

# A comparative study on carbon stock in Sal (*Shorea robusta*) forest in two different ecological regions of Nepal

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Estimation of total biomass and carbon sequestration in any forest is crucial as it gives ecological and economic benefits through various environmental services. With an aim to quantify the carbon stock densities in the two different ecological regions—the Hills and the Terai, two Community Forests (CFs) having the dominance of *Shorea robusta* were selected from Gorkha (in the Hills) and Chitwan (in the Terai) districts for the purpose of the study. Systematic random sampling with 1% sampling intensity was used to collect necessary data. The total carbon stock in the CFs of the Hills and the Terai were found to be 234.54 t ha<sup>-1</sup> and 479.29 t ha<sup>-1</sup>, respectively. The biomass carbon stock density in the CF of the Terai was found to be higher (384.20 t ha<sup>-1</sup>) than the one in the Hills (123.15 t ha<sup>-1</sup>). Carbon densities of different carbon pools such as tree; sapling; leaf litter, grass and herbs were significantly higher ( $P < 0.05$ ) in the Terai than in the Hill forest whereas dead wood and stumps and the soil organic carbon density were found to be not significantly different in these regions. Similarly, the highest amount of soil organic carbon (SOC) was found in the uppermost soil horizon in the forests of both the regions. These results revealed that the biomass carbon stock density was higher in the Terai *S. robusta* forest than in the Hill *S. robusta* forest. However, the SOC obtained was in inverse relation to that of the biomass carbon stock in both the ecological regions. It would not be biased if different ecological regions with similar forest types are intervened with different management strategies for having more carbon stocks and for the conservation of biodiversity in the days to come.

**Key words:** Biomass carbon, carbon stock density, ecological regions, *Shorea robusta*, soil organic carbon

Carbon stock is the absolute quantity of carbon held within a pool at a specified time whereas carbon sequestration is the process of increasing the carbon content of a carbon pool other than the atmosphere (FAO, 2011). In other words, carbon sequestration is understood as the removal of carbon from the atmosphere by storing it in the biosphere (IPCC, 2000). Forests play a profound role in reducing ambient carbon dioxide (CO<sub>2</sub>) levels as they sequester 20–100 times more carbon per unit area than croplands (Brown and Pearce, 1994). Hence, vegetation and soils play role of viable sinks of atmospheric carbon and may significantly contribute mitigation of global climate change (Bajracharya *et al.*, 1998; Lal, 2004). Biological sequestration of CO<sub>2</sub> by forest has numerous benefits to other emission reduction technologies. Firstly, it is considered to be more effective than other carbon sequestration methods

(Banskota *et al.*, 2007), and so it has become a least cost-solution in the world. Secondly, managing forests sustainably in tropical areas will greatly reduce carbon emissions as it is estimated that global deforestation alone accounts for about 17.4% (IPCC, 2007) of the global greenhouse gases emissions. Thirdly, there is a high potential for enhancing the carbon sequestration in the vegetation and soils of the Himalayan region through improved management of degraded lands (Upadhyay *et al.*, 2005).

Soil organic carbon (SOC) stocks display a high spatial variability (Cannell *et al.*, 1999). In fact, most of the studies concern only the topsoil (e.g. 0–30 cm), although carbon sequestration or loss may also occur in deeper soil layers (Bird *et al.*, 2002; Fontaine *et al.*, 2007). SOC is an important index of soil quality because of its relationship to

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crop productivity (Lal *et al.*, 1997). In this regard, SOC sequestration has numerous economic as well as ecological implications in terms of trading carbon credits, improving quality of soil and water resources, and achieving food security.

Sal (*Shorea robusta*) is the most dominant species of the tropical and subtropical broadleaved forests of Nepal (Jackson, 1994). The *Shorea robusta* forest in Nepal is confined to the Hills and Terai ecological regions. It shares the highest tree volume i.e., 109.4 million m<sup>3</sup> (28.2% of the total tree volume) (Amatya and Shrestha, 2010). *S. robusta* forests not only have higher economic value, but also serve as an important ecological benefit in the form of abating global warming and climate change through conserving atmospheric CO<sub>2</sub> (Shrestha, 2008).

About 1.45 million households or 35 percent of the population of Nepal are involved in community-based forest management program through forming 17,685 Community Forest User Groups (CFUGs) who are managing 1,652,654 hectares of national forest handed over to them (DOF, 2015). Among these CFUGs, few of them have got reward for the carbon enhancement in their forests (Adhikari, 2016) as pilot programs. There is still a hope that the financial resources required to assist the developing countries in undertaking mitigation, and adaptation activities will become more and more significant in the future (UNFCCC, 2015) including Nepal. To ensure the carbon credit getting from one or other programs, it is very crucial to account carbon accumulation in forest to make the communities get benefited from carbon credits and biodiversity conservation. In spite of the protection of forests from local communities for 33 years, only a little attention has been paid so far to forest and soil inventories considering carbon stocks. Hence, amount of soil and biomass carbon sequestered is unknown (Shrestha, 2008) in these forests. In Nepal, most of the studies have been conducted in forests for their tangible economic benefits whereas a very few studies have been done on intangible benefits such as carbon sequestration and biodiversity conservation. Information on carbon stocks in different forest ecosystems in Nepal is still lacking (Shrestha and Singh, 2008).

The participation in Reducing Emissions from Deforestation and Forest Degradation plus (REDD+) mechanism has brighter prospect for

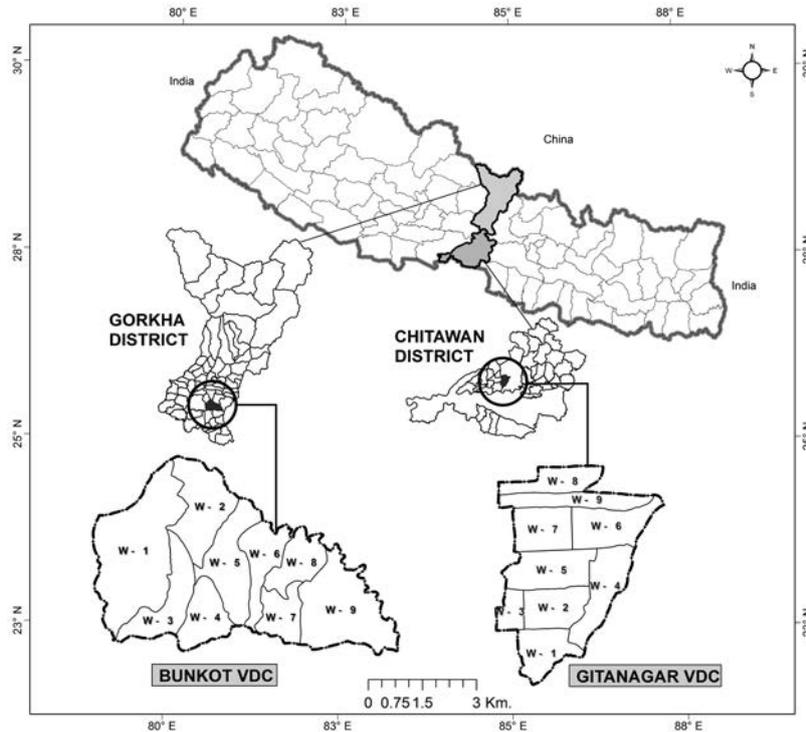
Nepal so as to generate carbon revenues as well as non-carbon benefits for the nation and her people where preliminary estimates show that REDD+ may bring between \$20-86 million per year to Nepal (UN-REDD, 2014). To provide somewhat base-line information regarding REDD+ and to improve the carbon sink of the forests (REDD-IC, 2015), this study could be a reference document since forest reference level is yet to be finalized in the national scenario. Therefore, the first step is to estimate the amount of carbon stocks in the forests of different conditions and types for getting credits from forest carbon in days to come. Hence, the present study aims to quantify and compare the carbon stock densities and to compare the soil carbon densities with at different depths in the community forests having dominance of *S. robusta* in the two different ecological regions of Nepal.

## Materials and methods

### Study area

Located between 27°15' and 28°45' N latitude and between 84°27' and 84°57' E longitude, Gorkha District lies in the hilly region of Central Nepal. The total area of the district is 3,610 km<sup>2</sup> with an altitudinal variation of 228–8,163 m above the mean sea level (amsl) (CBS, 2006). The district exhibits wide range of climate, from sub-tropical in the south to alpine in the north, with 23.1°C mean annual temperature and 1,500.20 mm average annual precipitation (DHM, 2015). Two community forests having the dominance of *S. robusta* were selected from Gorkha (in the Hills) and Chitwan (in the Terai) districts for the study (Fig. 1).

One of the two CFs selected for the purpose was Ghaledanda Ranakhola CF situated in the Bunkot Village Development Committee (VDC) of Gorkha District. The CF selected for the purpose lies in the sub-temperate region with an area of 181.63 ha and with 750–1,000 m altitudinal variation amsl (CBS, 2006). Most of the land is plain consisting of clayey loam soil; the soil is reddish under the *S. robusta* cover and blackish near the water holes. The CF is managed by a total of 459 households with 3,014 family members. The forest is consisted of medium-sized trees and dominated by *S. robusta* associated with *Schima wallichii*, *Castanopsis indica* and *Lagerstroemia parviflora*.



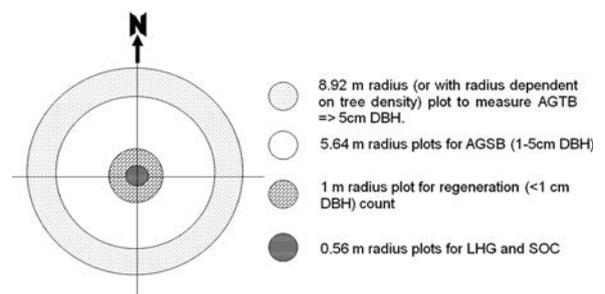
**Fig. 1: Location map of two study areas in Chitwan and Gorkha districts of Nepal**

Another CF selected for the purpose was Nawajyoti Buffer Zone CF situated in the Barandabar Corridor Forest of Geetanagar VDC in Chitwan District. Located between 27°21' N and 27°52' N latitude and between 83°54' E and 84°48' E longitude, Chitwan District lies in the Inner-Terai region of Central Nepal; the total area of the district is 2,205.90 Km<sup>2</sup> with an altitudinal variation of 141 m to 1,947 m amsl (CBS, 2006). Moreover, subtropical type of climate prevails in the district with the yearly average temperature of 26°C and 1,512 mm average annual precipitation (DHM, 2015). The total area of the CF is 44.7 ha with an altitudinal variation of 175 m to 250 m amsl, and is managed and conserved by the Buffer Zone Community Forest User Group (BZCFUG) with a total of 302 households with 1,791 family members. Most of the land is plain consisting of clayey loam soil. The soil is reddish under the *S. robusta* cover and blackish near the water holes, similar to the one in the CF of Gorkha District. Likewise, there are yellowish fertile alluviums in some parts of the forest. The community forest is primarily dominated by *S. robusta* with a number of broad-leaved associate species including *Sapium insigne* and *Bombax ceiba*.

**Forest sampling and plot allocation**

For forest carbon inventory, systematic random

sampling technique with 1% sampling intensity was used. For the purpose of plot allocation, both the forests were stratified on the basis of species composition, and then, on the basis of proportion allocation, concentric circular sample plots (CCSPs) were allocated randomly in each stratum. A total of 75 and 20 CCSPs with the radii of 8.92 m (for measuring trees and poles), 5.64 m (for measuring saplings), 1 m (for measuring seedlings) and 0.56 m (for taking the samples of the leaf litter, herbs, grass and soil) (Fig. 2) were laid out in the CFs of Gorkha and Chitwan Districts, respectively using the method described by ANSAB (2010).



**Fig. 2: Layout of a CCSP in the field**

**Measurement of sample plots**

The diameter (at breast height) and height of all the trees, poles and saplings were measured using D-tapes and Suunto-clinometers, respectively

while the seedlings were counted in the respective sample plots and all the herbaceous and woody vegetation inside the innermost 0.56 m–radius plots were clipped and collected separately to take the fresh weights; the representative sub-samples of 300 m of all the herbaceous plants, woody vegetation, leaf litters and grasses were taken to the soil laboratory of the Institute of Forestry (IOF), Pokhara for oven drying.

### Soil sample collection

The soil samples from various depths (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm) were collected using the methodology adopted by Awasthi *et al.* (2005). All the samples were bagged, labeled and sent to the soil laboratory for further analysis. The pit method was used for determining the bulk densities (Pearson *et al.*, 2005) of the soil samples. Besides, several published and unpublished information were also collected from the secondary sources so as to fulfill the objectives of the study.

### Data analysis

The biomass and carbon stock density from each site were analyzed using the allometric equation and the guidelines mentioned in “Forest Carbon Inventory Directives, 2011” prepared by the REDD Implementation Centre under the Ministry of Forests and Soil Conservation of the Government of Nepal (GoN, 2011).

The analysis of the soil samples were performed, adopting Walkey and Black Method (Jackson, 1958), in the Regional Soil Testing Laboratory of Pokhara. The aggregates of all the sources of carbon pools were added to obtain the total carbon stock. The carbon content was assumed to be 47% of dry biomass (IPCC, 2006 cited

in GoN, 2011). The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools. In order to compare the carbon stock densities between the two ecological regions, t-tests were performed at 5% level of significance with the help of R-Statistical Package Version 2.11.1 (RDCT, 2012). The graphs and tables were constructed using MS-Excel 2010.

## Results and discussion

### Biomass carbon stock density

The total carbon stock density of the forest vegetation including carbon in the trees, saplings, leaf litters, herbs and grass together with the dead wood and stumps was found to be 123.15 t ha<sup>-1</sup> and 384.20 t ha<sup>-1</sup> in the *Shorea robusta* forests of the Hills and the Terai, respectively. The above ground biomass carbon stock density comprised of 91% among the total biomass carbon stock density and the rest 9% belonging to the below ground (root) in both the ecological regions (Table 1). The bulk amount of carbon was found to be stored in the trees (including poles) followed by the leaf litters, herbs and grasses in both the regions. The t-test showed that there was significant difference ( $P < 0.05$ ) in the carbon stock densities of these pools with respective to the ecological regions; the amount of carbon density was found to be significantly higher in the Terai forest than in the Hill forest. On the other hand, the dead wood and stump carbon stock density had no significant difference ( $P > 0.05$ ) with respect to the ecological regions (Table 1). This signifies that same sorts of rules prevailing in the CFs that the users extract forest biomass one or other ways for fulfilling their daily needs.

**Table 1: Biomass carbon stock densities in the study areas**

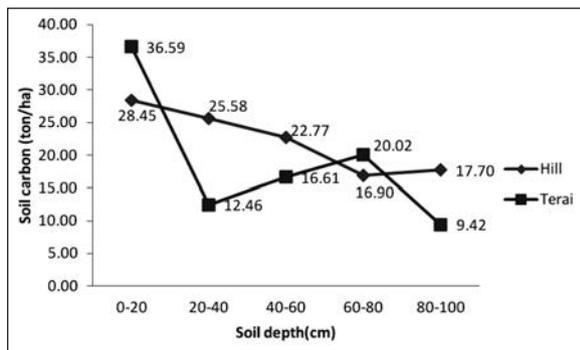
Carbon pools	df	Hill CF	Terai CF	Mean	P-value	Remarks
Tree carbon density (t ha <sup>-1</sup> )	114.004	115.22	359.69	237.455	0.000031	*
Sapling carbon density (t ha <sup>-1</sup> )	36.298	0.28	0.39	0.335	0.002886	*
Herbs, grass and leaf litter(t ha <sup>-1</sup> )	14.977	7.51	23.92	15.715	0.000016	*
Dead and stump carbon(t ha <sup>-1</sup> )	32.151	0.14	0.20	0.170	0.135100	
<b>Total of biomass carbon density</b>		<b>123.15</b>	<b>384.20</b>	<b>253.675</b>		
Soil organic carbon (t ha <sup>-1</sup> )	5.678	111.39	95.09	103.240	0.558200	
<b>Total carbon density</b>		<b>234.54</b>	<b>479.29</b>	<b>356.915</b>		

Remarks: \* = significant at  $P < 0.05$

Carbon on branches, leaves, and roots is included in their respective pools

### Soil organic carbon

The soil organic carbon (SOC) of *Shorea robusta* dominant CF was found to be higher in the Hill *S. robusta* forest (111.4 t ha<sup>-1</sup>) as compared to the one in the Terai *S. robusta* forest (95.1 t ha<sup>-1</sup>) (Table 1). The SOC contained in the topmost layer of soil (0–20 cm depth) in the Hill forest was found to be highest (28.45 t ha<sup>-1</sup>) and lowest (16.9 t ha<sup>-1</sup>) within the horizon of 60–80 cm depth (Fig. 3). Similarly, the SOC of the topmost layer of soil in the Terai forest was found to be highest (36.6 t ha<sup>-1</sup>) and lowest (9.4 t ha<sup>-1</sup>) within the end horizon of 80–100 cm. Even though the cumulative value of the SOC is quite different in these community forests, there was no significant difference ( $P>0.05$ ) in storing organic carbon per unit area with respect to the ecological region (Table 1). The overall trend of the SOC showed the gradual decrease in carbon density with the increase in the soil depth in the Hill forest but there was no such significant trend in the Terai forest. However, the SOC density was found to have decreased from top to bottom with the increase in the soil depth in both the ecological regions (Fig. 3).



**Fig. 3: Ecological region-wise SOC density at different soil depths**

Although the trend line was found to have decreased drastically within the lowest horizon (80–100 cm depth), it was quite fluctuating within the middle horizons (40–60 cm and 60–80 cm depths) in the Terai forest. This clearly indicates the seepage of SOC from the water holes in the *S. robusta* forest of the Terai ecological region. The main reason of difference in the SOC density is because of the difference in their bulk densities and the alluvial deposition in the soils of the Terai forest.

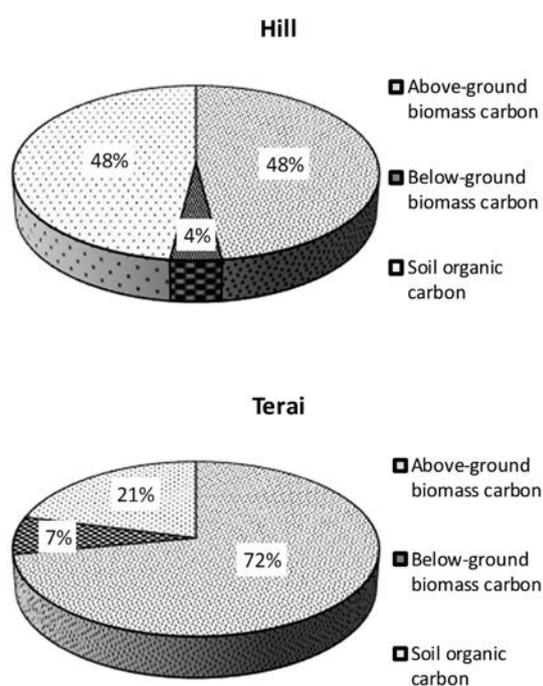
### Total carbon stock density

The combined carbon stock density is the sum of biomass carbon stock density and the SOC stock

density (Table 1). The total organic carbon in the *Shorea robusta* dominated forest was found to be 234.54 t ha<sup>-1</sup> in the Hill *S. robusta* forest while it was 479.29 t ha<sup>-1</sup> in the Terai *S. robusta* forest. A study conducted in the Kusumdanda Community Forest in Palpa District which is also situated in the Hill ecological region of Nepal, showed the carbon stock density in a *Shorea robusta* forest to be 186.95 t ha<sup>-1</sup> (Nepal, 2006) and later, 235.95 t ha<sup>-1</sup> Shrestha (2008), which are almost similar to the results of this study conducted in the same ecological region. Another study conducted by ANSAB in the same CF (Ghaledanda Ranakhola CF in Gorkha) in 2011 estimated 211.184 t ha<sup>-1</sup> of carbon stock whereas the SOC was calculated only up to 30cm depths (ANSAB, 2011). The total organic carbon in the Terai (479.29 t ha<sup>-1</sup>) was found to be far greater than the average carbon stock of the tropical forests (285.0 t ha<sup>-1</sup>) of the world (Jina *et al.*, 2008) although lower than the mean carbon stock estimation of the CF in Nepal (Acharya *et al.*, 2009). This might be the reason of the availability of greater average diameter and height classes of the trees in the *S. robusta* dominated forest in the Terai as compared to the one in the Hills. The carbon stock density estimated in this study was higher than the average carbon stock in Nepalese forest (161.1 t ha<sup>-1</sup>) estimated by the Global Forest Resource Assessment Report of FAO (2006). The reason behind might be because of the use of the projected Forest Inventory data of 1994 by the FAO in its report.

However, the SOC in the Terai *S. robusta* forest was found to be lesser than that in the Hill *S. robusta* forest. Besides, the SOC content was also found to be low as compared to the biomass carbon content in the Terai forest whereas it was almost equal in the forest situated in the Hill region. In the case of SOC, it is highly dependent on bulk density, content of organic matters, type of soil and parent material since bulk density depends on several factors such as compaction, consolidation and amount of carbon present in soil (Morisada, *et al.*, 2004 and Leifeld *et al.*, 2004 cited in Ranabhat *et al.*, 2008). Also, this clearly indicates the higher collection of leaf litter and plant residues by the community forest users from the Terai *S. robusta* forest, or the alluvial deposition in the soils of the Terai *S. robusta* forest, because of which the organic matter content in the soils is significantly decreased.

In the case of the Hill *S. robusta* forest, both the above ground biomass and the SOC were found to possess 48% of carbon and the below-ground biomass (4%) whereas in the case of the Terai *S. robusta* forest, more than two third of the carbon was found to be accumulated in the above-ground biomass (72%) followed by SOC (21%) and the least (7%) in the below-ground biomass (Fig. 4). The above-ground biomass carbon in the Terai forest was almost 1.5 times more than that in the Hill forest whereas the SOC content was in reverse order as the Terai *S. robusta* forest contained less than half proportion of SOC than the Hill *S. robusta* forest.



**Fig. 4: Different carbon pools in the Hill and Terai *S. robusta* forests**

## Conclusion

The total biomass carbon density was found to be significantly higher in the Terai *S. robusta* dominated CF (384.2 t ha<sup>-1</sup>) than in the Hill *S. robusta* dominated CF (123.2 t ha<sup>-1</sup>). However, the SOC in the Hill CF (111.4 t ha<sup>-1</sup>) was found to be more than the one in the Terai CF (95.1 t ha<sup>-1</sup>). It was found that the SOC decreased with the increase in soil-depth in both the ecological regions. The SOC contributed 48% of the total carbon pool in the Hill *S. robusta* forest whereas it accounted for 21% in the case of the Terai CF. Similarly, the total carbon stock density was

found to be significantly higher in the Terai CF (479.3 t ha<sup>-1</sup>) than in the Hill CF (234.5 t ha<sup>-1</sup>). These results reveal that the communities have been conserving remarkable amount of carbon in their forests through proper forest management. However, replications of similar types of research on both the ecological regions are crucial to get valid inferences for the generalization of the result throughout the nation.

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