Tree Species Richness, Phytomass Carbon Stock and Soil Organic Carbon in Tropical Deciduous Barandabhar Forest, Chitwan, Nepal

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Assessing carbon stocks in forest ecosystems is essential for the development of effective management strategies. This study was carried out with aim to assess the tree species richness, phytomass carbon stock, and soil organic carbon (SOC) in Barandabhar forest in Chitwan, Bagmati Province, Nepal under four management regimes within forest such as: Buffer Zone Forest (BZ), Buffer Zone Community Forest (BZCF), Community Forest (CF), and Protected Forest (PF) using concentric circular plots of 20 m radius (each of 0.12 ha). Altogether 256 sample plots were employed. Among them, 119 plots were in BZ, 48 plots in BZCF, 56 plots in CF, and 33 plots in PF. All tree species in each plot were recorded and their height and diameter at breast height (DBH ≥ 5cm) were measured to calculate phytomass carbon stock. Soil parameters such as pH, Bulk density, and SOC for soil samples collected from 0–10 cm depth in each plot were also analysed. In total, 30 tree species were recorded in the study, with *Shorea robusta* contributing the highest phytomass carbon stock. The mean phytomass carbon stock across the study area was 201±5 t/ha, while the mean SOC in the soil was 10.2±0.2 t/ha. Across the regimes, the highest phytomass carbon stock was recorded in the BZCF i.e., 239 ± 14 t/ha, followed by PF (207 ± 12 t/ha), BZ (202 ± 6 t/ha), and CF (162 ± 8 t/ha), respectively. The better predictors of phytomass carbon were soil pH and bulk density including tree basal area. These findings emphasize that forest management practices could have a significant impact on the carbon storage potential of forests.

Keywords: Bulk density; Concentric Circular Plot; Carbon sequestration; Forest management regimes; Soil properties.

Forests are home to a diverse assemblage of terrestrial flora and fauna that also include soil microorganisms. It plays a vital role in the global carbon cycle; trees convert carbon into biomass by sequestering atmospheric carbon through photosynthetic process (Alexandrov, 2007). The biomass enters the detritus cycle after the trees die, which help to establish a sound ecosystem (Brown & Lugo, 1992). In the context of global climate change, carbon sequestration and storage through forests are highly important parts of climate regulation (Brown et al., 1996; Mori et al., 2017). Therefore, a comprehensive assessment of the phytomass carbon stock and soil organic carbon is essential (Banik et al., 2018).

Ecologically significant forests are increasingly being designated as protected areas to safeguard their conservation value amid growing global focus on forest protection and biodiversity conservation (Andam et al., 2008; Morales-Hidalgo et al., 2015). In addition, different forest management practices can alter tree species richness by influencing forest ecosystem functioning, service provisions, and overall productivity (Dieler et al., 2017). Forests in Nepal are managed under several management regimes. They can be broadly categorized into community-managed and government-managed forests. Recently, the country has applied 11 different forest management regimes (FRA/DFRS, 2014). Among these, Protected Forests (PF) and Buffer Zone

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Forests (BZ) are under the jurisdiction of the Province Forest Ministry and the Department of National Parks and Wildlife Conservation (DNPWC), respectively. Likewise, Community Forests (CF) and Buffer Zone Community Forests (BZCF) are under the control of local community management with oversight from the Province Forest Ministry and the Department of National Parks and Wildlife Conservation (DNPWC), respectively.

In Nepal, several studies have assessed carbon stocks across different land-use types, forest management regimes, and plant species (KC et al., 2018; Kafle et al., 2019). However, understanding the variation in carbon storage between protected areas and community-managed forests in the lowland region of Nepal is rarely done. The Barandabhar forest is located in the Siwalik Valley (Inner Tarai) region in the Chitwan district of Nepal as a corridor that links the lowland forests to the forests in the mid-hill. Various regions of this forest have been conserved under the regimes: PF and CF managed under Province Forest Ministry, and BZ and BZCF under DNPWC. In view of ecological importance of these forest management regimes, the Barandabhar forest offers an avenue to understand the variation in tree species composition and carbon stocks. This study hypothesised that forests managed under different regimes exhibit significant differences in carbon stocks and soil physico-chemical properties. Accordingly, the study aims to assess tree species richness, phytomass carbon stock, and soil organic carbon across the management regimes in the Barandhabhar forest. In line with the national and international climate initiatives such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) (MoFSC, 2015), this study will contribute to understand the role of forest management in maintaining the diversity and carbon stocks in Nepal.

Materials and Methods

Study area

The study was conducted in the Barandabhar Forest of Chitwan District, situated in the Siwalik (Inner Tarai) at latitude 27°36'21.60" N and longitude 84°22'47.28" E (Figure 1). A section of the Barandabhar Forest lies within Chitwan National Park, established in 1973. The forest is managed by Chitwan National Park as part of its buffer zone under a participatory management approach, and a part by the Divisional Forest Office, Chitwan. Both sections cover a total area of 103.03 km^2 (District Level Forest Area Profile, 2081/82, Division Forest Office, Chitwan). Similarly, Buffer Zone Forest (BZ) in Barandabhar Forest has an area of 69.22 km^2 (District Level Forest Area Profile, Chitwan 2081/2082, Division Forest Office, Chitwan) and is managed by Chitwan National Park. Finally, Buffer Zone Community Forest (BZCF) has an area of 2.54 km^2 (Annual Report 2076/077, Chitwan National Park) and is managed by the community under the supervision of Chitwan National Park. These regimes have generally been under formal management for several decades. The four distinct forest management regimes are administered by different government authorities. Each regime employs different conservation-oriented silvicultural practices, which emphasize protection-based management, limited harvesting, and monitoring of regeneration. A summary of the key silvicultural activities practiced in each regime is presented in Table 1. PF and CF are situated to the north of the East-West highway, whereas BZ and BZCF are situated to the south of it (Figure 1). The area under BZCF is within 500 metres of the nearest human settlements. In proximity to human settlements, these four regimes are subject to different kinds of anthropogenic disturbances. A summary of key anthropogenic disturbances active in each of the four regimes is provided in Table 2.

The study area lies in the south-eastern region of Bharatpur Metropolitan City and experiences a seasonal dry tropical climate. Seasonal temperatures range from a summer maximum of 36.1°C to a winter minimum of 8.6°C (DHM, 2024). Mean annual rainfall is 2475 mm and rainfall peaks at 620/ mm in July and drops to a minimum of 5/ mm in November (Figure 2).

Sampling design and data collection

To measure tree-related attributes and soil parameters, the sampling area of four regimes was stratified into 15 transects. Transects were located 100 m from the east–west highway and 25 m from side roads, with a spacing of 500 m between them. The distribution of transects across regimes were: the BZCF (transects 2–11, located within 500 m of human settlements, covering 0.06 km^2); the BZ (transects 2–11, extending from the BZCF boundary into the forest interior, with 0.15 km^2; the CF (transects 1, 12, and 13, and covering 0.07 km^2); and the PF (transects 14 and 15, covering 0.04 km^2). Circular sample plots (each of radius 20 m and covering 0.12 ha) were positioned using GPS (GARMIN, model: GPSMAP 64s), and were established every 100 m along each transect. A total of 256 sample plots were used for the study, with 119 plots in BZ, 48 in BZCF, 56 in CF, and 33 in PF.

Table 1: Silviculture activities in different forest management regimes of Barandabhar Forest

Silviculture activities in the forest management regime	Time (Years)	Dominant tree species	References
Buffer Zone Forest (BZ)			
No silvicultural practice has done because this forest regime has been restricted area			DNPWC, (2015)
Buffer Zone Community Forest (BZCF)			
Shrub management and stand Cleaning activities	Every year Every year	*Shorea robusta*	Banadevi Barandabhar Community Forest, (2022)
Pruning activities	Every year		
Thinning activities	Every year		
Singling activities	Every year		
Tree improvement program	Every year		
Deadwood collection activities	Every year		
Rambel Community Forest (CF)			
Cleaning activities	Every year	*Shorea robusta*	Rambel Community Forest, (2021)
Pruning activities	Every year		
Thinning activities	Every year		
Singling activities	Every year		
Weeding activities	Three times in first year, twice in second year, once in third year		
Selection and protection of mother tree	Every year		
Protected Forest (PF)			
Coppice with standard system	Every year	*Shorea robusta*	Division Forest Office, (2023)
Shelterwood system	Every year		
Selection system	Every year		

Table 2: Anthropogenic disturbances in different forest management regimes of Barandabhar Forest

Anthropogenic disturbances in the forest management regime	References
Buffer Zone Forest (BZ)	
Firewood and Fuel wood, small timber for use in agriculture, house construction or repair and cattle grazing	DNPWC, (2015)
Buffer Zone Community Forest (BZCF)	
Forest fires	Banadevi Barandabhar Community Forest, (2022)
Encroachment	
Illegal extraction and smuggling of forest products	
Uncontrolled grazing	
Rambel Community Forest (CF)	
Illegal and covert removal of forest products	Rambel Community Forest, (2021)
Causing forest fires during the dry/summer season	
Encroachment	
Uncontrolled grazing	
Lack of public awareness about the importance of forests	
Protected Forest (PF)	
Illegal extraction and smuggling of forest products	Division Forest Office, (2023)
Forest fires and wildfire incidents	
Forest encroachment and unmanaged land use	
Problems related to forest boundary demarcation	

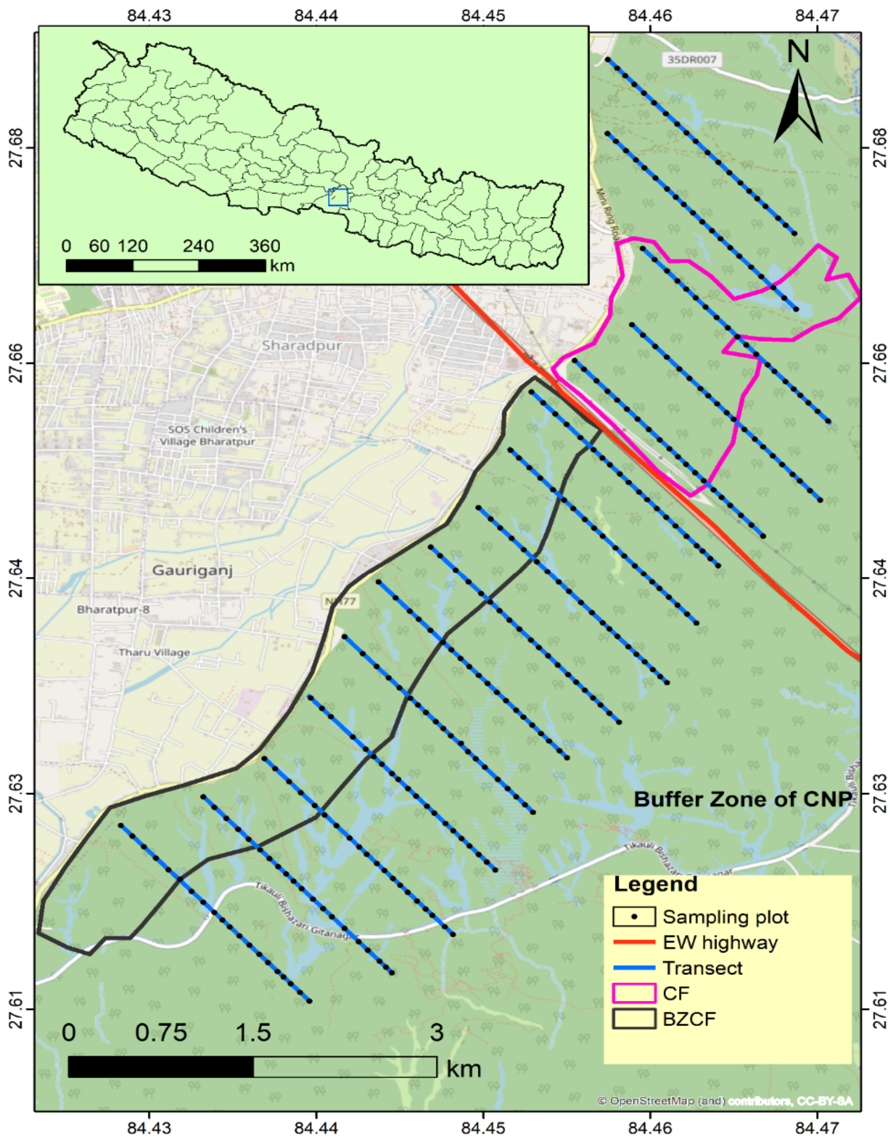

Figure 1: Map of the study area showing the distribution of sample plots

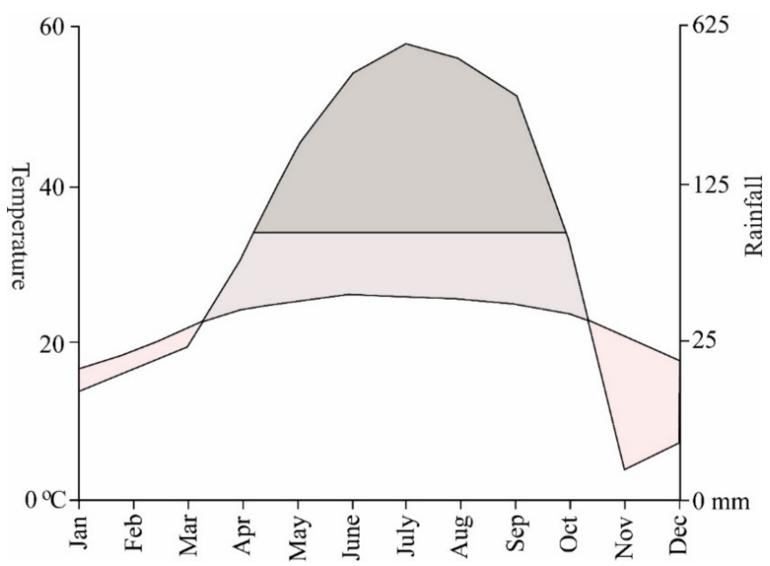

Figure 2: Rainfall and temperature of the study area (Rampur climate monitoring station, Chitwan, Nepal, Lat: 27.65 N, Lon: 84.35 E, alt: 189 m asl, Meteorological station index: 902; 1989 to 2024)

The four Concentric Circular Sample Plots (CCSPs) were used for tree measurements with different radii and diameter at breast height (DBH) thresholds. The technique of sampling design was followed by FRA/DFRS (2014) and FRTC (2021). A tree is defined as the woody species with a minimum ≥ 5 cm DBH (Chave et al. 2005). The methods included four concentric radii: r_1 = 20 m (1,256.6 m²) for trees with Diameter at Breast Height (DBH) ≥ 30 cm; r_2 = 15 m (706 m²) for DBH ≥ 20 cm; r_3 = 8 m (201.1 m²) for DBH ≥ 10 cm; and r_4 = 4 m (50.3 m²) for DBH ≥ 5 cm (FRA/DFRS, 2014). Since different DBH thresholds were used to sample trees in the four concentric circles, the number of trees in each circle was extrapolated to account for all trees (DBH ≥ 5 cm) within the full plot of radius 20 m (FRTC, 2021). Within each plot (1,256 m²), DBH of each tree at 1.3 m above ground level was measured using a diameter tape, and tree height was measured with a range finder (Powerline 660, Class 1 Laser Product, 905 nm, 6×25 optics, typical range 5–660 m; Apresys International Inc., USA) for all trees with DBH ≥ 5 cm (Figure 3). Tree specimens not identified in the field were collected for herbarium preparation following standard procedure (Bridson & Forman, 1998) and identified in the Central Department of Botany, Tribhuvan University, Kathmandu. Shrestha et al. (2022) and Plants of the World Online (https://powo.science.kew.org/) were followed for plant nomenclature.

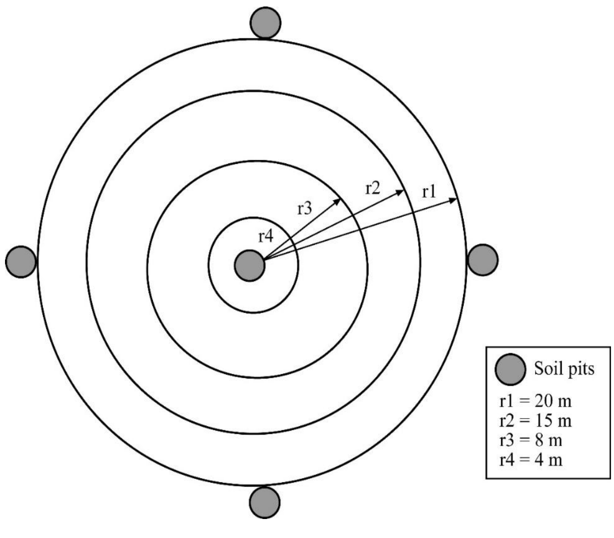

Figure 3: Concentric circular sample plots with soil pits

A slightly modified soil sampling method, as described in FRA/DFRS (2014), was followed. Five soil cores were collected, one from each cardinal direction (north, east, south, and west) and one from the centre. Soil samples were collected using a core with an inner diameter of 4.5 cm to a depth of 10 cm (ring volume = 158.96 cm³). Samples were placed in labelled zipper bags and transported to the laboratory at Birendra Multiple Campus, Bharatpur, Chitwan, Nepal. Fresh weight was recorded, and samples were oven-dried at 60°C for 24 h, weighed, then further dried for 72 h at 60°C. Dried soil was ground to fine particles and passed through a 2 mm sieve to remove stones and plant residues. Plant residues < 2 mm were considered part of the soil organic matter (Karki et al., 2016).

Data analysis

The collected field data were systematically organized and analyzed to quantify tree species richness and tree density following the method described by Rice and Westoby (1983), Shrestha et al. (2023), and ter Steege et al. (2023).

The estimation of above-ground biomass was carried out following the allometric equation developed by Petersson et al. (2012) as:

$$AGTB = 0.0509\ \rho\ D^2\ H$$

Where, AGTB = above ground tree biomass (kg), ρ= wood-specific gravity (g/cm³), D = tree diameter at breast height (cm), H = tree height (m)

Basal area, as described in FRTC (2019), was estimated by following the equation:

$$BA = \pi(DBH)^2/40000$$

Where BA= Basal area (ha), DBH = Diameter at Breast Height (m)

Wood specific-gravity values (Appendix 1) were taken from *Wood Densities of Tropical Tree Species*, published by the United States Department of Agriculture (Reyes et al., 1992). For some species, the wood specific-gravity values were taken from Sharma & Pukkala (1990). The biomass stock density (kg/m²) was calculated by aggregating the above-ground tree biomass (AGTB) of all individuals within the sampling area and dividing it by the total area sampled. The value was converted to t/ha by multiplying 10. To estimate phytomass carbon stock density (t/ha), biomass stock density values were converted using a carbon fraction of 0.47 (Penman et al., 2006). The root-to-shoot ratio value of 1:5 (20% of above-ground carbon stock density) was used to estimate below-ground biomass carbon stock density (MacDicken, 1997). The total carbon stock density (t/ha) of trees of particular vegetation was calculated by summing up above-ground and below-ground tree carbon stock densities.

Laboratory analysis

Soil bulk density was determined using the core sampling method (Blake & Hartge, 1986).

Oven-dry (at 105°C) soil samples were used for moisture correction. The bulk density of soil was estimated by following the equation:

BD = W/V

Where, BD = Bulk density (g/cm^3), W = Oven Dry Weight of soil (g), V = Volume of soil (cm^3)

The carbon concentration (%) of the collected soil samples was analyzed in the Soil Analytical Laboratory of the Department of Birendra Multiple Campus, Bharatpur. The standard titration method (Walkley & Black, 1934) was applied to measure the carbon concentration. The soil organic carbon was calculated following Pearson et al. (2007) as:

SOC = Rho×d×%C

Where, SOC = Soil Organic Carbon per unit area (t/ha), Rho = Soil bulk density (g/cm^3), d = The total depth at which the sample was taken (cm), %C = Carbon concentration (%).

Moreover, the soil pH of the samples was determined using a microprocessor-based pH meter (Model-1010, ESICO), keeping a 1:2 soil:water ratio.

Statistical analysis

Before statistical analysis, the normality of the datasets was tested using the Shapiro-Wilk test. The results indicated that the data did not meet the assumption of normality ($p < 0.05$), even after transformations. Consequently, non-parametric tests were employed for further analysis. Specifically, the Kruskal-Wallis rank sum test was used for comparison of mean ranks, and pairwise comparisons were performed using Dunn's test with the '*dunn.test*' package in R (Dinno, 2017). Kendall's tau was used for correlation analysis with the '*Kendall*' package in R (Lee & Yu, 2013), and Kendall-Theil Sen Siegel non-parametric linear regression was employed for regression analysis using the '*mblm*' package in R (Mangiafico, 2016; R Core Team, 2024).

Results

Species richness and tree density

A total of 30 tree species (Appendix 1) were recorded across the four management regimes, with 22 species in BZ, 13 in BZCF, 12 in CF, and 15 in PF. Among forest regimes, BZ recorded the highest average species richness (30 ± 1.2 species/ha) and the highest average tree density (1070 ± 78 trees/ha), with a wide range in both variables (Table 3). CF also exhibited high species richness (27± 1.5 species/ha) but comparatively lower tree density (864 ± 75 trees/ha). BZCF had the lowest average species richness (15 ± 1.0 species/ha) despite relatively high tree density (917 ± 100 trees/ha). PF showed moderate species richness (21.5 ± 2 species/ha) but the lowest average tree density (859 ± 124 trees/ha). Species richness in BZ differed significantly from both BZCF and PF ($p < 0.05$). While BZCF differed from CF, PF showed no significant difference from CF. Moreover, tree density did not vary significantly across the regimes (Table 3).

Basal area across four forest regimes

Tree basal area varied significantly across forest regimes ($p < 0.05$), with the BZCF showing the highest average basal area (36 ± 2 m^2/ha), while the CF showing the lowest value (31 ± 1 m^2/ha) (Table 4).

Tree height, DBH and phytomass carbon stock

Average tree height in the study area ranged from 3.3 m to 30.7 m, with a mean of 11 ± 0.3 m while Diameter at breast height (DBH) varied between 7.8 cm and 91.3 cm, with a mean of 23.2 ± 1.01 cm. The phytomass carbon stock showed substantial variation, ranging from 43.5 t/ha to 489.2 t/ha, with an average of 201±5 t/ha. Bulk density values spanned from 0.86 g/cm^3 to 2.10 g/cm^3, averaging 1.56 ± 0.02 g/

Table 3: Comparison of species richness and tree density across four forest regimes

Regime	No of Plots	No. Species	Species Richness (species/ha) Average ± SE	Tree Density (trees/ha) Average ± SE
BZ	119	22	30 ± 1.2^{a}	1070 ± 78^{a}
BZCF	48	13	15 ± 1^{b}	917 ± 100^{a}
CF	56	12	27 ± 1.5^{ac}	864 ± 75^{a}
PF	33	15	21.5 ± 2^{bc}	859 ± 124^{a}

Note: Different superscript letters along columns indicate significant differences at $p < 0.05$

Table 4: Tree basal area (m²/ha) across four forest regimes

Regime	No. of Plots	Average ± SE
BZ	119	35 ± 1[a]
BZCF	48	36 ± 2[ab]
CF	56	31 ± 1[c]
PF	33	34 ± 2[abc]

Note: Different superscript letters along columns indicate significant differences at $p < 0.05$

cm³. Soil organic carbon (SOC) content ranged from 3.80 t/ha to 18.85 t/ha, with a mean of 10.22±0.17 t/ha (Table 5).

BZCF and PF were recorded with the highest average tree heights (14 ± 1 m and 14 ± 1.3 m, respectively). Tree heights of BZCF and PF were found significantly greater than that of CF ($p < 0.05$), which had the least average tree heights of 8.4 ± 0.5 m (Table 6). On the contrary, DBH of trees showed no significant variation across forest regimes ($p > 0.05$), with PF recording the highest value of 35 ± 4.4 cm and BZ showing the lowest value of 19.4 ± 0.8 cm. Moreover, phytomass carbon stock for BZ (202 ± 6.1 t/ha), BZCF (239 ± 14 t/ha), and PF (207 ± 12t/ha) exhibited significantly higher values ($p < 0.05$) compared to CF (162 ± 8 t/ha) (Table 6).

In the case of soil attributes (Table 6), pH showed no significant variation across regimes except between BZ and BZCF ($p < 0.05$); BZ soil was more acidic (5.7 ± 0.1) than BZCF (6.2 ± 0.1). Soil bulk density exhibited significant variation ($p < 0.05$) across regimes, with BZ and BZCF showing the highest values, CF showing moderate, and PF recording the least (1.3 ± 0.03 g/cm³) values (Table 6). Similarly, significant variation was also recorded in the case of SOC, with BZCF showing the highest average value (12 ± 0 t/ha), BZ and CF showing moderate values, and PF recording the lowest value (8.2 ± 0.4 t/ha).

Phytomass carbon storage in different DBH size classes

Across all regimes, the majority of trees were concentrated in the lowest DBH classes (5–20 cm), representing 13262 (83.0%) individuals in BZ, 4413 (79.8%) in BZCF, 5081 (83.6%) in CF, and 2975 (83.5%) in PF (Table 7). Likewise, the highest proportion of phytomass carbon was stored in the largest DBH class (≥50 cm), ranging from 68.2% in BZ, 72.0% in BZCF, 74.2% in CF, and 77.3% in PF, while the smallest size class (5–10 cm) consistently contributed the least (0.8–1.7%).

Tree density, carbon stock by species across regimes

Species-wise tree density analysis revealed *Shorea robusta* as the densest species in all regimes except in CF, where *Syzygium nervosum* exhibited the highest density (366 trees/ha) (Table 8). In terms of contribution to the phytomass carbon, *Shorea robusta* accounted for the highest carbon stock

Table 5: Summary of tree characteristics, phytomass carbon stock, soil bulk density, and SOC in the whole study area

	Average height (m)	Average DBH (cm)	Phytomass Carbon Stock (t/ha)	Bulk Density (g cm^{-3})	SOC (t/ha)
Minimum	3.27	7.79	43.5	0.86	3.80
Maximum	30.74	91.3	489.2	2.10	18.85
Mean±SE	11±0.3	23.2±1.01	201±5	1.56±0.02	10.22±0.17

Table 6: Tree height, DBH, phytomass carbon stock, and SOC across forest regimes

Regime	Statistic	Average height (m)	Average DBH (cm)	Phytomass Carbon Stock (t/ha)	pH value	Bulk density (g/cm³)	SOC (t/ha)
BZ	Mean±SE	10.01 ± 0.3[a]	19.4 ± 0.8[a]	202 ± 6.1[a]	5.7 ± 0.1[a]	1.7 ± 0.02[a]	10.3 ± 0.2[a]
BZCF	Mean±SE	14 ± 1[b]	28 ± 3[a]	239 ± 14[a]	6.2 ± 0.1[b]	1.6 ± 0.04[a]	12 ± 0.4[b]
CF	Mean±SE	8.4 ± 0.5[c]	20.5±2[a]	162 ± 8[b]	6 ± 0.1[ab]	1.5 ± 0.03[b]	10 ± 0.3[a]
PF	Mean±SE	14 ± 1.3[ab]	35 ± 4.4[a]	207 ± 12[a]	6 ± 0.1[ab]	1.3 ± 0.03[c]	8.2 ± 0.4[c]

Note: Different superscript letters along columns indicate significant differences at $p < 0.05$

Table 7: Phytomass carbon storage in different DBH size classes across forest regimes

DBH (cm)	No of trees	Tree percentage (%)	Phytomass carbon storage (%)
BZ			
5-10	6600	41.3	1.7
10-20	6662	41.7	11.1
20-30	1581	9.9	10.2
30-40	329	2.1	4.7
40-50	152	1.0	4.1
50>	669	4.2	68.2
BZCF			
5-10	1625	29.4	0.9
10-20	2788	50.4	11.5
20-30	730	13.2	10.8
30-40	83	1.5	2.7
40-50	33	0.6	2.1
50>	275	5.0	72.0
CF			
5-10	2575	42.4	0.8
10-20	2506	41.2	8.8
20-30	486	8.0	7.2
30-40	82	1.3	2.5
40-50	98	1.6	6.4
50>	330	5.4	74.2
PF			
5-10	1375	38.6	1.0
10-20	1600	44.9	9.0
20-30	258	7.2	5.5
30-40	41	1.2	2.1
40-50	53	1.5	5.1
50>	236	6.6	77.3

Table 8: Tree density and carbon stock by species across regimes

	BZ (No of Species=22)			BZCF (No of Species=13)			CF (No of Species=12)			PF (No of Species=15)		
Species	Tree Density/ha	Carbon Stock (t/ha)	Carbon Stock (%)	Tree Density/ha	Carbon Stock (t/ha)	Carbon Stock (%)	Tree Density/ha	Carbon Stock (t/ha)	Carbon Stock (%)	Tree Density/ha	Carbon Stock (t/ha)	Carbon Stock (%)
Shorea robusta C.F.Gaertn	716	172.71	85.61	805	230.62	96.33	276	139.63	86.24	438	185.94	89.97
Terminalia elliptica (Gaertn.) Roxb	49	18.18	9.01	-	-	-	73	11.16	6.89	112	9.43	4.56
Syzygium nervosum DC.	131	4.75	2.35	36	2.01	0.84	366	6.24	3.85	221	6.14	2.97
Lagerstroemia parviflora Roxb	46	1.96	0.97	-	-	-	58	1.37	0.84	25	1.66	0.80
Terminalia bellirica (Gaaertn.)Roxb	1	1.13	0.56	1	2.24	0.93	2	2.39	1.47	1	2.19	1.06
Dalbergia sissoo Roxb	-	-	-	17	1.56	0.65	-	-	-	-	-	-
Tectona grandis L.	-	-	-	12	1.40	0.58	-	-	-	-	-	-

(173 t/ha), followed by *Terminalia elliptica* (18.2 t/ha) in BZ. A similar pattern was also recorded in the remaining three forest regimes, with *S. robusta* contributing the most, followed by *T. elliptica* (Table 8). The percentage contribution of *S. robusta* to the total phytomass carbon stock was highest in BZCF (96.33%), followed by PF (89.97%), CF (86.24%), and BZ (85.61%). The three dominant top-storey species contributed 96.97%, 98.11%, 96.99%, and 97.51% of the total phytomass carbon stock in BZ, BZCF, CF, and PF, respectively (Table 8).

Relationship among tree species characteristics and soil attributes

Kendall's tau was implemented to assess the correlation among tree-related characteristics and soil attributes. There was a significant positive correlation ($p < 0.05$) between phytomass carbon and tree basal area, and soil pH (Table 9). Basal area exhibited a significant positive relationship with tree density and species richness ($p < 0.01$). Furthermore, pH value showed a significant negative correlation with species richness, but a positive correlation with soil organic carbon ($p < 0.01$). A strong positive correlation was observed between soil bulk density and SOC, with $p < 0.01$ (Table 9).

To further explore the relationships between phytomass carbon and other tree-related characteristics and soil attributes, Kendall-Theil Sen Siegel non-parametric linear regression was employed. Though the analysis does not return the R^2 values, a summary of the results is provided (Table 10). To visually assess the nature of the relationships, regression plots with significance levels of slope are presented in Figure 4.

Phytomass carbon did not show significant relationship ($p = 0.83$) with tree species richness (Table 10, Figure 4a). However, it showed a negative relationship with tree density ($p = 0.02$) (Figure 4b). Tree basal area, on the other hand, appeared as a good predictor of phytomass carbon stock (slope 5.83, $p < 0.01$) in the study area (Table 10, Figure 4c).

As regards the soil attributes of the study area, pH and bulk density emerged as strong predictors of phytomass carbon stock, with slope values of 12.89 and 27.01 ($p < 0.01$ for both), respectively (Table 8, Figure 4d, 4e). Soil organic carbon (SOC), however, did not show significant effects on phytomass carbon (Table 10, Figure 4f).

Table 9: Correlation analysis of tree-related characteristics and soil attributes

	Phytomass Carbon (t/ha)	Basal Area (m^2/ha)	pH	Bulk density(g/cm^3)	Tree density/ha	Species richness/ha	Soil organic Carbon (t/ha)
Phytomass Carbon (t/ha)	1.00						
Basal Area (m^2/ha)	0.72**	1.00					
pH Value	0.14*	0.11	1.00				
Bulk density(g/cm^3)	0.10	0.08	-0.05	1.00			
Tree density/ha	-0.06	0.42**	-0.02	0.03	1.00		
Species richness/ha	-0.01	0.17**	-0.24**	0.02	0.10	1.00	
Soil organic Carbon (t/ha)	0.08	0.01	0.19**	0.62**	-0.07	-0.07	1.00

*p-value < 0.05, **p-value < 0.01

Table 10: Summary of regression analysis showing the relationship of phytomass carbon stock with tree and soil characteristics

Variable	Parameters	Estimated Value	p-value
Species richness (per ha)	Intercept	178.92	<0.01
	Slope	0.17	0.83
Tree density (per ha)	Intercept	191.24	<0.01
	Slope	-0.008	0.02
Basal area (m^2/ ha)	Intercept	-5.53	0.24
	Slope	5.83	<0.01
pH value	Intercept	113.04	<0.01
	Slope	12.89	<0.01
Bulk density (g/cm^3)	Intercept	147.00	<0.01
	Slope	27.01	<0.01
Soil organic carbon (t/ha)	Intercept	189.98	<0.01
	Slope	0.24	0.59

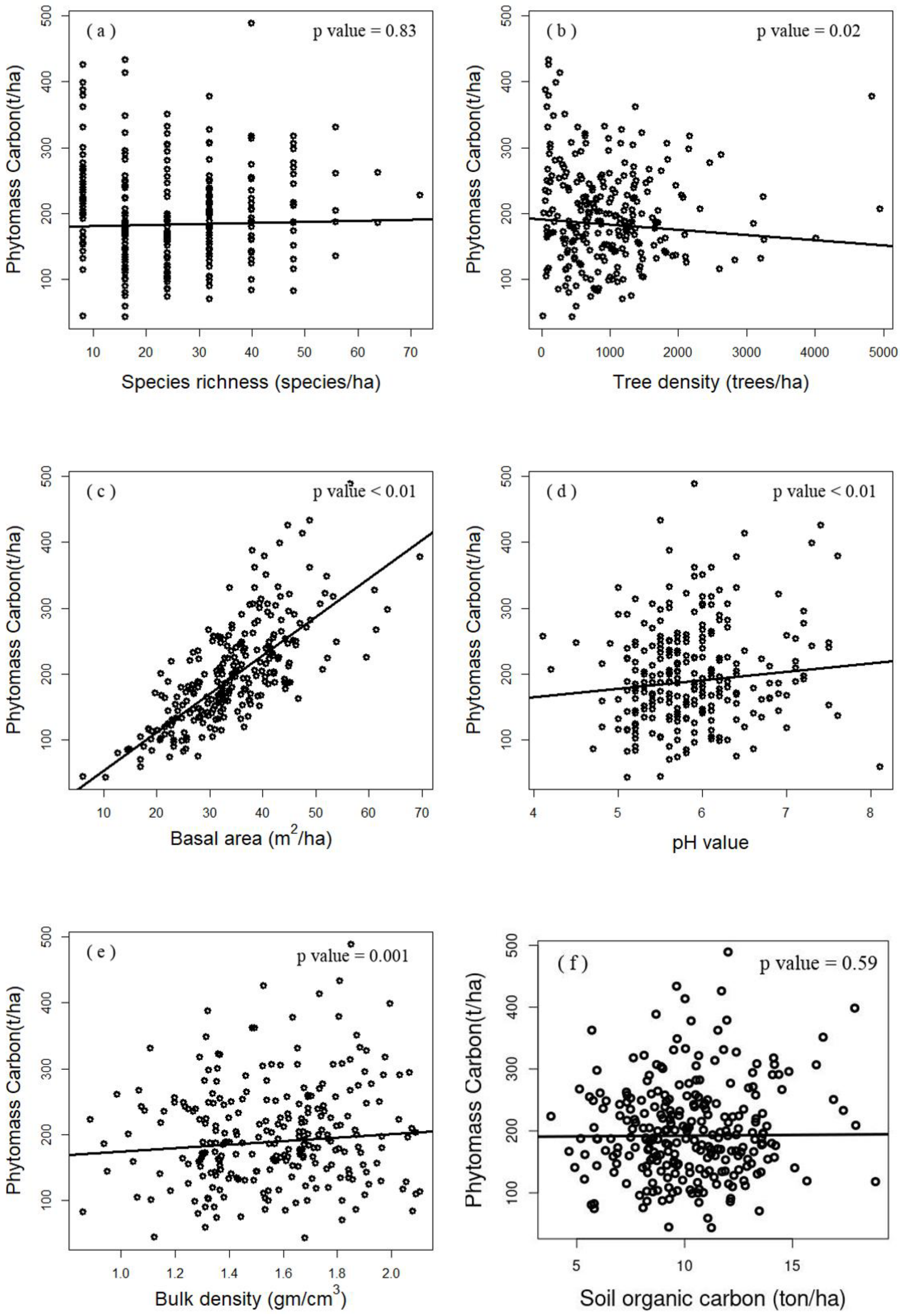

Figure 4: Regression plots showing relationships between phytomass carbon stock and tree-related characteristics and soil attributes

Discussion

The present study recorded a total number of 30 tree species in 256 sampling plots, which is comparable with the species number (29) reported by Banik et al. (2018) in *Shorea robusta* forests under two forest management regimes in Tripura, Northeast India. This similarity in species numbers suggests that the studied forest stands share ecological and structural characteristics typical of Sal-dominated ecosystems in South Asia. Furthermore, the species richness of our study area aligns closely with that reported from several protected areas and biological corridors in western Nepal. According to Uprety et al. (2025), the number of tree species in Banke National Park, Bardia National Park, Kamdi Corridor, Karnali Corridor, and Brahmadev Corridor was 30, 34, 27, 31, and 28, respectively. These results are consistent with the present findings. They indicate that the study area supports a tree species composition, which is comparable to present ecologically similar forest landscapes. The consistency in species richness across these areas may be attributed to the ecological connectivity provided by biological corridors that facilitate species movement, gene flow, and habitat continuity (MoFSC, 2015). Such connectivity reduces ecological isolation and helps to maintain stable species assemblages across the connected forest patches. Species preferences and silvicultural practices such as selection, shrub management, thinning, singling and cleaning activities cause the loss of biodiversity in community managed forests (Shrestha et al. 2010).

The average tree density recorded in the present study (969 ± 47 stems/ha) is similar with values reported from other *Shorea robusta* forest ecosystems in South Asia. Banik et al. (2018) reported a density of 1060.00 ± 11.12 stems/ha in *Shorea robusta* forests of Tripura, while Mohanta et al. (2020) reported 765 stems/ha from Sal-dominated stands in the Similipal Biosphere Reserve of Odisha, India. All these similarities indicate that the study area exhibits tree population patterns characteristic of *Shorea robusta* forest structure and regeneration dynamics. Tree densities recorded in biologically connected forest landscapes of western Nepal also belong to a similar ecological range. According to Uprety et al. (2025), Banke National Park, Bardia National Park, Kamdi Corridor, Karnali Corridor, and Brahmadev Corridor exhibit densities of 1381, 1478, 835, 654, and 1848 stems/ha, respectively. Likewise, the tree density of *Shorea robusta* in Kalika CF and Singhapur CF was 190.48 and 271.43 trees/ha, respectively, found in the community Sal forests of Kanchanpur district (Ayer et al., 2022). Moreover, the tree density found by FRA/DFRS (2014) of Terai *Shorea robusta* forests was 583.40 trees/ha. Variations in these values across the regimes might be due to variation in the scale of the studies (site specific vs national). Within the current study, the buffer zone (BZ) showed the highest tree density among the assessed management regimes. This pattern can be attributed to lower anthropogenic disturbance in the BZ, managed under the jurisdiction of Chitwan National Park (Table 2). The protection by the national park and the location of BZ in the interior of the forest are reasons for the lower anthropogenic disturbance in BZ.

The total average basal area of the present study was higher than the average basal area (23.44 m^2/ha) found by Chand et al. (2018) in *Shorea robusta* dominated Sahid Smriti Community Forest, Kanchanpur District. The total basal area of *Shorea robusta* dominated Terai forest was 18.38 m^2/ha reported by FRA/DFRS (2014), which was lower than that of the present study. Likewise, the basal area of this study was comparable with that of other Sal forests. Mohanta et al. (2020) reported a basal area of 27.1 to 37.34 m^2/ha in Sal forests of Odisha, India, while Behera et al. (2017) reported 35.53 m^2/ha in Katerniaghat Wildlife Reserve, Uttar Pradesh. Moreover, Uprety et al. (2025), reported basal area of Banke National Park, Bardia National Park, Kamdi Corridor, Karnali Corridor, and Brahmadev Corridor as 26.42, 27.40, 27.02, 27.77 and 40.65 m^2/ha, respectively. These differences in basal area might be due to the fact that the forest stands in the study area possess a greater proportion of mature trees and potentially experience more favorable regeneration and environmental conditions for growth. The similarity of the present results to those of the above-mentioned protected areas indicates that the study site supports a structurally well-developed forest with a substantial presence of large-diameter trees. Higher basal area is an indicator of reduced levels of anthropogenic disturbance and effective management measures, leading to sustained regeneration and dense canopy structure. Thus, the relatively high basal area observed in this study indicates an effective forest management practices. In addition, habitat continuity and limited extraction pressure collectively enhance stand stability and biomass accumulation in *Shorea robusta* dominated ecosystems such as the study area.

The analysis of species-wise contribution to the total phytomass carbon stock revealed that the top three species (*S. robusta, T. elliptica, and S. nervosum*) contributed more than 90% of the total phytomass carbon across all four regimes in the study area, a pattern also reported in the Sal forests of both Shuklaphanta National Park, Nepal (Bhatta et al., 2021), and Katerniaghat Wildlife Reserve forests, Uttar Pradesh, India (Behera et al., 2017), supporting our result that these species are dominant associates. The total phytomass carbon estimated in this study (200.72 t/ha) is comparable to that reported for tropical *Shorea robusta* forests in Makwanpur district, Nepal (242.42 t/ha; Bohara et al., 2021). Similarly, the value obtained here for trees with DBH ≥ 5 cm is consistent with the result (183.72 t/ha) reported by Ayer et al. (2022) in Kanchanpur Sal forests for trees with DBH ≥ 10 cm. The phytomass carbon reported by Regmi et al. (2021) for *Shorea robusta* forests in Dang District, Nepal (99.02 t/ha) was lower than that of the study area, likely due to the presence of larger diameter and height classes of trees in our study area. Similarly, the value observed in Dailekh community *Shorea robusta* forests (60.62 t/ha) was much lower, which may also be attributed to the dominance of smaller-sized trees (Rawal & Subedi, 2022). In contrast, the phytomass carbon stock estimated in this study is comparable to that of western Himalayan forests in India (234.2 t/ha; Dar et al., 2017) and the range reported for Collaborative *Shorea robusta* Forests in Mahottari district, Terai, Nepal (197–274.66 t/ha; Mandal et al., 2013). However, the total standing biomass of 178.77 – 345.04 Mg/ha is reported in Nagaland, Northeast India (Ao et al., 2024), and tree carbon stock of 137.5 t/ha is observed in the Tripureshwor Community Sal Forest, Surkhet (Poudel et al. 2025). The value obtained in our study site was higher than that reported for the Ramnagar community-managed *Shorea robusta* forest in the Far-Western Terai (163.12 t/ha; Joshi et al., 2021), likely due to the removal of large-diameter trees in Ramnagar CF. It was also comparable to the range (206.52 ± 14.91 to 239.78 ± 9.81 MgC/ha) observed in the tropical moist deciduous *Shorea robusta* forests of Similipal Biosphere Reserve, Odisha, India (Mohanta et al., 2020). Finally, the phytomass carbon recorded in the present study was higher than that reported for tropical dry deciduous forest 104.7 t/ha in Madhya Pradesh, India (Raha et al., 2020).

Among the DBH classes, large trees (DBH ≥ 50 cm) contributed the majority of the phytomass carbon in the study area, accounting for 68.2% in BZ, 72% in BZCF, 74.2% in CF, and 77.3% in PF. This pattern resembles with the findings of Mohanta et al. (2020). They have reported that large trees (DBH ≥ 50 cm) contributed the highest share of AGB, 47.3% in XDF and 39.9% in SDF forest regimes. Despite being fewer in number, trees with large-diameter are the reservoirs of carbon across all regimes, as shown by the results of this study.

The statistical analysis revealed notable variations in total phytomass carbon stock across the four regimes ($p < 0.01$; Table 4). Among them, BZCF recorded the highest average phytomass carbon, which is likely due to the combined protection provided by both the national park and community. This finding is consistent with Måren and Sharma (2021), who reported higher carbon stocks in forests protected by national parks and conservation areas (163 t/ha) compared to unprotected forests (114 t/ha) in the temperate region in the central Himalayas, Nepal. These results suggest that variations in phytomass carbon stock among regimes may be closely linked to differences in forest management approaches (see Tables 1 and 2). For instance, the phytomass carbon stock of CF is lower than that of the other three regimes in our study area. The significant differences in phytomass carbon stock of CF with the other three regimes might be due to the anthropogenic disturbances, like illegal removal of forest products, forest fires, encroachment, and uncontrolled grazing (Rambel Community Forest, 2021). In contrast, BZCF had the highest average phytomass carbon stock because of less anthropogenic disturbances, such as forest fires, encroachment, illegal extraction and smuggling of forest products and uncontrolled grazing. In addition, BZCF has the provision of good silvicultural practices, such as shrub management, cleaning, pruning, thinning, singling, tree improvement and dead wood collection. The importance of such silvicultural practices becomes clear when the phytomass carbon stocks of BZCF and BZ are compared. Even though the extraction of forest products is more restricted in BZ and anthropogenic disturbances are lower because it is in the strict conservation zone (Chitwan National Park, 2013), the phytomass carbon stock of BZ is lower than that of BZCF. This is silvicultural practices (present in BZCF, but not in BZ) that allow the removal of dead or diseased trees that would compete with healthy trees for nutrients and sunlight. By allowing healthy trees to grow and become large-diameter trees, these silvicultural practices increase the phytomass carbon stock of BZCF compared to BZ. Another reason of having the highest phytomass carbon in BZCF is the combined effort of National Park authorities and community user groups to protect biodiversity. This argument is further supported in PF. Due to effective silvicultural practices such as coppice with standard system, shelterwood system, and selection system, PF had more phytomass carbon even in the presence of anthropogenic pressure on this forest than CF and BZCF. The efficacy of silvicultural practices can be understood in terms of the intermediate disturbance level hypothesis (Connell, 1978; Huston, 1979). According to this theory, with no or little disturbances, only the competitive dominants can survive, while at sufficiently high level of disturbances, only fugitive species can survive. Thus, diversity is maximized at the intermediate level of disturbance (Abugov, 1982). Finally, besides management practices, the differences in carbon storage among tropical forests can indicate variation in a number of factors, including tree community composition, disturbance history, and successional stage (Ngo et al., 2013).

The average soil pH found in this study area was 5.73±0.05 in BZ, 6.17±0.12 in BZCF, 5.91±0.06 in CF, and 5.83±0.10 in PF. These values are close to those reported in mixed Sal forests by Kafle (2019) (5.3±0.67), and Paudel and Sah (1970) (5.26±0.58). The values also align closely with the result (6.6) obtained in agroforests of the Churia range, Makawanpur, Nepal (Magar et al., 2020). Likewise, Mohanta et al. (2020) reported average soil pH ranging from 5.37 to 5.66 in XDF and SDF Sal forests of Odisha, India, Sharma et al. (2025) studied from subtropical Sal forests in North Western Himalayas, and reported pH value ranging from 5.25 to 6.71, Poudel and Devkota (2021) reported pH value 5.12± 0.43 in the Sal forest of Tanahu Nepal, Kandel et al. (2024) reported average soil pH value ranged from 6.73 to 6.89 in the Terai regions of Nepal, which are comparable to the averages observed in this study, which might be due to the fact that *Shorea robusta* favours slightly acidic soil. Soil pH strongly affects the solubility and availability of many nutrient elements and influences nutrient uptake and root growth, besides controlling the activity of microbes (Brady & Weil, 2016). Soil pH is important in determining the availability of many elements and is a good indicator of forest fertility, with most macronutrients having maximum availability at pH 6.5- 7.5 (Black, 1968). Lower pH values (more acidic soil) found in BZ might be due to restrictions on forest product collection and silviculture practices, because this leads to the collection of leaf litter on the ground. Their decomposition increases microbial activities, which ultimately increases organic acids in soils. Similarly, higher pH values found in BZCF, CF and PF might be due to silvicultural activities such as the collection of leaf litter and branches during the cleaning of the forest, forest fires, which reduce leaf litter.

The average bulk density in the study area (1.56 ± 0.02 g/cm³ at 0–10 cm soil depth) is comparable to the values reported by Liu et al. (2016), who found averages of 1.29, 1.32, and 1.28 g/cm³ at soil profile depths of 78, 82, and 84 cm in north-eastern, middle-eastern, and south-eastern China, respectively. It was slightly lower than the mean values reported by Banik et al. (2018) in *Shorea robusta* forests (1.78 ± 0.04 g/cm³) and *Shorea robusta* plantations (1.95 ± 0.04 g/cm³), likely due to their deeper sampling depth (0-45 cm). In contrast, the bulk density observed in this study was higher than that reported for different agroforestry systems in Nepal, 1.06 g/cm³ in agrisilviculture, 1.29 g/cm³ in home gardens, and 1.03 g/cm³ in silvopasture (Magar et al., 2020), as well as higher than the averages of 1.28 g/cm³ over 1 m soil depth in *Shorea robusta* forests reported by Kafle (2019) and 1.18 g/cm³ over 0–100 cm reported by Ghimire et al. (2019) and 0.78 to 1.59 g/cm³ over 0-20 cm reported by Sharma et al. (2025) for *Shorea robusta* forests. Similarly, the higher bulk density value in this study is supported by that of *Shorea robusta* forests reported by FRA/DFRS (2014) (1.34 g/cm³). The minimum bulk density observed in the present study was in comparison with that found by Karki et al. (2016) in dense (0.91 g/cm³) and sparse (1.17 g/cm³) forest strata. These variations are due to differences in sampling depth and inherent soil properties across sites. Soil bulk density shows the ability of soil to provide structural support, water and solute movement, and aeration. Vegetation and management practices can affect the bulk density of soil, which influences soil cover, organic matter, soil structure and porosity of the soil (Brady & Weil 2016). Moreover, grazing and trampling by cattle can affect the soil structure due to soil compaction. This act increases its bulk density, which adversely affects root growth and decreases the size of soil pores that reduce soil permeability and water flow through the soil, as well as soil air capacity (Blouin et al. 2008; Bejarano et al. 2010; Lipiec et al. 2012). This means that the highly compacted soil will retain lower moisture content because of lower permeability and higher runoff that renders it less suitable for the growth of trees by reducing the nutrient supply of root systems (Saxena & Singh, 1984; Duan et al., 2019). In this context, the different management practices and levels of anthropogenic disturbances active in different regimes can affect soil compaction and hence bulk density (Cambi et al. 2017). For example, the highest average bulk density found in BZ might be due to trampling of the soil by wild animals, particularly mammals. In BZCF, the compaction and increase in bulk density can occur due to human movement during the silvicultural practices, such as logging, cleaning, pruning and grazing by cattle and wild animals.

In the study area, the average soil organic carbon (SOC) in the topsoil layer (0–10 cm) was 10.22 ± 0.17 t/ha. This value is lower than that reported for the same depth (26.6 ± 4.49 t/ha) in forest ecosystems of Delhi, India (Meena et al., 2019), and in the Central Terai forests of Nepal (39.3 ± 17.05 t/ha; FRA/DFRS, 2014), although the latter estimate was based on a deeper soil profile (0–30 cm). Since SOC is also stored at greater depths through leaching, root penetration, and microbial activity, values naturally increase with deeper sampling. For example, Meena et al. (2019) recorded 18.04 ± 2.88 t/ha at 10–20 cm depth, while Kafle (2019) reported 34.35 t/ha for 0–20 cm in the Kankali Community Forest, Chitwan. The SOC recorded in this study aligns with values from agroforests in Makwanpur (Magar et al., 2020). They have reported the SOC values of 7.70, 10.74, and 11.62 t/ha at 0–10 cm depth in agrisilviculture, home gardens, and silvopasture systems, respectively. By contrast, Pandey et al. (2019) reported higher SOC values (26.65–38.73 t/ha at 0–10 cm) in community-managed forests of Dadeldhura, far-western Nepal. Such differences among studies likely reflect variations in sampling depth and local ecological conditions. In particular, the presence of larger trees in the Dadeldhura forests may contribute to higher SOC through enhanced root turnover and decomposition. SOC controls soil erosion, stabilizes soil structure and increase porosity of soil, which helps the cycling of nutrients necessary for plants and provides energy for microbial and fauna activity (Schlesinger, 1997). It is therefore important to identify forest management practices that increase soil carbon. For instance, harvested forests have been found to possess higher SOC stock (Suberi et al., 2016). In our study area, lower SOC in CF and PF than BZCF and BZ is due to the presence of anthropogenic disturbances such as illegal extraction and smuggling of forest products, and uncontrolled cattle grazing, besides forest fires. These disturbances remove plant material that would become part of the SOC reservoir in the future. On the other hand, BZCF showed the highest average SOC, which is statistically different from the other three management regimes. This is because of the combined management of the national park and community users' group in BZCF, which conducts controlled silvicultural practices such as thinning, pruning, clearance of leaf litter, cutting and logging of the trees for the livelihood of local people. These practices help increase the input of plant phytomass and litter that become part of the SOC reservoir. In addition, there is low level of anthropogenic activities in BZCF, which would have decreased SOC if present at a higher level.

The analyses aimed at determining correlations between various tree-related characteristics and soil attributes, and revealed weak to strong relationships. Most importantly, the strong correlation between tree basal area and phytomass carbon, along with its high predictive power, is crucial for policy implementation in programs such as REDD+. In addition to storing large amounts of biomass, trees with greater DBH and height contribute to enhanced ecosystem resilience and the long-term stability of forests and surrounding areas (Pokhrel & Sherpa, 2020). Due to the reasons mentioned earlier, it can be emphasized that such forests require stronger protection to optimize carbon conservation and sequestration. It best helps support climate change mitigation efforts. This act can provide various benefits for biodiversity conservation and help policymakers at local, provincial, and national levels in resource management and development planning (Thompson et al., 2009). The outcomes of this research provide baseline information for climate change mitigation under initiatives such as REDD+, thus maintaining the integrity of tropical lowland forests.

Conclusion

The study demonstrates that forest management regimes significantly influence the carbon storage potential and structural attributes of the studied forest. The Buffer Zone Community Forest (BZCF), which is benefitting from dual protection by the community and the national park, stored the highest phytomass carbon stock, underscoring the effectiveness of integrated management approaches. Notably, a small number of large-diameter trees (*Shorea robusta* in particular) were responsible for the majority of the carbon stock across all regimes. Tree basal area, soil pH, and bulk density were identified as strong predictors of phytomass carbon, whereas species richness showed no significant relationship. These findings demonstrate that conservation strategies prioritizing large trees and quantifiable forest structural attributes, rather than species richness alone, are essential for maximizing carbon sequestration. The findings provide baseline data and actionable insights for forest managers and policymakers for optimizing management practices for climate change mitigation under initiatives like REDD+, while maintaining the ecological integrity of Tarai forests in Nepal.

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Author's contribution statement

V. P. Gautam: Research design, sample collection, laboratory analysis, data management, original draft writing, and formal analysis. **B. K. Sharma**: Research concept, sample collection, analysis, reviewing and editing the draft and supervision. **C. B. Baniya**: Data analysis and reviewing. **R. K. P. Yadav**: Research conceptualization, data analyses, original draft writing, reviewing and editing and supervision.

Data availability

The data used in the study are accessible upon request to the corresponding author.

Declaration

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work.

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Appendix 1: List of tree species and their respective wood densities (in units of g/cm^3)

SN	Species	Wood density (g/cm^3)	Reference
1	*Adina cordifolia*	0.59	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
2	*Albizia lebbeck*	0.55	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
3	*Albizia procera*	0.59	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
4	*Alstonia scholaris*	0.36	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
5	*Ardisia solanacea*	0.62	https://www.spikevm.com/list/specific-gravity-india.php
6	*Bombax ceiba*	0.33	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
7	*Careya arborea*	0.8	https://www.spikevm.com/list/specific-gravity-india.php
8	*Casearia graveolens*	0.62	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
9	*Cassia fistula*	0.74	Chowdhury and Ghosh (1958)
10	*Catunaregam spinosa*	0.68	https://eol.org/pages/1111390
11	*Cordia dichotoma*	0.53	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
12	*Dalbergia latifolia*	0.75	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
13	*Dalbergia sissoo*	0.76	https://www.spikevm.com/list/specific-gravity-india.php
14	*Dillenia pentagyna*	0.53	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
15	*Holarrhena pubescens*	0.64	https://www.spikevm.com/list/specific-gravity-india.php
16	*Lagerstroemia parviflora*	0.62	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
17	*Litsea monopetala*	0.4	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
18	*Madhuca longifolia*	0.74	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
19	*Mallotus nudiflorus*	0.44	Utilization of Pitali (*Mallotus nudiflorus*) for Manufacturing Commercial plywood in Bangladesh
20	*Melia azedarach*	0.56	https://www.spikevm.com/list/specific-gravity-india.php
21	*Semecarpus anacardium*	0.64	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
22	*Shorea robusta*	0.72	*Sharma and Pukkala (1990)*
23	*Spondias pinnata*	0.45	Wood anatomy and properties of three species in the genus *Spondias lakonensis* (Anacardiaceae) found in Thailand
24	*Syzygium cumini*	0.7	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
25	*Syzygium nervosum*	0.66	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
26	*Tamilnadia uliginosa*	0.68	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
27	*Tectona grandis*	0.5	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
28	*Terminalia elliptica*	0.75	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
29	*Terminalia bellirica*	0.72	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.
30	*Toxicodendron wallichii*	0.44	*Wood Densities of Tropical Tree Species*. United States Department of Agriculture.