DISCOVERY

57(304), April, 2021

Forest carbon dynamic according to altitudinal gradient in Nepal

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To Cite:
Gautam B, Mandal RA, Bhushal S, Badal D. Forest carbon dynamic according to altitudinal gradient in Nepal. *Discovery*, 2021, 57(304), 361-371

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Peer-Review History
Received: 02 February 2021
Reviewed & Revised: 04/ February/2021 to 12/March/2021
Accepted: 13 March 2021
Published: April 2021

Peer-Review Model
External peer-review was done through double-blind method.

DISCOVERY
SCIENTIFIC SOCIETY

ABSTRACT

The carbon stock is importantly being an issue under the Reducing Emission from Deforestation and Degradation. However, the study related to this is limited in Nepal. Thus, this study aims to assess carbon stock variation according to altitudinal gradient in terai and Chure. Three different sites in Rupandehi District of Nepal, namely Sainamaina, Butwal and Devdaha representing Terai to Chure has taken for the study purpose, Stratified sampling based on altitude was applied and total 135 nested plots for tree/pole, sapling as well as leaf, litter, herbs and grass (LHG) having size 250,100,1 m^2 respectively were established. The height and diameter of plants were measured and weight of LHG estimated. Furthermore, the soil samples had collected from 0-10, 10-20 and 20-30 cm depth. Chave et al. equation was used to calculate biomass and converted into carbon by multiplying with 0.47. Soil carbon was analyzed using Walkley Black method. Statistical analysis was conducted to compare carbon stock among different altitudinal gradient of Terai and Chure. The results showed that total carbon stock was the highest 192.85±19.08 t /ha in altitude <200m and it was the lowest 126.31±15.95 t/ha in 201-400m the difference was around 46.4 t/ha carbon between altitude <200m and 201-400 m. The soil carbon was the highest 83.24±0.99 t/ha in altitude <200m while it was the lowest 46.40±1.12 t/ha in 801-1000m altitude. One-way ANOVA showed that, there were significant differences among carbon stock according to altitude in Terai and Chure at 95% confidence level since p-value < 0.05 and Tukey's b HSD test also showed that the carbon stock of altitude less than 200 m was significantly differed from carbon stock of altitude 201-400m. The research will be useful to develop the baseline to show the carbon according to altitudes.

Keywords: carbon stock, Chure, Terai, altitudinal gradient.

1. INTRODUCTION

The forest carbon is importantly playing vital role to reduce the greenhouse gases. The carbon stores in ocean, atmosphere, soil and forest so there is exchange among them. Globally, forest store about 400 gega tons carbon (Peng et al. 2008; Pan et al. 2011). Globally, reducing emission from deforestation and degradation (REDD+) and Kyoto protocol have been a key role to incentivize for carbon sequestration (Hunt, 2009). Considering this, REDD+ mechanism have been accredited five main types of activities especially reducing deforestation and degradation, sustainable management of forest, forest enhancement and forest conservation as a carbon credit (Phelps et al. 2012). In addition, Kyoto protocol includes clean development mechanism (afforestation and reforestation as well as use of alternative energy), joint implementation and emission trading as a carbon credit (Banskota et al. 2007; Hiraldo & Tanner 2011). Thus, the importance of carbon sequestration through forest has been increasing and most of the countries in the world have been preparing for this. The carbon sequestration through forest can cut about 18% of global greenhouse gases which can play a vital role to mitigate and adapt against the climate change. Reduction of greenhouse gases through forest is the most cost effective ways (Lubowski & Rose, 2013).

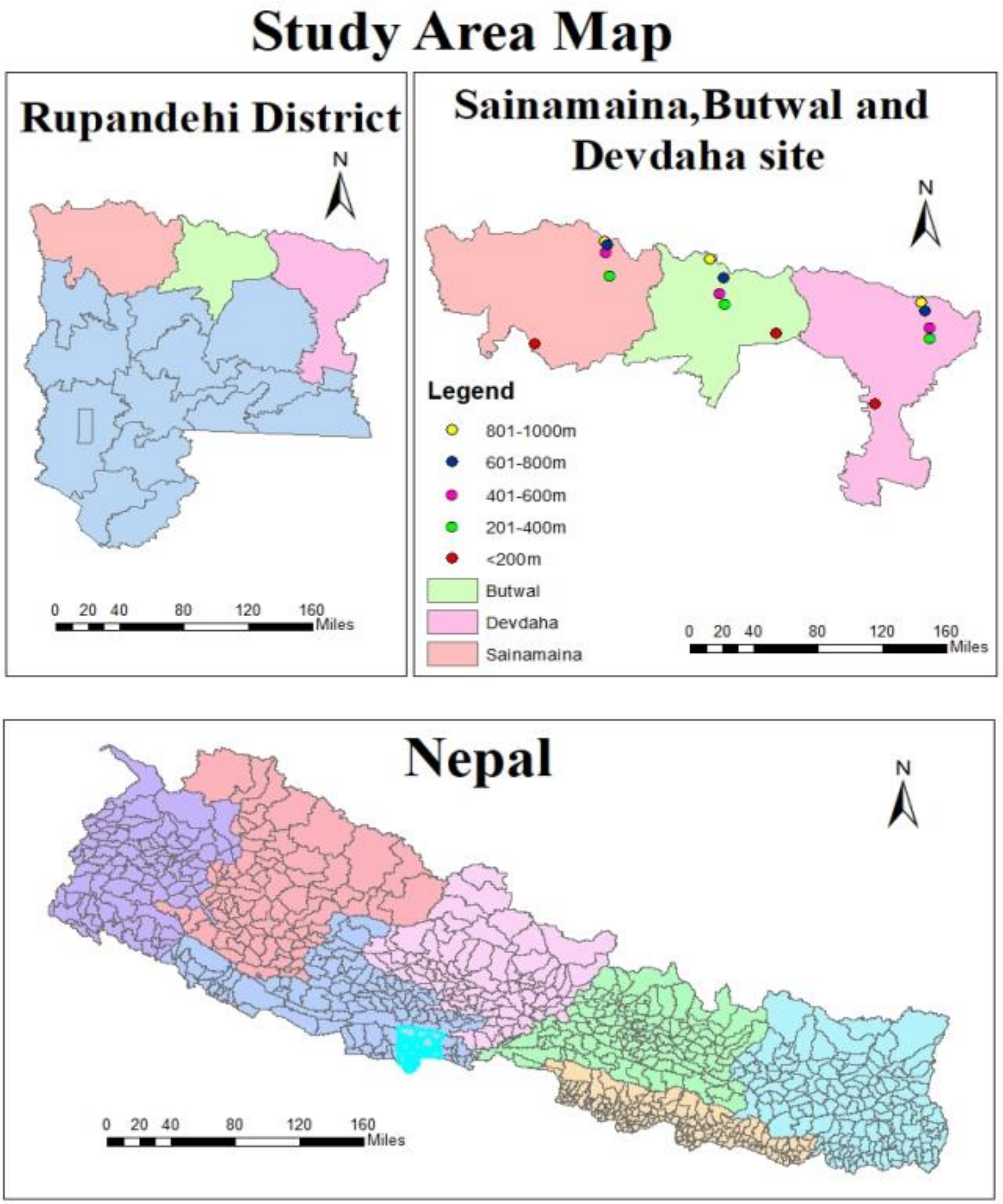

Figure 1:- study area map

Accreditation and price of carbon is interrelated to each other. The carbon price is generally high when the method of estimation and monitoring is more robust. This is main reason that the price of carbon of developed countries is higher than the developing countries. Generally, developed countries like America, Australia, Canada, Norway and other nations have been using the field measurement of carbon as well as the application of high resolution of image to monitoring the carbon (Neeff & Ascui,2009; Blom et al. 2010). The developing countries like India, China, Bhutan, Bangladesh and many countries have been applying both field and remote sensing techniques to assess and monitored the carbon stock but the precision is less because high resolution is costly (Romijn et al. 2012). Nepal has been following process applied in developing countries with the support of World Bank in general.

India, Bhutan, Pakistan, China have another important recognition because of beautiful landscape and characterized with high variation of altitudes (Palni & Rawal, 2010). The landscapes are composed of hills and plain. Beautiful landscape makes Nepal attractive due to variation in forest types (Ghimire, 2017). Specifically, the forests in Terai (plain area) and Chure (foot hills) are not completely same (Singh, 2017). So, carbon stock in these areas also varies but effect of altitudinal gradient on carbon stock and factors affecting to manage the forest are not assessed yet. Thus, this research was objectively conducted to assess and compare the carbon stocks at different altitude and factors affecting to manage the forest.

2. MATERIALS AND METHODS

Study site:

Rupandehi district lies on the southern and western part of Nepal. On the East, it shares border with Nawalparasi District, on West with Kapilvastu District, on North with Palpa district and on South with India. The elevation of the district lies between 86m to 1108m from sea level, where 86-225m & 122-1108 m altitude representing Terai and Chure region of the Rupandehi district. The district headquarter is Siddharthanagar. As per the national census 2011, the population of Rupandehi was 880,196. The total area of the district is 1,360 km² with 16.1% in Churia Range and rest in the Terai region. Upper Tropical, lower tropical and subtropical climate is found with maximum temperature 43.40ºc and minimum temperature 6ºC. Average relative humidity is 80% and average annual rainfall is 1174mm (District Profile, Rupandehi). There are about 26,524ha (20.28%) of forest area in Rupandehi district.

Mainly Sal (*Shorea robust*a), Asna (*Terminalia elliptica*) Saj (*Terminalia tomentosa*), Botdhairo (*Lagerstroemia parviflora*), Teak (*Tectona grandis*), Sissoo (*Dalbergia sissoo*), Masala (*Euclayptus*) Banjhi (*anogeissus latifolia*), Katus (*Castonopsis indica*), Chilaune (*Schima wallichi*), Pyari (*Buchania latifilia)*, Karma (*Adina cordifolia*), Harro (*Termenalia chebula*), Amala (*Phylanthus emblica*), Simal (*Bombax ceiba*), etc are the major tree species in this district.

Sampling design:

The study sites are in different altitudinal range below 200 m altitude to up to 1000m altitude. The stratified sampling was conducted to collect the sample based on altitude <200, 201-400, 401-600, 601-800 and 801-1000 m. Infact, region below the 200m is considered as known as Terai and higher than this is Chure. Three transects were drawn namely at Devdaha, Sainamaina and Butwal sites to collect the data from different altitude (Figure 1).

Forest data collection:

Primary and secondary data had collected and used in this research. Primary data had collected from field observation, direct measurement, group discussions and laboratory analysis while the secondary data and information had collected from internet surfing, books, reports, journals and community forest operational plan in order to meet the research objectives. Altogether 135 samples plot were established to collect biophysical data.Total 45 soil sample were collected ,to show variation in soil carbon at different altitude.The sample plot having 8.92 m radius established for tree/pole, plot of 5.64 m radius established for sapling, a sub plot of 0.56 m radius established for leaf, litter, herbs and grasses (LHG) collection and for soil sample collection.

The diameter at breast height (DBH at 1.3m height) and height of individual trees and pole greater than or equal to 5cm were measured and recorded. Only diameter was measured to collect the data of regeneration (sapling) having DBH<5cm. Sample of leaf, litter, herbs and grasses were collected. The destructive sampling was carried out for this so, the fresh weight was taken and their dry weight recorded in the lab.

Root Sample:

It is very difficult to sample the root parts of plants because forest conservator does not allow falling the trees and uprooting the tree. In addition, it is tedious, time and cost-consuming job so to simplify the process for estimating below ground root biomass,

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Mac Dicken (1997) recommends using the root: shoot ratio value of 0.10 or 0.15, which based on tropical forests. The (IPCC, 2006) also recommends the use of such default ratio based on root: shoot ratio for different types of forests, so we took a mean value of these two to come up with a value of 0.125.

Soil sample:

The soil samples at depth 0-10, 10-20 and 20-30 cm collected from the sub plot of 0.56 m^2 by means of metal corer of known volume and placed in the labeled sample bag. The collected samples brought to the laboratory to determine the carbon content. The soil samples were oven dried at 105 ^{0}C in the laboratory until they reached a constant weight to estimate soil bulk density.

Data Analysis:

The above ground biomass includes the above ground tree biomass (AGTB), above ground sapling biomass (AGSB) leaf litter, herbs &grasses (LHG) and below ground biomass include root sample.

Above ground tree biomass (AGTB):-

The equation developed by (Chave et al.2005) had applied to calculate the above ground tree biomass as in (ICIMOD WP, 2016).

$$AGTB = 0.0509 \times \varrho D^2 H$$

Where, AGTB = above ground tree biomass (kg) ϱ = dry wood density (gm/cm3) D = tree diameter at breast height (cm) H = tree height (m).

After taking the sum of all the individual weights of a sampling plot and dividing it by the area of a sampling plot (m2), the tree biomass stock has attained in kg/m^2. This value has converted to t/ha by using unitary method.

Above ground sapling biomass:-

To determine the aboveground sapling biomass national allometric biomass tables had used. These tables developed by the Department of Forest Research and Survey, and the Department of Forest, Tree Improvement and Silviculture Component (TISC) (Tamrakar, 2000). Some of species did not listed in the national allometric biomass table. So, the values for related or similar species has used. The biomass values of saplings include foliage, branch and stem components. The following regression model had used for an assortment of species to calculate biomass:

$$Ln\ (AGSB) = a + b\ ln\ (D)$$

Where, Ln = Natural log; [dimensionless] AGSB = Aboveground Sapling Biomass; [kg] A = Intercept of allometric relationship for saplings; [dimensionless] B = Slope allometric relationship for saplings; [dimensionless] D = Over bark diameter at breast height (measured at 1.3m above ground); [cm]

Leaf, Litter, Herbs and Grass Biomass calculation

According to MFSC (2011), the following formula used to determine the Litter, Herbs and Grass Biomass

$$LHG = \frac{Wfield}{A} \times \frac{Wsample,dry}{Wsample,wet} \times \frac{1}{10000}$$

Where, LHGB = Biomass of seedling, sapling, Litter, Herbs, and Grasses [t/ha]

W field = Weight of the fresh field sample of Leaf Litter, Herbs, and Grasses, destructively sampled within an area of size A; [gm]

A = Size of the area in which seedling, sapling, litter, Herbs, and Grasses were collected; [ha]

W sub sample, Dry = Weight of the oven-dry sub-sample of Seedling, Leaf Litter, Herbs, and Grasses taken to the laboratory to determine moisture content; [gm]

W Sub Sample, Wet = Weight of the fresh sub-sample of Leaf Litter, Herbs, and Grasses taken to the laboratory to determine moisture content; [gm]

Similarly, the universal conversion factor generally, 0.47 was used to convert dry biomass of tree, sapling, regeneration, herbs, litter, grasses and dead wood into carbon content (Andreae & Merlet, 2001).

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Soil organic carbon:-

The soil samples had analyzed by Walkley Black Method (Walkley & Black, 1958) by digestion using Sulphuric acid and oxidized by the Potassium dichromate in laboratory. The soil samples were oven dried at 105º C to obtain constant weight.

The bulk density of soil sample had calculated for each soil depth for which soil carbon had estimated. Then, oven dried soil samples was divided by its volume to estimate bulk density (Mishara, 1968).

For calculation of soil organic carbon (SOC), the following formula was used (Chabbra et al. 2002).

Bulk Density (gm/cm3) = (oven dry weight of soil)/ (volume of soil in the core).

SOC= Organic Carbon Content percentage * Soil Bulk Density (gm/cm3)*thickens of horizon and was expressed in tons per ha.

Where,

SOC = soil organic carbon stock per unit area (t/ha)

% C = carbon concentration

ϱ = soil bulk density (gm/cm3)

d = total depth at which the sample was taken (cm)

Total carbon C (LU) = C (AGTB) + C (AGSB) + C (BB) + C (LHG) + SOC

Where, C (LU) = Carbon stock for a land use category (t C/ha)

C (ABTG) = Carbon in above ground tree biomass (t C/ha)

C (AGSB) = Carbon in above ground sapling biomass (t C/ha)

C (BB) = Carbon in below ground biomass (t C/ha)

C (LHG) = Carbon in litter, herb and grass (t C/ha)

SOC = Soil Organic Carbon (t C/ha)

3. RESULT AND DISCUSSION

Carbon stock in different altitudinal gradient: The above ground carbon pools include tree and pole, sapling, leaf, litter, herbs and grasses biomass and the below ground carbon pools includes root biomass and soil carbon. The above ground tree/pole carbon stock was found to be highest in, <200m altitude with 97.04 t/ha (Table 1). This followed by altitude 401-600m with 92.92 t/ha, altitude 601-800m with 89.16 t/ha, altitude 801-1000m with 84.92 t/ha and altitude 201-400m with 55.58 t/ha. The above ground sapling carbon stock was found to be highest in 401-600m altitude followed by 601-800m, 201-400m, 801-1000 and <200 M altitude with 0.67,0.51,0.48,0.39 and ,0.19 t/ha respectively. The above ground LHG carbon was found to be highest in <200m altitude followed by 201-400m, 401-600,601-800, and 801- 1000m altitude with 0.20,0.12,0.10,0.090 and 0.09 t/ha. Estimated total carbon stock was found to be highest in <200m altitude of Terai region with 192.86 t/ha and was followed by altitude 401-600m with 170.47 ton/ha, altitude 601-800m with 152.56 t/ha, altitude 801-1000m with 142.47 t/ha and altitude 201-400m with 126.32t /ha.

Table 1: Carbon stock variation in different altitude

Elevation m	Tree/pole (ton/ha)	Sapling (ton/ha)	LHG (ton/ha)	Root carbon (ton/ha)	Soil carbon (ton/ha)	Total carbon (ton/ha)
<200	97.04±15.97	0.19±0.07	0.20±0.03	12.18±1.99	83.24±0.99	192.86±19.08
201-400	55.56±10.65	0.48±0.11	0.12±0.007	7.024±1.32	63.10±3.85	126.31±15.95
401-600	92.91±7.98	0.67±0.25	0.10±0.01	11.71±1.00	65.06±2.26	170.46±11.52
601-800	89.16±9.76	0.51±0.17	0.09±0.01	11.22±1.22	51.58±1.47	152.56±12.65
801-1000	84.92±2.07	0.39±0.08	0.09±0.016	10.68±0.26	46.40±1.12	142.47±3.56

The below ground root carbon stock was found to be highest in <200m with 12.18ton/ha because the above ground biomass was highest in <200m altitude, and the default value was applied in above ground biomass. This was followed by carbon stock of 401-600m, 601-800m, 801-1000m with 11.71, 11.22, 10.68, and 7.02 ton/ha respectively.

The soil carbon stock was found to be highest in <200m altitude in Terai with 83.25 ton/ha and followed by this of 401-600m,201-400m,601-800m,801-1000m ,representing Chure with 65.06,63.10, 51.58 and 46.40 ton/ha respectively.

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Soil carbon according to soil depth*:* The clear trend had seen in soil carbon according to the soil depth. It was highest in 0-10 cm while lowest in 20-30 cm depth in all altitudinal gradients.

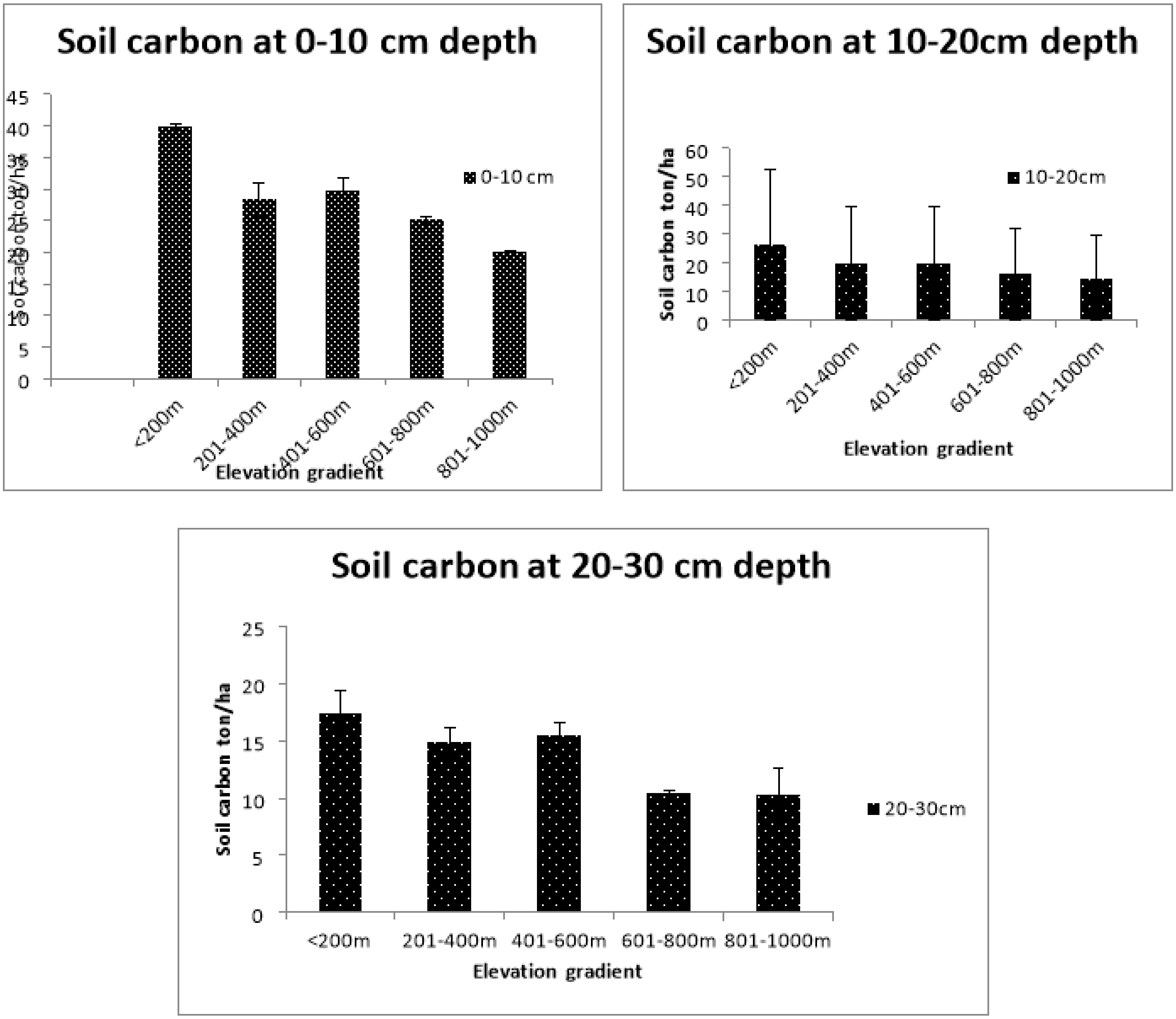

Figure 2: Soil carbon variation according to soil depth and altitude

The soil carbon decreased with respect to soil depth in all altitudinal range. All the altitudinal range contained greater SOC in the upper layer 0-10 cm followed by 10-20 and 20-30 cm depth. This may be attributed by the fact that higher amount of humus was present in the top layer of the soil profile and decreasing the organic matter with the increase in soil depth.

Comparison of carbon stock according to different altitude*:*

One-way ANOVA showed that, there was significant differences among carbon stock per ha according to altitude in terai and chure at 95% confidence level since p-value was less than 0.05. Tukey's b HSD test showed that the carbon stock of altitude less than 200 m was significantly differed from carbon stock of altitude 201m to 400m altitude, since the these values formed different subsets at 95% confidence level, where p value is <0.05.

Factors affecting the management of forest:

Mainly 8 factors were identified to manage the forest in Terai and Chure in different sites. These are Deforestation, grazing, encroachment, rocky terrain, slope, heavy rainfall, illegal trading and fire. More specifically, deforestation, grazing and

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encroachment together were the influencing factor in Devdaha site. Similarly, grazing, slope condition and encroachments were identified as major influencing factors to manage the forest in Sainamaina site. Moreover, the encroachment, rocky terrain and slope were identified as major influencing factor to manage the forest in Butwal site.

ONE WAY ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7917.856	4	1979.464	5.071	0.017
Within Groups	3903.410	10	390.341		
Total	11821.265	14			

Tukey B test

Elevation m	N	Subset for alpha = 0.05	
		1	2
200-400	3	126.3184	
800-1000	3	142.4763	142.4763
600-800	3	152.5628	152.5628
400-600	3	170.4681	170.4681
<200	3		192.8598

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

The highest Eigen value was recorded of Encroachment 1.98, 1.82 and 1.71 of Devdaha, Sainamaina and Butwal site respectively. So, this was the major factor affecting the management of forest in these sites in different altitudinal gradients.

Table: Eigen value of different factors in different site

Site (Eigen value)	Encroachment	Slope	Rocky terrain	Fire	Grazing	Illegal trading	Heavy rainfall	Deforestation
Devdaha	1.98	1.52	1.20	0.89	0.66	0.36	0.18	0.02
Sainamaina	1.82	1.44	1.27	0.91	0.68	0.38	0.17	0.05
Butwal	1.71	1.48	0.99	0.74	0.45	0.39	0.17	0.06

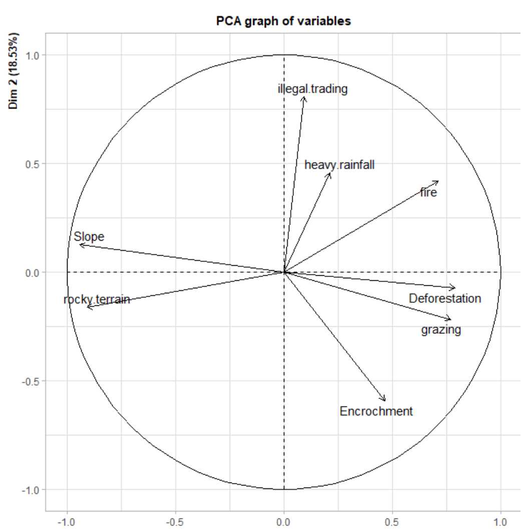

Figure 3A: Factors affecting the management of forest in Terai and Chure (Devdaha site)

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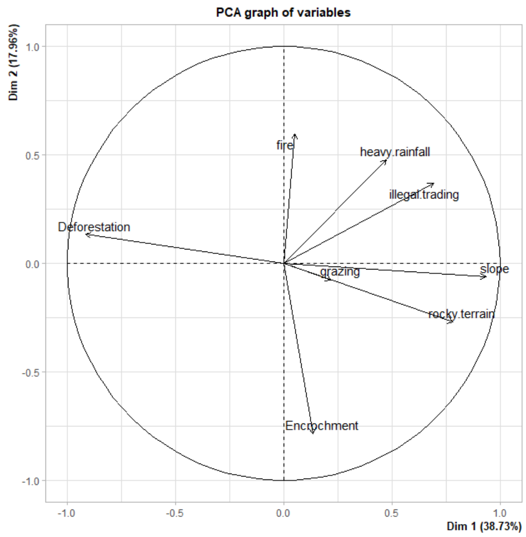

Figure 3B: Factors affecting the management of forest in Terai and Chure (Sainamaina site)

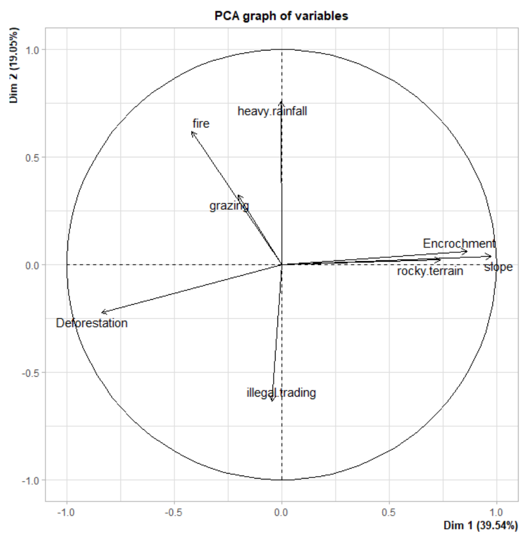

Figure 3C: Factors affecting the management of forest in Terai and Chure (Butwal site)

4. DISCUSSION

In Nepalese forest, an average carbon stock account to 203 t ha^{-1} (including shrub land) which is higher than the world's average i.e. 161.1 t ha^{-1} (FAO, 2006). In this study, the average carbon stock of different altitudinal gradient was estimated 157.06 t ha^{-1} including above ground tree C, below ground C, above ground sapling C, leaf litter, herb, grass C & soil C. The estimated average carbon stock of different altitudinal range found to be almost same from the world average record but it is less than Nepal (Sheikh et al. 2009). This indicates needs of improvement in protection in forests. The reason behind this may be disturbing factors like encroachment, deforestation and low density of stem in Chure area (Ghimire & Basnet, 2015; Mandal, 2019). Several factors affect the carbon stock in different altitude. The soil characteristics, density of plant, diameter and height distribution of the plant are major factors which affect the carbon stock (Li et al. 2010; Girma et al. 2014).

The result shows that total carbon stock in Terai forest is higher 192.86 ton/ha than Chure forest 148.11 ton/ha. Similar to our research, a study on total carbon stock in the Terai forest was 123.12 ton/ha & Chure forest is 116.94 ton/ha (DFRS/FRA, 2014) the slight difference in the total carbon stock might be due to the differences in species composition, site and tree density. The result shows that, the total carbon stock is highest in lower altitude and lowest in upper altitude, similar to our research Zhu et al. (2010) found that total carbon stock is significantly decreased with increased in altitude in Mt. changhai, Northeast china. The total soil organic carbon is greater in Terai compared to Chure, was supported by, DFRS (2015).

Chure region faced erosion and pressure on land due illegal human settlements resulting in decrease of soil organic carbon. The SOC of forest depend upon various biotic and abiotic factors such as microclimate, faunal diversity, land use, land management

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and crops (Shrestha & Singh, 2008). The significant decrease in soil carbon with the increase in soil depth supported by Khanal (2008), Ale (2010), Bhatta (2010), Maharjan (2010), Ranjitkar (2010), Sharma (2010), Basnet (2011) and Dutta et al. (2011). They found the maximum amount of SOC in the upper layer 0-10 cm as compared to the lower layer 80-100cm. The SOC decreased with increased in altitude, similar to our research ,A soil carbon research in Kathmandu district in *Pinusroxburghii* forest along altitudinal gradient at an elevation ranging between 1200-2200m, reported that the higher altitude soil carbon was found to be much more depleted of Carbon than the lower altitude soil (Sah and Brumme, 2003).

There are many factors affecting management of the forest. It is very difficult to manage the forest encroachment, fire and grazing in Terai and Chure area (Hengaju & Manandhar, 2015). Many study supports this finding that less carbon stock in Chure area because of fragile soil, low density of plant, grazing and frequent fire (Bjärnlid, 2016; Chalise et al. 2019). These factors are comparable with ours finding because geography of Chure are an almost similar in Nepal.

5. CONCLUSION AND RECOMMENDATION

The estimated total Biomass and carbon stock per ha was found to be highest in <200m altitude, due to good density, larger size tree present in there and the higher potential of species (*Shorea robusta* and *Termanalia tomentosa*) to sequestrate carbon. Both biomass and carbon decreased with increased in altitude, within 201-400m altitudinal range there is much more depleted carbon because of encroachment ,deforestation rate is high in there & poor quality, density of tree present in there.

The soil carbon stock was found to be highest in <200m altitude and lowest in 801-1000m altitude. The SOC decreased with increased in altitude, but within 201-400m altitudinal range there is lower soil carbon than 401-600m altitude, it may be due to the population pressure on forest land. Average soil organic carbon found in Terai region is higher compared to Chure region. It may be due to, Chure region faced erosion and population pressure on land due to illegal human settlement. The soil organic carbon (SOC) decreased with the increase in soil depth in all altitudinal range. The encroachment was one of the influencing factors affecting the carbon stock in Terai and Chure area. This study will be useful to establish the baseline of carbon stock in Terai and Chure. However, more researches are essential to compare the carbon stock according to forest types, climatic zones, aspect, and different soil types.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding:

There are no funding sources for this paper.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Data and materials availability:

All data associated with this study are present in the paper.

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