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Carbon Sequestration Potential in Sahid Smriti Community Forest: A Case Study of Terai Region of Nepal

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Abstract—*Climate change impacts have become highly visible affecting different aspects of ecosystem and human society. The main factor responsible for the current pace of climate change is attributed to emission of greenhouse gases mainly CO_2 by human activities. It is believed that the aim of reducing carbon sources and increasing the carbon sink can be achieved proficiently by protecting, conserving and managing the carbon pools in existing forests. The main objective of the study was to analyze the vegetation and to evaluate biomass accumulation and carbon content of all the carbon pools of the forest ecosystem. The study was conducted in Sahid Smriti community forest of terai region of Nepal. A total of 30 sample plots each of 500 m^2 were laid by systematic random sampling. Altogether 10 species and 144 trees were identified and measured. Shorea robusta was dominant species in the community forest having basal area of 9.73 m^2/ha and IVI of 75.33. The total carbon stock of the community forest was estimated to be 141.38 ± 21.83 t/ha. Aboveground carbon contributes 52% of the total carbon stock which is highest among all other carbon pools. CO_2 equivalent was estimated to be 518.86 t/ha. Carbon content in Shorea robusta (36.17 t/ha) was found to be highest followed by Adina cardifolia (16.09 t/ha). Carbon content in the community forest was found highest in DBH class (>80) cm and lowest in DBH class (10-20) cm. The study shows carbon sequestration potential in community forest of Nepal is enormous and can reward economic benefits to different stakeholders from carbon trading under clean development mechanism leading to conservation of forest sustainably.*

Keywords*: Climate change, community forest, carbon pools, biomass, carbon sequestration.*

1. INTRODUCTION

Climate change impacts have become highly visible affecting different aspects of ecosystem and human society. The anthropogenic activities that contribute to increase in greenhouse gas emission are the major cause of climate change. Carbon dioxide, methane and nitrous oxide contribute 88% role in global warming [13] and CO_2 alone shares 60% of the total global warming [28]. According to the IPCC, Fifth Assessment Report, climate change is already adversely affecting the ecosystem and predicted increase of 3.7 to 4.8 °C temperature if the condition remain same [16]. Climate change has also wide range of impacts on natural resources and biodiversity causing threats to forest conservation, species extinction and occurrence of pests and disease [15]. Deforestation and forest degradation contributes approximately 18% of total greenhouse gas (GHG) emissions by anthropogenic activities [34]. However, the contribution to GHG emission by deforestation and forest degradation has been reduced by 25 % (i.e., from an annual average of 3.9 billion tonnes in 2011 to 2.9 billion tones of CO_2 in 2015) which is due to increase in plantation forests [8].

The success of community forestry programme in Nepal is well known over the world which started in late 1970s. A total of 2.54 million households of Nepal are engaged in community-based forest management practice by forming 19,916 Community Forest User Groups (CFUGs) who are managing 18,79,998 hectares of National forest handed over to them [6]. Few CFUGs have got financial support for carbon enhancement in their forests [1] as pilot programs. To assist mitigation and adaptation activities against climate change in developing countries such as Nepal, the carbon trade can become a great hope [37].

Nepal is one of the most vulnerable countries to climate change in the world. The data trend from 1975 to 2005 shows that the mean annual temperature has been increasing by 0.06 °C while the mean rainfall has been decreasing by 3.7 mm (-3.2%) per month per decade [21]. The very simple and least cost effective solution to abate global climate change is carbon sequestration and management of forest sustainably [3, 12]. Forests pile up more carbon as compared to any other terrestrial ecosystems [22], where woody biomass holds maximum sequestered carbon [29]. According to preliminary estimates, REDD+ mechanism can bring between $20-86 million per year to Nepal through carbon and non carbon revenues [38]. Therefore, this study is based to estimate the amount of carbon stocks in the community forest which can serve to get carbon credits in future. The main objective of the study was to analyze the vegetation and evaluate biomass accumulation and carbon content of all the carbon pools of the forest ecosystem.

2. MATERIALS AND METHODS

2.1 Study area

The study was carried out in Sahid Smriti community forest of Kanchanpur district, Nepal (see Figure 1) located at 29^0 01' 43" N latitude and 80^0 11' 23" E longitude. The nature of the community forest is mixed covering an area of 296.51 hectares. The CF is divided in 3 blocks for management purpose. The forest is moderately steep with altitude ranging from 252 to 502 metre above sea level. The soil is mostly black and mixed sandy type.

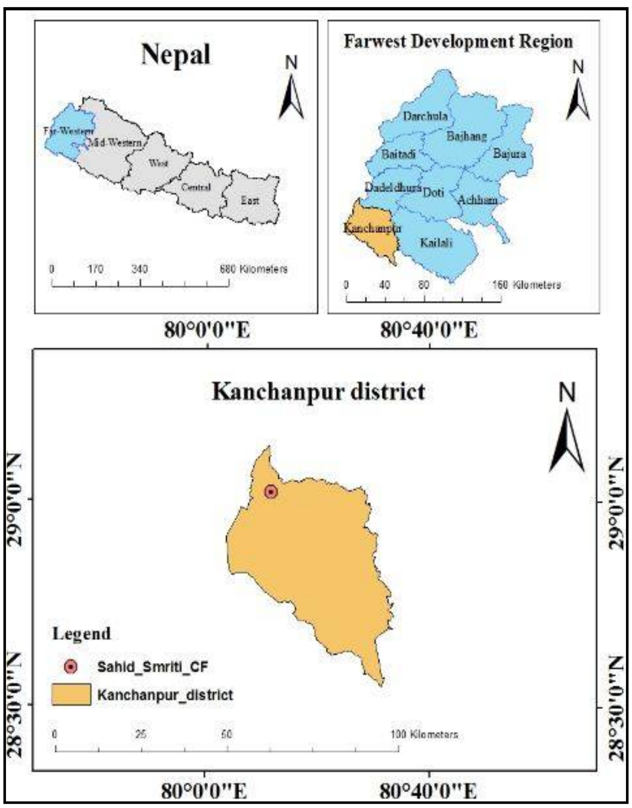

Figure 1: Location map of the study area

In 2017, average annual rainfall was 1512.12 mm where maximum rainfall was recorded in month of August. The maximum and minimum temperature of the study site was found 38^0C (June) and 14^0C (January), respectively. Similarly, average humidity was recorded to be 54.67% with maximum (71% in July) and minimum (37% in March).

2.2 Sampling Design

Systematic random sampling with 0.5% sampling intensity was applied. Altogether, 30 circular sample plots were laid out each of 500 m^2. In each sample plot, 12.62 m radius was taken to measure aboveground tree biomass (dbh ≥ 5 cm), nested plots with 5.64 m radius for aboveground sapling biomass (1-5 cm dbh), 1 m radius for regeneration (dbh < 1 cm) and 0.56 m radius for litter, herb, grass and soil organic carbon for collecting biophysical data [20]. Regenerations within 1 m radius plot were counted. All the litters, herbs and grasses inside the 0.56 m radius plot were clipped and collected and fresh weights of the samples were recorded and representative sub-samples were taken to laboratory for oven drying.

2.3 Vegetation Analysis

For the quantitative data analysis frequency, density, basal area of tree species was calculated [41] with some modifications. In order to express the dominance and ecological success of any species, with a single value, the concept of Importance Value Index has been developed and was calculated by adding the relative values of the three parameters density, frequency and basal area [5].

I.V.I. = R.D. + R.F. + R.B.A.

Where, I.V.I. = Importance Value Index, RD = Relative Density, R.F. = Relative Frequency and R.B.A. = Relative Basal Area.

2.4 Biomass and Carbon pool estimation

2.4.1 Aboveground Biomass (AGB)

The aboveground biomass was calculated by using the following equation [4].

$$AGB = 0.0509 \times \rho \times D^2 \times H$$

Where, AGB = Aboveground Biomass (kg), ρ = wood specific gravity (g/cm^3), D = Diameter at breast height (cm) and H = height (m).

2.4.2 Belowground Biomass (BGB)

The belowground biomass was calculated by multiplying the value of AGB by a constant 0.26 [14, 19].

2.4.3 Deadwood Biomass (DWB)

The deadwood biomass was calculated by adding AGB and BGB and then multiplying the sum with constant factor of 0.11 [14].

2.4.4 Leaf litter, Herb and Grass Biomass (LHGB)

The following formula was applied to estimate the biomass value of LHG [18].

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

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

Biomass of each pool was converted to carbon stock by multiplying biomass default carbon fraction of 0.47 [14].

2.4.5 Soil Organic Carbon (SOC)

Soil samples were collected from (0-10), (10-20) and (20-30) cm depths. Soil samples collected was oven dried at 80 ^{0}C for 48 hours in hot air oven at the laboratory. Titrimetric method was used for SOC determination [39]. Samples from each of the three depths was composted and well-mixed per sampling plot and then prepared for carbon measurement by removing stones and plant residue > 2mm as well as by grinding. The carbon stock density of soil organic carbon was calculated by following formula [24].

SOC (t/ha) = § x d x %C

Where, § = Soil bulk density (g cm^{-3}), d = total depth from which soil sample is taken (cm) and %C = carbon concentration (%).

2.4.6 Total carbon content and CO_2 equivalent

The carbon values of each forest carbon pools were summed to estimate total forest carbon stock as:

TC = C(AGB) + C(BGB) + C(DWB) + C(LHGB) + SOC

Where, TC = Total Carbon Stock (t/ha),

C(AGB) = Carbon in Aboveground Biomass (t/ha),

C(BGB) = Carbon in Belowground Biomass (t/ha),

C(DWB) = Carbon in Deadwood Biomass (t/ha),

C(LHGB) = Carbon in Leaf litter, Herb and Grass Biomass (t/ha) and SOC = Soil Organic Carbon [t/ha]

The total forest carbon stock was then converted into tones of CO_2 equivalent by multiplying by 3.67 [24].

3. RESULTS AND DISCUSSION

3.1 Vegetation analysis

A total of 10 tree species with 141 individual trees were identified and measured. The tree density was estimated to be 98 ind/ha where *Shorea robusta* contributes 19.33 ind/ha (maximum) and *Pterocarpus marsipium* contributes 2 ind/ha (minimum). Densities reported in Bardiya National Park (348 ind/ha) [31], Gorakhpur, India (408 ind/ha) [23] and Bhabar-Terai zone of Nepal (152-264 ind/ha) [27] was higher than observed density of the community forest. Frequency of *Mallotus philippensis* was estimated highest (43.33 %) in the community forest. The total average basal area was found 23.44 $m^{2/}$ha where *Shorea robusta* comprised of 9.73 m^2/ha alone. Of the recorded tree species, maximum IVI was estimated in *Shorea robusta* (75.33) and minimum in *Syzgium cumini* (9.44) (see Table 1). Estimated average basal area falls within the range of 16-61.1 m^2/ha reported in Corbett National Park, India [32]. Similarly, the basal area was higher than in the Terai region of Nepal (18.33 m^2/ha) [9] and lower as compared to study in Terai *Shorea robusta* forest (36 m^2/ha) of Bardiya National Park, Nepal [31].

Table 1: Species wise RD, RF, RBA and IVI

Tree species	RD (%)	RF (%)	RBA (%)	IVI
Dalbergia sissoo	14.29	12.82	6.95	34.06
Mallotus philippensis	19.05	16.66	2.05	37.76
Acacia catechu	4.08	5.13	0.44	9.65
Holoptelea integrifolia	6.12	7.69	3.72	17.53
Adina cardifolia	9.52	12.82	20.62	42.96
Schleichera oleosa	4.76	8.97	4.41	18.14
Shorea robusta	19.72	14.10	41.51	75.33
Lageresrtomia parviflora	18.37	14.10	8.46	40.93
Pterocarpus marsupium	2.04	3.85	8.29	14.18
Syzygium cumini	2.04	3.85	3.55	9.44
Total	99.99	99.99	99.99	299.97

(*Note*: RD = Relative Density, RF = Relative Frequency, RBA= Relative Basal Area and IVI = Importance Value Index)

3.2 Forest structure

The density of seedling (6496 ind/ha) is more than density of sapling (1478 ind/ha) and tree (98 ind/ha) in the community forest. The occurrence of high number of seedlings on the forest floor indicates that the forests are regenerating. This is also evident from the J-shaped distribution which is an ideal condition for regenerating forest.

3.3 Biomass and Carbon stock

3.3.1 Aboveground Biomass and Carbon

The AGB and carbon stock of the CF was estimated to be 155.37 t/ha and 73.03 t/ha, respectively. Block 3 has highest carbon stock followed by Block 2 and Block 1 (see Table 2). AGB of the CF (155.37 t/ha) falls in the range of AGB of subtropical forest of Asian continental region (100-160 t/ha) [14] and AGB of Indian forest (14-210 t/ha) [25]. The AGB value of the study is lower than AGB (406 t/ha) of Sal plantation of Meghalaya [26] and similar to AGB (154.94 t/ha) of Sal forest of Satpura plateau [26].

Table 2: Block wise carbon (t/ha) in different carbon pools

Block	AGC	BGC	DWC	LHGC	SOC	Total
1	40.35	10.49	5.59	0.68	43.2	100.31
2	82.63	21.48	11.45	0.66	32.8	149.02
3	96.1	24.99	13.32	0.9	39.46	174.77
Mean	73.03	18.99	10.12	0.75	38.49	141.38
SD	± 29.09	± 7.56	± 4.03	± 0.13	± 5.27	± 37.82
SE	± 16.79	± 4.37	± 2.33	± 0.08	± 3.04	± 21.83

(*Note*: SD = Standard Deviation and SE = Standard Error)

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3.3.2 Belowground Biomass and Carbon

The BGB and carbon stock of the CF was estimated to be 40.40 t/ha and 18.99 t/ha, respectively. Highest and lowest carbon content was found in Block 3 and Block 1, respectively (see Table 2). BGB value of this community forest is comparable to range of BGB (23-55.90 t/ha) of Chitwan Annapurna Landscape, Nepal [35] and higher than BGB value of Namuna community forest, Illam (13.54 t/ha) [17].

3.3.3 Deadwood Biomass and Carbon

The DWB and carbon stock of the CF was estimated to be 21.53 t/ha and 10.12 t/ha, respectively. The deadwood carbon was found highest in Block 3 and lowest in Block 1 (see Table 2). The DWB value of this study was found to be considerably higher than the DWB (3.6 t/ha) of South and South East Asia [7].

3.3.4 Leaf litter, Herb and Grass Biomass and Carbon

The LHGB and carbon stock of the CF was estimated to be 1.60 t/ha and 0.50 t/ha, respectively. Block 3 has the highest whereas Block 2 has lowest biomass and carbon content (see Table 2). The current value of LHGB falls in the range of litter biomass (1.52 ± 1.1 t/ha) reported in mixed forest of India [33]. However, the biomass value is lower than the litter biomass (3.5-4.2 t/ha) value of tropical evergreen forest of Western Ghats [36].

3.3.5 Soil Organic Carbon

The mean SOC of the CF was estimated to be 38.49 t/ha where, Block 1 has maximum (43.20 t/ha) and Block 2 has minimum (32.8 t/ha) value of SOC (see Table 2). The stocks of SOC for temperate (*Quercus leucotrichophora*) forest and subtropical (*Pinus roxburghii*) forest was (185.6-160.8) t/ha and (141.6- 124.8) t/ha [30] which is higher than the present estimate of SOC. The lower value of the SOC as compared to above study is because the present study site is of lower altitudinal gradient and variation in forest type. However, the value of SOC i.e., (35-113) t/ha in North east China [40] is comparable with the SOC value of present study.

3.3.6 Total Carbon stock and CO_2 equivalent

The total carbon stock was found to be 141.38 ± 21.83 t/ha with CO_2 equivalent value of 518.86 t/ha. The estimated total carbon stock of this study was found higher than the forest carbon stock estimated for Terai forests (124.14 t/ha) and Churia forests (116.94 t/ha) of Nepal [9, 10]. Total carbon stock of (165.91-216.16) t/ha in Sal mixed subtropical hill deciduous forests in Ludhikhola watershed of Gorkha district [2] is higher than the total carbon stock of the present study. AGC contributes maximum (73.03 t/ha) followed by SOC (38.49 t/ha) whereas, LHGC contributes minimum (0.50 t/ha). The percentage share of different carbon pools in the CF is shown below (see Figure 2).

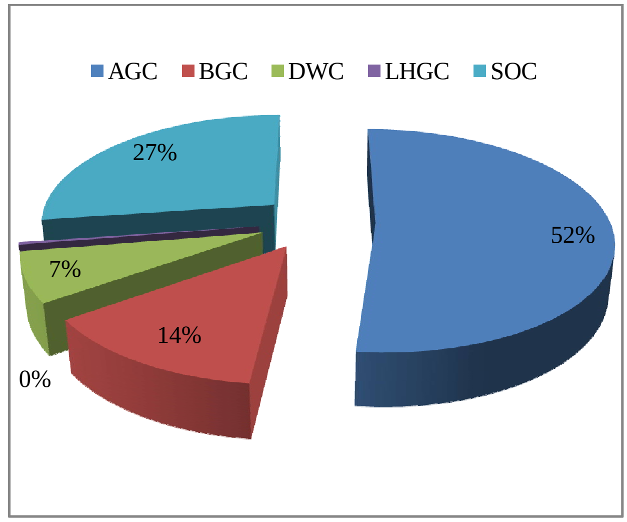

Figure 2: Percentage share of carbon pools

3.4 Diameter class wise Carbon content

DBH class (>80) cm has highest carbon with 33.11 t/ha followed by DBH class (70-80) cm with 12.70 t/ha. The lowest carbon content was found in DBH class (10-20) cm with 1.06 t/ha. The carbon content block wise with respect to DBH class is shown below (see Figure 3). In contrary to this study, high carbon stock was found at DBH class (20-30) cm [26]. Carbon stocks was found higher in big trees with greater DBH class because bigger trees would have high stem volume, high basal area long trees and large diameter [11].

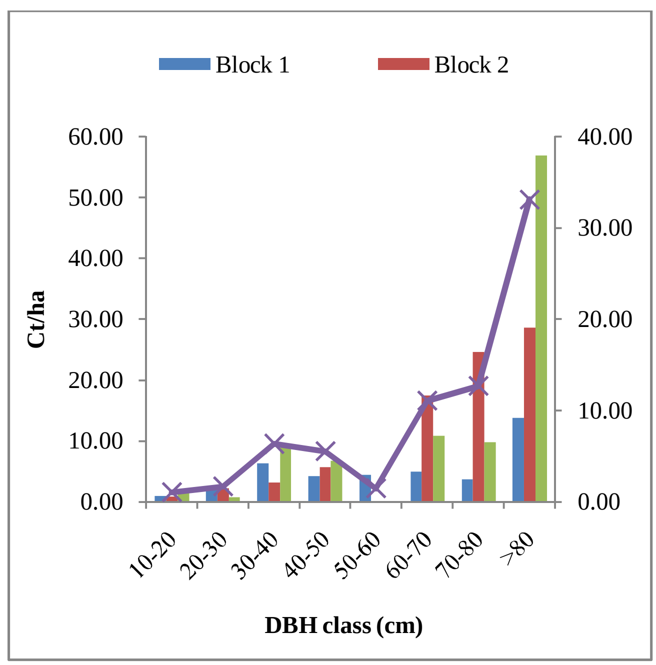

Figure 3: Diameter class wise carbon content

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3.5 Species wise Carbon content

The highest carbon content was found in *Shorea robusta* (36.17 t/ha) followed by *Adina cardifolia* (16.09 t/ha) and *Lageresrtomia parviflora* (4.99 t/ha). Similarly, lowest carbon content was found in *Acaica catechu* (0.25 t/ha) (see Figure 4).

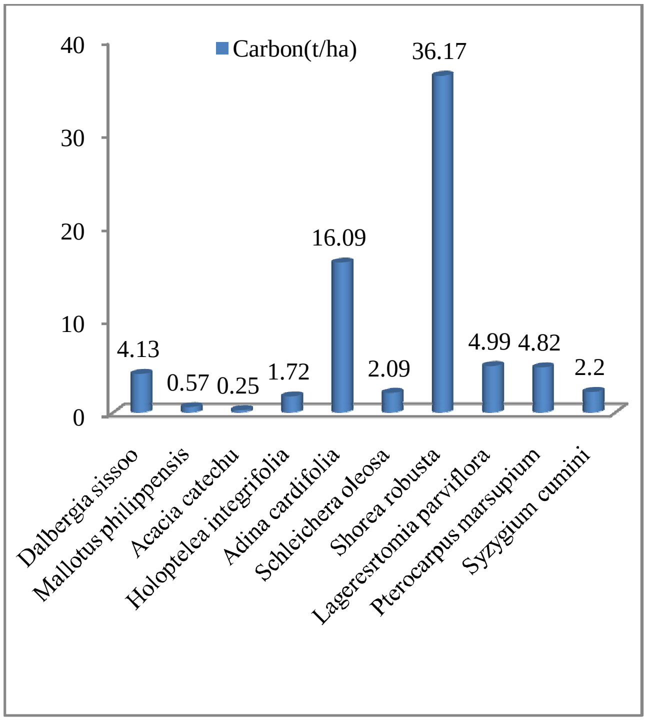

Figure 4: Species wise carbon content

4. CONCLUSION AND RECOMMENDATIONS

The study comprised of estimation of biomass and carbon stock in different forest carbon pools across 30 sample plots in the study site. The higher number of seedlings than saplings and trees in the study site concludes that the CF has potential to sequester more carbon in future. The total carbon content was estimated to be 141.38 ± 21.83 t/ha where AGC contributes maximum (52%). *Shorea robusta* being dominant species (IVI=75.33) with basal area of 9.73 m^2/ha got maximum carbon stock of 36.17 t/ha. The study shows carbon sequestration potential in CF of Nepal is enormous and can reward economic benefits from carbon trading which can assure active participation of people in conservation of forest sustainably. The study recommend conducting sufficient research related to carbon stock and sequestration in different forest conditions and management systems so that economic incentives can be claimed under CDM and to promote public awareness about role of forest as carbon sink.

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