

Carbon sequestration potential in natural forests of Himachal Pradesh, India

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Natural forests play a key role in the mitigation of atmospheric carbon dioxide by sequestering it in their biological system as well as in the soil. In the present study we have assessed the carbon sequestration potential of different natural forests of Bilaspur district, Himachal Pradesh, India, which were subjected to different levels of anthropogenic activities. Above- and below-ground carbon stock present in standing vegetation was analysed at six different forest sites of subtropical forests utilizing the non-destructive method. The stem density in the present study ranged from 474.75 to 799.75 trees/ha. The result shows that carbon stock was highest at site II (131.95 t C/ha) and lowest at site I (70.34 t C/ha), although highest tree density was observed at site I and lowest at site V. The average carbon stock of the study area was recorded as 107.35 t C/ha. The results suggest that tree density and carbon stock in these subtropical forests differ significantly and with proper management strategies and afforestation of the degraded areas, the potential of carbon storage can be enhanced further.

Keywords: Anthropogenic activities, carbon sequestration, natural forests, standing vegetation.

URBANIZATION, unplanned development and deforestation are some of the major factors responsible for continuous accumulation of greenhouse gases (GHGs) in the atmosphere. Among the GHGs, carbon dioxide (CO₂) plays a major role in enhancing global warming and climate change^{1,2} which in turn escalate carbon variation and destabilize the global dynamics³. Carbon sequestration refers to the processes involved in either removal of CO₂ from the atmosphere or diversion of the same from the source of emission and storing it in ocean, terrestrial and geological formations⁴. The terrestrial carbon pool interacts strongly with atmospheric CO₂ by two important processes, i.e. photosynthesis and respiration⁵. This interaction can be enhanced directly by afforestation and restoration of the degraded ecosystems⁶. The terrestrial carbon pool continues to accumulate atmospheric carbon until it is disturbed or halted, and is majorly destroyed by conversion of natural forests to managed ecosystems which involve degradation of soil, land and change in land-use type.

Forests are the major carbon pools as they interact strongly with atmospheric CO₂, fix carbon in the living systems and retain it for a long time period⁷. So they act as a major sector for mitigation of atmospheric carbon⁸ and are accountable for minimizing the effect of climate change⁹. Carbon sequestered by forest vegetation is mostly in the form of biomass⁷ and by analysing the forest biomass it becomes easy to evaluate the carbon storage potential of forests. This aspect can further be utilized to plan appropriate management strategies to mitigate CO₂ emissions and enhance the factors which help in carbon sequestration⁸. Different forest stands (single species, broadleaf, mixed conifers, young and old-forest stands) show different carbon storage potential^{6,10-12}. Grazing, forest fires and removal of litter and wood for fuel are some of the factors which are harmful to the forest ecosystem and cause loss of stored carbon¹⁰.

In the higher Himalaya, forests show dominance of *Pinus roxburghii*, due to favourable environmental conditions. The distribution of this species has reduced in the Shivalik chir pine forest (study area) due to anthropogenic activities, leading to reduction in tree density, biomass and carbon sequestration potential of the area¹³.

Estimation of carbon storage determinants within different ecosystems is important for understanding the pattern of carbon sequestration at both regional and global carbon cycles. This information can be utilized in the development of proper management strategies for maintenance of carbon sink and sustainable development of the ecosystem. The current study was carried out to estimate the carbon sequestration potential of the study area and to develop a comprehensive approach to enhance it.

The present study was carried out in 2017 at Bilaspur district, Himachal Pradesh, India which lies between 31°12'30"–31°35'45"N lat. and 76°23'45"–76°55'40"E long. It is a part of the outer hills (Shivalik) of the Himalaya with geographical area of 1167 km² and 13% area under forest cover. The climate of the study area is temperate to subtropical, generally dry with average rainfall of 1106.28 mm and temperature varying from 1.3°C to 40.7°C.

The study was carried out at six different forest sites of Bilaspur district, Himachal Pradesh, India (Figure 1) which differed from each other with respect to anthropogenic activities, topography and altitudinal variation. The forest sites were not much distinctive in species distribution and possessed many common species, except sites I and VI.

Permanent sample plots (quadrats of 20 m × 20 m) were laid down randomly in the study area. We adopted the non-destructive method for estimation of tree biomass. All individual trees ≥10 cm GBH (girth at breast height, i.e. at 132 cm from the ground) were counted and their GBH was also measured with the help of measuring tape and tree caliper. All trees above 10 cm GBH were marked and numbered with paint. GBH values were converted to

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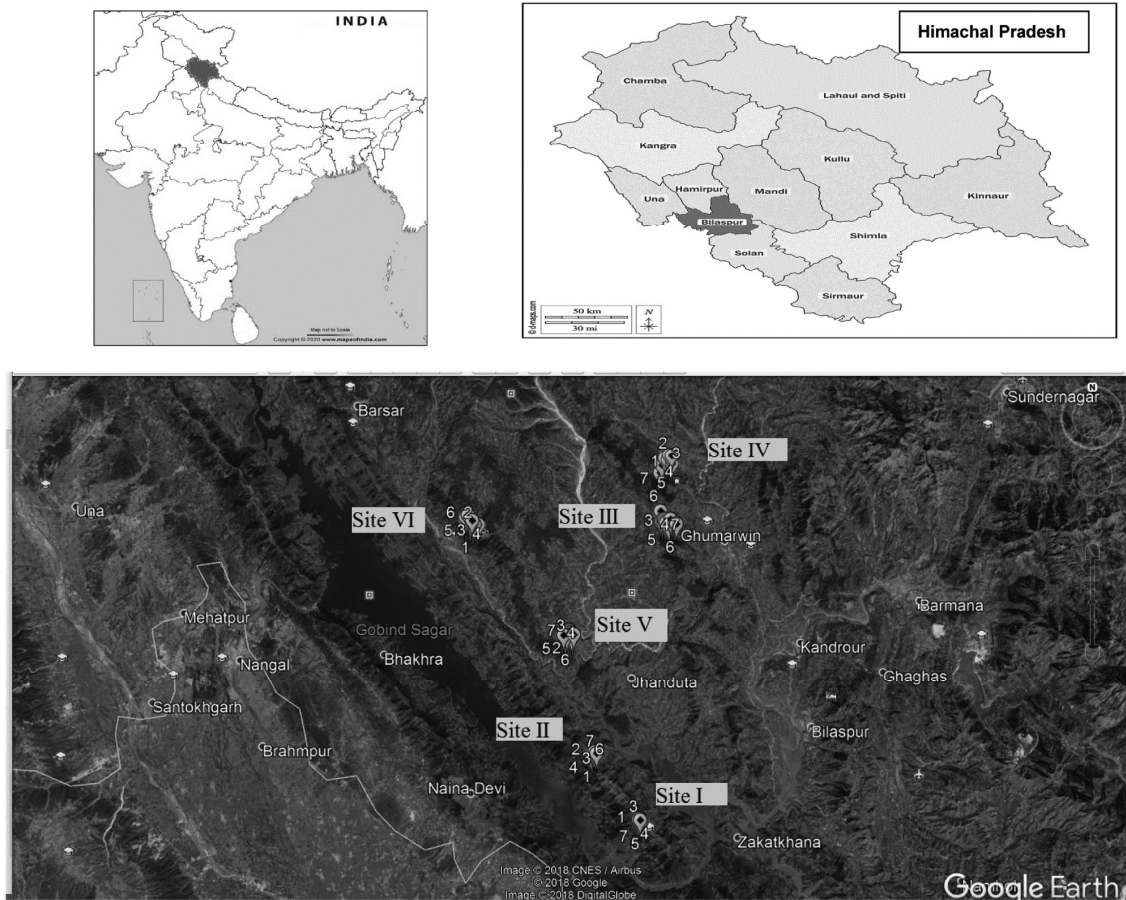


Figure 1. Base map of the study area and selected forest sites.

DBH (diameter at breast height), and these values were utilized. For estimation of carbon stock, above- and below-ground biomass was considered and the allometric equations utilized were Anderson and Ingram¹⁴, and MacDicken¹⁵ respectively. Carbon stock was estimated assuming that it made up 50% of the biomass^{3,16}.

Quantification and valuation of standing vegetation would help in determining the potential values of forests. Tables 1 and 2 provide data on tree density (trees/ha) and carbon stock (t C/ha) respectively.

Tree density was found to be the highest at site I (799.75 trees ha⁻¹) followed by site II (710.5 trees ha⁻¹), site IV (664 trees ha⁻¹), site III (632.25 trees ha⁻¹), site VI (593 trees ha⁻¹) and site V (474.75 trees ha⁻¹). Sites II, III and V had trees of DBH size class 21–30 cm with tree density of 325, 335.75 and 221.5 trees ha⁻¹ respectively, whereas sites I and IV were dominated by trees in the DBH size class 10–20 cm with tree density of 428.5 and 289.25 trees/ha respectively. Site VI showed the highest value for two DBH size classes, i.e. 10–20 and 21–30 cm with 228.5 trees ha⁻¹ tree density for each size class.

Dominance of DBH size class 21–30 cm can be seen in different forest sites showing mature growing pattern, except sites I and IV (broadleaf and mixed vegetation respectively)¹². This may be due to frequent fire incidences

in these forests. Under these conditions only the mature trees can survive and young trees with lower DBH size classes showed less survival rate¹⁷. Sharma and Baduni¹³ observed maximum tree density in DBH size class 40–50 cm, indicating mature established forests compared to the present study. Difference in diameter classes of the study area suggests that the forest vegetation shows poor regeneration potential and may be suppressed under environmental stress^{12,13}. Site V showed lowest tree density among the different sites, indicating that it was under tremendous anthropogenic pressure. The site also showed least tree density at 10–20 cm DBH size class, implying that the anthropogenic activities are inhibiting the growth of vegetation.

Within each site on a percentage basis, sites II, III and V were dominated by trees of DBH size class 20–30 cm with tree density 45.77, 53.1 and 46.66 respectively, whereas sites I and IV were dominated by trees in the DBH size class 10–20 cm with tree density of 53.58 and 43.56 respectively. Site VI showed highest value for two DBH size classes, i.e. 10–20 and 21–30 cm with 38.53% tree density for each size class.

Carbon present in the tree biomass showed considerable variation among different sites of the same forest. This may be due to the variation in tree density and tree

Table 1. Comparison of tree density (trees/ha) between different forest sites

Size class (DBH cm)	Site I	Site II	Site III	Site IV	Site V	Site VI
10–20	428.5	235.75	178.5	289.25	85.75	228.5
21–30	353.5	325	335.75	264.25	221.5	228.5
31–40	14.25	117.75	89.25	53.5	117.75	107.25
41–50	3.5	10.75	14.25	39.25	42.75	7.25
51–60	–	3.5	–	10.75	3.5	14.25
61–70	–	14.25	–	3.5	–	–
71–80	–	–	7.25	–	3.5	7.25
81–90	–	3.5	7.25	–	–	–
91–100	–	–	–	3.5	–	–
Total	799.75	710.5	632.25	664	474.75	593

Table 2. Comparison of carbon stock (t C ha⁻¹) between different forest sites

Size class (DBH cm)	Site I	Site II	Site III	Site IV	Site V	Site VI
10–20	19.36	12.09	10.02	12.1	4.71	10.2
21–30	44.73	47.32	46.77	38.73	30.97	29.96
31–40	4.26	36.35	25.06	16.91	36.61	30.76
41–50	1.99	5.05	7.85	22.32	23.13	3.33
51–60	–	2.87	–	10.13	3.32	12.57
61–70	–	19.83	–	4.1	–	–
71–80	–	–	13.37	–	7.11	13.35
81–90	–	8.44	16.59	–	–	–
91–100	–	–	–	11.82	–	–
Total	70.34	131.95	119.66	116.11	105.85	100.17

size. Biomass carbon of the trees is also affected by the age of the trees and the type of tree species present in the study area. Older forest stands can store higher carbon stock compared to growing forest stands⁶.

The DBH size class 21–30 cm possessed the highest potential for carbon storage for different forest sites, viz. site I (44.73 t C/ha), site II (47.32 t C/ha), site III (46.77 t C/ha) and Site IV (38.73 t C/ha), whereas for sites V and VI carbon storage was highest in DBH size class 31–40 cm with 36.61 and 30.76 t C/ha respectively. In sites I and IV, the size class 10–20 cm showed more number of trees than the size class 21–30 cm, but the carbon storage was higher in size class 21–30 cm. In sites II and III, the number of trees and carbon storage potential were high for size class 21–30 cm. Site V showed higher carbon storage potential than size class 31–40 cm, but the number of trees was higher in the size class 21–30 cm. In site VI the tree density was high for two size classes, i.e. 10–20 and 21–30 cm, but carbon sequestration potential was high for size class 31–40 cm (Tables 1 and 2).

The results show that the distribution pattern of trees can be related with disturbances in the forests which also influence the carbon sequestration pattern in different forest sites¹⁴. For standing vegetation the highest carbon stock was recorded for site II (131.95 t C/ha), followed by site III (119.66 t C/ha), site IV (116.11 t C/ha), site V (105.85 t C/ha), site VI (100.17 t C/ha) and site I (70.34 t C/ha) (Table 2). Although site I had the highest tree density, it showed the lowest carbon storage potential

among all forest sites due to the fact that this site has trees with small girth (broadleaf) compared to other sites (coniferous) which have trees with large girth^{2,12}. Comparison between conifer and deciduous forest stands for a long period, revealed that the former possessed high carbon sequestration potential and also faster growth^{12,17}. Pine forests can withstand frequent forest fires and their thick basal bark enables them to survive under fire conditions in the study region. Also, the self-pruning of lower branches of pine trees reduces the spread of fire to the canopy¹⁸.

However, all the study sites show high carbon sequestration potential in the future due to the presence of a large number of trees belonging to small DBH size classes, which accelerates their growth to reach at maturity. At present the smaller trees do not have high carbon storage potential, but in the near future they can store more carbon. Growing (young) vegetation showed greater carbon sequestration rate, while mature (older) vegetation stored more carbon. Thus mixed-age stands of forests are considered to be the best for carbon sequestration at different rates of CO₂ uptake¹⁹.

According to studies, forests sites are subjected to anthropogenic pressure, exploitation and forest fires, which further lead to reduction in tree density, biomass and carbon sequestration potential^{1,10,20}. Biomass assessment provides the carbon storage capacity of different forest sites in terms of their contribution to regional carbon stocks, thus recognizing the role of these forests in

carbon regulation and maintenance of nutrient cycling. Higher values of carbon stock in a forest can be directly related to reduction in anthropogenic disturbances²¹.

Vegetation/plantation, including natural as well as human-managed lands, absorb CO₂ from the atmosphere and can store it in their biomass and the soil. Vegetation improves the soil condition in the long term and these two factors are interrelated with each other; thus higher growth of forest stand can be related to higher carbon accumulation in the forest soil. The present study does not emphasize on mixed plantations over pine plantations due to the large carbon storage potential of pine trees, although other consequences of single species dominance can be observed from an ecological point of view¹². To enhance the carbon mitigation potential and conservation practices, participation of local people becomes important along with the efforts taken by the Forest Department, because the local rural population depends on forest-based products. Thus it is necessary to involve local people for sustainable development of the study site.

There is a strong need for developing policies which enhance tree plantation, in accordance with the geographical conditions of an area and also help in protection and conservation of biodiversity for sustainable management of forests²². Plantations are one of the most important and viable parts of management practices, which help in the restoration of degraded land, sequestering more carbon and reducing the timber pressure from natural forests^{5,19}. The intensity to disturb the environment through anthropogenic activities is increasing by the day. Thus it is essential to utilize proper management practices and regulatory policies to enhance the forest ecosystem services and reduce the effect of global warming and climate change.

The present study shows that the carbon sequestration potential of forest sites is considerably good due to the presence of adequate amount of trees in the study area. Although with the recruitment of young trees, carbon sequestration potential can be further enhanced. Preventing forests fires and other anthropogenic activities should be given more attention for proper management of the study area. Selection of species for plantation in the forest ecosystem must be taken into consideration while developing management policies to enhance carbon sequestration. The current study strongly believed that active participation of the local people is important for conservation, protection and sustainable management of the forests along with the forest department.

4. Sundquist, E. T. *et al.*, Carbon sequestration to mitigate climate change: US Geological Survey, Fact Sheet 2008, 2008–3097.
5. Lal, R., Carbon sequestration. *Philos. Trans. R. Soc. London, Ser. B*, 2008, **363**(1492), 815–830.
6. Lal, R., Forest soils and carbon sequestration. *For. Ecol. Manage.*, 2005, **220**(1–3), 242–258.
7. Vashum, K. T. and Jayakumar, S., Methods to estimate above-ground biomass and carbon stock in natural forests – a review. *J. Ecosyst. Ecogr*, 2012, **2**(4), 1–7.
8. Bhat, D. M. and Ravindranath, N. H., Above-ground standing biomass and carbon stock dynamics under a varied degree of anthropogenic pressure in tropical rain forests of Uttara Kannada District, Western Ghats, India. *Taiwania*, 2011, **56**(2), 85–96.
9. Shah, S., Sharma, D. P., Tripathi, P. and Pala, N. A., Carbon partitioning in subtropical *Pinus roxburghii* forest, Solan, India. *J. Trop. For. Sci.*, 2014, **26**(3), 355–361.
10. Semwal, D. P., Uniyal, P. L., Bahuguna, Y. M. and Bhatt, A. B., Soil nutrient storage under different forest types in a part of central Himalayas, India. *Ann. For.*, 2009, **17**(1), 43–52.
11. Liu, Y., Lei, P., Xiang, W., Yan, W. and Chen, X., Accumulation of soil organic C and N in planted forests fostered by tree species mixture. *Biogeosciences*, 2017, **14**(17), 3937–3945.
12. Aryal, S., Bhattarai, D. R. and Devkota, R. P., Comparison of carbon stocks between mixed and pine-dominated forest stands within the Gwalinidaha Community Forest in Lalitpur District, Nepal. *Small-Scale For.*, 2013, **12**(4), 659–666.
13. Sharma, C. M. and Baduni, N. P., Structural attributes and growing stock variations on different aspects of high Himalayan and Siwalik chir pine forests. *J. Trop. For. Sci.*, 2000, **12**(3), 482–492.
14. Anderson, J. M. and Ingram, J. S. I., Tropical soil biology and fertility: a handbook of methods. *Soil Sci.*, 1994, **157**(4), 265.
15. MacDicken, K. G., A guide to mountain carbon storage in forestry and agroforestry projects. International Institute for Agricultural Development, Forest Carbon Monitoring Programme, Arlington VA (US), Winrock, 1997.
16. Brown, S. and Lugo, A. E., The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica*, 1982, **14**(3), 161–187.
17. Naudiyal, N. and Schmerbeck, J., The changing Himalayan landscape: pine-oak forest dynamics and the supply of ecosystem services. *J. For. Res.*, 2017, **28**(3), 431–443.
18. Brown, P. M., Bhattacharyya, A. and Shah, S. K., Potential for developing fire histories in chir pine (*Pinus roxburghii*) forests in the Himalayan foothills. *Tree-Ring Res.*, 2011, **67**(1), 57–62.
19. Kely, M. J., The role of species mixtures in plantation forestry. *For. Ecol. Manage.*, 2006, **233**(2–3), 195–204.
20. Zhao, S. Q., Liu, S., Li, Z. and Sohl, T. L., Ignoring detailed fast-changing dynamics of land use overestimates regional terrestrial carbon sequestration. *Biogeosciences*, 2009, **6**(8), 1647–1654.
21. Lugo, A. E. and Brown, S., Tropical forests as sinks of atmospheric carbon. *For. Ecol. Manage.*, 1992, **54**(1–4), 239–255.
22. Bunker, D. E. *et al.*, Species loss and aboveground carbon storage in a tropical forest. *Science*, 2005, **310**(5750), 1029–1031.

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1. Li, K., Wang, S. and Cao, M., Vegetation and soil carbon storage in China. *Sci. China Ser. D (English edn)*, 2004, **47**(1), 49–57.
2. Bandy, M., Bhardwaj, D. R. and Pala, N. A., Variation of stem density and vegetation carbon pool in subtropical forests of northwestern Himalaya. *J. Sustain. For.*, 2018, **37**(4), 389–402.
3. Dixon, R. K., Brown, S., Solomon, A. M., Houghton, R. A., Trexler, M. C. and Wisniewski, J., Carbon pools and flux of global forest ecosystems. *Science*, 1994, **263**(5144), 185–190.