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FOREST CHARACTERISTICS AND CARBON STOCK ALONG AN ELEVATION GRADIENT IN PHULCHOKI HILL, NEPAL

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Abstract

The amount of carbon stored in forests depends on their age, species composition, and geographical locations. This study analyzed the tree species composition and carbon stock in three different forests in different elevation zones of Phulchoki Hill, Nepal. Tree species composition was assessed by quadrat sampling in the forests and carbon stock was determined by using allometric equation. Twenty-three tree species were found in the forests with high tree density and richness in *Schima-Castanopsis* Forest of Lower zone (1400-1800m). Above-ground tree carbon stock differed significantly among the forest types, ranging from 74.8 t/ha (lower zone) to 404.3 t/ha (upper zone). Tree basal area and biomass carbon stock increased with elevation and *Quercus semecarpifolia* contributed maximally (94%) to total carbon density at upper elevation zone. Hence, evergreen oak forests at higher elevations play crucial role to reduce and mitigate climate change by storing significant amount of carbon.

Introduction

Forests store large amounts of atmospheric carbon in biomass and hence play a crucial role in mitigating global climate change (Nunes *et al*. 2020, Alam *et al.* 2024). However, forests are under threat due to problems such as deforestation and degradation and have been facing challenges for conservation. Reducing carbon sources and increasing carbon sinks can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Propa *et al*. 2021).

There is increasing interest in estimating forest carbon storage globally due to its crucial role in mitigating climate change. Forest acts as one of the most effective nature-based solutions for natural recovery and adaptation to climate change (Fawzy *et al*. 2020). Hence, it is crucial to understand carbon storage in different forest types with varying composition and structure. Net biomass production varies with various factors like species composition, diversity and life-form of plant species (Pretzsch 2010, Ahmed *et al*. 2018). The rate of carbon sequestration is rapid during the early stage of tree growth and declines with the maturity of the trees (Ahmed *et al.* 2021, Li *et al*. 2023).

Forests of Nepal have greater potential for carbon sequestration with varied forest types and abundant coverage (DFRS 2015). The topographic variations such as elevation gradient in mountains provide an opportunity for studying carbon stock in different forest types. Quantification of sequestered carbon in diverse forest types could be important for their management and the development of a good mitigation and adaptation strategy for climate change effects. Hence, this study intends to understand the forest characteristics and carbon stock in the middle mountain forests of Nepal.

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Materials and Methods

The study was conducted on the west-facing slope of Phulchoki Hill, situated in the Kathmandu Valley, Bagmati Province, Nepal (27°34'16"N, 85°24'24"E) (Fig. 1). The hill harbors diverse forest types due to varied topography and wide elevation gradient. There are three major forests in the study sites at different elevation zone: (i) Schima-Castanopsis Forest (1400 to1800 m asl.), (ii) Oak-Laurel Forest (1800 to 2400 m asl.) and (iii) Evergreen Oak Forest (2400 to 2760 m asl.) (Shrestha 2002). The climate is subtropical to warm temperate with a mean annual temperature of 17.1°C, and the mean annual precipitation of 1527 mm.

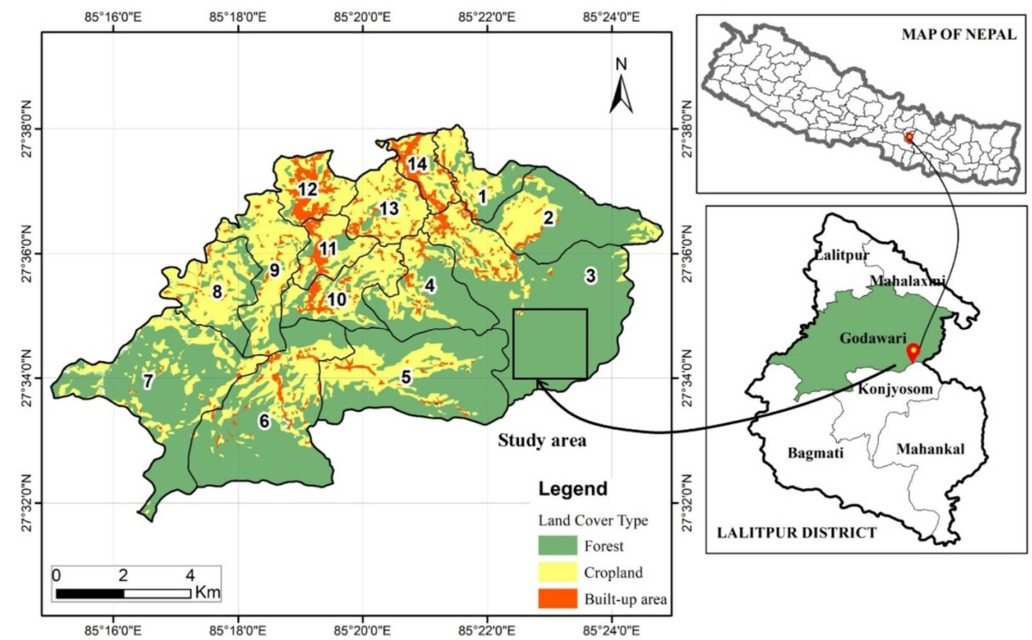

Fig. 1. Map of the study area (The numbers in the map represent ward numbers of Godawari Municipality).

Fifteen square plots (15×15 m^2) were sampled in each forest. Tree height and diameter at breast height (DBH) were measured. Species richness, Shannon-Wiener's diversity and Simpson's dominance index were assessed. Tree density, frequency and basal area were determined according to Mueller-Dombois and Ellenberg (1974). Above ground tree biomass (AGTB) was determined by allometric equation from Chave *et al*. (2005).

Belowground tree biomass was determined as 20% of AGTB (Mac Dicken 1997). The carbon stock of trees was calculated as 47% of AGTB according to IPCC (2006). The One-way analysis of variance (ANOVA) was employed to assess variation in tree DBH, density, basal area, and carbon stock among the forest types. Data were analyzed using the software R, version 4.0.1 (R Core Team 2020).

Results and Discussion

A total of 23 tree species were identified in the forests, belonging to 10 families and 14 genera. The numbers of tree species were 5, 10, and 17 in the upper, middle, and lower elevation zones, respectively (Table 1). This shows that species richness is decreasing with elevation.

Previous studies carried out in similar landscapes around Kathmandu Valley, Nepal such as Shivapuri-Nagarjun National Park and Chandragiri Hill (Sigdel 2008, Dani and Baniya 2022) showed the diversity index decreased with elevation and disturbance gradient. The variation in species richness of trees might be basically due to decreasing temperature, light intensity and soil characteristics (Negi *et al.* 2024).

The tree *Quercus semecarpifolia* was the major species in upper zone, *Quercus* spp. and *Myrica esculenta* in the middle zone, and *Schima wallichii* and *Castanopsis* spp. in the lower elevation zone. *Schima wallichii* and *Castanopsis indica* prefer lower (subtropical) zones throughout the Himalayan region (Shrestha 2002). The middle elevation zone of 1800-2400 m above sea level is a transition zone between subtropical and temperate forests, sharing many tree species common to lower zone.

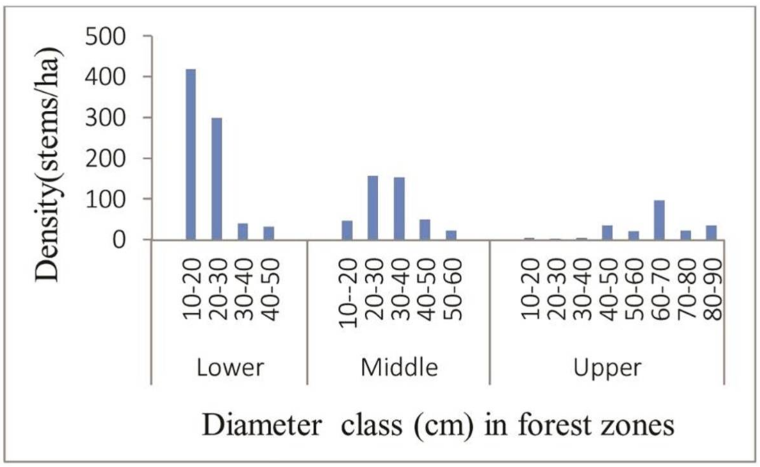

Fig. 2. Density of trees in different DBH class.

Tree species density and basal area varied significantly among forest types ($p < 0.001$). The lower zone showed high tree density followed by the middle and upper zones (Table 1). This could be due to high regeneration rate at lower elevations (Tenzin and Hasenauer 2016). Though tree species density was low, there was a higher basal area in the upper zone compared to other zones ($p < 0.001$). The mature trees with larger girth and fair height resulted in a higher basal area at upper elevation. Moreover, multiple factors influence tree species density and basal area, including soil fertility, water availability etc. (Xiong *et al.* 2023).

Tree diameter increased significantly in the forests along the elevation gradient ($p < 0.01$) with the highest tree diameter in upper zone (Table 1).This indicates the mature state of the forest and signifies low intensity of anthropogenic disturbance. The higher density of smaller-sized trees in lower zones reflects progressive regeneration in the previously degraded forest (Fig. 2). This pattern may be due to close proximity of forest to settlement areas (Bentsi-Enchill *et al.* 2022). Also, the diameter class distribution of trees reflects their age and disturbance regime or successional pattern.

Above-ground tree carbon stock differed significantly among the forest types ($p < 0.001$) ranging from 74.8 t/ha in lower zone to 404.3 t/ha in upper zone (Table 2). In the upper zone, the highest carbon storage was found in large sized trees with DBH class 60-70 cm (Fig. 3). It also signifies that these forests have huge potential for carbon storage. Lower tree carbon stock values were found in the middle and lower zones which is comparable to the findings from the National

Forest Inventory of Nepal, with biomass carbon of 107 t/ha (DFRS 2015). In the Chandragiri and Shivapuri hills located near the Kathmandu Valley, tree carbon stock was estimated as 52.75 to 87.13 t/ha (Gurung *et al.*, 2022) and 227.09 t/ha (Dhakal *et al*. 2024), respectively.

Table 1. Quantitative parameters of trees in three forest zones.

Parameters	Upper zone	Middle zone	Lower zone
DBH (cm)	60.39 ± 2.52^{a}	30.8 ± 1.1^{b}	20.1 ± 1.1^{c}
Height (m)	22.2 ± 0.45^{a}	11.6 ± 0.25^{b}	12.5 ± 0.73^{b}
Density (stems/ha)	228.2 ± 10.5^{c}	432.6 ± 21.9^{b}	793 ± 35.8^{a}
BA (m^2/ha)	68.19 ± 6.1^{a}	35.4 ± 2.85^{b}	28.5 ± 2.3^{c}
Number of species	5	10	17
Shannon's Index (H)	0.6	2.0	2.50
Dominance (D)	0.72	0.13	0.09

Different letters across rows indicate significant differences at $p < 0.001$.

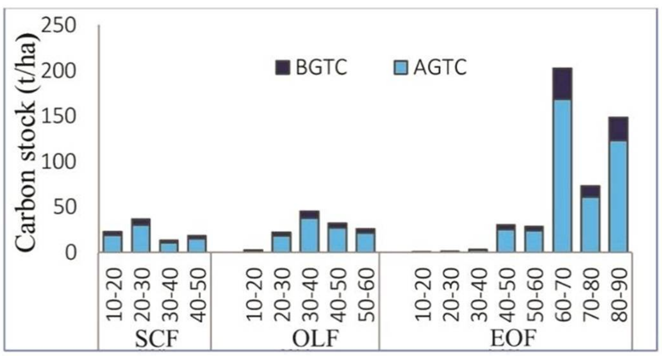

Fig. 3. Carbon stock of trees in different DBH class.

Table 2. AGTC and BGTC of trees in different forest zones.

Carbon stock	Upper zone	Middle zone	Lower zone
AGTC (t/ha)	404.3 ± 41.3^{a}	106.5 ± 11.8^{b}	74.8 ± 6.6^{b}
BGTC (t/ha)	80.86 ± 8.27^{a}	21.3 ± 2.36^{b}	14.9 ± 1.3^{b}
Total tree carbon (t/ha)	485.2 ± 49.6^{a}	128 ± 14.2^{b}	89.7 ± 7.9^{b}

AGTC: Above ground tree carbon, BGTC: Below ground tree carbon, Different letters across rows in superscript indicate significant differences at $p < 0.05$.

The variation in tree carbon stock in elevation zones resulted from differences in forest composition and stand structure. The stock is influenced by forest stand age and forest type (Wei *et al*. 2013). Generally, tree carbon stocks decrease with elevation possibly due to lower photosynthetic rates and soil mineralization at high elevations (Chimdessa 2023). However, AGTC may increase with elevation due to fewer disturbances and increased precipitation at higher altitudes (Reategui *et al*. 2023). The management practices and disturbance also influence the biomass and carbon stock of the forest (Kumi *et al*. 2021).

Based on tree species composition, in the lower zone, *Schima wallichii* and *Castanopsis indica* were the species with the highest carbon storage (Table 3). In the middle zone, more carbon (54%) was stored by *Quercus lanata*, *Myrica esculenta*, and *Q. glauca*. Similarly, *Q. semecarpifolia* in the upper zone stored a high amount of carbon (Table 3), which is supportive to Poudel *et al*. (2020). The tree *S. wallichii* is a major species of subtropical forests with good regeneration, contributing to high carbon storage in the lower zone (Tang *et al.* 2020). *Q. semecarpifolia* is the key species with the highest contribution to carbon sequestration in upper elevation zones.

Table 3. AGTC and BGTC of tree species in different forest zones.

Sl.	Name of Species	AGTC(t/ha)			BGTC(t/ha)		
		LZ	MZ	UZ	LZ	MZ	UZ
1	*Albizia julibrissin* Durazz.	2.12	-	-	0.42	-	-
2	*Betula alnoides* Buch.-Ham. ex D. Don	0.85	-	-	0.17	-	-
3	*Carpinus viminea* Lindl. ex Wall.	2.15	-	-	0.43	-	-
4	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	9.97	-	-	1.99	-	-
5	*C. tribuloides* (Sm.) A. DC.	8.33	2.47	-	1.67	0.49	-
6	*Engelhardia spicata* Lechen. ex Blume	4.06	-	-	0.81	-	-
7	*Eurya acuminata* DC.	1.90	8.95	-	0.38	1.79	-
8	*Ilex dipyrena* Wall.	-	-	20.8	-	-	4.2
9	*I. excelsa* (Wall.) Voigt	0.58	-	-	0.12	-	-
10	*Lindera pulcherima* (Nees) Benth. ex Hook.f.	0.48	0.04	-	0.10	0.01	-
11	*Lyonia ovalifolia* (Wall.) Drude	0.00	8.37	-	0.00	1.67	-
12	*Myrica esculenta* Buch.-Ham. ex D. Don	1.22	21.16	-	0.24	4.23	-
13	*Myrsine capitellata* Wall.	2.84	-	-	0.57	-	-
14	*Persea odoratissima* (Nees) Kosterm.	2.56	13.48	-	0.51	2.70	-
15	*Persea* sp.	-	-	0.1	-	-	0.02
16	*Quercus glauca* Thunb.	7.05	16.93	-	1.41	3.39	-
17	*Q. lanata* Sm.	2.06	20.33	-	0.41	4.07	-
18	*Q. leucotrichophora* A. Camus	-	1.34	-	-	0.27	-
19	*Q. semecarpifolia* Sm.	-	-	378.6	-	-	75.7
20	*Rhododendron arboreum* Sm.	2.92	13.37	0.1	0.58	2.67	0.02
21	*Rhus succedanea* L.	0.27	-	-	0.05	-	-
22	*Schima wallichii* (DC.) Korth.	25.41	-	-	5.08	-	-
23	*Sorbus* sp.	-	-	4.7	-	-	0.9

LZ: Lower zone, MZ: Middle zone, UZ: Upper zone.

Twenty-three tree species have been found in the study site, contributing to carbon sequestration. Tree density and diversity decreased in the forests with the increase in elevation. Tree carbon varied significantly across the elevation zones with sequence as upper > middle > lower zone. Tree size (DBH) and density influence the biomass carbon stock. *Schima wallichii* and *Castanopsis* sp. are the major trees contributing to carbon storage at lower zone, while *Quercus* spp. trees at upper zones have greater carbon storage with significant contributions to mitigating climate change. Developing appropriate management strategies to preserve existing forests is important for adapting to climate change impacts.

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References

Ahmed A, Ahmed T and Ataullah M 2021. Carbon stock of different parts of major plant species of three ecological zones of Bangladesh Sundarbans. Bangladesh J. Bot. **50**(2): 373-385.

Ahmed A, Ataullah M, Rashid P, Paul AR, Dutta S and Ali MS 2018. Species diversity, change in forest cover and area of the Sundarbans, Bangladesh. Bangladesh J. Bot. **47**(3): 351-360.

Alam MA, Yeasin M and Ahmed A 2024. Carbon pool and respiration of rhizosphere soils of different mangrove plant species in Bangladesh Sundarbans. Bangladesh J. Bot. **53**(1): 131-140.

Bentsi-Enchill F, Damptey FG, Pappoe ANM, Ekumah B and Akotoye HK 2022. Impact of anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage potential in an upland evergreen forest of Ghana, West Africa. Trees For. People **8**(5): 100238.

Chave J, Andalo C, Brown S, Cairns MQ, Chambers J. Eamus D, Fölster H, Fromard F, Higuchi N, Kira T and Lescure 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia **145**: 87-99.

Chimdessa T 2023. Forest carbon stock variation with altitude in bolale natural forest, Western Ethiopia. Glob. Ecol. Conserv. **45**: e02537.

Dani RS and Baniya CB 2022. Tree species diversity and regenerating potential along disturbance gradient in Chandragiri Hill, Kathmandu, Central Nepal. JIST. **27**(2): 109-124.

DFRS 2015. State of Nepal's forests. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS). 50 pp.

Dhakal TM, Thapa LB, Yadav RKP and Pokhrel CP 2024. Tree carbon stock and seasonal influence on soil properties in Shivpuri-Nagarjun NP, Nepal. Bangladesh J. Bot. **53**(3): 567-576.

Fawzy S, Osman AI, Doran J and Rooney DW 2020. Strategies for mitigation of climate change: a review. Environ. Chem. Lett. **18**(6): 2069-2094.

Gurung R, Adhikari HS, Dani RS and Baniya CB 2022. Tree carbon stock in middle mountain forest types: A case study from Chandragiri hills, Nepal. Banko Janakari **32**(2): 63-76.

IPCC 2006. Guidelines for National Greenhouse Gas Inventories, Volume 4: Agricultural, forestry and other land use. UK: Intergovernmental Panel on Climate Change, Cambridge.

Kumi JA, Kyereh B, Ansong M and Asante W 2021. Influence of management practices on stand biomass, carbon stocks and soil nutrient variability of teak plantations in a dry semi-deciduous forest in Ghana. Trees For. People **3**: 100049.

Li X, Ramos Aguila LC, Wu D, Lie Z, Xu W, Tang X and Liu J 2023. Carbon sequestration and storage capacity of chinese fir at different stand ages. Sci. Total Environ. **904**: 166962.

Mac Dicken KG 1997. A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock International Inst. for Agricultural Development. 87 pp.

Mueller-Dombois D and Ellenberg H 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York. 547 pp.

Negi VS, Pandey A, Singh A, Bahukhandi A, Pharswan DS, Gaira KS, Wani ZA, Bhat JA, Siddiqui S and Yassin HM 2024. Elevation gradients alter vegetation attributes in mountain ecosystems of eastern Himalaya, India. Front. For. Glob. Change **7**: 1-13.

Nunes LJR, Meireles CIR, Pinto Gomes CJ and Almeida Ribeiro NMC 2020. Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. Climate **8**(2): 21.

Poudel A, Sasaki N and Abe I 2020. Assessment of carbon stocks in Oak forests along the altitudinal gradient: A case study in the Panchase Conservation Area in Nepal. Glob. Ecol. Conserv. **23**: e01171.

Pretzsch H 2010. Forest dynamics, growth and yield: from measurement to model. Springer, Berlin. 664 pp.

Propa MJ, Hossain MI and Ahmed A 2021. Carbon stock and respiration of rhizosphere soils of sal (*Shorea robusta* Roxb. Ex. Gaertn. f.) in relation to some environmental variables of different Sal forests of Bangladesh. Bangladesh J. Bot. **50**(3): 685-693.

R Core Team 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reategui M, Reategui D, Morales E, Reategui R and Aguirre C 2023. Effect of geographic altitude on carbon stock in two physiographic units of the reserved forest of the Universidad Nacional Agraria de la Selva. Nat. Env. Poll. Tech. **22**(1): 319-325.

Shrestha TB, Lilleso JPB, Dhakal LP and Shrestha R 2002. Forest and vegetation types of Nepal: MFSC, HMG/Nepal, Natural Resource Management Sector Assistance Programme NARMSAP and Tree Improvement and Silviculture Component (TISC), Kathmandu.180 pp.

Sigdel SR 2008. Attitudinally coordinated pattern of plant community structure in the Shivapuri National Park, Nepal. Banko Janakari **18**(1): 11-17.

Tang CQ, Han PB, Li S, Shen LQ, Huang DS, Li YF, Peng MC, Wang CY, Li XS and Li W 2020. Species richness, forest types and regeneration of *Schima* in the subtropical forest ecosystem of Yunnan, southwestern China. For. Ecosyst. **7**(1): 35.

Tenzin J and Hasenauer H 2016. Tree species composition and diversity in relation to anthropogenic disturbances in broad-leaved forests of Bhutan. Int. J. Biodivers. Sci. Ecosyst Serv. Manag. **12**(4): 274-290.

Wei Y, Li M, Chen H, Lewis BJ, Yu D, Zhou L, Zhou W, Fang X, Zhao W and Dai L 2013. Variation in carbon storage and its distribution by stand age and forest type in Boreal and temperate forests in Northeastern China. PLoS ONE **8**(8): e72201.

Xiong K, Kong L, Yu Y, Zhang S and Deng X 2023. The impact of multiple driving factors on forest ecosystem services in karst desertification control. Front. For. Glob. Change **6**: 1220436.

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