International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133; Print ISSN: 2664-7125; Impact Factor: RJIF 5.28
Received: 03-06-2020; Accepted: 17-06-2020; Published: 04-07-2020
Volume 2; Issue 3; 2020; Page No. 22-29

Response of environmental variables and carbon enhancement in community forests, Nepal

Hari Prasad Pandey[1*], Ganesh Paudel[2], Shila Pokhrel[3], Narayan Pokhrel[4]
[1] Under Secretary, Ministry of Forests and Environment, Nepal
[2] Forest Officer, Ministry of Industry, Tourism, Forests and Environment, Gandaki Province, Pokhara, Nepal
[3] Forest Officer, Division Forest Office, Arghakhanchi district, Nepal,
[4] Scientific Officer, Ministry of Forests and Environment, Government of Nepal

Abstract
Forests are mainly govern by physio-climatic characteristics globally. Nepal possesses a diverse physio-climatic conditions primarily in Middle-hills physiographic zone due to diverse micro-climatic and topographic variation. The site-specific interrelationship between biomass (thereby carbon) with environmental variables are crucial for better understanding on objective-based forest management, which is insufficient for the country. Therefore, the study analyzed the relationships between biomass density, soil organic carbon (SOC) and total carbon density with environmental variables (type of community forests (CFs), elevation, slope, aspect, presence of wildlife, regeneration status (seedling and saplings count), and species richness) in two Middle-hills community forests of Western Nepal. Generalized linear model with log-linked function was used to analyze data Result showed CFs, elevation, slope, aspect and indication of wildlife has significant effect on carbon density of forests. Carbon density found decreased with increased elevation, stepper the slope, lesser the carbon density and north facing landscape harbor the highest carbon density. However, woody species richness and regeneration status has no significant impact on carbon density. Similarly, SOC has impacted significantly by forest type, elevation and aspect but not by species richness, regeneration, and slope and wildlife presence for the study area. In addition, forests have been enhancing biomass stock at least 40% of annual growth of forest despite users harvest annual allowable cut as prescribed by their operational plan. Study concludes that carbon enhancement in community-managed forests are significant without jeopardizing the conventional material use and biodiversity. Also, environmental factors impacted differentially for biomass and carbon conservation, therefore, a due consideration is needed at management level for objectified forest management.

Keywords: biomass density; soc; carbon density; environmental variables; community forests; western Nepal

Introduction

Forest acts as a carbon-dioxide (CO_2) sink by increasing above-ground biomass through increased forest cover and by increased levels of soil organic carbon (SOC) content (IPCC 2007) [21]. and contribute significantly to the mitigation of global climate change (Bajracharya *et al*. 1998 [5], Phillips *et al*. 1998, Lal 2004, Smith 2004). In fact, forest ecosystem plays very important role in the global carbon cycle as stores about 80% of all above-ground and 40% of all below-ground terrestrial organic carbon (IPCC 2001). Vegetation and soils together share almost 60% of the world's terrestrial carbon (Winjum *et al*. 1992) [4]. Replenishing carbon in the terrestrial ecosystem provides a multitude of benefits by improving soil fertility, ecosystems, and biodiversity, which in turn has been followed by other economic and environmental benefits (Janzen 2004) [22].

Geographically, Nepal belongs to sub-tropical region however her physio-climatic characteristic allows her to possess tropical to alpine climate (GoN 2014) [17]. and corresponding forests type. Almost 45 % of total land area is forested in the country (DFRS 2015b) [13], of which more than one third of forests are managed by the local communities (GoN 2016) [18].

The communities are managing their forests, degradation in the hills has been checked, forest conditions have improved in most places, with positive impacts on biodiversity conservation (Acharya and Sharma 2004) [1], and numerous degraded forest ecosystems have improved due to decentralization and participatory development strategies (Baskota *et al*. 2007) [6]. by which communities have had easier access to firewood, timber, fodder, forest litter, and grass (Acharya and Sharma 2004 [1], Kanel 2004) [23]. Regarding climate change community forest has been engaged in community based adaptation (Acharya and Paudel, 2016) [2]. and also serves as the carbon sink (Oli and Shrestha, 2009 [28]; Tripathi et. al., 2018) [41]. Estimation of above-ground biomass (Ketterings *et al*. 2001) thereby aboveground forest biomass carbon and soil carbon are the most critical step in quantifying carbon stocks (Gibbs *et al*. 2007) [16]. Carbon stock is vary with time, forests types, altitude in the forest ecosystem, thus, temporal stock of carbon under various forest types must be assessed (Shrestha and Singh 2008) [35, 34].

Various studies have been conducted published worldwide about the biomass estimation, carbon estimation and REDD+ monitoring and assessment issues (egAndersson and Ravikumar 2010; Arbonaut 2010; Arce 2008; BELSPO 2010; Biettam 2010; Bottcher *et al*. 2009; CBD 2011; Cerbu *et al*. 2009; CIFOR 2010; COP 2010; Davis 2010; Doswald *et al*. 2010; Durbin 2009; FAO 2009; FAO 2010 cited in (SEDAC 2011). Some studies have been done in CFs in a Nepalese context on the topics of biomass estimation, carbon calculation and carbon enhancement and related issues in various parts of the country (Upadhyay *et al*.

2005, Nepal 2006, Baskota *et al*. 2007 [6], Subedi *et al*. 2010 [37], ANSAB 2011, Bhusal 2011 [7], Pandey and Bhusal 2016) [29]. But very limited studies have been covering the information about elevation gradient, soil characteristics with regards to carbon density in community-managed forests in Nepal. Realizing these facts, this study was conducted with the aim of quantifying carbon in CFs by sampling randomly along five contour lines in two community-managed forests from Gorkha district, Western Himalayas, Nepal.

Study Area

Study was carried out in Gorkha district extends between 27^{0}15'-28^{0}45'N latitude and 84^{0}27'-84^{0}58'E longitude, in the middle hills and high mountains of the Western Development Region of Nepal, covers an area of 3614.70 km^2, with an elevation range of 228 m to 8,163 m mean above sea level (masl). Gorkha possesses five distinct type of forests according to altitudinal range, namely, tropical, sub-tropical, temperate, sub-alpine, and alpine, which offer a wide array of vegetation. The district receives an average annual rainfall 1776 mm and average annual maximum and minimum temperatures are 26.1^{0}C and 15.9^{0}C, respectively (DDC 2011).The study was carried out in two Community Forests (CFs), namely: Ghaledanda Ranakhola Community Forest (GRCF) and Ludi Damgade Community Forest (LDCF). In total, about 269 ha of forest has been studied giving a sampling intensity of 0.83% and 2.23 ha of forest area were surveyed.

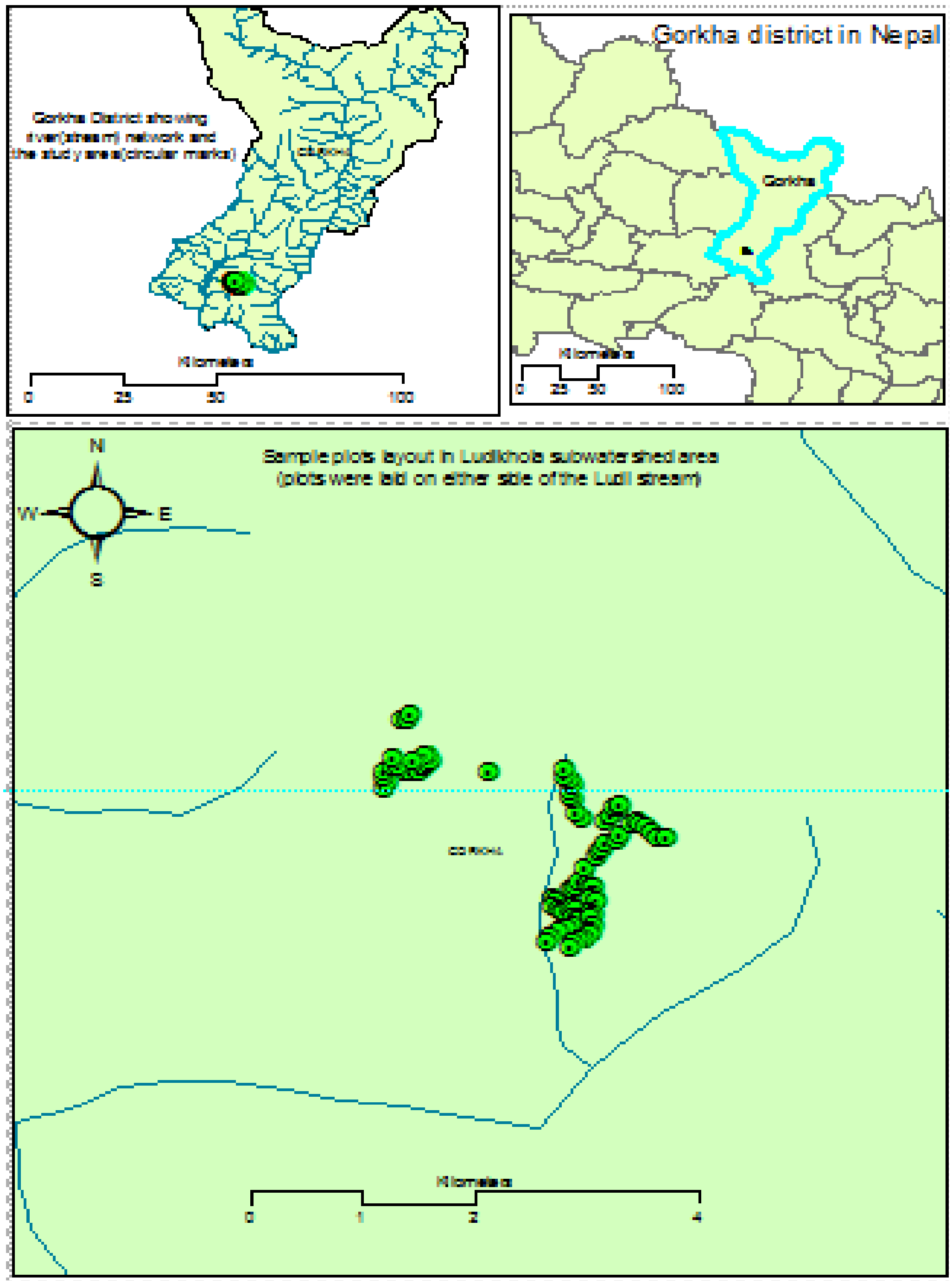


Fig 1: Map showing the study area and sample plot layout.

Ghaledanda Ranakhola Community Forest

Ghaledanda Ranakhola Community Forest (GRCF) was formally handed over to the Ghaledanda Ranakhola Community Forest Users' Group (GRCFUG) in 1998 to 459 households (HHs) (CFUG 2008) [8]. GRCF covers an area of 194.2 ha but this study considered only the area which falls under the Ludikhola sub-watershed (181.7 ha). The forest has a sub-tropical climate and characteristic, faces south-east, south and south-west, with an elevation ranging from approximately 700 m asl (above sea level) to 1100 m asl. Because of its sub-tropical nature, it was mainly dominated by S*horea robusta* (>80% crown dominated) and under-story of *Schima wallichii* and *Castanopsis indica.* Some mature unexploited *Schima wallichii* were also common in this forest (CFUG 2008) [8].

Ludi Damgade Community Forest

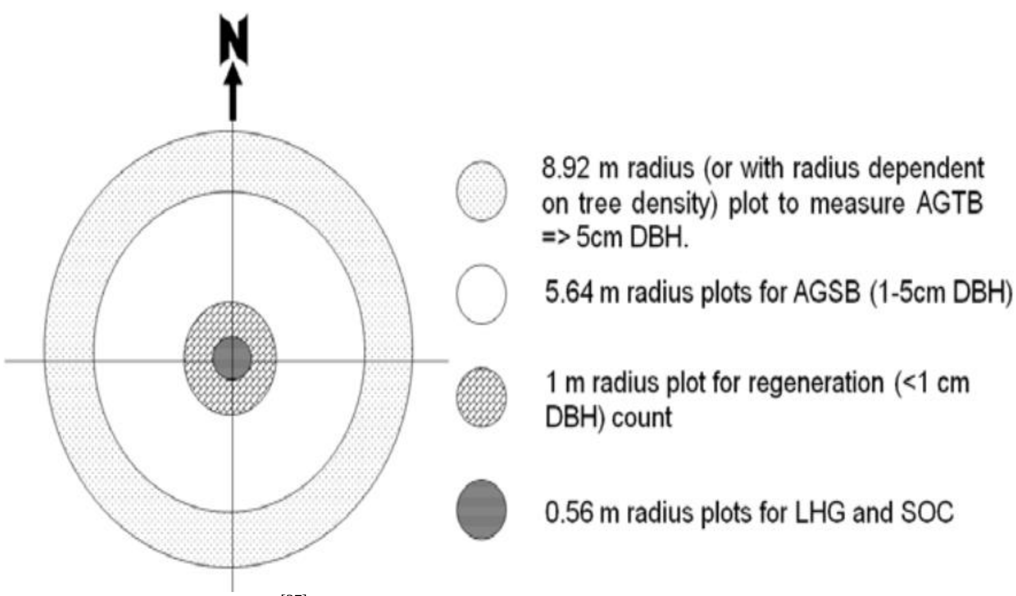
LudiDamgade Community Forest was handed over to the Ludi Damgade Community Forest Users Group (LDCFUG) in 1993, consists of 503 HHs, composed of different ethnicities and castes. Total forest area was 270.7 ha extended between 650 m masl to 1050 m masl, consists mainly of four species, namely; *Shorea robusta*, *Schima wallichii*and *Castanopsis indica* as naturally regenerated forest with *Pinus roxburghii* plantation in a small patch. Associated common species were *Clistocalis species, Syzigium cumini, Lyonia ovalifolia, Wendlandia coriacea,* and *Engelhardtia spicata*. This study was carried on 86.9 ha of this forest which was mainly dominated by *Schima wallichii*, *Castanopsis indica,* and the*Pinus roxburghii* plantation (CFUG 2008) [8].

Methods

Generally, carbon stock in the forest can be estimated by two methods, *viz*., destructive and non-destructive. The destructive method, where the biomass of felled trees is weighed in the field and samples (wood, roots, branches, leaf litters) burnt separately in the lab, is undoubtedly the most accurate method of estimating above-ground tree biomass but is costly and time consuming (De-Gier 2003) [11]. Realizing the facts of time and cost-effectiveness of non-destructive estimation method for a forest, we followed such procedure using allometric equations based on field data.

Sampling Design

Transects were run along the contours of elevation at 800, 850, 900, 950 and 1000 m masl and randomization was performed for maintaining the distance from one plot to the next with whole number of 10, 20,... by which concentric circular sample plot (CCSP, see: Figure 2) were laid out. Altogether 89 plots were sampled in a similar manner. The main reason for selecting circular plots was they were easy for layout, covering greater area with lesser perimeter which reduces the bias on the boarder trees whether to measure or not.



Source: (Subedi *et al*. 2010) [37].

Fig 2: Sample plot layout used in the forests

(AGTB = Above-ground tree biomass, AGSB= Above-ground saplings biomass, SOC= Soil organic Carbon, LHG= Leaf-litter, herbs and grass, and DBH= Diameter at breast height)

Soil Sampling

Soil organic carbon was determined by collecting samples from the default depth of 30 cm prescribed by the IPCC (IPCC 2006). Within a radius of 0.56 m, soil samples from three depth, 0-10 cm, 10-20 cm and 20-30 cm were collected from the centre of the plot, and bulk density, pH, Phosphorous and Potassium were analyzed in laboratory. The total carbon in the soil was measured as loss on ignition (LOI). Approximately, 200 g of composite soil was taken to the laboratory for bulk density, SOC, and pH analyses.

Measurements

Trees were first marked starting from the edge and working inwards to prevent accidental double counting. All the trees marked were then numbered from the middle to the edge starting at North and heading in a clockwise direction. Each tree was recorded, together with its species name. Trees on the border were included if >50% of their basal area fell within the plot and excluded if <50% of their basal area fell inside the plot. Trees with a girth at breast height (GBH>16 cm, 5 cm DBH) were measured in two places; one at 130 cm and one at 15 cm above the ground-level from uphills side. Total height of tree was measured by using Vertex IV and Transponder. Later GBH was converted into diameter at breast height (DBH) by dividing the GBH by π. Woody species having a girth <16 cm were regarded as regeneration and the number of individuals was counted within 5.64 m radius for saplings and within 1 m radius for seedlings plots. Woody species with a height less than 1.30 cm were considered as seedlings and woody species with a DBH>5 cm (GBH>16 cm) were considered saplings.

[Note: Tree species of height <1.30 m = seedlings; height >1.30 m and DBH<5cm = saplings, and height >1.30 m and DBH>5 cm = trees [including poles] (poles {DBH 5-30 cm} and trees{DBH>30 cm})]

Environmental variables such as altitude, slope and aspect were measured using GPS, clinometer, and compass, respectively. Data such as rainfall, annual average temperature, maximum-minimum temperature were acquired from the secondary sources.

Data Analysis

Data analysis was done according to the guidelines for measuring carbon stocks in community-managed forests following predictive allometric equations (models) in estimating Above-ground Tree Biomass (AGTB) developed by (Chave *et al*. 2005) [9]. to estimate forest biomass density. The biomass stock density of a sampling plot has been converted to carbon stock density using IPCC (IPCC 2006) default carbon fraction of 0.47 (IPCC 2006). Sapling (DBH<5cm) biomass is calculated by using national allometric biomass tables (Tamrakar 2000). Soil organic carbon (SOC) was calculated based on methodology used by Pearson *et al*. (2007) [30]. Measurements of root biomass are indeed highly uncertain, and the lack of empirical values for this type of biomass has for decades been a major weakness in ecosystem (Geider *et al*. 2001) [15]. To simplify the process for estimating below-ground biomass, we used MacDicken (1997) [26]. root-to-shoot ratio of 1:5 (MacDicken 1997) [26]. Biomass on leaf litter, grasses, dead wood, and stumps in Nepalese forest is less than 1% (DFRS 2015b), so they were excluded for analysis. The aggregate value gave the total biomass from the forests. SOC, soil pH, Phosphorous (P) and Potassium (K) constituent were analyzed in the lab taking the sample from the field. Lab work was done in Nepal Agriculture Research Council (NARC), Lalitpur, Nepal. In the laboratory, SOC was analysed using Walkley-Black's Wet Oxidation method (Walkley and Black 1934), bulk density by oven dry weight (103-105^{0}C) and soil pH by standard pH meter.

ANOVA and Tukey'sHSD tests were performed to see the carbon density differences. Correlation test was performed to see the relationship between biomass density (t/ha) with soil bulk density, soil organic carbon, soil pH, phosphorous and potassium content in the soil. Similarly, correlation test between SOC with soil pH, bulk density, Phosphorous (P) and Potassium (K) content were tested in R (Team 2018). The total forest carbon stock was converted to tone of CO_2 equivalent by multiplying by 44/12, or 3.67. The following generalized linear model (GLM) has been fitted and Quasi-Poisson log-link model was tested using F-test against three response variables, i.e. biomass density (t/ha) and SOC density (t/ha) and total carbon density (biomass carbon plus SOC) with the parameters under study.

Biomass density = $a_{ij}+a_1$*CFs*+ a_2*Elevation*+ a_3*Indication of wildlife*+ a_4*Aspect* + a_5*Slope* (^{0})+ a_6*Species richness* +a_7 *Regeneration status (Number of seedlings and saplings)*+e_{ij} *…(model 1)*

SOC = b_{ij} + b_1*CFs* + b_2*Elevation* + b_3*Indication of wildlife* + b_4*Aspect* + b_5*Slope* + b_6*Species richness* + b_7*Regeneration status (Number of seedlings and saplings)* + e_{ij} *… (model 2)*

Total carbon density = c_{ij} + c_1*CFs* + c_2*Elevation* + c_3*Indication of wildlife* + c_4*Aspect* + c_5*Slope* (^{0}) + c_6*Species richness* + c_7 *Regeneration status (Number of seedlings and saplings)*+e_{ij} *…(model 3)*

Where, a_{ij}, b_{ij} and c_{ij} are intercepts, a_1, b_1, c_1, a_2, b_2, c_2, a_3, b_3, c_3, a_4, b_4, c_4, a_5, b_5, c_5,a_6, b_6, c_6, a_7, b_7 and c_7 are constants for respective predicting variables and e_{ij}s are the error terms.

Results

Biomass Density

The highest biomass density was found at 850 m asl elevation whereas the lowest was in 950 m asl. The above-ground tree biomass and total biomass showed decreasing trends with increasing elevation from 800 to 950 m asl. Total biomass density of the study area was 151.14 t/ha (Table 1). Above-ground tree biomass density (Table 1) and the total carbon density (Table 2) fortunately the figure was equal and both were 117.8 t/ha.

Table 1: Trees, saplings and total biomass with respect to elevation

S.N	Elevation (m masl)	Tree biomass above-ground (t/ha)	Below-ground tree biomass (t/ha)	Sapling biomass (t/ha)	Total biomass density (t/ha)
1	800	188.25	37.65	15.52	241.42
2	850	147.33	29.47	4.35	181.15
3	900	106.8	21.36	23.11	151.27
4	950	33.06	6.61	2.27	41.94
5	1000	113.56	22.71	3.66	139.93
Total		589	117.8	48.9	755.71
Mean		117.8	23.56	9.78	151.14

Carbon Density and CO_2 Equivalent

Increasing carbon density with decreasing elevation within the study area in naturally regenerated forests was observed (Table 2). Mean carbon stock was 117.8 t/ha and CO_2 equivalent stock in the studied CFs was 431.93 t CO_2/ha (Table 2). The majority of the carbon stock was concentrated in trees of lower elevation. The major parts of carbon was stocked in aboveground tree biomass (55.37 t/ha) followed by soil organic carbon (26.76 t/ha). The aboveground carbon stock (trees + saplings) and the below-ground carbon stock (tree roots + soil) in the study area were almost equal i.e. 59.97 t/ha and 57.83 t/ha, respectively (Table 2).

Table 2: Biomass and soil carbon per unit area and CO_2 equivalent

S.N.	Elevation (m masl)	Above-ground tree carbon (t/ha)	Below-ground tree carbon (t/ha)	Sapling carbon (t/ha)	SOC (t/ha)	Total carbon density (t/ha)	CO_2 equivalent (t/ha)
1	800	88.48	17.7	7.3	43.72	157.2	576.40
2	850	69.24	13.85	2.05	48.13	133.27	488.66
3	900	50.20	10.04	10.86	36.09	107.19	393.03
4	950	15.54	3.11	1.07	53.07	72.79	266.90
5	1000	53.37	10.67	1.72	52.79	118.55	434.68
Total		276.83	55.37	23	233.8	589	2159.67
Mean		55.37	11.07	4.6	46.76	117.8	431.93

Analysis of Variance (ANOVA) test results show a significant difference ($p<0.05$) in carbon density with respect to altitudinal ranges (Table 3). The distribution of the residuals standard error (115.7; degrees of freedom (DF): 3423) was normal.

Table 3: ANOVA test of carbon density with elevation

Elevation (m masl)	Total carbon density (t/ha)	Error sum of square	P-value	Significant
800	157.20	46.96	<0.05	Yes
850	133.27	-6.94	>0.05	No
900	107.19	-18.24	<0.05	Yes
950	72.79	-34.30	<0.05	Yes
1000	118.55	23.60	<0.05	Yes

Multiple comparisons of mean carbon with elevation gradient was performed in R with 'Tukey HSD' test and result showed that elevation pairs 900-800 m, 950-800 m, 950-850 m, 1000-850 m, 1000-900 m, and 1000-950 m masl had significant difference ($p<0.05$) in carbon density. This result shows that the elevation gradient of less than 100 m have no significant difference in almost all cases (except non sig.1000-800 m and sig.1000-950 m) (Table 3).

Biomass Enhancement

The studied CFs were enhancing biomass stock at a rate of 40% of annual growth of the forests, as forests were in good conditions (Table 4).

Table 4: Forest condition and biomass enhancement in CFs. (Reg. = regeneration, cond. = condition, Criteria were based on 'Community Forest Resource Inventory Guideline 2004' (DOF 2004).

S.N.	Reg. (no./ha)	Criteria	Reg. cond.	Trees' growing stock	Criteria	Forest cond.	Increment per annum	AAC in CFs	Annual Biomass enhancement
1	Seedlings 32522	>5000 =good	Good	83.89 m^3/ha	50-200m^3/ha = fair	Good regeneration + fair tree growing stock = Good forest	3.5% to total growing stock	60% of annual increment	40% of annual growth of growing stock
2	Saplings 2696	>2000 =good							

Carbon was accumulated/added in community forest at a rate of 5.22 t/ha/year, which is about 19.2 tones per ha per annum of carbon-dioxide equivalent (Table 5). These data show that carbon is enhancing in the CFs, but the amount of carbon addition is a relative value for higher or lower comparisons.

Table 5: Forest carbon enhancement scenario for a year in CFs, Gorkha (Source: ANSAB 2011)

CFs	In 2010 (Ct)	In 2011 (Ct)	Change C stock (Ct)	In 2010 (Ct/ha)	In 2011 (Ct/ha)	Carbon enhanced (Ct /ha/year)	CO_2 equivalent (tCO_2/ha/year)
LDCF	55919.44	57337.03	1417.59	206.57	211.8	5.23	19.2
GRCF	37413.48	38361.59	948.11	205.95	211.17	5.22	19.14

Response of Environmental Variables

Biomass density, SOC density and total carbon density were taken as response variables and CFs, elevation, indication of wildlife signs, aspect, slope, regeneration count (seedlings and saplings) and species richness were considered as explanatory variables. The test result is presented in the Table 3. Result showed that CFs, elevation, presence of wildlife and slope have significant influenced on biomass density in the study area whereas aspect, regeneration status and woody species richness have no significant respones to biomass density of the forests (Table 6).

Table 6: Test outcomes between biomass, SOC and total carbon density with variables

S.N.	Variables	Biomass density	SOC density	Total Carbon Density
1	CFs	0.001160 *	0.0467783 *	0.0093010*
2	Elevation	6.857e-06 *	9.751e-06 *	0.0001293 *
3	Indication of wildlife	0.003710 *	0.3878397	0.0034458 *
4	Aspect	0.477874	0.0006305 *	0.0034458 *
5	Slope	0.001081 *	0.9602106	0.0021594 *
6	Regeneration status	0.104459	0.2922751	0.4233456
7	Species richness	0.507869	0.8770075	0.0666280
	Adj R^2			

* Significant at 5% significant level.

The biomass density for Ghaledanda Ranakhola CF was 168.27 t/ha where this figure for Ludi Damgade CF was 87.09 t/ha. Indication of wildlife showed the positive correlation with biomass density for study area. Test result (Table 3) showed the significant higher biomass density (203.17 t/ha) having the plots of wildlife signs with plot having no wildlife indication (117.18 t/ha). This result indicates that forest biomass can be conserve together with wildlife conservation in CFs in Middle-hills of Nepal.

The SOC has significant influenced by CFs, elevation and aspect (Table 3). Other variables under study have seemed no significant response to SOC. The SOC density in Ghaledanda CF was 46.67 t/ha and Ludidamgade CF was 51.71 t/ha which is significant difference due to community forests (Table 3). Elevation has also influenced on SOC density. SOC was highest at 1000 m masl whereas lowest in 900 m masl but not follow any trend. However, higher the biomass density constitutes higher SOC density in the soil (Table 2). Similarly, SOC significantly varied with different aspects. The SOC density for east, west, south and north was found to be 48.4, 53.11, 42.12, 55,55 t/ha respectively. North facing slope has the highest SOC in CFs.

Total carbon stock density has significant response from CFs, elevation, aspect, indication of wildlife and slope. Total carbon density for Ghaledanda Ranakhola CF was 125.73 t/ha whereas Ludidamgade CF was found to be 92.65 t/ha. This showed that significant difference in mean carbon density due to community forests. Carbon density was significantly higher having some indication of wildlife (143.37 t/ha) to having no wildlife signs (102.84 t/ha). Similarly elevation has significant difference on carbon density (for detail see Table 3). Aspect and slope have significant different carbon density in the study area. The higher was the slope; the lower was the carbon density. Total carbon density was highest in north facing slope. The final models were plotted and showed the smooth Q-Q plots.

Discussions

Biomass and Carbon Density

The results showed that biomass density (Table 1) and thereby carbon density (Table 2), was highest in the lowest elevation and decreases with increasing elevations up to 950 m asl but increased carbon density at 1000 m asl. It was because the area at 1000 m asl was mostly covered with plantation of *Pinus roxburghii*, was an uniform stand of young trees contributed more carbon density. Analysis of Variance test shows carbon density was significantly different ($p<0.05$) with respect to elevation (Table 3). The decreasing trend of carbon density with increasing elevations was attributed to lesser DBH-sized trees at the higher elevations. These results were concordant with the outcome of a study of 31 CFs of Ludhikhola sub-watershed area. The carbon storage was about 245 t/ha, 240 t/ha, 210 t/ha, 180 t/ha and 170 t/ha in the elevations range < 520 m, 521-640 m, 641-760 m, 761-880m and >881m respectively with elevation interval of 120 m masl (ANSAB/ICIMOD/FECOFUN/NORAD 2010). Similar findings were attributed because both study sites belongs to same watersheds and have similar biological and physio-climatic settings. Just reverse results were seen as increasing carbon density with increasing elevation in CFs of Kayarkhola sub-watershed, Chitwan district, at elevation range of <360 m to 840 m and the CFs of Charnawati sub-watershed, Dolakha district, at elevation range of <1320 m to >2580 m masl (ANSAB/ICIMOD/FECOFUN/NORAD 2010). This was due to the fact that the difference in species compositions that tropical broadleaved in Chitwan, the sub-tropical to lower temperate (*Quercus*) in Dolakha and the sub-tropical broadleaved forest in this study. Also this result justified by the difference in physio-climatic settings, vary in proportion of forest per households (0.11 ha, 0.12 ha, 0.08 ha in Kayarkhola - Chitwan, Charnawati - Dolakha and present study sites, respectively) that the study forests had the highest pressure on the forest (lowest ratio).

Carbon density of the study area was 117.8 Ct/ha (Table 2). This result was far less than the result found in 2010 and 2011 studied by ANSAB (ANSAB 2011) [3]. The difference in result was the exclusion of carbon accounting from leaf-litter, herbs and grasses, and branches in present study where ANSAB (2011) [3]. included those carbon pools. Also, ANSAB (2011) [3]. had lesser sampling intensity than present study had (0.86%). Moreover, ANSAB (2011) [3]. laid out more sample plot at lower elevation where trees were relatively larger in size and stand was denser than higher elevation had for Ludhikhola watersheds.

A similar studies from different ecological zones of Nepal showed higher carbon densities than present study found. For example, carbon density in *Shorea robusta* dominated forests in Terai (CFs in Nawalparasi district) was 460.67 t/ha (Bhusal 2011) [7]. while it was 186.95 t/ha (Nepal 2006) and 235.95 t/ha (Shrestha 2008) [34]. Also this result can be compared with the national average of carbon density (176.95 t/ha) (DFRS 2015b) and Middle-hills forests (138.11 t/ha) (DFRS 2015a) [13]. The lesser carbon density was due to consist of smaller-sized *Shorea robusta* in Mid-hills forest, dominance of young (small DBH) trees in present study area, and methodological differences.

This result is comparable with the finding across the boundary. The result is far less than the carbon density estimated in tropical regions of different areas. For example, humid tropical forest of eastern coast of Tamilnadu, India (307 t/ha) (Ramachandran *et al*. 2007) [32], tropical rain forest of Thailand (275 t/ha) (Terakunpisut *et al*. 2007) [40], broadleaved forests of tropical

America (170 t/ha), tropical Africa (260 t/ha), and tropical Asia (215 t/ha). The lesser density of carbon was attributed the sub-tropical nature of the forest with smaller-sized trees in present study area. The lower carbon density in this present study is due to the result of small-sized trees (more than 80% trees less than 15 cm DBH), and sub-tropical species compositions. Other reason would be the difference in physio-climatic settings of the regions.

Conclusions

Under the same management system and same species dominated condition, CFs, elevation; slope, aspect and presence of wildlife have significant difference on carbon density in CFs. In general, carbon density decreased with increased elevation. The stepper the slope, the lesser the carbon density and north facing landscape harbor the highest density of carbon. However, woody species richness and regeneration status (number of seedlings and saplings) have no significant influence on carbon density to the study sites. Presence of wildlife has little influence on SOC whereas the aspect has significant role on it. Except different CFs, elevation and aspect, SOC has no significant influence from woody species richness, regeneration status, slope and wildlife. Community forests have been enhancing biomass stock at least 40% of annual growth of forest even if users harvest annual allowable cut as prescribed by their operational plan. Enhancement of carbon density in CFs, despite continuous utilization of forests' products by communities, shows high potentiality for carbon trading under clean development mechanism (CDM) and reducing emissions from deforestation and forest degradation in addition to carbon conservation, forest management and carbon enhancement as an economic incentives to the local communities without compromising the traditional use right and biodiversity conservation upon the forests.

Acknowledgements

Authors are thankful for the community forests users' groups from Gorkha district, Nepal for their kind cooperation during field work. Mr. Manoj Bhusal, Mr. Kamal Acharya, Mr. Gyandra Karki and Mr. Nawaraj Paudel for their tremendous support in data collection and editing. We are thankful to Dr. Suman Aryal for insightful comments, English editing and constructive suggestion on the manuscript.

References

1. Acharya KP, Sharma RP. Forest Degradation in the Mid-hills of Nepal. Pages 90-99 *in* Forestry journal of the Institutue of Forestry, Pokhara, Nepal, 2004.
2. Acharya R, Paudel G. Implementation status of community adaptation plans: a case study from Parbat District, Nepal. International Journal of Environment. 2016; 5(3):119-126.
3. ANSAB. Carbon stocks in Community Forests in Ludikhola Watershed Area, Gorkha, Nepal.*in* H. P. Pandey, editor. Asian Network for South-Asian Agriculture and Bio-Resources, Kathmandu, 2011.
4. ANSAB/ICIMOD/FECOFUN/NORAD. REDD+ Pilot Project: Report on Forest Carbon Stock in Community Forests in three watersheds (Ludikhola, Kayarkhola and Charnawati). ANSAB, ICIMOD, FECOFUN, NORAD, Kathmandu, Nepal, 2010.
5. Bajracharya RM, Lal R, Kimble JM. Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position. In: Lal R, Kimble JM, Follett RF, Stewart BA (eds) Soil processes and the carbon cycle. CRC Press, Boca Roton, FL, USA, 1998, 353-367.
6. Baskota K, Karky BS, Skutsch M. Reducing Carbon Emissions through Community-managed Forests in the Himalaya. www.bookicimod.org (ICIMOD), 2007.
7. Bhusal M. An Analytical Study of Carbon Stock in Shores robusta Forest of Two Different Ecological Zones of Nepal (case study from Gorkha and Chitwan district). Tribhuvan University, Pokhara, 2011.
8. CFUG. Community Forest Operational Plan of Community Forest User Groups.Community Forest User Groups, Gorkha, 2008.
9. Chave J, Andalo C, Brown S, Cairns M, Chambers J, Eamus D, *et al*. Tree allometry and improved estimation of carbon stock. Oecologia, 2005, 87-99.
10. DDC. District Profile of Gorkha. District Development Committee, Gorkha, 2011.
11. De-Gier A. A new approach to woody biomass assessment in woodlands and shrublands. In: P. Roy(ed). Geoinformatics for Tropical Ecosystem, 2003, 161-198.
12. DFRS. Middle Mountains Forests of Nepal. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS), Kathmandu, Nepal, 2015.
13. DFRS. State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal, Department of Forests Research and Survey, Kathmandu, 2015.
14. DOF. Community Forest Resource Inventory Guideline (Amended) {Samudayik Ban Shrot Sarbhekchhan Margadarshan, Parimarjit}.*in* M. o. F. a. S. C. Department of Forest, Government of Nepal, editor. Community Forest Division, Kathmandu, Nepal, 2004.
15. Geider RJ, Delucia EH, Falkowski PG, Finzi AC, Grime JP, Grace J, *et al*. Primary productivity of planet earth: biological determinants and physical constraints in terrestrial and aquatic habitats. Global Change Biology. 2001; 7:33.
16. Gibbs HK, Brown S, Niles JO, Foley JA. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental Research Letters. 2007; 2:13.
17. GoN/MoFSC. Nepal National Biodiversity Strategy and Action Plan 2014-2020. Ministry of Forests and Soil Conservaion, Kathmandu, 2014.
18. GoN/MoFSC. Forestry Sector Strategy 2016-2025.*in* M. o. F. a. S. Conservation, editor. Government of Nepal, Ministry of Forests and Soil Conservation, Kathmandu, 2016.
19. IPCC. Climate Change 2001: Mitigation, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change., University of Cambridge, Cambridge (UK), 2001.
20. IPCC. Good practice guidelines for National Greenhouse gas inventories, IPCC, Switzerland, 2006.
21. IPCC. Climate Change 2007: The Physical Science Basis Summary for Policymakers'. Geneva, 2007.
22. Janzen HH. Carbon Cycling in Earth Systems: A Soil Science Perspective. Agric. Ecosyst. Environ. 2004; 104:399-417.

23. Kanel RK. Twenty-five Years of Community Forestry: Contribution to Millennium Developement Goals. *in* Twenty-five Years of Community Forestry: Fourth National Workshop on Community Forestry. Department of Forest, Community Forest Division, Kathmandu, 2004, 118-123.
24. Ketterings QM, Coe R, van-Noordwijk M, Ambagau V, Palm CA. Reducing uncertainty in the use of allometric biomass equations for predicting aboveground tree biomass in mixed secondary forests. Forest Ecology and Management. 2001; 146:199-209.
25. Lal R. Soil carbon sequestration to mitigate climate change. Geoderma. 2004; 123(1-2):1-22.
26. MacDicken K. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects (Arlington, VA: Windrock International), 1997.
27. Nepal S. A Comparative study on Carbon Sequestration from two forest types in Community Forestry System Tribhuvan University, Pokhara, 2006.
28. Oli BN, Shrestha K. Carbon status in forests of Nepal: An overview. Journal of Forest and Livelihood. 2009; 8(1):62-66.
29. Pandey HP, Bhusal M. A comparative study on carbon stock in Sal (Shorea robusta) forest in two different ecological regions of Nepal. Banko Janakari, 2016.
30. Pearson TRH, Brown SL, Birdsey RA. Measurement guidelines for the sequestration of forest carbon U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square.
31. Phillips O, Malhi Y, Higuchi N, Laurance W, Nunez P, Vasquez R, *et al*. Changes in the carbon balance of tropical forests: evidence from long-term plots. Science. 1998; 282(5388):439-442.
32. Ramachandran A, Jayakumar S, Haroon RM, Baskaran A, Arockiasamy DI, *et al*. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. Current Science. 2007; 92:323-331.
33. SEDAC. Natural Resource Management Index, 2011 Release (2006–2011). Socioeconomic Data and Applications Center (SEDAC), 2011.
34. Shrestha BM, Singh BR. Soil and vegetation carbon pools in a mountainous watershed of Nepal. NatrCyclAgroecosyst. 2008; 81:179-191.
35. Shrestha BP. An Analytical Study of Carbon Sequestration in Three Different Forest Types of Mid-Hills of Nepal.Tribhuvan University, Pokhara, 2008
36. Smith P. Carbon sequestration in croplands: the potential in Europe and the global context. Eur J Agron. 2004; 20(3):229-236.
37. Subedi BP, Pandey SS, Pandey A, Rana EB, Bhattarai S, Baskota TB, *et al*. Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests. Norad, ICIMOD, ANSAB, FECOFUN, Kathmandu, Nepal, 2010.
38. Tamrakar PR. Biomass and Volume Tables with Species Description for Community Forest Management.*in* N.-T. Ministry of Forests and Soil Conservation, editor, Kathmandu, 2000.
39. Team RCR. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2018.
40. Terakunpisut J, Gajaseni N, Ruankawe N. Carbon sequestration potential in aboveground biomass of Thong phaphun national forest, Thailand. Applied Ecology and Environmental Research. 2007; 5:93-102.
41. Tripathi S, Thapa C, Sharma A, Paudel G. Biomass Carbon Content in Schima- Castanopsis Forest of Midhills of Nepal: A Case Study from Jaisikuna Community Forest, Kaski. International Journal of Environment. 2018; 6(4):72-83.
42. Upadhyay TP, Sankhayan PL, Solberg B. A review of carbon sequestration dynamics in the Himalayan region as a function of land-use change and forest/soil degradation with special reference to Nepal. Agriculture, Ecosystems and Environment. 2005; 105:449-465.
43. Walkley A, Black IA. An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 1934; 37:29-38.
44. Winjum JK, Dixon RK, Schroeder PE. Estimating the global potential of forest and agroforest management practices to sequester carbon. Water Air soil Pollut. 1992; 64(1-2):213-227.