Soil organic carbon stocks under different forest types in Pokhare khola sub-watershed: a case study from Dhading district of Nepal

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Abstract

Assessment of carbon stock in vegetation and soil is an essential step in estimating the carbon sequestration potential of an ecosystem. This study was carried out to quantify total carbon sequestration in different forest types of the Pokhare Khola sub-watershed (forested area of 312 ha), Dhading, Nepal. The inventory for estimating the above and belowground biomass of different forests was carried out using the stratified random sampling method with 0.5% sampling intensity for plant biomass. The dry biomass was calculated using allometric models.

Four soil profiles from each forest types were excavated and soil samples were taken from the soil profile up to 1 m depth at intervals of 20 cm. The soil bulk density was collected using a core ring sampler of 9.5 cm long and 4.2 cm diameter and organic carbon content was assessed using the Walkley and Black method. The total soil carbon stock in all forest types was estimated at 42,523 t/ha, Shorea forest 62%, Schima-Castonopsis forest 25%, Pine-Shorea forest 5.5%, and degraded forest 7.5%. The distribution pattern of carbon stock was mainly due to the biomass of the stand, carbon content of soil and area coverage of these forest types. The total biomass carbon in forest was found as 77.68 t/ha and SOC sequestration 58.6 t/ha.

The study showed that soil organic carbon was higher in the upper layer (0–20cm) in all forest types and rapidly declined below the 20–40cm depth. The rate of SOC concentration is in decline trend as the depth increased. The study revealed that a Shorea forest and Schima-Castonopsis forest are better than a Pine-Shorea forest and degraded forest in carbon stocking.

Keywords: biomass, biomass carbon, bulk density, carbon sequestration, carbon stock, soil organic carbon.

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1 Introduction

Carbon sequestration is the removal of carbon from the atmosphere by storing it in the biosphere. About 2/3 of terrestrial carbon is sequestrated in the standing forest, forest under storey plant, leaf and forest debris, and in forest soils (Sedjo *et al.* [1]). Forest and wooded areas are natural carbon sinks. This means that trees store carbon by sequestrating atmospheric carbon in the growth of wood biomass through the process of photosynthesis; thereby increasing the soil organic carbon (Brown and Pearcel [2]).

The carbon pool in the terrestrial ecosystem can be broadly categorized into vegetative carbon and soil carbon components. Vegetative carbon can be further categorized into carbon in the aboveground biomass, belowground biomass (Hamburg [3]). These stocks are dynamic, depending upon various factors and processes operating in the system, the most significant being land use and land use changes, soil erosion and deforestation (IPCC [4]).

Forests and wooded areas are large reservoirs of carbon as well as potential natural carbon sinks. Trees store carbon by sequestering atmospheric carbon in the growth of wood biomass through the process of photosynthesis; thereby increasing the soil organic carbon (Brown and Pearcel [2]). Forest carbon sinks are believed to offset a significant proportion of carbon emissions associated with fossil fuel combustion. The surface soil organic carbon pool (SOCP) and turnover time are particularly sensitive to a range of factors such as climate, topography, soil and crop management, and other anthropogenic conditions. This study aims to estimate the aboveground, belowground biomass carbon stock in four forest types and soil organic carbon in four forest types under a different soil profile of Pokhare khola sub-watershed, Dhading district, Nepal.

2 Materials and methods

2.1 Description of study area

The Pokhare khola sub-watershed (27º46′28″–27º48′06″N latitude and 84º53′32″–84º55′11″E longitude) is a middle mountain sub-watershed in Nepal, covering an area of 5.36 (536 ha) square kilometers The Prithvi Highway passes through the lower part of the watershed along Trishuli River and is 65 kilometers west from the capital city, Kathmandu. The area covers part of ward numbers 2 and 3 of Pida VDC. The location map is presented in Figure 1. The watershed terrain lies in the middle mountain ranges.

The watershed consists of moderate to very steep slopes with an altitude ranging from 400 m to 1079 m asl. The sub-tropical climate with an of average 8º and 31ºC temperature and the average rainfall recorded at Dhading is 1370 mm and average rainy days in a year is 104. The predominant soil in the watershed comprises of cambisols followed by luvisols in the lower part of the watershed and leptosols in some of the degraded area. The watershed has mixed sub-tropical vegetation with dense Shorea forest at lower altitude, mixed with other sub-tropical vegetation; pine at middle altitude and temperate broadleaf

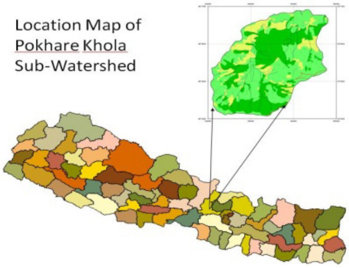

Figure 1: Location map of study area.

forest (Schima-Castanopsis) at higher altitude. Forests can be classified to dense Shorea forest, Pine-Shorea forest, Schima-Castanopsis forest and degraded forest.

2.2 Data collection

2.2.1 Sampling

Stratified random sampling was used for collecting data for plant biomass. 7 sample plots of 20 m x 25 m for trees (> 30 cm dia.) nested quadrate of size 10m x 10m for poles (10–29.9 cm dia.), 5m x 5m for sapling (> 5 cm dia.) and 1m x 1m for regeneration, grass and herb were laid out at different aspects for collecting biomass. Tree species whose height was less than 1m and diameter less than 5 cm were considered as shrub (Shrestha and Singh [5]).

2.2.2 Biophysical measurements

Diameter at breast height of each tree within the plot was measured using a diameter tape and the height of each tree was estimated using a Sunto clinometer and Abney’s level. For woody shrubs, the diameter was measured at 15 cm aboveground level. All under storey bushes, grasses and herbaceous plants were clipped and the fresh weight of the samples were determined and a representative sub-sample of 300 gm was taken to the laboratory to be oven dried.

2.2.3 Soil sampling

Four profiles from each forest types were dug at the center part of the plot up to 1 m depth for deep soils and up to bed rock for shallow soils. Soil samples at different depths (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm) were taken. A core ring sampler of 9.5 cm long with 4.2 cm diameter was used for bulk density. The soil samples were air-dried in the shade, and ground manually passed through a 2-mm sieve. All the soil samples were analyzed in the laboratory.

2.3 Data analysis

2.3.1 Biomass estimation

The biomass of tree includes all parts such as stems, branches, twigs, leaves and roots.

2.3.1.1 Aboveground biomass estimation The total stem volume of each tree was calculated using the relationship developed by Sharma and Pukkala [6].

$$\ln (V) = a + b * \ln (d) + c * \ln (h) \qquad (1)$$

where V = the total stem volume with bark, d = the diameter at breast height (cm), h = the tree height (m), and a, b, and c are species specific constants shown in table 1.

Table 1: Parameters a, b, and c for major tree species.

SN	Species	a	b	C	R^2
1	Shorea forest	-2.4545	1.9026	0.8352	98.3
2	Pine-Shorea forest	-2.9770	1.9235	1.0019	99.2
3	Schima-Castanopsis forest	-2.7285	1.8155	1.0072	98.3
4	Miscellaneous spp in hill forest	-2.3204	1.8507	0.8223	97.7

After calculating the volume of the tree, it was multiplied by the density of the wood (Chaturvedi and Khanna [7]) of the species to get the aboveground biomass (dry weight stem biomass). The biomass of branches and leaves were estimated using 45% and 11% of the stem biomass respectively (Sharma [8]).

2.3.1.2 Under-growth biomass Regeneration/under-storey bushes, grasses and herbaceous layers were clipped and weighed. Representative samples of undergrowth of about 200 grams were taken, dried at room temperature, recording its weight and oven dried for 72 hours at 75°C. Oven dry biomass values for litter, under storey bushes and grasses were calculated using the following formula by Lasco *et al.* [9]:

$$ODW = \frac{TFW - (TFW * (SFW - SODW))}{SFW} \qquad (2)$$

where ODW = Total oven dry weight, TFW = Total fresh weight, SFW = Sample fresh weight, SODW = Sample oven dry weight

The biomass of woody perennial shrubs was calculated using the equation developed by Hasse and Hasse [10]:

$$Y = a\,D^b \qquad (3)$$

where Y is the total dry biomass (kg), D is the diameter 15 cm above the ground (cm), a, and b are constants whose values were considered as –4.264 and 1.016 respectively, and with a correction factor of 1.0232 (Hasse and Hasse [10]).

2.3.1.3 Belowground biomass estimation The root biomass of trees varies according to species, age, microclimate and soil. For this study the following relationships were used for estimating the root biomass (FAO [11]).

For coniferous vegetation:

$$\text{belowground biomass} = 0.25 \text{ x aboveground biomass.} \tag{4}$$

For broadleaf vegetation:

$$\text{belowground biomass} = 0.30 \text{ x aboveground biomass.} \tag{5}$$

2.3.2 Estimation of net carbon content

The aboveground tree carbon (stem, branch and leaf carbon) and root carbon were calculated using the stock method. The total carbon was assumed to be 43% of the biomass. Total 10 gm (8 gm stem with bark + 2 gm leaf) of oven dried undergrowth was burnt in an electrical furnace at 400ºC for 30 minutes, ash content (inorganic elements in the form of oxides) left after burning was weighed, carbon % of undergrowth and leaf litter was determined by the ash content method (Negi *et al.* [12]). The following formulae were used for computing the total above and belowground biomass organic carbon.

$$\begin{gathered}\text{Total aboveground biomass organic carbon}\\ = (\text{total aboveground biomass of tree} + \text{total branch and litter biomass}\\ + \text{total under storey biomass} + \text{shrub biomass})^{*}\ 43\%\end{gathered} \tag{6}$$

and

$$\begin{gathered}\text{Total belowground biomass organic carbon}\\ = (\text{total root biomass of tree})^{*}\ 43\% + \text{total soil organic carbon.}\end{gathered} \tag{7}$$

2.3.3 Soil organic carbon (SOC)

Collected soil samples were analyzed in the soil laboratory and the soil organic C percentage was calculated (Negi *et al.* [12]).

$$\begin{gathered}\text{Carbon }\% = 100 - (\text{Ash weight} + \text{molecular weight}\\ \text{of } O_2\ (53.3) \text{ in } C_6H_{12}O_6)\end{gathered} \tag{8}$$

The formulae used for determining above and belowground biomass organic carbon were:

$$\begin{gathered}\text{Total aboveground biomass organic carbon}\\ = (\text{total aboveground biomass of the tree x } 43\%\\ + \text{Undergrowth biomass x Carbon }\% + \text{litter biomass x Carbon }\%)\end{gathered} \tag{9}$$

$$\begin{gathered}\text{Total belowground biomass organic carbon}\\ = (\text{total root biomass of tree}) \text{ x } 43\% + \text{total soil organic carbon})\end{gathered} \tag{10}$$

The Walkey-Black method was applied for measuring the soil organic carbon (McLean [13]). The total soil organic carbon was calculated using the formula given below (Awasthi *et al.* [14]):

$$\begin{gathered}\text{SOC } (\text{kg/m}^3) = \text{Organic Carbon Content }\%\\ \text{x soil bulk density } (\text{kg/m}^3) \text{ x thickness of horizon (m).}\end{gathered} \tag{11}$$

Further, the soil organic carbon was expressed in tons per hectare.

2.3.4 Bulk density

Soil bulk density was determined using the core sampling method (Blake and Hartge [15]). The oven dry weight of soil samples will be determined for moisture correction. The dried soil was then passed through a 2 mm sieve, the sieved soil was weighed and the volume of stones was recorded for stone correction. The following formula was used to calculate the bulk density using stone correction (Pearson *et al.* [16]).

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Ovendry mass (g/cm}^3\text{)}}{\text{Core volume (cm}^3\text{)} - \dfrac{\text{Mass of coarse fragments (g)}}{\text{Density of rock fragment (g/cm}^3\text{)}}} \qquad (12)$$

where, the coarse fragments are > 2 mm. The density of rock fragments is 2.65 g/cm^3.

Statistical analysis was carried out using SPSS and simple modeling using MS Excel while preparing the database. The least significant difference (LSD) was used for multiple comparisons of means. The variability in soil and biomass carbon was measured in terms of range, standard error of means (SE) and analysis of variance (ANOVA).

3 Result and discussion

3.1 Properties of forest stand

Biomass and biomass carbon sequestration mainly depends on density and size of the stand. The mean diameter (22.12 cm) in a Pine-Shorea forest followed by degraded forest (17.11 cm) and Shorea forest (16.78 cm) and found least in a Schima-Castanopsis forest (14.48 cm). Similarly a Shorea forest stand has more trees (1338 trees/ha), a Schima-Castanopsis forest (904 trees/ha), a Pine-Shorea forest (730 trees/ha) and degraded forest (480 trees/ha).

3.2 Aboveground biomass estimation

The biomass of tree and underground vegetation varies with forest types, age of the stand, density of vegetation, species, aspect and elevation. Aboveground tree biomass was higher (170.95 ± 23.03 ton ha^{-1}) in dense Shorea forest (S) (table 2) followed by Pine-Shorea forest (PS) (128.96 ± 31.27 ton ha^{-1}) (table 2) and Schima-Castonopsis forest (SC) (91.3 ± 13.56 ton ha^{-1}) (table 2) and was found lower (63.82 ± 27.81 ton ha^{-1}) in degraded forest (DF) (table 2). Undergrowth biomass was higher (5.73 ± 1.2 ton ha^{-1}) in the Shorea forest (table 2) followed by the Schima-Castnopsis forest (3.07 ± 1.32 ton ha^{-1}) (table 2) and was found lower (0.76 ± 0.43 ton ha^{-1}) in the degraded forest (table 2). Undergrowth biomass was in order of DS > SC > PS > DF. The leaf litter biomass was found higher (1.6 ± 0.66 ton ha^{-1}) in the PS forest (table 2) and lower (0.32 ± 0.1 ton ha^{-1}) in the DF (table 2). It was in order of PS > SC > DS > DF.

The result showed that total aboveground biomass was higher (177.64 ± 23.43 ton ha^{-1}) in the S forest (table 2). It is due to a higher density of vegetation in the S forest in comparison to other forest types. The total aboveground biomass of the PS forest was found in the second position (132.82 ± 31.66 177.64 ± 23.43 ton ha^{-1}) (table 2) followed by the SC forest, found in second position (95.47 ± 14.21 ton ha^{-1}) (table 2). It is because larger and matured trees of pine species were found in the PS forest in comparison to other forest types. The total aboveground biomass was lower (65.00 + 27.65 ton ha^{-1}) in the degraded forest (table 2). Similar results were found in Lalitpur and Palpa districts, Nepal. Karki [17] reported that the aboveground tree biomass of the Schima-Castonopsis forest in Kafle CF forest in Lalitpur was 91.76 ton ha^{-1}. Shrestha [18] reported an aboveground tree biomass of Shorea forest in Bharkes CF in Palpa district was 177.24 ton ha^{-1}.

Table 2: Total aboveground biomass (ton ha^{-1}) in different forest types.

Forest Types	Types of Biomass	Biomass (ton ha^{-1})	Min^{m}	Max^{m}	S Error
Shorea forest	Tree Biomass	170.95	66.12	338.15	23.03
	Leaf litter Biomass	1.06	0.07	2.23	0.19
	Undergrowth Biomass	5.73	0.54	17.28	1.2
Total Aboveground Biomass		177.74	66.73	357.64	24.42
Pine-Shorea forest	Tree Biomass	128.96	25.55	190.73	31.27
	Leaf litter Biomass	1.6	0.37	3.77	0.66
	Undergrowth Biomass	2.26	0.53	6.90	1.34
Total Aboveground Biomass		132.82	26.45	201.40	33.27
Schima-Castonopsis forest	Tree Biomass	91.3	51.44	138.15	13.56
	Leaf litter Biomass	1.1	0.37	3.77	0.25
	Undergrowth Biomass	3.07	0.53	6.90	1.32
Total Aboveground Biomass		95.47	52.34	148.82	15.13
Degraded forest	Tree Biomass	63.82	14.28	181.14	27.81
	Leaf litter Biomass	0.32	0.07	0.74	0.10
	Undergrowth Biomass	0.76	0.05	2.70	0.43
Total Aboveground Biomass		64.90	14.40	814.58	28.34

3.3 Aboveground carbon stock

3.3.1 Carbon content in undergrowth and leaf litter

Carbon content (% carbon) of the biomass varies on species, component of biomass (leaf, bark, stem, root, leaf litter). The carbon content of undergrowth and leaf litter are shown in table 3. The carbon content of undergrowth was found maximum (44.63%) in a Pine-Shorea forest and minimum (43.67%) in a Schima-Castonopsis forest, while the carbon content of leaf litter was found maximum (44.46%) in a Shorea forest and minimum (43.17%) in a Schima-Castonopsis forest. Negi *et al.* [12] observed that the maximum carbon is stored in the order of coniferous > deciduous > evergreen > bamboo and he found 44.07%, 43.46%, and 46.11% carbon in bark, leaf, and wood biomass of a pinus ruxburghii forest respectively and 41.72%, 42.58%, and 45.46% carbon in bark, leaf, and wood biomass of a shorea robusta forest respectively.

Table 3: Carbon content in under-growth and leaf litter.

Forest Types	Undergrowth Carbon %				Leaf Litter Carbon %			
	Mean	Min	Max	SE	Mean	Min	Max	SE
Shorea	44.00	43.91	44.09	0.03	44.44	44.25	44.60	0.07
Pine-Shorea	44.61	44.30	45.00	0.13	43.86	43.75	44.00	0.06
Schima-Castonopsis	43.64	43.45	43.83	0.08	43.21	42.59	43.76	0.21
Degraded	44.33	44.25	44.41	0.03	43.47	43.20	43.80	0.11

3.3.2 Total aboveground carbon stock

The photosynthesis process carbon from the atmospheric CO$_2$ includes products of organic compounds. All the organic compounds containing carbon are stored in different plant tissues as food. Thus, carbon appears as a part of the plant biomass. The total aboveground organic carbon includes carbon on the aboveground tree biomass (e.g., branch, stem, leaves), litter fall, twigs and biomass of undergrowth (Gautam [19]).

3.4 Belowground biomass and carbon stock

Belowground biomass (root) was found higher (52.97 ton ha^{-1}) in a Shorea forest (S) followed by Pine-Shorea forest (PS) (35.10 ton ha^{-1}). Root biomass of Schima-Castonopsis forest (SC) and degraded forest (DF) was 28.31 ton ha^{-1} and 19.37 ton ha^{-1} respectively. Obviously carbon sequestration from root was in order of S > PS > SC > DF and carbon stock was 22.78 + 3.02 ton ha^{-1}, 15.09 + 3.04 ton ha^{-1}, 12.17 + 1.83 t / ha^{-1} and 8.32 + 3.57 ton ha-1 respectively (table 4).

Table 4: Belowground biomass carbon (in tons per hectare).

Forest Types	Root Biomass	Root Carbon	Min^{m}	Max^{m}	SE
Shorea forest	52.97	22.78	8.88	43.97	3.02
Pine-Shorea forest	35.10	15.09	2.81	211.80	3.04
Schima-Castonopsis	28.31	12.17	7.09	18.23	1.83
Degraded forest	19.37	8.32	1.88	23.44	3.57

The carbon stock in forest vegetation varies according to geographical location, plant species, and age of the stand (Van Noordwijk *et al.* [20]).

3.5 Soil carbon sequestration

3.5.1 Bulk density

Great variation was found in bulk density in all types of forests in different soil profiles. A gradual increase in bulk density was seen with the increase in depth in each forest type. A significant difference in bulk density was seen at depth (0–20 cm), (20–40 cm), (40–60 cm), (60–80 cm) and (80–100 cm) within the forest type as well as in all other forest types. Bulk density increases as we go deeper and deeper due to natural compaction of soil (table 5). Bulk density depends on several factors such as compaction, consolidation and the amount of SOC present in the soil but it is highly correlated to the organic carbon content (Morisada *et al.* [21]; Leifeld *et al.* [22]). Bulk density of top humus soil layer was found 1.25 (ton m^{-1}) in the forest of the same study area at the depth of 0–20 cm irrespective of forest types (Tiwari *et al.* [23]). Bulk density was slightly higher in a degraded forest than other forest types, as a degraded forest has an open space due to heavy grazing and trampling of soil by livestock as well as movement of people. The soil type was observed to also be of low permeability due to the high clay lateritic type of red soil.

Table 5: Bulk density (tons m^{-3}) in different forest types.

Forest Types	Soil Depth (cm)	Bulk Density tons m^{-3}	Min^{m}	Max^{m}	SE
Shorea forest	0–20	1.20	0.95	1.44	0.09
	20–40	1.36	1.21	1.41	0.06
	40–60	1.40	1.07	1.55	0.09
	06–80	1.45	1.16	1.65	0.09
	80–100	1.47	1.40	1.60	0.07
Pine-Shorea forest	0–20	1.27	1.00	1.43	0.08
	20–40	1.38	1.19	1.49	0.06
	40–60	1.44	1.26	1.58	0.06
	06–80	1.47	1.09	1.62	0.11
	80–100	1.52	1.10	1.77	0.14
Schima-Castonopsis forest	0–20	1.17	1.08	1.33	0.05
	20–40	1.22	1.09	1.42	0.07
	40–60	1.27	1.06	1.51	0.08
	06–80	1.30	1.26	1.33	0.01
	80–100	1.32	1.26	1.39	0.02
Degraded forest	0–20	1.40	1.39	1.42	0.01
	20–40	1.43	1.27	1.74	0.09
	40–60	1.46	1.28	1.75	0.09
	06–80	1.46	1.25	1.70	0.09
	80–100	1.49	1.34	1.72	0.08

3.5.2 Soil organic carbon

Organic carbon was found higher at the upper level of soil in almost all cases. In a Schima-Castonopsis forest OCC was higher than other types of forest (table 6). The greater the depth, the lower the OCC in all forest types.

Table 6: Organic carbon content (OCC %) in different types of forest.

Soil Depth (cm)	Organic carbon content (OCC %) in different forest types			
	Shorea forest	Pine-Shorea forest	Schima-Castonopsis forest	Degraded forest
0–20	0.94	0.76	2.33	0.58
20–40	0.39	0.41	0.61	0.21
40–60	0.24	0.19	0.35	0.21
60–80	0.20	0.17	0.28	0.20
80–100	0.26	0.11	0.21	0.16

Table 7: Total carbon stock in different types of forest.

Type of Forest	Carbon Source	Carbon stock tons / ha	Forest Area in ha	Carbon stock in watershed (in ton)
Shorea forest	Aboveground	76.50	174	13311.00
	Root carbon	22.78	174	3963.72
	Soil carbon	51.54	174	8967.96
	Total	150.82		26242.68
Pine-Shorea forest	Aboveground	41.07	76	3121.32
	Root carbon	12.17	76	924.92
	Soil carbon	88.54	76	6729.04
	Total	141.78		10775.28
Schima-Castonopsis forest	Aboveground	57.63	20	1152.60
	Root carbon	15.09	20	301.80
	Soil carbon	43.94	20	878.80
	Total	116.66		2333.20
Degraded forest	Aboveground	27.92	42	1172.64
	Root carbon	8.32	42	349.44
	Soil carbon	39.29	42	1650.18
	Total	75.53		3172.26

3.6 Total carbon stock

The sum of carbon in aboveground biomass, root, and soil is the total carbon stock (table 8).

Table 8: Total carbon stock in different forest types.

Forest Types	Forest Area	% Area Cover	CS in ton	CS in %
Shorea forest	174	55.77	26242.68	61.71
Pine-Shorea forest	20	6.41	2333.20	5.49
Schima-Castonopsis forest	76	24.36	10775.28	25.34
Degraded forest	42	13.46	3172.26	7.46
Total	312	100%	42523.42	100%

4 Conclusions

The total biomass carbon in forests was found to be 77.68 ton ha^{-1}. Similarly, soil organic carbon sequestration was found to be 58.6 ton ha^{-1}. The highest biomass carbon was found in a Shorea forest followed by a Pine-Shorea forest. The highest SOC was found in a Schima-Castonopsis forest followed by a Shorea forest. Total carbon sequestration was highest in a Shorea forest, which was in order of Shorea forest (61.72%) > Schima-Castonopsis forest (25.33%) > Pine-Shorea forest (5.49%) > degraded forest (7.46%). Thus, total carbon sequestration by all forest types was 42523 ton ha^{-1}.

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