Allocation of biomass and carbon stocks in seven woody species of tropical deciduous forests, Dang, Gujarat

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Literature on the biomass estimates and carbon cycles of Asian tropical deciduous forests is very limited. In this study, seven woody species were selected, with four representatives each in chronosequence, and harvested from deciduous forests of Dang, Gujarat for assessing their biomass and carbon content. All the species showed a carbon percentage between 40% and 45%. The regression equations of total biomass versus aspect ratios. Int. J. Numer. Method H., 2018, 1, 1–13.

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ABOUT 17% of the global CO₂ emissions occur due to deforestation and land-use change¹. Reduction of emissions through deforestation and forest degradation (REDD+)

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was initiated by the United Nations Framework for Convention on Climate Change (UNFCCC) to minimize CO₂ emissions by managing forests. Hence, accounting carbon (henceforth C) stocks at regional and national levels is a major trial for REDD+ implementation around the world. There still remain uncertainties in biomass and carbon stocks from the tropics as studies are few, incomplete and outdated. Asia contains 58% of world’s tropical deciduous forests while they form 60% of Indian forest cover. But in a review, Becknell et al. stated that only 9% of the data out of total 229 global studies covered Asia, suggesting the need for biomass and carbon estimates from India.

Destructive harvesting method provides us with actual data of biomass which is required to validate other indirect methods of biomass estimation, such as the use of non-destructive in-situ measurements, allometric models and remote sensing. Short-lived components in a deciduous forest also contribute significantly to biomass production and nutrient cycling forming 62% of dry matter. The perennial aerial structure, the roots and the foliage make up 82%, 14% and 4% of the total vegetation carbon density. Hence, we applied destructive tree harvesting method with apportionment of tree into seven components for above-ground biomass estimation. This study involved an inventory for biomass and carbon stock estimates. It is the first of its kind study in Gujarat after the Forest Survey of India did a forest resource survey in 1981 and published volume equations in 1996.

Many studies have been published on above-ground biomass (AGB) estimates in tropical forests around the world whereas the volume of literature on below-ground biomass estimates in tropical areas is relatively small. Root biomass is commonly estimated from standard root to shoot biomass ratios which may be species- or biome-specific (coniferous versus deciduous). However, changes in tree biomass allometry may also affect allometric equations for root biomass and root to shoot biomass ratios. As below-ground biomass in tree roots may account for a significant portion of total forest biomass and may provide an additional important C pool, the inclusion and improvement of root biomass estimates is imperative. This leads to underestimates of forest biomass and carbon stocks since the rest of the parts contribute significantly to forest biomass and thereby, leading to many uncertainties in forest carbon accounting. The most commonly used regression equation is that of a straight line

\[
\text{In biomass} = a + b \text{ln dbh},
\]

where biomass is the y (dependent) variable and the diameter at breast height (dbh) is the x (independent) variable.

In the present study, the woody species, viz. *Adina cordifolia*, *Bridelia retusa*, *Casearia graveolens*, *Dalbergia latifolia*, *Ougeinia oojeinensis*, *Schleichera oleosa* and *Terminalia bellirica* have been selected for estimating their biomass, carbon content and carbon capturing potential. The purpose was to estimate the total biomass and carbon stocks of selected species. In this communication, an attempt has been made to derive a relationship between biomass and girth class by obtaining a regression equation of biomass versus girth class. Also, the variation of biomass of different parts of the plant with carbon content was determined. The knowledge of carbon stocks of tropical dry deciduous forests in Gujarat state thus obtained will be helpful further to analyse carbon fluxes in future.

The study site was selected from the Dang forests, also called as ‘the Dangs’ district in south Gujarat situated at lat. 20°33’50” and 21°04’52” and the meridians of long. 73°27’58” and 73°56’38” (Figure 1). The total area of the district is 1764 km² comprising 77.4% of forest areas forming 1035.3521 km² (ref. 16). Dang tract is hilly having Sahyadri mountains on the eastern side going up to about 1100 m which descend as one moves towards the west extending to the edge of plains of Gujarat. Hills are low and flat-topped in north and west directions. Most of the area in the Dangs lies between 300 and 700 m above mean sea level.

The Dang forests consist of mixed tree growth among which teak (locally sag) is the predominant species in...
most parts of the area. The forests are mostly of deciduous type both moist and dry and a small portion being evergreen. They are continuous in all parts except at the places where the slopes are too steep to retain the soil and where biotic interference has cleared or opened it out. A significant area of Dang is a part of Purna Wildlife Sanctuary (160.8 km²) and Vansda National Park (23.9 km²). The Dang forests consist of plains belonging to Malabar region, hilly tract which are a part of Western Ghats as well as the coastal region alongside the Arabian sea, all of which extend to the state of Maharashtra. The diurnal range of variation in temperature does not exceed 5°C. The temperature is not uniform throughout the district but varies with altitude. Annual minimum and maximum temperatures are around 10°C and 45°C (ref. 17). The climate can be said to be warm and dry for most of the year except during monsoon season which extends from June to September bringing out nearly all annual rainfall (1635 mm for 2011), thus being very supportive for vegetative growth.

Hard, impermeable Deccan trap basalt rock covers the entire district making the soils iron rich. In the areas of basalt lava flows, soils are black, clayey to loamy in texture and red coloured in some areas. However, the major portion of the district comprises of lateritic soils. Dark black to red sandy soils occupy some portions in both the west and east sides.

The study site includes 7 ranges, 4 in Dang north division and 3 in Dang south division. They were stratified into various compartments. Sampling of 0.002% was done and according to the area of each compartment, the number of 20 m x 20 m quadrats to be laid was calculated. The nearest whole number was taken as the number of quadrats to be laid. The quadrats were laid using measuring tape and nail.

In each quadrat, all the trees were enumerated and measured for their girths. The individuals with girths greater than 10 cm were classified in five different girth classes, viz. 11–30, 31–60, 61–90, 91–200 and >200 cm. As girth class increases in proportion to age, the widening girth represents increasing age and thus this method is similar to chrono-sequence approach which is widely used to study forest growth processes for different tree species\textsuperscript{[13,18]}. The study was designed to harvest minimum trees with sufficient sample size to acquire information on species and size distribution in a forest. Hence, only one individual of each species from each girth class was selected for harvesting. The sample individuals with details of height, diameter, wood-specific gravity of the species (referred from global wood density database)\textsuperscript{[19,20]}, above-ground and below-ground biomass are given in Table 1. All the species had at least one individual in each of the first four girth classes. \textit{Adina cordifolia} was the exception with the individual missing in 61–90 cm girth class. No species showed presence of an individual in the highest girth class of \(>200\) cm except \textit{Adina cordifolia}. This indicated that this forest was second-growth or secondary forest as per the definition by FAO.

The selected individuals were completely uprooted and separated in 6 above-ground parts, viz. trunk, primary branches, secondary branches, twigs, leaves and fruits (if present) and roots as below-ground part. Thus, below ground biomass consisted only of roots, mostly coarse roots. Only \textit{Adina cordifolia} showed the presence of fruits in the harvesting season which was near the onset of monsoon (the second week of June). The girth of trunk and primary branches and the lengths of trunk, primary and secondary branches were measured using measuring tape. The heavy parts for large trees, i.e. roots, trunk and branches were weighed using analytical balance with a precision of 10 g and the twigs, leaves and fruits were measured using analytical balance with a precision of 0.5 g. Five hundred gram samples from all seven parts of each tree were analysed in the lab. The biomass was obtained after drying the samples in an oven at 70°C till constant weight was obtained. The percent dry weight of each sample was extrapolated to get the biomass of the whole part of the plant. The dried samples were crushed and powdered and sieved through 0.02 mm. The carbon analysis was done using C, N, H, S and (O) analyser of Perkin Elmer, Model 2400 Series II.

There is limited literature already published on below-ground biomass assessments from different types of forests around the world\textsuperscript{[11]}. Some of the assumptions made here are that all the species are approximately in similar climatic and soil conditions and therefore the biomass and carbon content is characteristic of each of the species itself. To support our assumption, we tested the soil for its pH, bulk density and organic carbon. The factors like bulk density, forest type, soil texture and pH of the soil that influence the SOC stock were also studied.

For developing allometric equations of biomass, all the harvested individuals which contain one individual of each girth class of each species were selected to give four representative samples for each species specific equation and 28 samples for multi-species regression equation. A

| Table 1. Soil characteristics of selected site |
| --- |
| Range | Mean TOC% | Mean pH | Mean BD (g/cm\(^3\)) |
| Singana | 0.50 ± 0.22 | 5.78 ± 0.02 | 1.15 ± 0.06 |
| Ahwa (W) | 1.30 ± 0.80 | 5.91 ± 0.33 | 1.21 ± 0.12 |
| Ahwa (East) | 1.50 ± 0.34 | 6.01 ± 0.3 | 1.18 ± 0.04 |
| Chikhalai | 2.99 ± 0.01 | 5.45 ± 0.01 | 1.16 ± 0.01 |
| Ahwa (W) | 3.20 ± 0.76 | 5.58 ± 0.26 | 1.17 ± 0.15 |
| Ahwa (W) | 2.42 ± 0.80 | 5.35 ± 0.01 | 1.16 ± 0.10 |
| Loachali | 2.27 ± 0.87 | 5.76 ± 0.36 | 1.01 ± 0.09 |
| Ahwa (W) | 0.89 ± 0.47 | 5.95 ± 0.01 | 1.15 ± 0.01 |
| Singana | 1.7 ± 0.63 | 5.61 ± 0.05 | 1.17 ± 0.01 |
| Loachali | 2.28 ± 0.21 | 5.83 ± 0.02 | 1.17 ± 0.06 |
| Waghai | 3.32 ± 0.23 | 5.45 ± 0.01 | 1.17 ± 0.01 |
| Subir | 3.15 ± 0.12 | 5.99 ± 0.05 | 1.12 ± 0.03 |
| Subir | 1.95 ± 0.15 | 6.24 ± 0.03 | 0.75 ± 0.05 |

TOC, Total organic carbon; BD, Bulk density; ±, Standard error.
set of local site-specific allometric equations were deve-
loped by using straight line equation as mentioned
previously and applying the following pan-tropical allo-
metric models to the empirical data19

\[
\ln \text{AGB} = a + b (\ln D) + c (\ln D)^2 + d (\ln D)^3 + e (\ln \rho),
\]

(2)

\[
\ln \text{AGB} = a + b \ln D + c (\ln H) + d (\ln \rho),
\]

(3)

where AGB, \(D\), \(\rho\) and \(H\) are tree above-ground biomass
(in kg), diameter (in cm), wood density (in g/cc) and
height (in m) respectively, and \(a\) (the constant), \(b\), \(c\), \(d\)
and \(e\) (co-efficient) are the model parameters. Equation
(2) is a general model which is preferred when height is
not available, as used by Chave21 (model II) while deve-
loping best fit pantropical equations. Equation (3) is a gen-
eral model proposed first by Schumacher and Hall22. A
wide variety of regression models have been developed
and applied in different forest types and geographies23–26.
The co-efficients were obtained by feeding the empirical
values in the models. Log was applied on both sides to
reduce the heteroscedasticity of data. The first three mod-
els are developed using straight line eq. (1) and general
eq. (2). Local model 1 included only diameter as the in-
dependent variable and subsequently, variables \(H\) and \(\rho\)
were added in subsequent local models 2 and 3. This was
done to observe the effect of each variable on the fitness
of the model. Local models parallel to the 2 equations
given by Chave for dry forests were developed and local
coefficients were generated. All the equations were com-
pared with parameters of goodness of fit, viz. significan-
ty (\(P\) value), coefficient of determination (\(R^2\)) and residual
standard error (RSE), also called as root mean squared
error (RMSE).

Forest management strategies including a change in
tree species affect the soil organic matter27,28 and hence,
soil organic carbon and associated factors were measured.
Table 1 puts light on carbon content of soils in the same
plots from where the trees were sampled.

It can be observed that the maximum carbon content
was seen in Waghai and Subir areas respectively, fol-
lowed by Chikhali range. The carbon content ranged from
0.05% to 3.32% and the average carbon content was
found to be 1.61%. The highest carbon content was found
in Waghai range which also showed highest bulk density
of 1.69 g/cm³. In general, it can be observed from the
table that all the quadrats do not show a much significant
difference in pH, bulk density and soil organic carbon.

The above-ground parts were portioned into trunk,
main branch, secondary branch, twigs and leaves while
the below-ground biomass mainly consists of coarse
roots. The proportion of biomass in stump and coarse
roots did not show significant relation with girth. In all
the plants, above-ground parts showed higher proportion
of biomass than below-ground parts. However, we could
only weigh the stump and coarse roots, which was the
limitation of the study.

\(S.\ oleosa\) showed highest biomass in both girth classes
11–30 and 31–60 cm, \(B.\ retusa, C.\ graveolens\) showed highest
in 61–90 cm and \(A.\ cordifolia\) showed highest
biomass in girth class 91–200 cm. This was probably due
to their larger girths compared to others in the respective
girth classes as the plants showing highest biomass values
in any of the parts had highest girth in that range of girth-
class. Commercial logging which selectively aims to cut
tree species having higher wood densities, large GBH or
high basal area likely lead to an overall decline in carbon
storage of those forest regions by 70%, 29% and 17%
respectively10.

A generic equation of stem biomass using diameter at
breast height (\(D\)), wood-specific gravity (\(\rho\)) and height
(\(H\)) was determined for all species (Table 2). The equa-
tions are represented with the \(Y\)-intercept, degree of free-
dom (\(df\)), coefficient of determination (\(R^2\)), absolute sum
of squares, residual standard error and \(P\)-value of differ-
ent species. It was observed that total biomass of all the
tree species showed positively significant correlation
with square of diameter at breast height (\(D\)) and height
(\(H\)). Wood density seemed to play a less significant role.

The estimation of above and below ground biomass
pools is of great importance for characterization of struc-
ture and function of ecosystems19. One of the widely used
approaches for modelling stand development dynamics is
the chronosequence approach that allows study of forest
growth processes for different tree species12,18. Girth is
representative of age because it increases along with age.
Thus, this method is on the lines of chronosequence
approach. Biomass estimates from allometric equations
also indicate the potential for C storage. Carbon account-
ing is thus directly dependent on biomass dynamics29,30
and hence, accurate information on biomass is very much
needed. Developing local and regional models to provide
better estimates of, specifically, total (both above-ground
and below-ground) biomass28 serves this purpose. There-
fore, these equations would help in estimating biomass of
deciduous forests with greater accuracy on a larger scale.

Estimation of these existing carbon reservoirs would
fill the knowledge gap of carbon stocks in tropical
deciduous forests and thereby aid in decision- and policy-
making processes regarding carbon management in
forests. Thus, allometric equations obtained would be as
helpful as the yield tables to estimate biomass and carbon
sequestration potential of species, forest stands, forest
types, etc. Therefore, development of regional allometric
equations cannot be understated11.

From Table 3 it was found that local models with all
three variables were a better fit than models with only
diameter and diameter and height.

Table 4 shows a comparison of the biomass estimates
of all trees obtained using local models and Chave
models I and II using paired \(t\)-test. From Tables 3 and 4,
Table 2. Description of trees with their above-ground and below-ground biomass

| Range      | Trees               | Height (m) | GBH (cm) | D (cm)  | ρ (g/cc) | AGB (kg) | BGB (kg) | Total    |
|------------|---------------------|------------|----------|---------|----------|----------|----------|----------|
| Loavchali  | Adina cordifolia    | 4.1        | 18.1     | 5.73    | 0.59     | 4.75     | 3.38     | 8.13     |
| Ahwa (W)   | Adina cordifolia    | 6.0        | 37.2     | 11.78   | 0.59     | 29.3     | 9.88     | 39.2     |
| Ahwa (W)   | Adina cordifolia    | 33.1       | 195.0    | 62.07   | 0.59     | 2488.01  | 521.23   | 2769.24  |
| Waghai     | Adina cordifolia    | 36.2       | 235.3    | 74.80   | 0.59     | 2700.43  | 317.31   | 3017.74  |
| Ahwa (W)   | Bridelia retusa     | 4.25       | 11.1     | 3.50    | 0.50     | 1.59     | 0.45     | 2.04     |
| Ahwa (W)   | Bridelia retusa     | 8.0        | 45.3     | 14.32   | 0.50     | 39.74    | 10.8     | 50.54    |
| Ahwa (E)   | Bridelia retusa     | 12.5       | 77.2     | 24.51   | 0.50     | 283.61   | 51.66    | 335.27   |
| Subir      | Bridelia retusa     | 15.0       | 100.3    | 31.83   | 0.50     | 170.43   | 235.04   | 405.47   |
| Loavchali  | Casearia graveolens | 3.6        | 16.5     | 5.09    | 0.62     | 3.62     | 1.95     | 5.57     |
| Ahwa (W)   | Casearia graveolens | 6.5        | 40.3     | 12.73   | 0.62     | 2248.01  | 521.23   | 2769.24  |
| Ahwa (W)   | Casearia graveolens | 12.1       | 81.1     | 25.78   | 0.62     | 2620.8   | 71.02    | 333.09   |
| Ahwa (W)   | Casearia graveolens | 12.6       | 119.1    | 37.88   | 0.62     | 3170.33  | 60.82    | 377.85   |
| Ahwa (W)   | Dalbergia latifolia | 4.6        | 14.5     | 4.46    | 0.75     | 170.43   | 235.04   | 405.47   |
| Ahwa (W)   | Dalbergia latifolia | 8.4        | 50.2     | 14.32   | 0.75     | 39.74    | 10.8     | 50.54    |
| Ahwa (W)   | Dalbergia latifolia | 12.5       | 100.3    | 31.83   | 0.75     | 170.43   | 235.04   | 405.47   |
| Chikhali   | Dalbergia latifolia | 15.0       | 100.3    | 31.83   | 0.75     | 170.43   | 235.04   | 405.47   |
| Singana    | Dalbergia latifolia | 20.4       | 150.1    | 47.75   | 0.75     | 1551.19  | 317.19   | 1868.38  |
| Singana    | Ougeinia oojeinensis | 5.0        | 14.6     | 4.46    | 0.70     | 3.91     | 0.88     | 4.783    |
| Ahwa (W)   | Ougeinia oojeinensis | 7.8        | 54.5     | 17.19   | 0.70     | 56.01    | 14.97    | 70.98    |
| Singana    | Ougeinia oojeinensis | 10.0       | 67.3     | 21.33   | 0.70     | 206.10   | 43.90    | 250.00   |
| Ahwa (W)   | Ougeinia oojeinensis | 15.3       | 147.0    | 46.79   | 0.70     | 513.79   | 58.08    | 571.87   |
| Ahwa (W)   | Schleichera oleosa  | 8.1        | 24.2     | 7.64    | 0.96     | 55.97    | 5.87     | 61.84    |
| Ahwa (W)   | Schleichera oleosa  | 10.1       | 48.3     | 15.28   | 0.96     | 101.87   | 32.88    | 134.75   |
| Ahwa (W)   | Schleichera oleosa  | 12.2       | 65.0     | 20.69   | 0.96     | 190.93   | 50.07    | 241.00   |
| Ahwa (W)   | Schleichera oleosa  | 26.1       | 106.3    | 33.74   | 0.96     | 331.04   | 221.1    | 552.14   |
| Ahwa (W)   | Terminalia bellirica| 5.3        | 18.4     | 5.73    | 0.72     | 5.019    | 2.33     | 7.35     |
| Chikhali   | Terminalia bellirica| 13.5       | 43.5     | 13.69   | 0.72     | 101.87   | 32.88    | 134.75   |
| Ahwa (W)   | Terminalia bellirica| 15.2       | 73.0     | 23.24   | 0.72     | 217.44   | 57.68    | 275.12   |
| Chikhali   | Terminalia bellirica| 22.0       | 145.1    | 46.15   | 0.72     | 1299.55  | 172.25   | 1471.8   |

Table 3. Local site-specific allometric equations

| a    | b    | c    | d    | e    | df  | P (Sig value) | Adj. $R^2$ | RSE |
|------|------|------|------|------|-----|---------------|------------|-----|
| ln ρ | ln D | (ln D)^2 | (ln D)^3 |       |     |               |            |     |
| Local model 1: ln AGB = a + b ln D | 2.288 | 1.188 | 26   | <0.001 | 0.935 | 0.289       |
| SE   | 0.357 | 0.06  |       |      |      |             |            |     |
| Local model 2: ln AGB = a + b ln (D^3H) | 2.159 | 2.218 | 2.163 | 0.41  | 24   | <0.001 | 0.951 | 0.217 |
| SE   | 0.502 | 0.482 | 0.205 | 0.344 |      |      |      |     |
| Local model 3: ln AGB = a + b ln ρ + c ln D + d ln ρ + e ln (D^3H) | 2.678 | 0.938 | 2.605 | 0.344 | 24   | <0.001 | 0.951 | 0.217 |
| SE   | 0.325 | 0.041 | 0.175 | 0.344 |      |      |      |     |

df, Degrees of freedom; ρ value, significance value at 95% confidence interval; RSE, Residual standard error; SE, Standard error; AGB, Above-ground biomass; Adj. $R^2$, Adjusted coefficient of determination.

It is clear that local model 3 with all the variables independently fitted performs the best of all equations (Figure 3). The pan-tropical models showed significant difference in estimation of AGB as shown by paired $t$-tests.

After analysing the mean carbon content of seven species using CNHS/O analyser, it was multiplied with the total biomass of the particular species in each girth class and maximum carbon stored by the individual plant species was obtained in each girth class (Table 3).

The mean carbon content in all tree species across different girth classes was analysed by pooling and averaging carbon content of all different parts of each species. The mean across all girth classes of selected plant species was found to be as depicted in Figure 2.
Table 4. Comparative analysis by paired T-test of equations

| Models                                      | RMSE   | t     | df  | Sig. (2-tailed) |
|---------------------------------------------|--------|-------|-----|----------------|
| Local model 1 ln AGB = a + b ln D²          | 2.753  | 0.2926| 27  | 0.7721         |
| Local model 2 ln AGB = a + b ln ((D²)H)     | 2.594  | 0.0027| 27  | 0.9978         |
| Using all the three variables independently fitted |        |       |     |                |
| Local model 3 ln AGB = a + b ln ρ + c ln D + d ln H | 2.29   | 0.3334| 27  | 0.7414         |
| Pan-tropical model for dry forests ln AGB – ln Chv | 2.339  | 0.0677| 27  | 0.9465         |
| Models without height H ln AGB = a + b ln ρ + c ln D + d (ln D)² + e (ln D)³ | 2.392  | 0.1363| 27  | 0.8926         |

RMSE, Root mean squared error; df, Degrees of freedom.

Figure 2. Mean carbon content of plants across all girth classes. SE, Standard error (represented by error bars).

Figure 3. Scatter plot of best fit regression model.

To sequester higher carbon stocks, species having higher standing carbon stock and higher wood density and longer rotation periods must be planted more. Thus, *A. cordifolia* shows the highest carbon sequestration potential while *T. bellirica* shows the least potential. Also, *S. oleosa* and *D. latifolia* have high wood densities, 0.96 kg/cm³ and 0.75 kg/cm³, with *S. oleosa* having the highest among all the species. According to Bunker et al., planting species with higher wood densities increases the above-ground carbon storage by 75%.

All the tree species showed a stored carbon percentage between 40% and 45%. *Adina cordifolia* again dominated the other species by having nearly 45% carbon while *O. oojeinensis* and *S. oleosa* on an average possessed 44.29% and 43.98% carbon. These figures are close to the conventional conversion of biomass to carbon percentage of 45%, as described by Singh and Singh.

The increased interest in REDD+ and CDM to promote afforestation and reforestation as an offset to greenhouse gas emissions has created more demand for biomass estimation models. The present study has generated primary baseline data in Gujarat on development of allometric relationships for biomass estimation and carbon sequestration of dominant economically important species. The results of this study are in accordance with the established pan tropical models, suggesting that inclusion of a larger number of the representative individuals and independent variables like local wood density would give...
more robust biomass estimates. The regression equations developed will be useful for regional estimation of biomass and carbon stocks of the state and same species in similar type of forests elsewhere.

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