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# Carbon sequestration potential in community and collaborative forests in Terai, Nepal

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**Abstract:** The objectives of this research are to assess and compare the current annual carbon increment (CACI) in community managed forests and evaluate the carbon sequestration potential in the forests. For this three community forests (CFs) namely Budhha, Chureparwati and Chyandanda and three collaborative forests (CFMs) they were Banke- Maraha, Tuteshwarnath and Gadhanta- Bardibash of Terai region in Nepal were selected as research sites. Statistically, randomize block design (RBD) was set to carry out the sampling. Thus, altogether 176 permanent plots were established applying stratified random sampling. The diameter and height of trees, pole and sapling (DBH > 5 cm) were measured from each plots for three consecutive years. Meanwhile, samples of regeneration (DBH < 5 cm, herbs, shrub and litter were collected from concentric plots. Additionally, the soil samples were collected from 0 - 10, 10 - 30 and 30 - 60 cm depths. The biomass was calculated using the allometric equation and collected samples were analyzed in lab. Later, the biomass was converted into carbon which was further employed to assess the carbon sequestration potential. The monetary valuation was calculated at the rate of carbon sequestration US$ 5 t ha$^{-1}$. The result revealed that estimated current annual carbon increment (CACI) was 2.85 t ha$^{-1}$ in Chyandanda CF however leakage was -1.68 t ha$^{-1}$ in Banke- Maraha CFM. Moreover, the multiple comparisons Tukey's test showed that there were significant differences in CACIs among the forests. The worth of carbon sequestration potential was US$ 11613.41. Thus, these forests demonstrate the great potentiality under Reducing Emission from Deforestation and Forest Degradation (REDD+) mechanism.

**Key words:** Biomass, emission, increment, leakage, mechanism, REDD+, reward, value.

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## Introduction

Globally, forest Carbon sequestration is recognized as cost effective and efficient option to address the issues of climate change. Hence, the Reducing Emission from Deforestation and Forest Degradation (REDD+) mechanism has been objectively functioning for this. The main priority of selection of REDD+ project is having large continuous block of forests and damaged due to

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deforestation and forest degradation (Skutsch & Van Laake 2009). Specifically, Tarai region of Nepal is known as rich contiguous block of forests having high deforestation and forest degradation (DFRS 2014) which probably meet the targeted goal of REDD+ mechanism. Thus this study is conducted here in community and collaborative forests of Tarai region.

The carbon sequestration refers to the capture or removal of carbon dioxide ($CO_2$) from the atmosphere and stores it in tree biomass (Jindal *et al.* 2008). As carbon sequestration importantly addresses the issue of climate change (Torres *et al.* 2013), it has a global concern under the reward policy (Muradian *et al.* 2012) of Reducing Emission from Deforestation and Forest Degradation (REDD+) mechanism (Skutsch & Van Laake 2009). In fact, the live and dead trees store 60 % of the carbon in forest ecosystems. The avoided deforestation and forest degradation could globally generate worth of 1 - 4 billion t $CO_2$ potential (Mackey *et al.* 2013). Moreover, it could be doubled through afforestation, reforestation and sustainable forest management. In addition, the tropical forests endow with natural insurance against many threats specifically drought, flood, and vector-borne diseases (Metsaranta *et al.* 2010). These risks could be exacerbated by climate change but keeping forests intact or expanding forest can contribute to mitigate and adapt against these risks (Murray *et al.* 2009).

Forest areas have been decreasing because of human disturbances and the consequences are release of $CO_2$ emission to the atmosphere. Indeed, forest area of a football ground size is converted into other land in every two seconds around the world. From 1750 to 2011, $CO_2$ emissions from fossil fuel combustion and cement production have released 365 (335 to 395) Gt C to the atmosphere, while deforestation and other land use change are estimated to have released 180 (100 to 260) Gt C. This results in cumulative anthropogenic emissions of 545 (460 to 630) Gt C (IPCC 2013). The estimated net emission of $CO_2$ was 9747 Gg for the base year 1994/95 in Nepal from all sources while it was 8117 Gg from the land-use change and forestry sectors (MoPE 2004). In contrast, forest conservation, sustainable forest management, and forest enhancement can reduce the $CO_2$ emission and that would be rewarded under REDD+ mechanism.

Many successful studies claim that the community managed forests are offering the carbon sequestration potential in Nepal (Carlson 2009; Karky & Skutsch 2010). In this context, interest is growing among the forest users to know and work for carbon sequestration potential. Presently, there are 18133 user committees managing 1.7 million ha of forest as community forests and 21 committees are managing about 76 thousand ha of block forests as collaborative forests. These forests may be potential for carbon sequestration. Obviously, the research questions raise, how can it be harness for carbon sequestration potential and how can it be linked with global REDD+ mechanism. This study tries to answer these research questions. Moreover, research hypothesis was set whether there were significant differences in current annual carbon increment (CACI). The reward policy under the REDD+ mechanism is one of the better option (Carlson 2009) but it needs sufficient records of forests carbon stocks change, which is very limited in developing countries like Nepal. Hence, this research is carried out objectively to assess and compare the CACI in community managed forests and evaluate the carbon sequestration potential in the forests.

Tarai region is situated in southern part of Nepal characterized by different land and population dynamics. This region is known as bowl of grain in Nepal because having low land plains in Tarai are highly suitable for farming. Total area of Tarai is 2,016,998 ha. Out of this, the total forest area is 411,581 ha (20.41 %) and other wooded land (OWL) is 502 ha (0.47 %). Here, the protected area (PA) is 69,847 ha (16.97 %), buffer zone is 27,074 ha (6.58 %) and remaining forests are 314,660 ha (76.45 %) which have been managed mainly under community and collaborative forest regimes (DFRS 2014). Despite these, the past records showed decreasing trend of forests. The coverage of Terai forests declined almost to 60 % from 1927 to 1977 and 1.7 % from 1978 to 1991. The estimated forest loss was recorded about 32,000 ha with annual rate of 0.40 % in between 1991 to 2010 (DFRS 2014).

The high population growth is considered as the main cause of deforestation and forest degradation. The total population of Nepal was 26,494,504 in 2011 but more 50.3 % of this is living in Tarai. Remarkably, the population density in Tarai soared to 392 persons per square kilometer and the growth rate was 1.75 % here, the highest in the nation (CBS 2012). Apparently, the high populations have resulted heavy pressure on the forest to meet their demand of forest products.

Ironically, the community forests exclude the distant people living away from the forests up to India boarder. Realizing this circumstance, collaborative forest management (CFM) regime has come into functional to supply forest products for these citizens. However, there is high deficit of forest product. The reason behind it is, the CFM implementation unit restricts in collection of fallen log only, though the scheme has emphasized on sustainable forest management (Karna 2008). The Terai forest contained 50.66 Tg of carbon with 123.14 t $ha^{-1}$ excluding plant having DBH < 5cm, climbers, fine roots, grasses, bamboos and herbs. These forests are potential to sequester the carbon (DFRS 2014).

## Materials and Method

Three community forests (CFs) and three collaborative forests (CFMs) were selected for this study in Mahottary district, Nepal. They are natural forests but differ in management modalities. Selected community forests are Budhha (69.73 ha), Chureparwati (441.7 ha) and Chyandanda (41.35 ha) while collaborative forests are Banke- Maraha (2006 ha), Tuteshwarnath (1334 ha) and Gadhanta- Bardibash (1450 ha) (Fig. 1). Mahottari district is situated at 26° 36' to 28° 10' N and 85° 41' to 85° 57' E. The average annual temperature ranges between 20 - 25° C and average annual rainfall recorded between 1100-3500 mm. The valuable Sal (*Shorea robusta*) is the dominant species associated with Saj (*Terminalia tomentosa*), Botdhairo (*Lagerstroemia parviflora*), Harro (*Terminalia chebula*) and Barro (*Terminalia bellerica*).

### *Data collection*

Randomized block design (RBD) was set for the research experiment. Based on this design, the stratified random sampling was carried out to gather the biophysical data. Three main strata namely tree, pole and regeneration based on stage of the plants in the forest were delineated on the map using GPS coordinates. For this purpose, the participatory map of each stratum was prepared by preliminary survey and participatory rural appraisal (PRA) technique. The present map of study site from Google earth was also used for stratification. Then, the strata were delineated using GPS coordinates boundary of each stratum.

The pilot sampling was carried out to calculate the number of sample plot (MacDicken 1997). For this, 10 - 15 sample plots were taken from each stratum of collaborative and community forests. Next, diameter at breast height (DBH) and height of trees in the sample plots were measured to determine the minimum number of sample plots based on co-efficient of variance (MacDicken 1997). Altogether 176 samples were collected from collaborative and community forests. They were 32, 33 and 31 from Banke- Maraha CFM, Tutesh-warnath and Gadhanta- Bardibas CFM respectively as well as 30 from Chureparwati CF, 25 from Budha CF and 22 from Chyandanda CF.

The data were collected following major steps. Firstly, the sample plots were distributed randomly on each stratum of the map. Latter, the coordinates of sample plots were uploaded in GPS. Secondly, sample plots were permanently established in the field (Baithalu & Parthasarathy 2013) by navigating the uploaded GPS coordinates. After, sample plots were allocated according to the nature of the stratum, particularly for tree stratum, 20 m x 25 m size sample plot was established with nested plots of 10 m x 10 m for poles, 5 m x 5 m for sapling, 5 m x 2 m for seedling and 1 m x 1 m for litter, herbs and grasses. Meanwhile, soil sample was fixed at the centre of the plot. The height and diameter of trees, poles and sapling (dbh > 5 cm) were measured in the sample plot. Sapling (1 cm < dbh < 5 cm), seedlings, herbs and shrubs were counted in the sample plot and their fresh weights of some of them were recorded to find the moisture content. Soil samples were collected from three different depths like 0 - 10 cm, 10 - 30 cm and 30 - 60 cm in order to determine the soil carbon (Chabbara *et al.* 2002; Eggleston *et al.* 2006). The measurements were continued for three consecutive years in order to identify the change in carbon stock. The current market price of carbon was explored from the web search.

### *Data Analysis*

Collected data were analyzed to estimate the carbon stock, current annual carbon increment and carbon sequestration. At the same time, the mean carbon stocks per ha variation was also compared using statistical analysis to know whether they were differed in these forests or not.

*Estimation of carbon stock and CACI* : Above Ground Tree dry Biomass (AGTB) was calculated by using allometric equation - $AGTB = 0.0509 x \rho D^2 H$ (Chave *et al.* 2005) for tree, poles and sapling (dbh = 5 - 10 cm). This equation does not perform

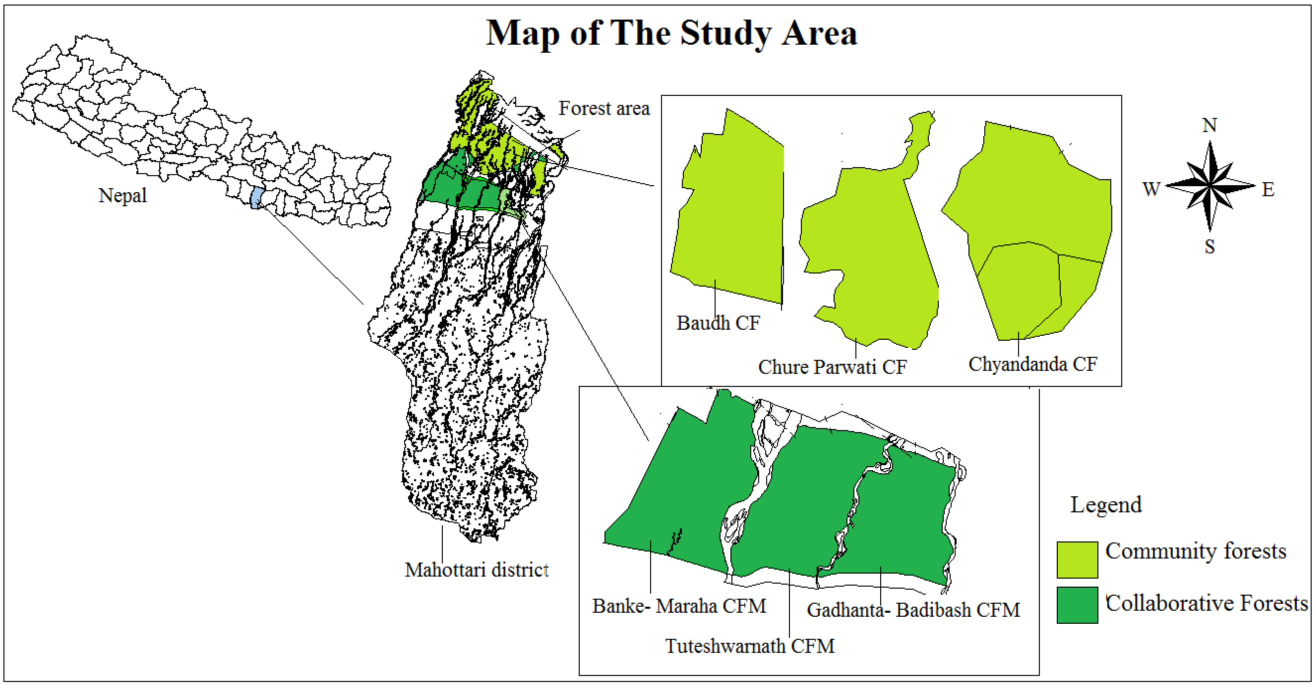


**Fig. 1.** Map of the study area.

precise result for dbh < 5 cm (Chave *et al.* 2005). Thus, for this biomass was calculated using the equation compiled by Tamrakar (2000) and its samples were taken to get dry biomass as this allometric equation provides only the fresh weight. Samples of sapling (dbh < 5 cm), seedling, leaf litter, herbs and grass (LHG) together were carried out in the laboratory to dry and their dry biomass was calculated using unitary method. The root biomass was calculated by using root shoot ratio 0.125 (MacDicken 1997). The dry biomass was converted into carbon by multiplying with 0.47 (Eggleston *et al.* 2006)

Soil carbon content was analyzed by Walkley and Black method (Walkley & Black 1958).

*Formula used for carbon analysis:*

Bulk density (BD g/ cc) = (oven dry weight of soil)/ (volume of soil in the core)

SOC = Organic carbon content (%) x soil bulk density (Kg/ cc) x thickens of horizon.

Total C = Total biomass C + soil C

Carbon stock change $\Delta$ C = carbon stock $(_n)_{year}$ - carbon stock $(_n)_{year}$

Current annual C increment (CACI) = C stock $_{n\ year}$ - C stock $_{(n-1)\ year}$

$CO_2$ removal or carbon sequestration = CACI*44/12

*Calculation of value of carbon sequestration*: market value of carbon sequestration was calculated using US$ 5 $t^{-1}$ $CO_2$ removal (Molly *et al.* 2012).

*Statistical analysis*: The mean carbon stocks per ha variation was compared applying one way ANOVA and Tukey's test (Sarker *et al.* 2014) by using SPSS software version 20.

## Results and discussion

The results are presented into three parts based on the research objectives. They are status of CACI in the forests, comparison of CACI and the carbon sequestration in forests of two different management regimes.

### *Current Annual Carbon Increment in Community and Collaborative Forests*

The estimated current annual carbon increment varied in collaborative and community forests. The estimated CACI was found to be highest, 2.85 t $ha^{-1}$, at third year in Chyandanda community forest but it was the leakage -1.68 in t $ha^{-1}$ in Banke- Maraha CFM (Table 1). Though many factors are affecting the apparent variation in CACI in these forests, the main reliable reasons are harvesting and logging, past effects of illegal felling, stage of the existing plants and applied silvicultural practices. Silvicultural operations like

**Table 1.** Carbon stock and CACI (t ha$^{-1}$) in community forests and collaborative forests.

| CFM/CF | N | Year 1 | Year 2 | Year 3 | CACI ( C of yr 2 - yr 1) | CACI ( C of yr 3 - yr 2) | Average CACI |
|---|---|---|---|---|---|---|---|
| Banke- Maraha CFM | 32 | 197.09 | 196.69 | 195.01 | -0.40 | -1.68 | -1.04 |
| Tuteshwarnath CFM | 33 | 222.58 | 223.41 | 223.89 | 0.83 | 0.48 | 0.65 |
| Gadhanta- Bardibash CFM | 31 | 274.67 | 275.12 | 276.02 | 0.45 | 0.90 | 0.68 |
| Buddha CF | 30 | 163.95 | 165.65 | 167.76 | 1.70 | 2.11 | 1.90 |
| Chure- Parwati CF | 25 | 172.05 | 173.35 | 175.08 | 1.30 | 1.73 | 1.51 |
| Chyandanda CF | 22 | 92.08 | 94.38 | 97.23 | 2.30 | 2.85 | 2.58 |

**Table 2.** Comparison of CACI in community managed forests.

| Variance | Sum of Squares | df | Mean Square | F | *P* - value |
|---|---|---|---|---|---|
| Between Groups | 225.62 | 5 | 45.12 | 149.54 | 0.000 |
| Within Groups | 50.39 | 167 | 0.30 | | |
| Total | 276.01 | 172 | | | |

thinning, pruning and cutting unwanted species as prescribed in their community forest operational plan were applying in community forests whereas they were not practiced in collaborative forests except collection of dead and fallen trees. Most of the plants were of growing stage particularly pole and sapling size in Chyandanda community forests in comparison to other forests. On the other hand, some permanent sample plots were disturbed due to illegal harvesting, fire and grazing in Banke-Maraha CFM (Table 1).

Karky & Banskota (2007) showed that CACI in natural *Shorea robusta* forest of Ilam district in Nepal was 3.1 t ha$^{-1}$ and CACI of mid hill forest of Lalitpur district and high mountain forest of Manang district in Nepal were 1.41 and 1.13 t ha$^{-1}$ respectively. These values are comparable with results of Chure Parwati and Buddha community forests.

### *Comparison of average current annual increment of carbon*

The hypothesis was set whether there was significant difference in current annual carbon increment in different community managed forests. The one way ANOVA showed that there was significant (0.00 < *P*) differences in CACI of community forests at 5 % level of significance (Table 2).

The Multiple Comparisons Tukey's HSD showed that there were significant differences in CACIs among the forests except between Tuteshwarnath and Gadhanta- Bardibash CFMs as well as Buddha and Chure- Parwati CFs (Table 3). The current annual increment of carbon stock depends up on the site quality, species, nature of plant growth, silvicultural practices and age of the plants (Joshi & Ghose 2014; Prakash 2001). Specifically, the very good site quality has high soil fertility, porosity, and soil moisture which favours for high CACI of plants. In addition, the fast growing species shows high CACI than the others. Same way, application of silvicultural operations like thinning, pruning, cleaning, climber cutting and clearing favour the carbon growth of plants. Interestingly, the growth of the plant is slow in very early stage like seedling stage but when the plants enter into young stage particularly in sapling and pole stage they have fast growth. The mature and over plants have about stagnant growth (Lal 2007). So, the presence of more young plants in community forests showed higher CACI per ha than that of collaborative forests. Similar reason was valid for differences in carbon sequestration too because the calculation of carbon sequestration is completely based on CACI in the community forests and collaborative forests. The very dense old forests have high carbon stock but the generally CACIs recorded low (Tewari and Karky 2007).

### *Value of Carbon Sequestration Potential in Collaborative and Community forests*

The annual carbon sequestration or $CO_2$ removal per ha was differed generally according to the stage of plants present in the community forests. The Chyandanda community forest is

**Table 3.** Multiple comparison of CACI in community managed forests using Tukey's HSD Test.

| Forests | Subset for alpha = 0.05 | | | |
|---|---|---|---|---|
| Category | 1 | 2 | 3 | 4 |
| Banke- Maraha CFM | -1.04 | | | |
| Tuteshwarnath CFM | | 0.66 | | |
| Bardibash-Gadhanta CFM | | 0.68 | | |
| Budha CF | | | 1.52 | |
| Chure- Parwati CF | | | 1.89 | |
| Chyandanda CF | | | | 2.58 |

dominated by the pole and sapling stage plants and hence the annual carbon sequestration was found to be highest 9.45 t ha$^{-1}$. On the other hand, it was recorded lowest around 2.4 t ha$^{-1}$ in Tuteshwarnath CFM. These values were found to be close with the finding of Karky & Banskota (2007) which was 11.37 t ha$^{-1}$ in community forest of Ilam.

The value of carbon sequestration varied according to the quantity carbon sequestration. The certified emission reduction (CER) i.e. carbon sequestration was about 2.40 t ha$^{-1}$ in Gadhanta-Bardibash collaborative forest. The CER was multiplied with the rate of carbon sequestration (US $ 5 t ha$^{-1}$) (Molly *et al.* 2012) and its effective area (1231 ha) to show its monetary value. Thus, the estimated total value of carbon sequestration was the highest about US$ 15280.95 in Gadhanta-Bardibash CFM because of the highest total carbon sequestration with 3056.19 ton. On the other hand, the estimated total value of $CO_2$ emission was -US$ 33341.60 in Banke- Maraha collaborative forest due to leakage about -6668.32 ton. Hence, the overall value of carbon sequestration in these community and collaborative forests was US$ 11613.41 (Table 4). In reality, this indicated that, such forests have high potentiality of CER under REDD+ mechanism. However, national REDD+ demonstration project initiated by government of Nepal has not included this region in proposed Emission Reduction Plan Idea Note (ER-PIN). Here, the studies done by Karky & Banskota (2007), undoubtedly the values of carbon sequestration may alike as well. Notably, the risk embeds in valuation of carbon sequestration is beyond the scope of this research.

## Conclusion and recommendations

The estimated current annual carbon increment (CACI) per ha was found to be highest in Chyandanda community forest and lowest with negative in Banke- Maraha CFM. The negative value is the leakage in REDD+ mechanism. Consequently, the annual rate of carbon sequestration per ha in this community forest was found to be highest. Moreover, the monetary value of the carbon sequestration was the highest in Gadhanta- Bardibash CFM because of the highest total carbon sequestration.

The high rate of carbon sequestration per ha per annum in community forests and low rate of this in collaborative pointed out; there is the necessity of management practices in collaborative forests too in Tarai. Indeed, the higher CACIs in these forests are the evidence for the higher CER. Besides, the large contiguous blocks in Tarai forests obviously show the great potentiality under REDD+ mechanism. However, such forests are out of the scope of proposed national REDD+ demonstration project.

The permanent sample plots and the records of measurement were properly maintained during the research work and it should be continually documented in order to find the future trend of carbon sequestration.

The scope of the research should be extended to analyze the risk of forest carbon market.

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**Table 4.** Carbon sequestration potential in community managed forests.

| CFM/CF | Area (ha) | Effective area (ha*) | C- sequestration (t ha$^{-1}$) | Total C-sequestration (t) | Value (US $) | Remarks |
|---|---|---|---|---|---|---|
| Banke- Maraha CFM | 2006 | 1750 | -3.81 (emission) | -6668.32 | -33341.60 | Leakage |
| Tuteshwarnath CFM | 1334 | 1221 | 2.40 | 2934.47 | 14672.35 | |
| Gadhanta- Bardibash CFM | 1450 | 1231 | 2.48 | 3056.19 | 15280.95 | |
| Buddha CF | 69.73 | 55.22 | 6.98 | 385.44 | 1927.21 | |
| Chure- parwati CF | 441.7 | 421 | 5.56 | 2338.96 | 11694.82 | |
| Chyandanda CF | 41.35 | 29.21 | 9.45 | 275.93 | 1379.69 | |
| Total | | | | | 11613.41 | |

*Note: The effective area denotes the remaining areas after deduction of river, stream and open areas.

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