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Assessment of Carbon Sequestration Potential in Degraded and Non-Degraded Community Forests in Terai Region of Nepal

Rajeev Joshi[1,2,*], Hukum Singh[3], Ramesh Chhetri[1,4] and Karan Yadav[5]
[1]*Forest Research Institute (Deemed to be) University, Dehradun, Uttarakhand 248195, India*
[2]*Amity Global Education (Lord Buddha College), Affiliated to CTEVT, Tokha Municipality 11, Kathmandu 44600, Nepal*
[3]*Forest Ecology and Climate Change Division, Forest Research Institute, P.O New Forest, Dehradun, Uttarakhand 248006, India*
[4]*Kali Gandaki Polytechnic Institute, CTEVT, Ghiring 1, Tanahun 33900, Nepal*
[5]*Department of Forestry, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand 246174, India*

Abstract

This study was carried out in degraded and non-degraded community forests (CF) in the Terai region of Kanchanpur district, Nepal. A total of 63 concentric sample plots each of 500 m^2 was laid in the inventory for estimating above and below-ground biomass of forests by using systematic random sampling with a sampling intensity of 0.5%. *Mallotus philippinensis* and *Shorea robusta* were the most dominant species in degraded and non-degraded CF accounting Importance Value Index (I.V.I) of 97.16 and 178.49, respectively. Above-ground tree biomass carbon in degraded and non-degraded community forests was 74.64±16.34 t ha^{-1} and 163.12±20.23 t ha^{-1}, respectively. Soil carbon sequestration in degraded and non-degraded community forests was 42.55±3.10 t ha^{-1} and 54.21±3.59 t ha^{-1}, respectively. Hence, the estimated total carbon stock was 152.68±22.95 t ha^{-1} and 301.08±27.07 t ha^{-1} in degraded and non-degraded community forests, respectively. It was found that the carbon sequestration in the non-degraded community forest was 1.97 times higher than in the degraded community forest. CO_2 equivalent in degraded and non-degraded community forests was 553 t ha^{-1} and 1105 t ha^{-1}, respectively. Statistical analysis showed a significant difference between degraded and non-degraded community forests in terms of its total biomass and carbon sequestration potential ($p<0.05$). Studies indicate that the community forest has huge potential and can reward economic benefits from carbon trading to benefit from the $REDD^+$/CDM mechanism by promoting the sustainable conservation of community forests.

Key Words: biomass, carbon, carbon pools, climate change, community forest

Introduction

Forests play an important role in the climate system (Sohel et al. 2019). Globally, Forests act as both source and sink of carbon (IPCC 2006; Liu et al. 2019). It is believed that the carbon sequestration by growing forests has enormous potential and can be a cost-effective option for the mitigation of global climate change (Brown et al. 1996). However, forest ecosystems is being degraded in various ways especially community dependency on forests, human encroachment, road construction, desertification, mining activities, etc. Those all factors alter climate change adapta-

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Corresponding author: Rajeev Joshi[1,2]

[1]Forest Research Institute (Deemed to be) University, Dehradun, Uttarakhand 248195, India
[2]Amity Global Education (Lord Buddha College), Affiliated to CTEVT, Tokha Municipality 11, Kathmandu 44600, Nepal
Tel: +9779848758306, Fax: +977-01-4363228, E-mail: joshi.rajeev20@gmail.com

tion and mitigation efficiency of forests. Based on the damage or the disturbance, the community forests have been classified into two groups' *i.e.* degraded and non-degraded forests (Jina et al. 2008). Similarly, soil also plays an important role in carbon sequestration by increasing soil organic carbon. Once the plant dies or the plant material decomposes the carbon is released to the soil (Banik et al. 2018). Thus, the forests and soil can be well managed to sequester or safeguard substantial amounts of carbon on the land (Sharma et al. 2011).

Several studies have shown that well-managed community forest areas can be effective at reducing deforestation: for example, analyses that compared deforestation inside and outside managed community forest areas (Nepstad et al. 2006; Joppa et al. 2008; Scharlemann et al. 2010). Similarly, the carbon stored in community forests network can lead to the effective storage of global carbon. It is an approach to mitigate increasing deforestation and forest degradation and address the negative impacts on rural livelihood with the participation of local people. Community Forestry program is a bottom-up approach that addresses livelihood and abates environment degradation through good governance and sustainable forest management (Gautam et al. 2008).

Community forests in Nepal are the part of national forests that are managed by the community themselves through Community Forest User Groups (CFUGs) which were evolved after the late 1970s when massive deforestation happened in state-controlled forests. In Nepal, the community managed forests are offering the enormous potential for carbon sequestration and hence can play a major role in the $REDD^{+}$ scheme (Karky and Skutsch 2010). Worldwide, this handing over of national forest to CFUGs is highly appreciated because of several successful and magical changes and most common ones are preventing deforestation and forest degradation, conservation of diversity and forests resource, restoring and increasing in stocks, generating high incomes, supporting in poverty alleviation etc. but still there is a severe doubt to manage the forests through community forests in Terai and inner terai region of Nepal due to the development of infrastructure particularly roads and desirous interest of users to trade the timber from the community forests (Pokharel et al. 2007).

CO_2 has been identified as one of the major greenhouse gases (Shahid and Joshi 2018). Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change (Dey et al. 2014). A large number of studies regarding the carbon estimation were found in Nepal but very few research works were found regarding the degraded and non-degraded community forests. Hence, it is necessary to quantify the carbon stocks in order to understand the potential role of community forests in carbon sequestration. The main objective of this study was to provide the baseline information for the carbon sequestration potentiality and to quantify carbon sequestered in the degraded and non-degraded community forests of Kanchanpur district, Nepal.

Materials and Methods

Study area

The study was carried out in Ganesh and Ramnagar community forests (CF) of Kanchanpur district of Nepal. It is located in Farwestern Province at southwestern part of Nepal which lies between 28.8372° N latitude and 80.3213° E longitudes (Fig. 1). The elevation of the district ranges lower tropical below 300 meters and upper tropical ranges from 300-1000 meters. Ganesh CF is a natural mixed Sal broad-leaved forest with dominant species *Mallotus philippensis* which covers an area of 434.48 ha at 221-300 m.a.s.l. Ramnagar CF is natural Sal forest that covers an area of 197.16 ha at 120-145 m.a.s.l. Other species such as *Adina cordifolia*, *Anogeissus latifolia*, *Lagerstroemia parviflora*, *Schleichera oleosa*, *Pterocarpus marsupium*, etc. were observed on both sites. The average

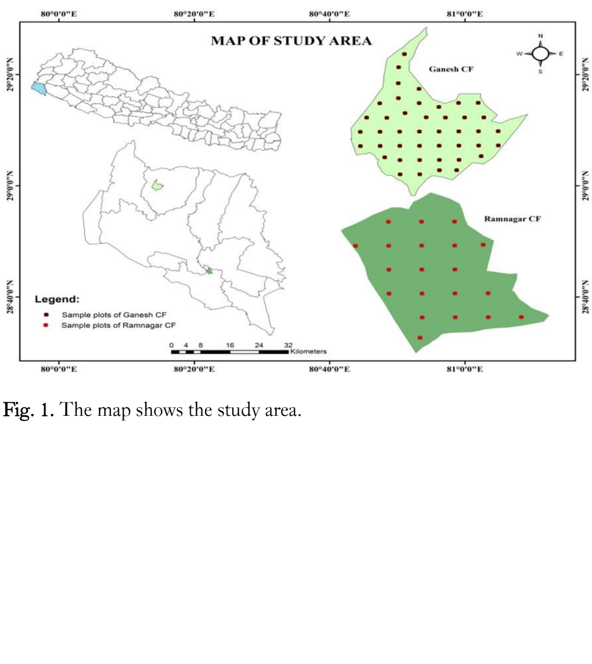

Fig. 1. The map shows the study area.

annual rainfall ranges to 1512.12 mm and temperature ranges to 13°C to 38°C.

Data collection and analysis

Selection criteria for degraded and non-degraded community forests

Presence or absence of regeneration

The most important criteria for the selection of degraded and non-degraded community forests site was based on the presence or absence of regeneration (*Shorea robusta*) in community forests.

Crown cover

Those sites with less than 40% crown cover were considered as degraded and those having crown cover above 60% as non-degraded community forests (Jina et al. 2008).

Grazing

The presence of the hoofmarks and dungs of livestock, broken tops of seedlings and saplings, signs of trampling, etc. were the criteria to determine the grazing pressure on community forests.

Fodder extraction

Community forest sites from where fodder extraction was only for a few weeks in a year, were taken as non-degraded and sites having no restriction on fodder extraction and consumption were considered as degraded community forests (Jina et al. 2008).

The number of lopped branches per tree

The community forests sites where the lopped branches per tree were 50% and more were taken as degraded and sites having less than 20% lopped branches per tree as non-degraded((Jina et al. 2008).

Based on the selection criteria, Ganesh community forest was considered as degraded community forest and Ramnagar community forest as non-degraded community forest.

Forest sampling design and measurement

The selected community forests were delineated with the help of GPS and Arc Map 10.5 software. Systematic sampling with a sampling intensity of 0.5% was applied. Total 63 concentric sample plots each of 500 m^2 was laid in both Ganesh CF and Ramnagar CF. Circular plot of radius 12.62 m, 5.64 m and 1m was used for sampling trees (DBH > 5 cm), saplings (DBH 1 to 5 cm), and regeneration (DBH < 1 cm) respectively. Leaf litter, herbs, grass, and soil were measured at the center of a circle with a 0.56 m radius. Diameter at breast height (dbh) of each tree within the plot was measured using diameter tape at 1.3 m and the height of each tree was determined using Silva clinometer.

All the understory bushes, grasses, and herbaceous plants within 0.56 m radius were clipped and the fresh weight of the sample was determined. Representative subsamples of 500 gm were taken to the lab for oven-dry (72 hours at 60°C). Two replication of soil samples from each sample plot were collected up to 30 cm depth (0-10 cm, 10-20 cm, and 20-30 cm) for analyzing soil organic carbon and bulk density.

Biomass and carbon estimation

Non- destructive estimation of biomass was carried out in the study. The following procedure was considered for the study.

Aboveground tree biomass (AGTB) and sapling biomass (AGSB)

The Above Ground Tree Biomass (AGTB) was calculated by using allometric equation, $AGTB = 0.0509 \times D^2 \times \rho \times H$ [where, ρ=Wood specific density (kg m^{-3}), D=Tree diameter at breast height (cm), H=Tree height (m)] (Chave et al. 2005) for trees and poles (dbh > 5 cm). This allometric equation does not perform precise results for the saplings having dbh < 5 cm (Chave et al. 2005). Thus, the Above Ground Sapling Biomass (AGSB) was estimated using the national algometric biomass tables, $Log (AGSB) = a + b \log (D)$ where, Log=natural log [dimensionless]; a=intercept of allometric relationship for saplings [dimensionless]; b=slope allometric relationship for saplings [dimensionless]; and D=over bark diameter at breast height (measured at 1.3 m above ground) [cm]. These tables are developed by the Department of Forest Research and Survey (Forest Resource Assessment Nepal 2015) and the Department of Forest, Tree Improvement, and Silviculture Component (TISC) (Tamrakar 2000).

Leaf, herb and grass biomass (LHGB)

To determine the biomass of leaf litter, herbs, and grass (LHG), all the understory bushes, grasses, and herbaceous layers were clipped and weighed. The total weight of the clipped samples was taken in each sample plot and samples were taken destructively in the field within a small area of 1 m^2. Fresh samples were weighed in the field a well-mixed and sub-sample was then placed in a marked bag. Then, the sub-sample had been used to determine an oven-dry (60°C for 72 hours) to wet mass ratio that had been used to convert the total wet mass to oven-dry mass. The carbon content in LHG was calculated by multiplying LHG with the IPCC (2006) default carbon fraction of 0.47. The following formula was applied to estimate the biomass value of leaf, litter, twigs, grass, and herbs (Lasco et al. 2005).

$$ODW_{(t)} = [TFW - \{TFW \times (SFW - SODW)\}]/SFW$$

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

Belowground biomass (BGB)

Belowground biomass (BGB) was calculated by multiplying the value of AGB with the constant factor 0.26 as prescribed by Good Practice Guidelines (GPG) of IPCC (2006), Mandal and Joshi (2015) (BGB=AGB×0.26). Where, BGB=Below-ground biomass and AGB=Above-ground biomass.

Deadwood biomass (DWB)

Deadwood biomass (DWB) was estimated by adding above-ground biomass and below-ground biomass and then multiplying the sum with a constant factor of 0.11 of IPCC (2006) as given below: DWB=(AGB+BGB)×0.11.

Soil organic carbon (SOC)

Soil samples were air-dried for 10 days and then the titrimetric method based on Walkley and Black (1934) method was used for SOC determination. The carbon stock density of soil organic carbon was calculated as (Pearson et al. 2007).

$$SOC = \S \times d \times \%C$$

Where, SOC=soil organic carbon stock per unit area (t/ha); §=soil bulk density (gm/cc); d=the total depth at which the sample was taken (cm), and %C=carbon concentration (%). Soil bulk density (§) was obtained as the ratio of oven dry mass (gm) to core volume (cc).

Total carbon stock

Finally, the carbon values for each forest carbon pool were summed to estimate total forest carbon stock. The total forest carbon stock was then converted into tones of CO_2 equivalent by multiplying by 3.67, as suggested by Pearson et al. (2007). The following equation was used to calculate the total forest carbon stock.

$$TC = C\ (AGTB) + C\ (AGSB) + C\ (LHG) + C\ (BB) + C\ (DWB) + SOC$$

Where, TC=Total carbon stock [t ha^{-1}]; C (AGTB) = Carbon stock in aboveground tree biomass [t ha^{-1}]; C (AGSB)=Carbon stock in aboveground sapling biomass [t ha^{-1}]; C(BB)=Carbon stock in belowground biomass [t ha^{-1}]; C (DWB)=Carbon stock in deadwood biomass [t ha^{-1}]; C (LHG)=Carbon stock in leaf litter, herb and grass [t ha^{-1}] and SOC=Soil organic carbon [t ha^{-1}].

Statistical analysis

Statistical analysis such as univariate analysis under General Linear Model was performed to study the significant difference between two variables. Statistical analysis was conducted using the SPSS software.

Results and Discussion

Aboveground tree and sapling biomass and carbon stock.

The above-ground tree biomass (AGTB) and carbon stock in Ganesh (degraded) CF was found to be 163.07 t ha^{-1} and 76.64 t ha^{-1}, respectively which was lower than in Ramnagar (non-degraded) CF (biomass 347.06 t ha^{-1} and carbon 163.12 t ha^{-1}). Similarly, the above-ground sapling biomass (AGSB) and carbon stock in Ganesh (degraded) CF was estimated to be 3.51 t ha^{-1} and 1.65 t ha^{-1}, respectively which was lower than in Ramnagar (non-degraded) CF accounting biomass 26.84 t ha^{-1} and carbon 12.62 t ha^{-1}. The above-ground tree and sapling biomass of Ramnagar (non-degraded) CF was found to be dominant due to the occurrence of larger sized trees and saplings which consequently have higher biomass values. This study was also similar to the outcomes of Jati (2012) which reported that total tree biomass carbon was estimated to be higher in managed (non-degraded) community forests than the degraded community forests. Similarly, AGB (373.9 t ha^{-1}) of Ramnagar (non-degraded) CF was found considerably more than AGB (100-160 t ha^{-1}) estimated by IPCC (2006) for the subtropical forest of Asian continental region. The AGB of this CF is slightly lower than AGB (406 t ha^{-1}) of Sal plantation of Meghalaya and considerably higher than AGB (154.94 t ha^{-1}) of Sal forest of Satpura plateau as reported by Rabha (2014). The difference in above-ground carbon stock in these community forests might be due to variation in forest age, forest type and site, geographical regions and its locality factors.

Leaf, herb and grass biomass (LHGB) and carbon stock

The carbon stock of LHG was estimated to be 1.09±0.21 t ha^{-1} in Ramnagar (non-degraded) CF whereas it was 0.63±0.06 t ha^{-1} in Ganesh (degraded) CF which shows a considerably low quantity of carbon stock compared to other carbon pools. The current study reflects that the non-degraded CF, to be slightly more efficient for sequestrating more amount of carbon in LHG than the degraded CF. As it is understood that the quantity of LHG biomass depends greatly upon the grasses, herbs and available litter on the ground of the community forests. If the CFUG members are regularly collecting the LHG, then there will be less chance of having higher amounts of LHG on the floor. Since there was no such strict rule to restrict the collection of LHG in Ganesh (degraded) community forests. Hence, this may be a reliable reason having low carbon stock in LHG of Ganesh (degraded) community forests.

The current study of LHG biomass of Ganesh (degraded) CF falls slightly in the same range of LHG biomass of mixed forests of India (1.52±1.1 t ha^{-1}) reported by Singh et al. (2011) but it was lower than Ramnagar (non-degraded) CF *i.e.* 2.32 t ha^{-1}. Similarly, the LHG biomass of both CFs was found to be lower than the LHG biomass (3.5-4.2 t ha^{-1}) of the tropical wet evergreen forest of Western Ghats as estimated by Swampy et al. (2010). The carbon quantity in LHG in both CFs was recorded to be higher than that of Shyalmati watershed (0.283 t ha^{-1}) (Chhetri 2010). The collection of LHG at any time can have both merits as well as demerits because on the one hand due to harvesting of the LHG it may decrease the forest fuel loads which will minimize the severe forest fire and on the other hand during the collection of LHG, there might be chances of crushing and trampling to the sapling and small plants which may effect on the growing stock of community forest.

Belowground biomass (BGB) and carbon stock

BGB obtained from the Ganesh (degraded) CF and Ramnagar (non-degraded) CF were found to be 43.31 t ha^{-1} and 97.21 t ha^{-1}, respectively. It also shows the higher carbon stock compare to Namuna Community forests studied by Karki (2008). However, in another study conducted by (Dhakal 2009) in a naturally regenerated forest of Pashupati Community Forest of Sarlahi had 181.83±26.34 t ha^{-1} which is higher than the present studied CFs. The main reason behind lower carbon stock may be the younger trees and low tree density.

Deadwood biomass (DWB) and carbon stock

The deadwood biomass of Ganesh (degraded) and Ramnagar (non-degraded) CF was found to be 54.83 t ha^{-1} and 21.53 t ha^{-1}, respectively. Bastienne and Pablo (2008) estimated DWB of world forests 0 to >600 t ha^{-1}. In comparison to these, the present study estimates are less than that of world forests. However, the DWB of both the CFs is considerably higher than DWB (3.6 t ha^{-1}) of South and South East Asia as estimated by Food Agriculture Organization of the United Nations (2010).

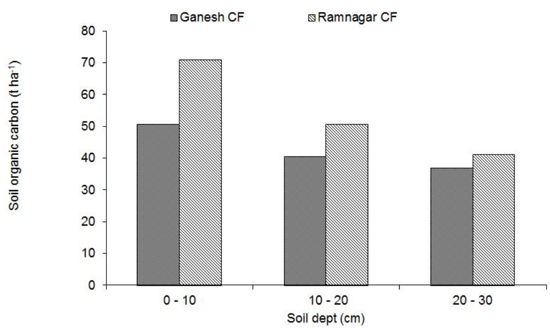

Fig. 2. Graph showing the amount of soil organic carbon stock in each horizon.

Soil organic carbon (SOC) stock

The mean SOC of Ganesh CF was lower than Ramnagar CF estimated to be 42.55±3.10 t ha^{-1} and 54.21±3.59 t ha^{-1}, respectively. Similarly, the total SOC pool in Ganesh degraded and Ramnagar non-degraded CF was found to be 127.64 t ha^{-1} and 162.64 t ha^{-1} respectively. The SOC value of Ganesh CF was estimated to be less than that of Ramnagar CF. In both degraded and non-degraded types of CFs, the maximum SOC was estimated to be in the upper layer (0-10 cm) and gradually it was found to be in decreasing trend with the increase in soil depth. Therefore, the results indicated that with an increase in soil depth, SOC was found to be in decreasing trend while the bulk density was found to be in increasing trend in both CFs (Fig. 2).

Similarly, in the study done by Zhu et al. (2010) the SOC value was obtained to be 70 t/ha which was comparable with the present SOC value of upper layer (70.81 t ha^{-1} up to 0-10 cm soil depth) of Ramnagar non-degraded CF but it was lower in Ganesh degraded CF (50.51 t ha^{-1} up to 0-10 cm soil depth). The result obtained by Sheikh et al. (2009) was different from this study because his study was related to the altitudinal variation of SOC in altitude of 1600-2200 masl in the coniferous subtropical and broadleaf temperate forests of Garhwal Himalaya.

Total biomass and carbon stock

In the study, the total quantity of carbon stock was estimated to be higher in non-degraded (Ramnagar) CF compared to degraded (Ganesh) CF accounting 301.08±27.07 t ha^{-1} and 152.68±22.95 t ha^{-1} respectively. The total carbon stock in each community forests may vary from site to site due to various factors. Therefore, from the study, the result showed that there is a significant difference in the total amount of carbon stock between degraded and non-degraded community forests. The p-value was estimated to be <0.05 *i.e.* 0.0006, thus the null hypothesis is rejected which indicates that there is significant difference in total carbon stock between the degraded and non-degraded community forests (Table 1).

Table 1. Total carbon sequestration in degraded (Ganesh) and non-degraded (Ramnagar) community forests

Carbon pools	Carbon stock (t ha^{-1})		p-value
	Ganesh CF	Ramnagar CF	
Aboveground tree carbon	76.64±16.34	163.12±20.23	$p<0.05$
Aboveground sapling carbon	1.65±0.33	12.62±1.84	
Leaf litter, herb & grass carbon	0.63±0.06	1.09±0.21	
Belowground carbon	20.36±4.25	45.69±5.11	
Deadwood carbon	10.85±2.26	24.36±2.72	
Soil organic carbon	42.55±3.1	54.21±3.59	
Total	152.68±22.95	301.08±27.07	

Total carbon stock for two community forest types is significantly different with p-value 0.0006 ($p<0.05$). The R-square value for the univariate analysis was 0.409 for biomass and carbon. The above-tabulated information (Table 1) is shown below in graphical form which shows the total carbon content variation in different carbon pools of both CFs (Fig. 3).

The numerous reasons behind the results of the study may be due to various effects of drivers of deforestation and forest degradation. Considering the scientific management of forest, forest management practices and silvicultural operations in Ramnagar (non-degraded) CF was well-practiced than in Ganesh (degraded) CF. Generally, it was seen that the CFUG members of Ganesh (degraded) CF were illegally collecting the small timber, LHG, and fuelwood. This type of activity was not so common in Ramnagar (non-degraded) CF. In addition; uncontrolled grazing and sudden fire also had been observed more in Ganesh (degraded) CF. All the above factors might be the reasons for affecting the carbon stock in both CFs.

Although, limited studies were carried out regarding the carbon stock in the degraded and non-degraded type of

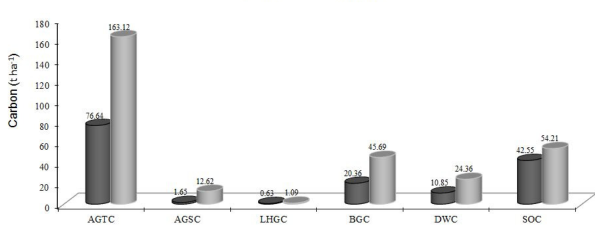

Fig. 3. Total carbon (t ha^{-1}) in different carbon pool of both CFs.

community forests of Terai Nepal. However, the study done by Bhatt (2004) showed that the natural forests had higher carbon storage than the community forests which was conducted in mixed broadleaf forests of Phulchoki watershed. It was concluded that low carbon content in the community forest was due to the high consumption and encroachment of people. Although Jati (2012) carried out the comparative study of the carbon assessment in preserved and managed forests of Kumvakarna Conservation Community Forest, KCAP, Taplejung, and the results showed that the managed forests (109.10 t ha^{-1}) having more amount of carbon storage than the preserved forests (177.44 t ha^{-1}). It was concluded that the managed forests to be more efficient for carbon storage although the disturbances such as fuelwood collection, grazing, timber harvesting, and fodder collection were found more in managed forests. All the above study shows lower carbon content than that current study of Ramnagar (non-degraded) CF.

Similarly, Nizami (2010) reported the mean carbon stocks in subtropical managed and unmanaged forests of Pakistan and estimated carbon content to be 114±2.26 t ha^{-1} and 27.77±1.66 t ha^{-1} respectively which was comparatively lower than Ganesh (degraded) and Ramnagar (non-degraded) CF. ANSAB (2010) estimated carbon stock in *Shorea robusta* mixed sub-tropical hill deciduous forest in Ludikhola of Gorkha (165.91 t ha^{-1} to 216.16 t ha^{-1}). This value of carbon stock is lower than that of Ramnagar (non-degraded) CF and higher than Ganesh (degraded) CF. Accordingly, *Shorea robusta* was reported with the highest biomass and carbon stock in both of the community forests. The percentage share of different carbon pools in degraded (Ganesh) and non-degraded (Ramnagar) CFs is represented in the pie chart (Fig. 4).

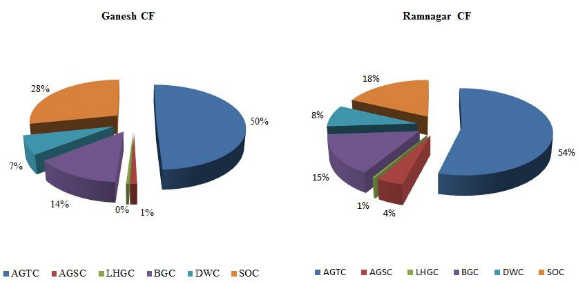

Fig. 4. Carbon (t ha^{-1}) in different carbon pool of both CFs.

Conclusion

The total carbon stock density as revealed from this study was significantly higher in the non-degraded community forest (301.09±27.07 t ha^{-1}) than in the degraded community forest (150.68±22.95 t ha^{-1}). Similarly, soil organic carbon (SOC) was found gradually decreasing in the deeper horizon of the soil with the increase in soil depth while the bulk density was found to be increased in both CFs. The SOC contributed 28% of the total carbon pool in the degraded community forest whereas in the case of the non-degraded community forest it accounted for 18%. Further, it was found that the total carbon stock of the non-degraded community forest was 1.97 times higher than in the degraded community forest. Moreover, CO_2 equivalent in degraded and non-degraded community forests was 553 t ha^{-1} and 1105 t ha^{-1}, respectively. Carbon sequestration potential showed a significant difference between degraded and non-degraded community forests in terms of its total biomass and carbon sequestration potential ($p < 0.05$). All the values of measured carbon pools were higher in a non-degraded type of CF than in the degraded type of CF. Similarly, the leaf litter, herbs, and grass had very little contribution towards the total carbon stock of both community forests. Hence, this study fulfilled the objectives to estimate and compare biomass and carbon stock of the degraded and non-degraded type of CF. Evidence of the strong association of carbon stock of non-degraded community forests has enormous potential and can reward economic benefits from carbon trading under CDM mechanism leading to conservation of forest sustainably.

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