomass per unit area is estimated by:

$$LHG\ Biomass = (W_{field}/A) * (W_{subsample}\ Dry/W_{subsample}\ Wet) * (1/1000)$$

Where,

LHG = Biomass of leaf litters, herbs, and grasses (t/ha)

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

$W_{subsample}$ Dry= Weight of oven dry sub sample of leaf litters, herbs and grasses taken to the laboratory to determine moisture content (g); and

$W_{subsample}$ Wet = Weight of fresh sub sample of leaf litters, herbs and grass taken to the laboratory to determine moisture content.

A = Size of the area in which leaf litters, herbs and grasses taken

2.3.2. Below Ground (BGB)

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 [18].

2.4. Soil Analysis

2.4.1. Bulk Density

The soil bulk density is the dry weight of soil per unit volume of soil. Oven dry weights of soil samples were determined for moisture correction. The dried (for 24 hours at constant temperature of 105°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:

$$\text{Bulk density } (gm/cm^3) = \frac{(\text{Oven dry weight of soil in gm})}{(\text{Volume of the soil in cm3})}$$

Where,

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

2.4.2. Soil Organic Carbon (SOC)

The Walkey-Black method was applied for measuring the percentage of soil organic carbon [19]. The SOC % was measured in the Regional Soil Laboratory, Hetauda, Province 3, and Nepal. Total soil organic carbon was calculated using the following formula [20]:

SOC= Organic carbon content % x soil bulk density (gm/cm^3) x thickness of horizon (cm)

2.5. Estimation of Net Carbon Stock

The biomass carbon was calculated using stock method. The carbon stock is assumed to be 47% of dry biomass [21]. 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 carbon stock = Total above ground carbon stock (i.e. Tree, pole carbon stock + LHG carbon stock) + Total below ground carbon stock + Soil organic carbon

3. Results and Discussion

3.1. Properties of Pinus roxburghii Forest Stand

The mean diameter, mean height and total number of trees per hectare of the *Pinus roxburghii* forest stand was found 31.90 cm, 19.20 m and 109 respectively (Table 1). This shows that the number of stem per hectare for *Pinus roxburghii* forest of mid hills of Nepal is quiet high than 47.19 as reported [22]. A study also reported that mean diameter and mean height of Pine forest of sub-tropical region of Nepal was 18.10 m and 31.17 cm respectively [23].

Table 1. *Descriptive statistics of measured samples of Pinus roxburghii forests.*

Types of forest	Density/ha	Diameter (cm)			Height (m)		
		Min.	Max.	Mean	Min.	Max.	Mean
Pinus roxburghii forest	95	10.60	84.41	31.90	8.00	37.50	19.20

3.2. Above Ground Biomass Estimation

The biomass of forest consists of two layers as aboveground and belowground and varies with species, aspects and elevation. Total aboveground biomass included tree/pole biomass, and biomass of leaf litters, herbs and grasses. The total above ground biomass in *Pinus roxburghii* forest was found 299.86 t/ha with tree/pole biomass 288.74 t/ha and LHG biomass 10.36 t/ha (Table 2).

Table 2. *Distribution of aboveground biomass in Pinus roxburghii forests.*

Types of Forest	Above ground tree/pole biomass (t/ha)		Leaf litters, herbs and grasses biomass (t/ha)		Total Biomass (t/ha)	No. of plots
	Mean	SD	Mean	SD		
Pinus roxburghii forest	288.74	22.08	10.36	1.02	299.10	24

3.3. Above Ground Carbon Stock

The above ground carbon stock included tree/pole carbon stock and leaf litters, herbs and grasses carbon stock. The total above ground carbon stock in *Pinus roxburghii* forest was found 140.56 t/ha with tree/pole carbon stock 135.70 t/ha and leaf litters, herbs and grasses carbon stock 4.86 t/ha respectively (Table 3). A study conducted in *Pinus roxburghii* forests of the mid hills of Nepal reported that total carbon stock density of the forest vegetation including carbon in the trees, poles, saplings, together with leaf litters, herbs and grass was found to be 120.80 t/ha [13].

Table 3. *Aboveground carbon stock in Pinus roxburghii forests.*

Types of Forest	Carbon stock (t/ha) by		Total above ground Carbon stock (t/ha)
	Tree/pole	Leaf litters, herbs and grasses	
Pinus roxburghii forest	135.70	4.86	140.56

3.4. Below Ground Biomass and Carbon Stock

The below ground biomass in *Pinus roxburghii* forest was found 57.74 t/ha, which is 20 % of the above ground tree/pole biomass. The total below ground carbon stock in *Pinus roxburghii* forest was found 27.14 t/ha (Table 4). Root carbon stock of *Pinus roxburghii* forests of the mid hills of Nepal was also found 24.16 t/ha [13]. Similar below ground carbon stock density in natural *Pinus roxburghii* in Kumaun Central Himalaya, India was also reported [24].

Table 4. *Below ground biomass and carbon stock in Pinus roxburghii forests.*

Types of Forest	Below ground biomass (t/ha)	Below ground carbon stock (t/ha)	No. of plots
Pinus roxburghii forest	57.74	27.14	24

3.5. Soil Carbon Stock

3.5.1. Bulk Density

There was some variation in the bulk density (BD) with respect to depth in the *Pinus roxburghii* forest soil. There was a gradual increase in the BD with increase in soil depth. The minimum BD (0.67 g/cm^3) was recorded at the top soil (0-20cm) while maximum BD (1.47 g/cm^3) at 20-40 cm soil depth. Table 5 shows the depth wise average BD and organic carbon % for *Pinus roxburghii* forest respectively.

Table 5. *Bulk density and organic carbon % in different soil depths in Pinus roxburghii forests.*

Soil Depth (cm)	Bulk density (gm/cm^3)		Organic carbon (%)	
	Mean	SD	Mean	SD
0-20	0.94	0.80	1.62	1.02
20-40	1.08	0.65	0.95	1.07

3.5.2. Soil Organic Carbon (SOC)

The soil organic carbon in the forest depends upon forest types, climate, moisture, temperature, soil organic matter and types of soil. Total SOC in *Pinus roxburghii* was found 45.35 (t/ha). The SOC was higher at the upper layers that gradually decreased in the soil depth. Table 6 presents the depth-wise distribution of SOC stock in *Pinus roxburghii* forest. Accordingly the maximum SOC was found at the top soil (0-20 cm) whereas the minimum SOC was reported at the depth of 20-40 cm. The average soil organic carbon in the top soil layer (0-20 cm) is 1.64 times higher than that of 20-40cm depth. The higher organic carbon percentage in the top layer could be attributed to rapid decomposition of forest litter in a favorable environment. It was reported that 51.27 t/ha soil carbon stock in a *Pinus roxburghii* forest in Daman hills of Makawanpur district of Nepal [25], this findings are closer to that value. A study also revealed that the soil carbon stock in a *Pinus roxburghii forest* of hilly regions of central Nepal was 43.94 t/ha) [13]. A study of soil carbon in Garhwal

Himalayan Region of India revealed 46.07 t/ha organic carbon in *P. roxburghii* forest in 0-30 cm soil layer [26]. Similar soil carbon stock density was reported in natural *Pinus roxburghii* in Kumaun, Central Himalaya, India [24].

Table 6. *Soil organic carbon (t/ha) in Pinus roxburghii forests.*

Soil depth (cm)	***Pinus roxburghii* forest**		
	Mean	**SD**	**No. of plots**
0-20	28.20	1.06	24
20-40	17.15	1.09	24
Total	**45.35**		

3.6. Total Carbon Stock in Pinus roxburghii Forest

Total carbon stock is sum of total above ground carbon, below ground (root) carbon and soil organic carbon. Total carbon stock in *Pinus roxburghii* forest of Okhe community forest was found 213.05 t/ha with total above ground carbon stock 140. 56t/ha, below ground carbon stock 27.14 t/ha and soil organic carbon 45.35 t/ha (Table 7). Of the total carbon stock in *Pinus roxburghii* forest about two third of the carbon was found to be accumulated in the aboveground biomass (66%) followed by SOC (21%) and the least (13%) in the below-ground biomass (Figure 2).

Table 7. *Total carbon stock in Pinus roxburghii forest.*

S.N	Forest strata	Carbon stock (t/ha)
1.	Above ground	140.56
2.	Below ground (root)	27.14
3.	Soil	45. 35
	Total	213.05

It was reported that above ground carbon sequestration rate of conifer including *Pinus roxburghii* and *Pinus wallichiana* forests in the central hilly region of Nepal 1.35 t/ha/year [23]. A study conducted in the Kusumdanda Community Forest in Palpa District which is also situated in the Hill ecological region of Nepal, showed the similar type of carbon stock density in *Pinus roxburghii* [27]. A study revealed that 188.90 t/ha total carbon stock density in a *Pinus roxburghii* forest in mid hills of Makawanpur district of Nepal [13]; this findings are closer to that value. Similar total carbon stock density in natural *Pinus roxburghii* in Kumaun Central Himalaya, India was also reported [24].

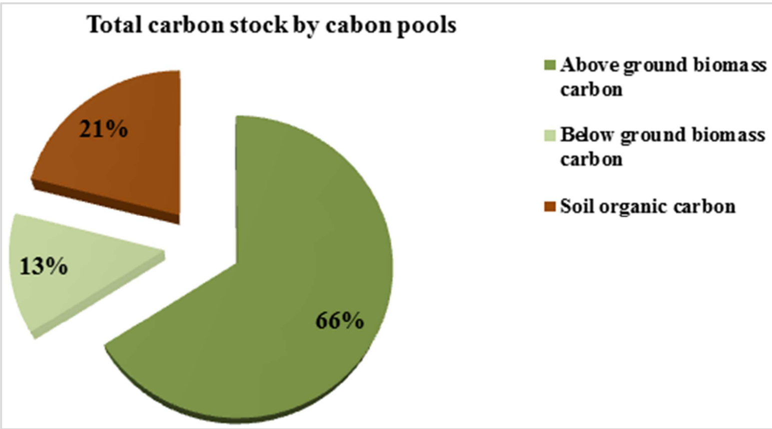

Figure 2. *Total carbon stock by different pools in Pinus roxburghii forest.*

4. Conclusion

The total carbon stock in *Pinus roxburghii* forest was found 213.05 t/ha with the above ground Carbon stock 140.56 t/ha, root carbon stock 27.15t/ha and soil organic carbon 45.35 t/ha. Soil organic carbon was found to be decreased with increase in depth and 1.64 times higher in 0-20 than in 20-40 cm soil depth. Carbon stock in different strata of *Pinus roxburghii* forest was found in the order of above ground carbon stock > soil organic carbon stock > below ground carbon stock. Of the total carbon stock in *Pinus roxburghii* forest higher carbon stock density was found to be accumulated in the aboveground biomass (66%) followed by SOC (21%) and the least (13%) in the below-ground biomass. It can be thus concluded that *Pinus roxburghii* forests are important for sinking carbon contributing to climate change mitigation. Hence, sustainable management of existing *Pinus roxburghii* forest is recommended.

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