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RESEARCH ARTICLE

Assessing the Carbon Sequestration Potential of Subtropical Pine Forest in North-western Himalayas - A GIS Approach

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Abstract The present investigation was carried out to determine carbon sequestration potential of Solan Forest Division of Himachal Pradesh during 2006-2007. There are six land uses viz., Chir pine, Ban oak, Deodar, Other broadleaves, Culturable and Un-culturable, which are distributed in 538 compartments along altitudinal gradient from 900 to 2,100m. The study reveals that among various land uses, the Other broadleaved species will result in maximum expected carbon (19.88 Mt) which will be 28.81, 23.95, and 3.07 times higher than standing carbon in Ban oak, Deodar and Chir pine, respectively. The Solan Forest Division on the whole, has potential to sequester 17 times more carbon over standing carbon of 1.67 Mt, if forest species are extended to their corresponding altitudinal limits in the "land area available for planting" i.e., Un-cultrable land area in the forest division however, to have an accurate estimate of the carbon sequestration potential of the area, other attributes that decides the establishment of plantation of different species such as slope, aspect, soil, climate, etc. need to be taken into consideration beside altitude.

Introduction

The forestry sector cannot only sustain its carbon but also has the potential to absorb carbon from the atmosphere. They store large quantities of carbon in vegetation and soil, exchange carbon with the

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atmosphere through photosynthesis and respiration. The world forests contain about 830 Pg C (10^{15} g) in their vegetation and soil, with about 1.5 times as much in soil as in vegetation (Brown, 1995).

India has maintained approximately 64 M ha of forest cover for the last decade. The rate of afforestation in India is one of the highest among the tropical countries, currently estimated to be 2 M ha per annum. The annual productivity has increased from 0.7 m^3/ha 1985 to 1.37 m^3/ha in 1995. Increase in annual productivity directly indicates an increase in forest biomass and hence higher carbon sequestration potential (Lal and Singh, 2000). Further the carbon pool for the Indian forests is estimated to be 2026.72 Mt for the year 1995. Estimates of annual carbon uptake increment suggest that our forests and plantations have been able to remove at least 0.125 Gt of CO_2 from the atmosphere in the year 1995. Assuming that the present forest cover in India will sustain itself with a marginal annual increase by 0.5 M ha in area of plantations, we can expect our forests to continue to act as a net carbon sink in future (Lal and Singh, 2000).

These estimates are based on macro level studies (Ravinder, 1997) and no attempts have been made so for to access the biomass and carbon sequestration potential at micro levels. Such kind of micro-level study is essential for sustainable forest management in the country where heavy degradation has been caused by anthropogenic activities and different forest management prescriptions of the past warranted in different periods of time to meet the local and national needs. Therefore, the present investigation is an attempt to determine carbon sequestration potential of pine forests falling under Solan Forest Division in north-western Himalayas.

Material and methods

Study area

The study was carried out in Solan Forest Division of Himachal Pradesh, which is located between 30^0 45' 00" to 31^0 10' 00" N latitude and 76^0 55' 00" to 77^0 15' 00" E longitude, covering an area of about 57,158 ha. The study area falls under subtropical region where climate varies from extreme hot in the lower elevation and extreme cold in higher elevations. Precipitation is in the form of rains mainly during rainy season. The forests of Solan Forest Division have mainly Chir pine as principal crop and mostly confirm to the Champion and Seth's Forest type 9 C1a- Lower or Shiwalik Chirpine forests. They lie between 900-2,100 m above mean sea level (a.m.s.l.).

The over storey vegetation comprises of *Pinus roxburghii, Quercus leucotricophora, Cedrus deodara, Terminalia data, Dalbergia sissoo, Pyrus pashia, Albizia chinensis, Juglans regia, Celtis australis, Acacia catechu,* etc., and the under storey vegetation comprises of *Berbaris* species, *Prinsepia utilis, Indigofera* species, *Rosa* species, *Sarcococca saligna, Rubus* species, *Hedera helix, Euphorbia* species etc.

Used data

The digitization work was done on GTCO Calcomp Digitizing Table using CARTALINX 1.2. The elevation data covered in 10 toposheets (1:25,000), acquired from Survey of India Dehradun were used to generate Digital Elevation Model (DEM). After digitizing contours at an interval of 100 m, the contour coverage was then imported into IDRISI32 for further analysis. CARTALINX 1.2 (Geographical Information Application System) and IDRISI 32 (Image Processing and GIS software) are developed by Clark Lab, Clark University, Worcester MA, USA. The vector contour coverage was transformed into Triangulated Integrated Network (TIN). TIN is used to generate raster image surface with the module TINSURF. Finally vector contour coverage and TIN coverage was used to generate DEM (Raster layer). The DEM was then stratified into four elevation classes, i.e., 900-1,200 m, 1,200-1,500 m, 1,500-1,800 m and 1,800-2,100 m, using reclass module in IDRISI32. The classified DEM was then used in the process of determining biomass distribution along altitudinal gradient.

The stock map available with the State Forest Department was digitized for land use types and compartment/forests distributed in five forest ranges of Solan Forest Division. As a result the Land use coverage depicting existing six land uses as Chir pine (*Pinus roxburghii*), Ban oak (*Quercus leucotricophora*), Deodar (*Cedrus deodara*), Other Broadleaves, Culturable and Un-culturable (blank) and forest compartment coverage comprising of 538 compartments and sub-compartments were then imported into IDRISI32 for further processing. The inventory data of Solan Forest Division as a result of enumeration done in 2001 (Forest Working Plan, 2002) were used to generate data on above ground tree biomass carbon.

Estimation of Carbon

Above ground carbon

The volume of trees of each diameter class was transformed into biomass by multiplying it with specific gravity. The specific gravity was determined using maximum moisture method (Smith, 1954). However, biomass of herbaceous and shrub vegetation was determined by destructive method following standard sampling technique with 1×1 m quadrate size.

The carbon content of trees was determined by multiplying biomass with a conversion factor of 0.50 (Koach, 1989) and biomass of herbaceous and shrub vegetation with a carbon conversion factor of 0.45 (Woomer, 1999). The carbon of surface litter was determined after its collection within a 50×50 cm frame placed centrally within each quadrate. Samples were weighed, sub sampled and oven dried at 65 ± 5^{0}C to a constant weight. Ash corrected dry weight was assumed to contain 45 per cent carbon (Woomer, 1999).

Below ground carbon

The below ground carbon (root and soil carbon) was ascertained manually. The fallen trees (three in number) of Chir pine as a result of landslide in the study area were weighed separately for root and stem after cleaning with water. The root is to stem weight ratio was then taken as standard to determine the root biomass of the entire forest assuming that all tree species bears the same root is to stem weight ratio as Chir pine. The carbon content of root biomass was then determined by multiplying it with a carbon conversion factor of 0.45 (Woomer, 1999).

The root samples of herbaceous and shrub vegetation under different land uses were collected from an area of 25×25 cm frame within each quadrate up to a depth of 40 cm. The roots samples were stored in cloth bags for further laboratory analysis. The samples were dispersed in water and passed through a 2 mm sieve. Roots were collected from the sieve and washed in water without distinguishing live and dead roots. Roots were then oven dried at 65 ± 5^{0}C to a constant weight. Ash corrected dry weight was assumed to contain 45 per cent carbon (Woomer, 1999).

Independent soil carbon of the six land uses was determined by taking soil samples within a sample plot of 10×10 m from each elevation class at 10-20 and 20-40 cm depths (two depths). Five sub- samples of soil within main sample plot were collected by digging five monoliths of 20×50 cm (subsurface area) by 50 cm deep. Composite samples from all subsamples were obtained for each depth. Samples were air dried in shade, grounded with wooden pestle, passed through 2 mm sieve and stored in cloth bags for further laboratory analysis. Thus in total 48 soil samples were analyzed for bulk density and organic carbon. Bulk density (g cm^3) was determined using specific gravity method (Singh, 1980) and organic carbon per cent was determined following Walkley and Black (1934). The soil organic carbon pool inventory expressed as Mega grams per ha (Mg ha^{-1}) for a specific depth was computed by multiplying the soil organic carbon (g Kg^{-1}) with bulk density (g cm^{-3}) and depth (cm) (João Carlos *et al*., 2001).

Carbon sequestration potential of Solan Forest Division was determined in different steps using IDRISI32 as: (i) Estimation of increment (ii) identifying land area available for planting, (iii) identifying land area suitable for planting and (iv) prediction of carbon.

Estimation of increment

The current annual increment (CAI) of different forest species was computed from the CAI per cent computation table based on diameter classes (Forest Working Plan, 2002).

$$\text{Increment} = \frac{\text{Volume} \times \text{CAI\%}}{100}$$

The land use, elevation, carbon and increment data were then subjected to GIS analysis in IDRISI32.

Identifying land area available for planting

The land use image was used to isolate the land area under Un-culturable land use by masking the image after allotting value of zero to all the land uses and a value of one to Un-culturable land use. This helped in separating the area of Un-culturable land use (barren) from the land use image which was assumed to be "land area available for planting".

Identifying land area suitable for planting

The suitability of forest species to "land area available for planting" was decided based on the basis of altitudinal limit of the forest species. The area falling under 900-1,200 m elevation was proposed to be planted under Other broadleaves and area falling under 1,200 - 1,500 m elevation was proposed to be planted under Chir pine. The area that falls under 1,500 - 2,100 m elevation was considered to be planted either under Ban oak (Option 1) or Deodar (Option 2) as the altitudinal limit of both the species is same (Troup, 1921).

The DEM was classified into four elevations i.e., 900-1,200 m, 1,200-1,500 m, 1,500-1,800 m and 1,800-2,100 m using RECLASS module in IDRISI32. The classified DEM was then integrated with masked image "land area available for planting" to identify "land area suitable for planting" for different forest based land uses. The details of "land area suitable for planting" for different forest based land uses are given in table1.

Prediction of carbon

The carbon image (Raster) showing biomass carbon for 538 forest compartments falling under Solan Forest Division were regressed individually against land use, elevation class and CAI image in STATISTICS module in IDRISI32. The carbon prediction equations, so developed were applied on the image "land area suitable for planting" with the assumption that plantation of forest species will be extended to their corresponding altitudinal limits in the area.

Results and discussion

Carbon sequestration potential

The data pertaining to the potential of the forest species based on CAI is given in table 2. The Chir Pine showed CAI value of 2.50 cu m ha^{-1} which was highest among all the forest species growing in this region. It may be attributed to the dominance of younger diameter classes that shows initial fast rate

Table 1 Details of "land area suitable for planting" under different forest based land uses

Species	Altitudinal range (m)	Area available for planting (ha)
Other broadleaves	900-1200 m	21637
Chir pine	1200-1500 m	22216
Ban oak	1500-2100 m	1561
Deodar	1500-2100 m	1561
Total		45414

Table 2 Total and average Current Annual Increment (CAI) of different forest based land uses

Land use	Total increment	CAI/ha (cum)
Chir pine	79402.50	2.50
Deodar	1904.42	1.22
Ban oak	1139.53	0.73
Other broadleaves	16876.86	0.78

of growth. When trees are in their active growth phase, they remove higher carbon from the atmosphere (Schroeder and Ladd, 1991). As forest ages, however, their growth slows and eventually stops, and they are no longer a net sink of carbon (although they continue to store it) (Schroeder and Ladd, 1991).

The CAI for other species were in order as Deodar (1.22 cum ha^{-1}) > Other broadleaves (0.78 cum ha^{-1}) > Ban oak (0.73 cum ha^{-1}). Schroeder and Ladd (1991) argued that mean annual growth rate to characterize the carbon removal from the atmosphere over an extended period of time is misleading. According to him three tropical species i.e*., Pinus patula, Leucaena* species and *Azadirachta indica*, are though capable of putting same mean annual increment of 20 ha y^{-1}, yet their carbon storage ability is greatly different on a long term basis.

On the other hand, the data pertaining to CAI distribution in different elevations presented in table 3 reveals that increment growth increased with increase in elevation from 900 to 2,100 m. The CAI ranged from 0.17 to 1.19 cum ha^{-1}. The variation in CAI along altitudinal gradient was due to less stocking of stands at lower elevations as compared to higher stocking and old age stands at higher elevations.

Regression analysis

The results on account of regression analysis between carbon attributes (tree, under storey, root, soil, above ground, below ground and total carbon) as dependent and land use as independent variables are given in table 4. The relationships of under storey, soil carbon, below ground and total carbon with land use were significant with adjusted value of r^2 as 0.68, 0.58, 0.54 and 0.45, respectively which indicate variation in carbon attributes as explained by various land uses. However, variation in rest of the carbon attributes (above ground and root carbon) could not be explained by land uses. The relationships between land use, CAI and elevation were unable to explain any significant variation in carbon attributes.

In order to determine the carbon sequestration potential of the Solan Forest Division, the regression equation (Linear) based on relationship between total carbon and land use was applied on the "available land area for planting" i.e., Un-culturable land use

Table 3 Average Current Annual Increment of forests at different elevations (m)

Elevation (m)	CAI/ha (cum)
900-1200	0.17
1200-1500	0.81
1500-1800	0.90
1800-2100	1.19

Table 4 Result of regression analysis between carbon variable (tree, under storey, root, soil, above ground, below ground and total) and land use

Variable (Y)	α	β	Adjusted r^2
Tree carbon	-7.99	56.33	0.13
Under storey carbon	-5.51	34.65	0.68*
Root carbon	-3.86	25.60	0.32
Soil carbon	-17.46	124.77	0.58*
Above ground carbon	-13.50	90.99	0.26
Below ground carbon	-20.85	147.32	0.54*
Total Carbon	-34.42	238.77	0.45*

(*P value < 0.05)

coverage in STATISTIC module in IDRISI 32 (Table 5). It can be seen that expected carbon in the Other broadleaves land use is 19.88 Mt that will result into gross carbon of 20.12 Mt and same is 6.47 Mt in Chir pine that will result into a gross carbon of 6.90 Mt if plantations of these species are extended to their altitudinal limit in the "available land area for planting". On the other hand, under option 2, the expected carbon under deodar comes out to be 0.83 Mt and in ban oak under option 1, it comes out to be 0.69 Mt with a gross carbon of 0.84 and 0.98 Mt, respectively. The lower expected carbon under Deodar and Ban oak is due to the less area available for planting in their corresponding altitudinal limit. The total carbon stock

Table 5 Standing, expected and gross carbon (t) for the Solan Forest Division

Land use	Standing carbon (Mt), Total	Expected carbon (Mt),Total	Gross carbon (standing + expected carbon)
Chir pine	0.43 (175.49)	6.47 (204.35)	6.90 (379.84)
Ban oak	0.28 (192.77)	0.69 (443.00)	0.98 (635.77)
or			
Deodar	0.01 (180.76)	0.83 (681.80)	0.84 (862.56)
Other broadleaves	0.25 (275.30)	19.88 (920.60)	20.12 (1195.9)
Culturable	0.26 (37.41)	0.26 (37.41)	0.26 (37.41)
Un-culturable	0.67 (12.99)	0.67 (12.99)	0.67 (12.99)
Total	1.65	Option 1: 28.03 Option 2: 27.90	Option 1: 28.93 Option 2: 28.79

(Values in parenthesis are in t ha^{-1})

of Solan Forest Division will therefore increase from 1.67 Mt to a level of 27 Mt. Higher carbon sequestration potential of Other broadleaves may be attributed to the more land area available for planting in its altitudinal limit (900-1,200 m). However, at higher elevations (above 1,200 m), most of the area is already occupied by the respective species in their altitudinal limit and have limited potential for carbon sequestration.

Conclusion

There was increase in CAI with increase in elevation from 900 to 2,200 m. Among forest species, CAI was highest in chir pine (1,200-1,500 m). The maximum expected carbon is reported in Other broadleaves category (19.88 Mt) which comes out to be 28.81, 23.95, and 3.07 times higher than standing carbon in Ban oak, Deodar and Chir pine, respectively, however, on per hectare basis (19.88 t ha^{-1}) it comes out to be 4.50, 2.07 and 1.34 times higher than Chir pine, Ban oak and Deodar, respectively. There is vast area available for planting of broadleaved species such as, *Celtis australis*, Bamboos, *Terminalia alata*, *T. chebula*, *Bauhinia variegata*, *Acacia catechu,* etc. in the lower elevation i.e., 900 to 1,200 m, however, at higher elevation, the area is already occupied by forest species in their corresponding altitudinal limits and area available for planting is very less. The Solan Forest Division on the whole, has potential to sequester 17 times more carbon over standing carbon of 1.67 Mt, if forest species are extended to their corresponding altitudinal limits in the “land area available for planting” i.e., un-culturable land area in the forest division however, to have an accurate estimate of the carbon sequestration potential of the area, other attributes that decides the establishment of plantation of different species such as slope, aspect, soil, climate etc. needs to be taken into consideration beside altitude.

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