Above-ground carbon stock assessment in different forest types of Nepal

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This study assessed the above-ground carbon stock in the five major forest types, representing two physiographic regions and four districts of Nepal. Altogether, 116 circular sample plots were laid out systematically in different forests types to inventory the forest. Total above-ground biomass was derived with allometric equations. Results indicated variation in age of the stand (18-75 years), above-ground carbon stock per hectare (34.30-97.86 dry wt. ton ha^{-1}) and rate of carbon sequestration (1.30-3.21 t $ha^{-1}yr^{-1}$), according to different forest types. The rate of carbon sequestration by different forest types depended on the growing nature of the forest stands. Tropical riverine and *Alnus nepalensis* forest types demonstrated the highest carbon sequestration rates in Nepal.

Key Words: Above-ground biomass, carbon, forest types, Nepal

Globally, forests act as a natural storage for carbon, contributing approximately 80% of terrestrial above-ground, and 40% of terrestrial below-ground biomass carbon storage (Kirschbaum, 1996). They play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric C into the growth of woody biomass through the process of photosynthesis and also by increasing the soil organic carbon (SOC) content (Brown and Pearce, 1994). Carbon sequestration from atmosphere can be advantageous from both environmental and socioeconomic perspectives. The environmental perspective includes the removal of CO_2 from the atmosphere, the improvement of soil quality, and the increase in biodiversity (Batjes and Sombroek, 1997); while socioeconomic benefits include increased yields (Sombroek *et al.*, 1993) and monetary incomes from potential carbon trading schemes (McDowell, 2002).

The Kyoto Protocol recognized the importance of forest in mitigating the greenhouse gas emission (i.e. carbon dioxide, methane and other compounds) and has included forest and soil C sequestration in the list of acceptable offsets (UNFCCC, 1997). Thus, reducing emission from deforestation and forest degradation has emerged as an incentive mechanism for developing countries. However, updated national forest inventory data and technical capacity is poor; and accounting of changes in forest cover biomass stock, carbon emission and carbon removal are limited in the developing countries like Nepal (Dangi and Acharya, 2009). Therefore, this study has endeavoured to assess the above-ground carbon stock in the different forest types of Nepal.

Materials and methods

Study area

The study was conducted in five major forest types of four districts representing two physiographic regions of Nepal (Table 1). Chitwan district includes both Terai and Mahabharat foothills while Lalitpur, Kavre and Kaski districts represent the mid-hills region of Nepal.

Sample plots

There were 32, 34, 16, 16 and 18 number of sample plots employed in Tropical riverine, Hill Sal, Pine, *Schima Castanopsis* and *Alnus nepalensis* forests, respectively to inventory the forest. The plots were circular in shape, and the sizes varied as follows: trees (Size = 500 m^2), poles (Size = 100 m^2) and saplings (Size = 25 m^2). Field measurement was done by systematic sampling. Diameter at breast height (1.3 m from the ground level) was measured with diameter tape and tree height was measured with the Sunto Clinometer.

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Table 1 : District and geographical region wise distribution of studied forest types

S.N.	Forest type	District	Name of CF	Geographical Region	Major Species
1	Tropical riverine	Chitwan	Kumrose CF	Terai	*Terminalia tomentosa, Trewia nudiflora*
2	Hill Sal *(Shorea robusta)*	Chitwan	Amritdharapani CF	Mahabharat Foothills	*Shorea robusta*
3	Pine	Lalitpur	Saraswati CF	Midhills	*Pinus roxburghii, Pinus wallichiana*
4	*Schima-Castanopsis*	Kavre	Gaukhureshwar CF	Midhills	*Schima-Castanopsis*
5	*Alnus nepalensis*	Kaski	Andherikhola CF	Midhills	*Alnus nepalensis*

Equations used for biomass calculation

Total above-ground biomass (AGB) of hill community forests was calculated using different biomass equations produced by TISC (2000) according to the forest type and the species. Fresh weight of biomass was converted to dry weight using conversion factor of FORESC (1996). Similarly, the AGB of CFs located in the Terai was calculated using the Brown (1989) equation recommended for broadleaved species in tropical humid regions with precipitation from 1500 to 4000 mm and DBH limits from 5 to 130 cm, i.e.:

$$AGB = e^{[-3.141+0.9719*Ln(DBH*DBH*H)]} \quad ......1$$

Where,

AGB = Dry wt. of above-ground biomass (kg)

DBH = Diameter at breast height (cm).

H = Height of the tree (m).

Accuracy calculation of biomass measurement

Accuracy of biomass measurement was calculated using equation (2) and accuracy percentage was calculated using equation (3) and presented in Table 4.

$$\text{Accuracy (Bj)} = \bar{B} - \mu = t.\ Sx/\sqrt{n} \quad ....2$$

T = t value at infinity (1.96)

Sx = Standard deviation

n = number of plots

$\bar{B}$ = mean biomass

$$\text{Accuracy (Bj) Percentage} = Bj/\bar{B} *100 \quad ....3$$

Results and discussion

Majority of pole size stands were found in Hill Sal, *Schima-Castanopsis* and Tropical riverine forests. While in *Pine* and *Alnus nepalensis* forest, both tree size and pole size stands were found more or less same (Table 2).

Variation in age of the stand ranged from 18-75 years, variation in above-ground carbon per hectare from 34.70-97.86 ton ha^{-1} and variation in rate of carbon sequestration from 1.30-3.21 ton ha^{-1}year^{-1} in different types of forests (Table 3).

Table 2 : Maximum, mean and mode value of height and dbh of forest types

S.N.	Forest type	Max ht (m)	Mean ht (m)	Mode ht (m)	Max dbh (cm)	Mean dbh (cm)	Mode dbh (cm)
1	Tropical riverine	27.5	15.65	19	123	29.49	18.5
2	Hill Sal	30.0	12.75	9	89	19.56	13.9
3	Pine	26.0	18.10	19	46	31.17	30.0
4	*Schima-Castanopsis*	13.5	6.95	6	32	8.86	6.0
5	*Alnus nepalensis*	22.0	15.50	14	40	32.00	22.0

Table 3 : Above-ground carbon stock and carbon sequestration rate of different forest types of Nepal

S.N.	Forest types	Age of the stand (yr)	A.G Biomass Dry wt (ton ha^{-1})	Total AG carbon stock (ton ha^{-1})	AG Rate of carbon sequestration (ton ha^{-1} year^{-1})	Accuracy of biomass estimation (%)
1	Tropical riverine forest	25	178.83	80.47	3.21	17.65
2	Hill Sal forest	75	217.47	97.86	1.30	19.20
3	Pine forest	28	86.02	38.70	1.35	16.14
4	*Schima-Castanopsis*	22	76.24	34.30	1.56	11.27
5	*Alnus nepalensis*	18	76.00	34.60	1.92	14.56

Age of the forest types varied from 18-75 years and above-ground biomass varied from 76 ton ha^{-1} to 217 ton ha^{-1}. Above-ground biomass (ton ha^{-1}) was found to be highest in Hill Sal forest and lowest in *Alnus nepalensis* forest (Fig. 1). The figure shows that the age of all forest types except hill Sal was more or less same but above-ground biomass was different. This was due to slow and fast growing nature of the studied forest types.

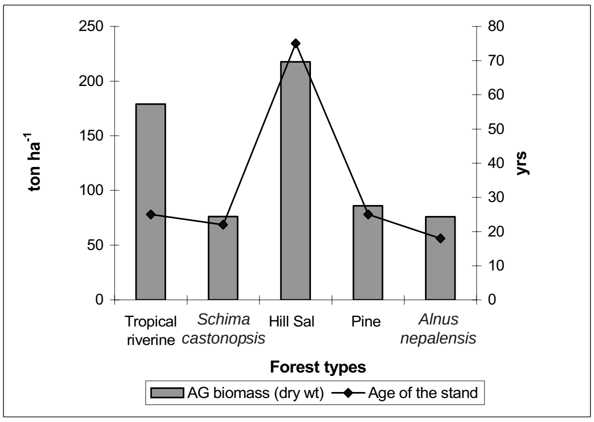

Fig. 1 : Relationship between Age and AG biomass of the different forest stands

Mean dbh of the forest types varied from 8.86-32.00 cm and age varied from 18-75 years (Fig. 2). From the figure, it is clear that tropical riverine, Pine and *Alnus nepalensis* have higher mean dbh against age of the stands as compared to *Schima Castanopsis* and Hill sal forest. This indicates that above three forest types are fast growing in nature than the other two.

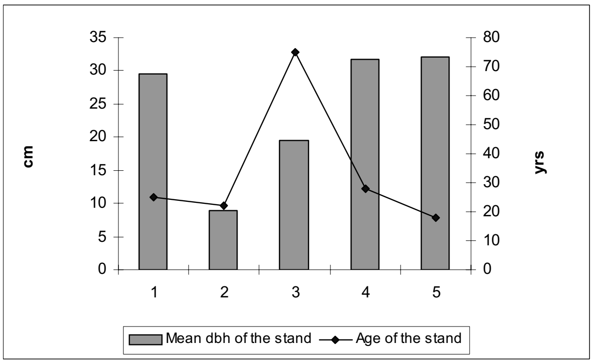

Fig. 2: Relationship between Age and Mean dbh of the different forest stands.

Note: 1 = Tropical riverine, 2 = *Schima-Castanopsis,* 3 = Hill Sal, 4 = Pine, 5 = *Alnus nepalensis*

Above-ground biomass per hectare was found to be highest in Hill Sal forest and lowest in *Alnus nepalensis* forest although their mean dbh were 19.56 cm and 32.00 cm respectively (Fig. 3).

From the figure, it can be clearly noticed that although the mean dbh of tropical riverine, *Pine* and *Alnus nepalensis* forest were more or less same, the above-ground biomass (ton ha^{-1}) of these forests were different. This was due to variation in density of stands per plot, site quality and growing nature of the stand (i.e. tapering).

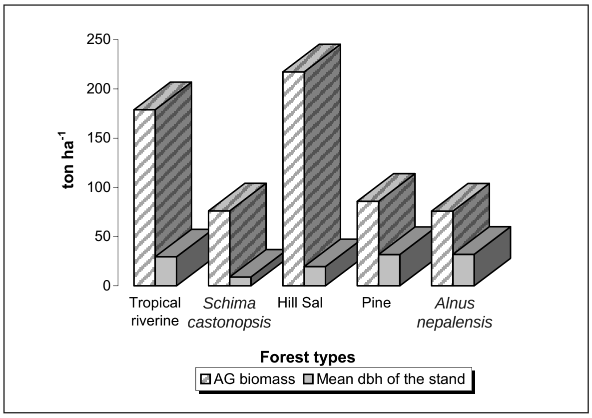

Fig. 3 : Above-ground biomass of different forest stands

The above-ground carbon stock of Hill Sal forest and Riverine forest were found to be higher i.e. 97.86 and 80.47 ton ha^{-1}, respectively whereas the above-ground carbon of *Schima-Castanopsis*, Pine amd *Alnus nepalensis* forests was lower i.e. 34.3, 38.7 and 34.6 ton ha^{-1} respectively (Fig. 4). The carbon stock ha^{-1} for Terai forest (80.47 ton ha^{-1}) and Hill forest (35.86 ton ha^{-1}) was more or less same as reported by Oli and Shrestha (2009) for Terai forest (76 ton ha^{-1}) and Hill forest (37 ton ha^{-1}).

Both Hill Sal and Riverine forests lie in Terai region of Nepal and are considered as "Tropical forest". Remaining three forests types represent Mid-hill region and are considered as "Sub tropical forest". The results show that "Tropical forests" had higher level of above-ground carbon stock than "Sub tropical forests".

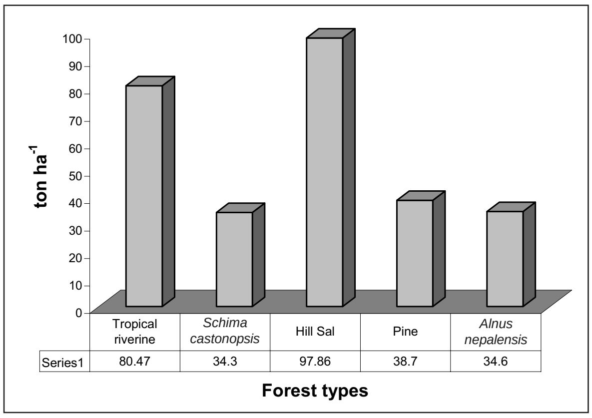

Fig. 4 : Above-ground carbon stock in different forest stands

Above-ground carbon sequestration rate of tropical riverine forest was found to be highest (i.e. 3.21 ton $ha^{-1}yr^{-1}$ (Fig. 5). Gorte (2009) also reported that Moist tropical forests are important for carbon sequestration, because they typically had high carbon contents. Tropical riverine forest, Pine and *Alnus nepalensis* are fast growing species thus had higher carbon sequestration rates while *Shorea robusta*, *Schima-Castanopsis* were slow growing species, thus had lower rates of carbon sequestration.

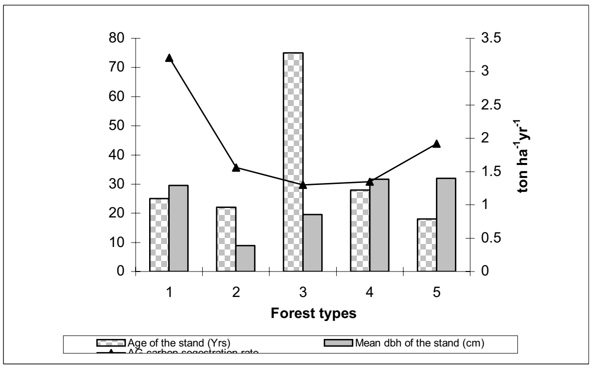

Fig. 5 : Age, Mean dbh and carbon sequestration rate of different forest stands

Note: 1 = Tropical riverine, 2 = *Schima-Castanopsis*, 3 = Hill Sal, 4 =Pine, 5 = *Alnus nepalensis*

Rana *et al.* 1989 reported carbon sequestration rate of Chir pine forests in the Central Himalayan Region ranged from 4.5 to 8.4 t $C/ha^{-1}year^{-1}$. However, this study suggested only 1.35 t C $ha^{-1}year^{-1}$ which was much lower (Fig. 5) than reported. This might be due to inappropriate site for planted pine forest. The result of this study was also supported by Jina *et. al,* 2008 who estimated carbon sequestration rate in degraded Pine forest, ranging from 1.01-1.27 ton $ha^{-1}yr^{-1}$. Mean carbon sequestration rate of five forest types was found to be 1.86 t C $ha^{-1}year^{-1}$ which seems logical and similar to the findings of Dhital (2009) i.e. 1.88 t C $ha^{-1}year^{-1}$ under normal management condition in the Community Forests (CFs) of Nepal.

Table 4 compares the findings of the study conducted at different time. It shows that carbon stock and carbon sequestration rate varied according to forest types.

Conclusions

There was considerable variation in the above-ground carbon stock and rate of carbon sequestration rate according to forest types and its geographical location. Forests representing the Terai region of Nepal had high above-ground carbon stock per hectare compared to hilly region. However, carbon sequestration rate of forest types depended on growing nature of the forest stands. Tropical riverine, Pine and *Alnus nepalensis* forests are important for carbon sequestration in tree biomass in Nepal, as seen from the comparatively higher carbon accumulation rates.

References

Batjes. N.H. and Sombroek, W.G. 1997. Possibilities for carbon sequestration in tropical and sub-tropical soils. *Global Change Biology* **3:** 161-173.

Brown, K. and Pearce, D. 1994. The economic value of non-market benefits of tropical forests: carbon storage. In: Weiss, J. (ed.), *The Economics of Project Appraisal and the Environment:* New Horizon in Environment Economics. E. Elgar, Aldershot, pp 102–119.

Table 4 : Carbon sequestration potential of different forest types

Forest type	Carbon stock ($t\ ha^{-1}$)	Carbon séquestration rate ($t\ ha^{-1}yr^{-1}$)	Reference
All Central Himalayan Forests	250.00-300.00	6.00-8.00	Singh and Singh, 1985,1992
Seven Central Himalayan Forests	166.80-440.10	6.83-7.42	Rana et al, 1989
Temperate forest of the world	125.00	4.19	Malhi, 1998, Press et al 2000
Chirpine degraded forest		1.07-1.27	Jina et al, 2008
Oak degraded forest		1.47-1.84	Jina et al, 2008
Pine forest	38.70	1.35	This study
Tropical Riverine forest	80.47	3.21	This study
Hill Sal forest	97.86	1.30	This study
Alnus nepalensis forest	34.60	1.92	This study
Schima Castanopsis forest	34.30	1.56	This study
Average	57.18	1.86	This study

Brown, S., Gillespie, A. J. R. and Lugo, A. E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* **35(4):**381–902.

Dangi R. and Acharya, K. P. 2009. A Quick Review of Potential Benefits and Costs of REDD in Nepal. In Acharya, K. P., Dangi, R. B., Tripathi, D. M., Bushley, B.R., Bhandary R.R., and Bhattarai, B. (eds.). 2009. Ready for REDD? Taking Stock of Experience, Opportunities and Challenges in Nepal. Nepal Foresters' Association: Kathmandu, Nepal.

Dhital, N. 2009. Reducing Emissions from Deforestation and Forest Degradation (REDD) in Nepal: Exploring the Possibilities. *Journal of Forests and Livelihoods* **8(1):**56-61.

FORESC, 1996. Biomass table of ten preferred species by forest users' group in the hills of Nepal. Forest Research and Survey Centre (FORESC), Ministry of Forests and Soil Conservation, Kathmandu.

Gorte, R.W. 2009. Carbon sequestration in forests, Congressional research service report for Congress, USA.

HMG/Nepal, 2000. Biomass and volume tables with species description for Community forest management. TISC technical paper series no. 101 90 p.

Jina, B.S., Sah, P., Bhatt, M.D. and Rawat Y.S. 2008. Estimating carbon sequestration rates and total carbon stock pile in degraded and non-degraded sites of Oak and Pine forest of Kumaun central Himalaya. *Ecoprint* **15:**75-81

Kirschbaum, M.U.F. 1996. The carbon sequestration potential of tree plantations in Australia. In: (eds.), Environmental Management: The Role of Eucalypts and Other Fast Growing Species, Eldridge, K.G., Crowe, M.P., Old, K.M. CSIRO Forestry and Forest Products, 77–89.

Malhi, Y., A.D. Nobre and J. Grace. 1998. Carbon dioxide transfer over a central Amazonian rain forest. *Journal of Geophysical Research* **103:**593-631.

McDowell, N. 2002. Developing countries to gain from carbon-trading fund. Nature 420:4. Parts 1 and 2, Global Environmental Change 4, 2 and 3, 1994, pp. 140-59, 185-200.

Oli, B.N and Shrestha. K. 2009. Carbon status in forests of Nepal. An overview. *Journal of Forest and Livelihood* **8 (1):**62-66. 2009.

Press, M.C., N.J. Huntley and S. Levin. 2000. Ecology: Achievements and Challenge. Blackwell Science, Oxford, UK.

Rana, B.S., Singh, R.P., and Singh, S.P., 1989. Carbon and Energy Dynamics of Seven Central Himalayan Forests. *Tropical Ecology* **30:**253-269.

Singh, S.P. and Singh, J.S. 1985. Man and Environment: The Central Himalayan Case. *Biol. Mem.* **11(1):**47-59.

Sombroek. W.G., Nachtergaele, F.O. and Hebel. A. 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. *Ambio* **22:**417-426.

UNFCCC, 1997. Kyoto Protocol to the Convention on Climate Change, Bonn, Germany. Climate Change Secretariat. Van Noordwijk, M., Cerri, C., Woomer, P.L., Nugroho, K., Bernoux, M., 1997. Soil carbon dynamics in the humid tropical forest zone. *Geoderma* **79:** 187–225.