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Assessment of Carbon Stock and its Relationship with Species Richness and Disturbance in Community Forests of Kayarkhola Watershed, Central Nepal

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Abstract Forests play an important role in absorbing the atmospheric carbon dioxide. However, the carbon sequestration potential of a forest is affected by several natural and anthropogenic factor. The aim of this research is to assess and quantify the forest carbon stock and study the effect of species richness, strata, invasive species, grazing, fodder collection, and slope in community forest of Kayarkhola watershed, Central Nepal. A total of 50 circular sampling plots throughout six community forests were taken to quantify tree and sapling biomass. Forest carbon stock was calculated in three major pools- above and below ground tree biomass and above ground sapling biomass in accordance with dense and sparse strata. The total carbon stock stored in dense and sparse forest strata was estimated to be 177.18 tons/ha and 128.175 tons/ha respectively. This study shows that the individual effect of the disturbance factors such as grazing, fodder collection, presence of invasive species and strata doesn't have significant impact on the tree biomass. However, the combined effect can be significant. The combined effect of species richness, grazing and slope was observed to have greater effect on the tree's biomass of community forest in central Nepal.

Keywords: *carbon stock, community forest, disturbance, tree biomass*

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1. Introduction

Forest ecosystems provide a number of provisioning, regulatory, supporting and cultural services that are important to the lives and livelihood of humans, and they play an important role in maintaining habitats that support important global biodiversity [1]. Compared to other terrestrial ecosystems, forest store the highest quantity of carbon [2], with the majority of sequestrated carbon in woody biomass. Because of this, forests can play an important role in climate change mitigation [3]. Trees absorb atmospheric carbon dioxide in the form of carbon, and hence reduce the accumulation of greenhouse gas (GHGs) in the atmosphere. Deforestation and forest degradation influence the amount of carbon in the atmosphere, with the deforestation and forest degradation contributing an estimated 18% of total annual anthropogenic greenhouse gas emissions [4]. This argument has been supported by the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) that the forestry sector alone contributes 17.4% of the all greenhouse gases from human caused sources; most of which is due to deforestation and forest degradation [5]. The IPCC fifth assessment report (2014) also clearly identifies the forestry sector as one of the key sectors for GHGs emissions [6]. However, the recent estimates of global carbon emission from 2011 to 2015 point to a 25% reduction in emission resulting from deforestation and forest degradation. This drop is linked to net growth in planted forest [7].

In Nepal, a forest inventory conducted by Department of Forest Research and Survey (2015) estimated the nation's forested area to be 44.74% including other wooded land, with anthropogenic pressure of deforestation in Churia region mostly due to grazing [8]. Some previous studies such as Food and Agriculture Organization of the United Nations estimated the deforestation rate of Nepal maintained at 1.63% per annum from 1990 to 2005. The average deforestation rate in the southern plains from 1991 to 2001 was estimated to be 2.7% per annum [9]. These data validate the shrinking of forest cover over the last four decades. Nepal's Ministry of Forest and Soil

Conservation [10] has identified nine drivers of deforestation and forest degradation: high dependency on forests and forest products (timber, fuel wood and other non-timber forest products), illegal harvesting of forest products, unsustainable harvesting practices, forest fire, encroachment, overgrazing, infrastructure development, resettlement and expansion of invasive species. The sustainable management of forests is essential to addressing these drivers of deforestation and forest degradation, reducing pressures in forests and promoting biodiversity conservation. While conserving and reducing forest biomass loss can provide a relatively cheap options for climate change mitigation by reducing emission from deforestation and forest degradation [4], these forests are also important in supporting the livelihood of surrounding forest dependent communities and particularly the local poor as they directly extract the forest products from their nearby forests in order for their survival and daily activities upon the forest could get the benefits and maintain sustainable livelihood. Therefore, it is important to understand how the forest carbon stocks is affected by different assemblage and management factors. This study aims to estimate forest carbon stock and study the effect of species richness, strata, and disturbance factors such as fodder collection, grazing and presence of invasive to carbon stocks in community forests of in Kayarkhola Watershed, Central Terai, Nepal.

2. Materials and Methods

2.1. Study Area

This study was carried out in Kayarkhola Watershed Area (between 27°40’07.79’’ - 27°46’37.15’’N and 84°33’25.88’’ - 84°41’48.85’’E) which is located in the Chitwan district, State 3 of Nepal (Figure 1). Altitude of this watershed ranges from 245 m to 1944 m. This region is characterized mainly by upper tropical (300m-1000m above sea level) and lower tropical (<300m above sea level) climate. Temperature reaches up to 29-32°C in summer and remains 16-19°C in winter. The average annual rainfall is 1436.32 mm. According to the broader climatological classification of forests, forests in Kayarkhola watershed fall under tropical broadleaved. *Shorea robusta* mixed sub- tropical hill deciduous forest forms major forest type associated with *Lagerstroemia parviflora*, *Adina cordifolia*, *Schima wallichii*, *Mallotus philippensis* and *Terminalia tomentosa*, representing the lower altitudinal dominant tree species. Other species found in this region were *Casearia graveolens*, *Cassia fistula*, *Albizia lebbeck*, *Nyctanthes arbortristis*, and *Castanopsis tribuloides*. Within this watershed lies 16 community forest covering an area of 2381.96 hectare [11]. This study was conducted in six Community Forest within this watershed representing tropical to sub-tropical zones.

2.2. Sample Design

Carbon stock measurement can be carried out in both rectangular and circular plots. Nevertheless, circular samples were taken for the study because they are relatively easy to establish especially in sloping terrains and also reduce the edge effect problem that normally occurs in rectangular plots. Over the watersheds, 50 plots in six community forests were taken randomly to cover dominant vegetation types. Using Hawth’s Analysis Tool for ArcGIS, 50 random points were generated and GPS locations of these points were uploaded in GPS device and located in the field. The radius of each sample plot is dependent on the density of the forest, the default being 8.92 m for moderately dense vegetation as illustrated by [12]. Several sub plots were established within each plot for specific purposes: inside of the 8.92 m radius plot, a sub plot with a radius 5.64m was established for sapling (woody plants with 1-5 cm DBH) (Figure 2). Sampling intensity was taken to be 1% of the total area of sample plots.

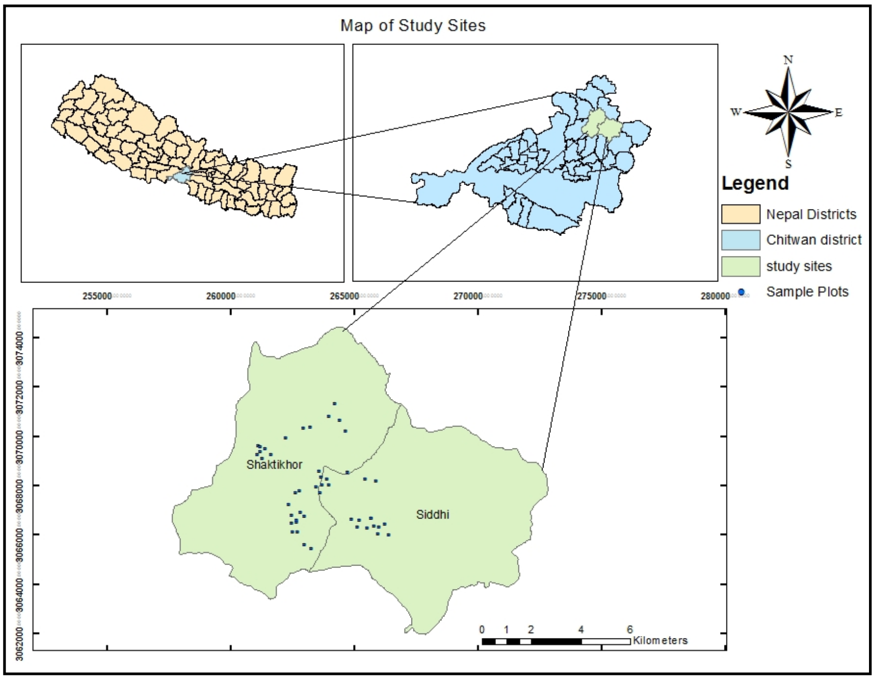

Figure 1. Study site

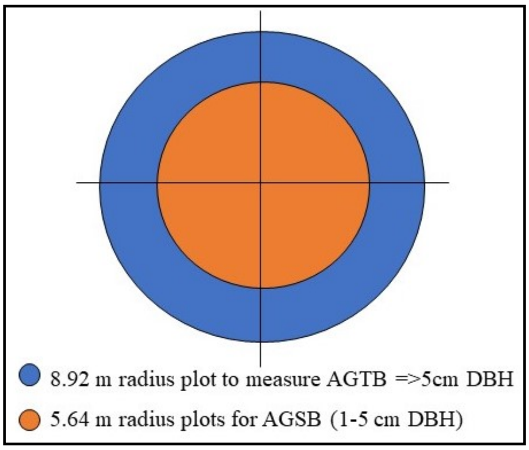

Figure 2. Dimension of sampling plots and sub plots used

In conducting the measurement, the procedures of IPCC were taken into consideration ensuring that measurements meet the quality necessary to be eligible for the VCS standards [13]. For the analysis, all forest areas were stratified on the basis of canopy cover into two strata (sparse with <70% vegetation cover and dense with >70% canopy cover) using Geographic Information System (GIS) applications. In order to measure the carbon pool of each selected permanent plots, methods and guidelines described by [14] was used. Further, the current estimate of forest carbon stock was done using allometric equations developed and tested by [15]. This includes a non-destructive methods of carbon stock measurement of any forest ecosystem by measuring the DBH and height of the tree and saplings.

2.3 Data Management and Analysis

Field measurements were recorded on field data sheet and then entered manually into spreadsheets. Data entry was done immediately after the completion of field measurements. The data were analyzed using statistical packages in MS-Excel and R programming. The data collected was subjected to summary statistics to obtain mean values for stem and seedling densities, species frequency and above ground carbon. The forest carbon stock was calculated by summing the carbon stock of individual carbon pools of that stratum (equation 1).

$$C(T) = C(AGTB) + C(AGSB) + C(BGTB) \qquad (1)$$

Where,
C(T) = Total carbon stock in the plot (tons/ha)
C(AGTB) = Carbon stock in above ground tree biomass (tons/ha)
C(BGTB) = Carbon stock in below ground tree biomass (tons/ha)
C(AGSB) = Carbon stock in above ground sapling biomass (tons/ha).

The quantity of aboveground tree biomass (AGTB) was estimated using [14] originally developed by [15]. It uses three variables: namely, wood specific gravity, tree height and DBH. Wood-specific gravity relevant to Nepal was used in the analysis of biomass. In case of the species with missing data, the general value was derived from the average specific gravity of species from the same taxonomic class [16,17]. Nepal-specific biomass tables were used to estimate aboveground sapling (1–5 cm DBH) biomass (AGSB) [18]. Since the national allometric biomass table does not contain all species present in Nepal, values for related or similar species were used. One of the most common descriptors of the relationship between root (below ground) and shoot (above ground) biomass is the root to shoot ratio, which has become the standard method of for estimating root biomass from the more easily measured shoot biomass. Thus, for estimating the BGTB, recommended root-to-shoot ratio of 1:5 was used [12]. All biomass estimates were converted into carbon stock by multiplying by 0.47 [13].

Besides, above ground carbon was subjected to t-test to examine the significance differences in these variables among the factors (tree density, invasive alien species, fodder collection, species richness, gazing, canopy cover/ strata, slope, and aspect) that influence the forest carbon stock data. Also, multiple regression model was applied using R programming (3.4 version) [19] to identify the factors which significantly influence the total biomass in the study area.

3. Results

3.1. Forest Composition and Structure

Altogether 39 species of trees (n=940), saplings (n=418) and seedlings (n=638) belonging to 25 genera were identified and recorded from 50 sample plots of the forest in Kayarkhola watershed area. The dominant species were *Shorea robusta*, *Lagerstroemia parviflora, Adina cordifolia, Schima wallichii, Mallotus philippensis, Terminalia tomentosa* and *Syzygium cumini.* Of the total number of tree species, *Shorea robusta* alone accounted for 46.5% relative density, *Lagerstroemia parviflora* had a contribution of 13.03%, and *Mallotus philippensis* (8.92%). *Terminalia tomensota* and *Syzygium cumini* had almost similar relative density with 2.75% and 2.54% respectively. Other tree species such as *Sapium insigne, Cassia fistula*, *Eurya accuminata, Semicarpus anacardium, Terminalia chebula* had a total contribution of 20.34% in terms of their density. It was calculated that the average tree density in dense and sparse strata was 759/ha and 673/ha respectively. The lowest density was found in *Alstonia scholaris* and the highest density was in *Schleichera oleosa.* Similarly, the average seedling density (DBH<1cm) and sapling density (DBH<5cm) were 32634 seedlings/ha and 758 saplings/ha. The mean density of seedlings per hectare was much higher than that of saplings and trees (Figure 3). The occurrence of high number of seedlings on the forest floor indicates the forest was regenerating.

3.2 Forest biomass and carbon stock

Total carbon stock content of the six community forests in three different pools; AGTB, BGTB and AGSB was calculated and each pool was further divided into dense and sparse forest stratum. The total area of dense and sparse forest strata in six community forest under study was 812.94 ha and 224.1 ha respectively. It was found that AGTB accounted to be maximum both for dense and sparse forest type (Figure 4).

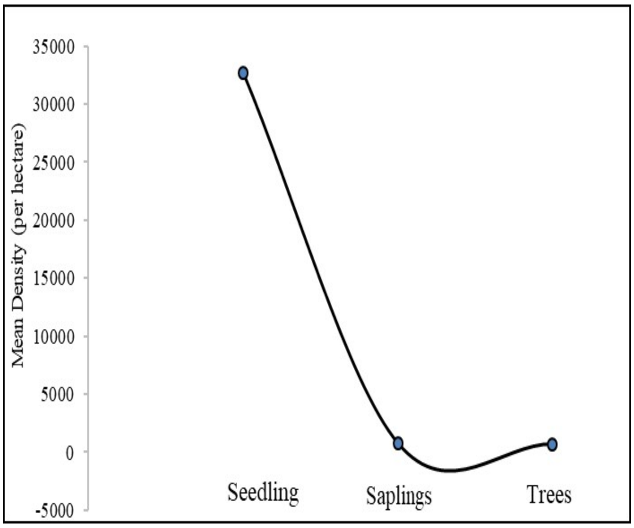

Figure 3. Forest structure in study area

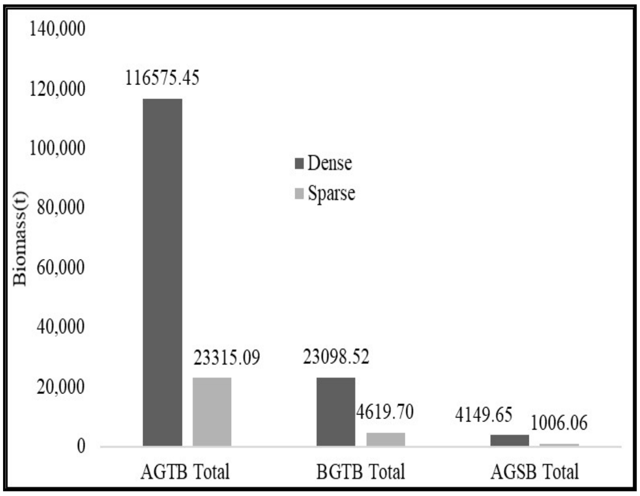

Figure 4. Strata wise carbon content in three pools

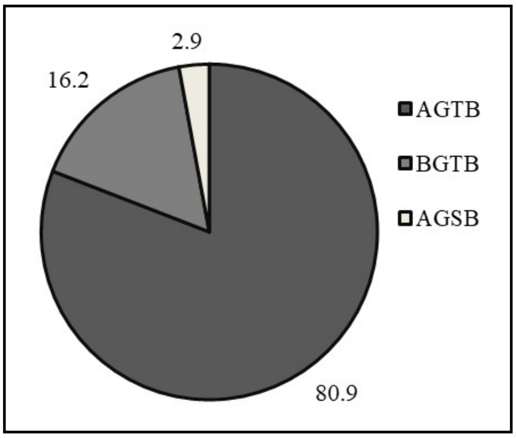

Figure 5. Percentage of biomass distributed in major carbon pools

The total carbon stock estimated at AGTB in dense strata was 116575.45 tones. The BGTB in dense strata was slightly lower than the AGTB value in sparse strata with the difference of 216 tones. The minimum carbon stock content was calculated in AGSB with 4149.65 tones in dense and 1006.06 tones in sparse forest strata. Overall, the maximum carbon was stored in dense AGTB strata and minimum in sparse AGSB. Similarly, the total carbon stock stored in both dense and sparse forest strata was calculated to be 144036.71 tones and 28724.28 respectively. The weighted average value of carbon stock was 177.18t/ha for dense strata and 128.175t/ha for sparse forest strata.

In all 50 sample plots, the above ground tree biomass contained was observed to contribute the highest (81.9%) among all carbon pools. Below ground tree biomass value was calculated to be 16.2%. Similarly, the above ground Sapling biomass contributed the least with 2.9% among all the major pools of carbon (Figure 5).

3.3. Relationship of Biomass with Influencing Factors

Relationship between frequency and biomass of above ground live biomass (AGTB and AGSB) were established (Figure 6). The saplings having biomass range 20kg to 60 kg were frequent and the frequency decreased significantly as the sapling biomass increased from 60 to up to 120 kg. However, the frequency distribution of tree species didn't show similar pattern as the sapling specimens. Data shows that trees are most frequent when their AGTB value is about 100 t/ha and decreased unevenly with some fluctuations with the increment of biomass. The overall trend shows that species with very low and very high biomass content are less frequent both in case of AGSB and AGTB (Figure 6).

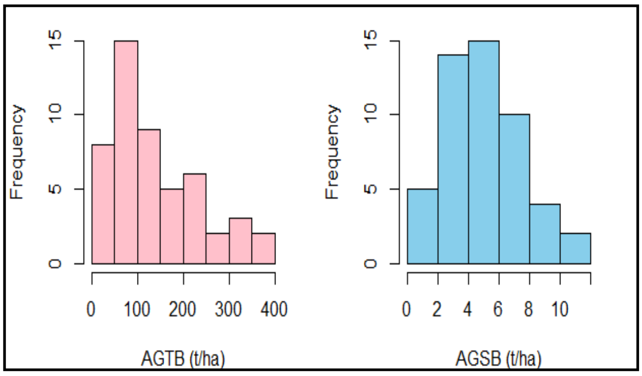

Figure 6. Frequency of trees and saplings with respect to their biomass

The effect of grazing, invasive alien species (IAS), fodder collection and forest strata on AGTB and AGSB was studied. The interquartile range of biomass was high where grazing was absence, but the median value of biomass was approximately 100 t/ha for both areas, disturbed and undisturbed by grazing. Similarly, an average value of 120 t/ha AGTB was observed in areas without invasive species, which was slightly greater than AGTB value distributed in areas with invasive species. In case of fodder collection, there was a difference in average value of AGTB between places disturbed and undisturbed by fodder collection. Most plots were disturbed by local people for fodder collection. The average value of AGTB was 125 t/ha which was about 40 t/ha more than plots without disturbance by fodder collection. The AGTB value was observed to be concentrated towards dense forest strata. Similar distribution was observed between AGSB and disturbance factors. However, there was no significant difference in AGTB and AGSB with the individual effect of fodder collection, grazing, IAS presence and strata (Table 1).

Table 1. Result of Significance Test (p-values) of Biomass with Major Influencing Factors

Factors	AGTB	AGSB
Fodder Collection	0.54	0.96
Grazing	0.55	0.84
IAS Presence	0.84	0.63
Strata	0.22	0.43

In order to observe the effects of the combination of disturbance factors, multiple regression was carried out using R-program. Models were selected using statistical procedures with Akaike Information Criterion (AIC) values checked by removing auto correlated variables (Table 2).

Table 2. Model Selection Procedures

Model	AIC
Tree Density + IAS + Fodder Collection + Species + Grazing + Canopy Cover + Slope + Aspect	472.91
Tree Density + IAS + Fodder Collection + Species + Grazing + Slope + Aspect	471.87
Tree Density + IAS + Species + Grazing + Slope + Aspect	470.79
Tree Density + Species + Grazing + Slope + Aspect	470.67
Tree Density + Species + Grazing + Slope	469.07
Species + Grazing + Slope	468.03

While taking all the parameters (tree density, IAS, fodder collection, species richness, grazing, canopy cover, slope and aspect), AIC value was maximum while it was minimum with only three variables (species richness, grazing and slope) indicating that the combined effect of these three factors influenced the total biomass value.

The effect of species richness, grazing and slope on the total biomass value of forest was significant ($p<0.05$). Slope and grazing showed negative correlation while species richness showed a positive correlation with the total biomass (Figure 7). The total biomass was 16.12 t/ha greater in area having high species richness than in the areas with low species richness. Similarly, biomass value decreased by 82.52 t/ha in area with grazing than no grazing area. Biomass value increased to nearly 300 t/ha from about 150 t/ha when species richness increased from 2 to 10 respectively. In contrast, total biomass value decreased with slope increment. It was observed that 325 t/ha biomass decreased to less than 100 t/ha when slope increased from around 5 to 80 degrees. The difference between the biomass value between areas with grazing and no grazing was found to be about 80 t/ha.

4. Discussion

4.1. Carbon Sock Assessment

Forest act as carbon reservoir as it stores large amount of carbon in trees, understory vegetation, forest floor and soil [20]. Conversely, human activities degrade a forest, both the reservoir and sink potential are damaged, and the forest becomes the substantial source of carbon dioxide emission [21]. Trees are long lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, forest can capture and retain large amount of carbon over long periods. These stocks are dynamic, depending upon various factors [22,23] and processes operating in the system, most significant being land use, land use changes, soil erosion and deforestation [24].

The average weighted carbon stock in the study area was found to be 152.68t/ha with 177.18t/ha and 128.175t/ha in dense and sparse forest strata respectively. This is comparable with the study done at middle hills of Nepal in [8] where the carbon stock estimate was found to be 138.11t/ha, however due to the altitudinal variations between this study and the current study, the dominance of species and the dominance of carbon content was also different. The altitudinal variations of the study at middle hills was taken from 110 m to 3300 m and hence, *Schima wallichii* (32%) was more dominant species followed by *Shorea robusta* (30%) [8]. But this current study had high dominance of *Shorea robusta* (46.5%) followed by *Lagerstroemia parviflora* (13.2%) showing the carbon stock was more concentrated to the dominant species due to their higher frequency of occurrence.

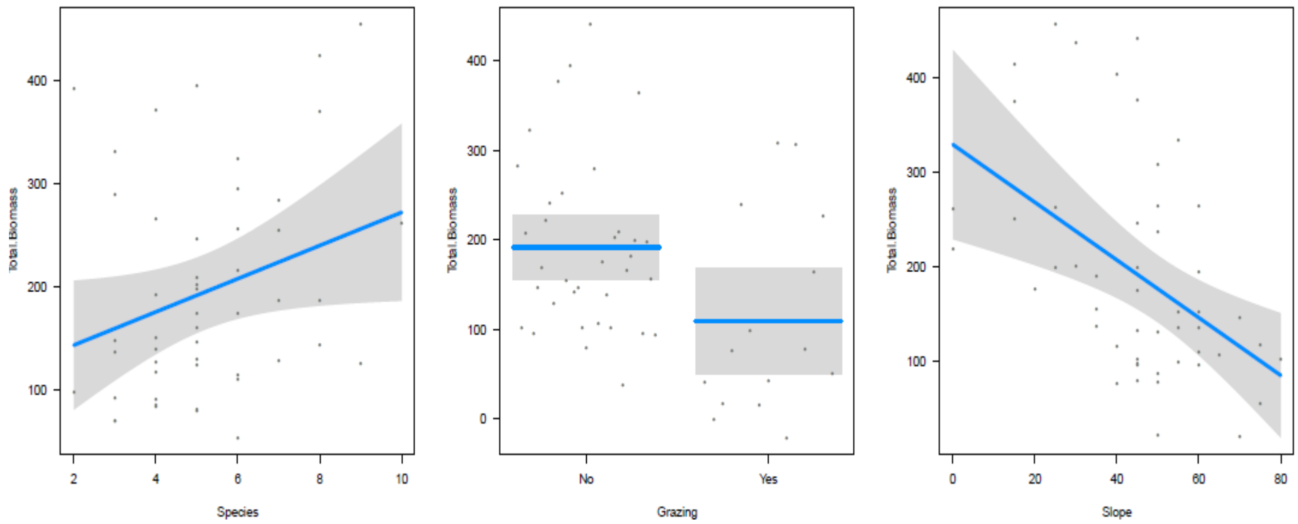

Figure 7. Relationship of biomass with significant influencing factors

Another study done in Churia forests of Nepal [25] showed the average above ground live biomass as 186.48 tons/ha which is slightly more than this study. The similarity on the results between this study and current study is that carbon stock estimate was highest in *Shorea robusta* showing the dominance of this particular species in both study area. The reason for this difference in above ground live biomass is the DBH class distribution of tree species where the trees in Churia were more matured with higher values of DBH and height, than Kayarkhola watershed in an average, although the number of trees found in a hectare of forest was higher in study of Churia (716 trees/ha) hills than this study (731 trees/ha).

A study conducted in Chitwan Annpuarna Landscape (CHAL) [26] showed the average live tree biomass 224.54 t/ha, contributing more than 97% of the total forest biomass in the entire region. This value is higher than the value as compared to this study. This is primarily because most of the carbon was concentrated in the dense needle-leaved forest. Such forests are mostly found in high altitude and relatively inaccessible with fewer human activities. In the present study, the lower value of carbon stock is due to the high dependency of disadvantaged and indigenous community such as Chepang on the community forests for their livelihood [14,17].

4.2 Factors influencing carbon stock

It is evident that forest disturbance reduced the capacity of the forests to sequester carbon. The present study constitutes three disturbance variables, viz., fodder collection, grazing, and invasive species' presence or absence in the study area which were the potential source of carbon stock change. Carbon stock value in dense and sparse strata was also analyzed to predict the impact of canopy openings and human disturbance for carbon stock distribution. A study conducted in natural pasture land in Africa concluded that grazing land subject to heavy grazing pressure has significantly reduced vegetative cover and biomass yield, particularly on steep slopes [27]. This study is compatible with this research outcome that there is significant reduction in the tree biomass in the place of disturbance created due to grazing though the opposite finding has also been reported that the controlled grazing aids forest improvement [28]. Forest canopy is one of key determinants that affects the growth and survival of plants [28] and so can make significant difference to the quantity of carbon stock in community forests. Canopy cover creates different micro-climates in forests by obstructing the penetration of light and precipitation to the forest floor thereby influencing tree growth. Species richness, grazing and slope were the major factors which influenced the biomass value positively or negatively. As the species richness increased the biomass value increased because of higher concentrations of woody materials, more stems, branches etc. In contrast, the total biomass value decreased with increasing slope because in areas with high slope, the nutrient concentration of soil is lost due to frequent landslide, erosion activities which provide null condition to grow the plant species. As a result, the species richness is also diminished resulting the lowered value of biomass. Grazing often disturbs the natural forest floor with loss of seedling and saplings by cattle or goats. They also feed on saplings which ultimately reduces the total biomass of forest carbon stock.

5. Conclusion

This study assessed the carbon stock and various factors influencing tree biomass carbon in community forests of Kayarkhola watershed. This study indicates that, although individual effect of the disturbance factors such as grazing, fodder collection, presence of invasive species and strata doesn't have significant impact on the tree biomass, the combined effect can be significant. The combined effect of species richness, grazing and slope was observed to have greater effect on the tree's biomass of community forest in Central Nepal. Assessment of carbon stock and its influencing factors in community managed forest is crucial to understand the quantity of carbon storage in the particular forest and also to identify the measures to improve the quality of the forest. Such study will inform the forest managers and the communities on how well their management interventions has been doing to enhance forest carbon stock and to consider alternative forest management strategies.

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Conflicts of Interests

The authors declare that there is no conflict of interests regarding this paper.

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