Chapter 5: Accounting biomass and carbon stocks in different land-use systems of Gandhinagar, Gujarat

Abstract: Carbon sequestration by terrestrial ecosystems including vegetation and soil has been highlighted since the formation of UNFCCC. Land-use change and land-use intensification due to increased population growth leading to deforestation, agricultural intensification and urbanization is the second major source of carbon emissions after fossil fuel burning according to IPCC. This work aims to study vegetation carbon stocks in different land-use systems in Gandhinagar, Gujarat. It was found that natural vegetation consisting of forests sequestered more carbon than other land-use systems. Urban ecosystem significantly stored more carbon than rural areas contrary to our assumption. *Azadirachta indica, Prosopis juliflora and Acacia nilotica* were the top three species leading in total carbon stocks.

Keywords: Carbon Sequestration, Urban Ecosystems, Land-Use Change
5.1. Introduction

Land use change is very much linked to global climate change being the second largest source of carbon emissions. Land use/cover type with vegetation and soil is an important source as well as sink of C storage, and modification and alteration of land-use patterns is accountable for large fluxes of carbon (C) (Canadell, 2002). In the tropics, C cycle is affected primarily by the tree sources (Singh & Chand, 2012). This has brought attention of the scientists worldwide to conservation of trees both in natural wooded lands like forests as well as managed ecosystems like the urban. Though forest areas are considered as the basic ecosystems for tree resources, a large number of trees also exist outside the continuous forested areas across the continents (Singh & Chand, 2012). The way of managing forest cover and trees outside forests affects the source and sink dynamics of carbon dioxide as trees grow, die and decay.

The nexus between land use change and climate change has been cited by many studies since the last decade (Chuluun & Ojima, 2002; Li et al., 2017; N. M. Mahowald et al., 2017). The role of terrestrial ecosystems as sources and sinks of C has been highlighted, underscoring the impact of land cover changes on the global climate (Houghton, 1994; Houghton & Goodale, 2004). Based on various potential scenarios, it has been predicted that atmospheric temperature in 2100 will be increased in 1.8–4.0°C, on average, considering the best estimate (IPCC, 2000). However, in its sixth assessment report, IPCC has set the goal of maximum 1.5°C. In addition, the Earth Systems Research Laboratory/National Oceanic and Atmospheric Administration (ESRL/NOAA) estimated that annual increase in atmospheric concentration of CO₂ is around 3 ppm per year since 2015 with uncertainty of 0.11 ppm per year (NOAA 2017) and the trend seems to continue with increasing rate of rise on a year-over-year basis because CO₂ emissions from anthropogenic sources currently exceed the capacity of absorption of the terrestrial ecosystems and oceans.

Carbon is exchanged naturally between terrestrial aboveground and belowground C stocks, and the atmosphere through chemical, physical, geological, and biological processes, although anthropogenic activities affect these fluxes between the different C
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pools. Soil organic carbon (OC) is considered the largest C stock in most terrestrial ecosystems, well above the C pool in plants (Chaturvedi et al., 2011). Carbon, which is removed from the atmosphere by forest ecosystem processes, is stored both in vegetation and soils. The large potential of trees for either removing CO₂ from the atmosphere or adding it was discovered in early research about forests, the carbon cycle, and climate (Brown et al., 1989). More recently, research has gone in depth emphasizing on other mechanisms exploring how forest canopies affect the radiative forcing of the atmosphere or the large scale estimation of carbon stocks in different ecosystems or the accuracy of large scale estimations and so on (Dicken, 2015; Mahowald et al., 2017).

Forests are the major C sinks in India, and therefore, accurate estimates of different forest C pools and their changes are critical for understanding the C budget. Tropical deciduous forests are globally extensive but are less focused on than temperate and tropical rainforests. They occur in semi-arid regions and Deccan peninsula in India and need more attention by researchers for their biogeochemistry and their potential carbon reserves (Becknell, Kissing Kucek, & Powers, 2012; Chaturvedi & Raghubanshi, 2015; L. Singh & Singh, 1991).

The role of temperate forests in India is important because of their potential to accumulate large amounts of C in different pools. However, there is a paucity of data on C stock assessment in tropical deciduous forests of India, and more so in the region of Gujarat. Hence the present study was undertaken with the following objectives: (1) to assess the biomass and C pools of the main ecosystem components among the different land use types in Gandhinagar district, Gujarat and (2) to assess the changes in the size and contribution of these C pools to the total ecosystem C stock.

Land-use and land cover changes (LULCC) have affected one third of total land on earth (Vitousek et al., 1997), primarily through deforestation and conversion of natural vegetation for agriculture and other uses (Hurtt et al., 2009; Ellis, 2011). The impacts of past, present and potential future LULCC on climate and the carbon cycle have been addressed in a number of recent studies (Matthews et al., 2004; Brovkin et al., 2004, 2013; Shevliakova et al., 2009; Pongratz et al., 2010). The climatic consequences of
LULCC can be divided in terms of its physical and chemical effects. The former effects involve alterations of physical land surface characteristics such as changes in albedo and roughness length, which in turn affect regional boundary layer dynamics and land–atmosphere energy and water exchange. The chemical effects include changes in the atmospheric GHG composition, which then affects the climate at the global scale.

Over the historical period, LULCC-associated CO₂ emissions have increased atmospheric CO₂ concentration by 15–20 ppm, making about 35% of the total GHG emissions since 1850 (Matthews et al., 2004; Brovkin et al., 2004; Pongratz et al., 2010; Arora and Boer, 2010; Foley et al., 2005). The consequences of global warming may increase or decrease local temperatures depending upon the geographical location. Furthermore, Canadell (2002) and Arora (2013) have discussed about the controversial effects of LULCC on land–atmosphere interactions, which are driven by atmospheric CO₂ concentration: the carbon–temperature feedback and the carbon–concentration feedback which may result in contradictory effects. Increased primary productivity gives a negative climate feedback by CO₂ fertilization effect of vegetation while risen carbon concentration gives a positive climate feedback as a result of enhanced microbial respiration of soils in a warmer climate. However, LULCC reduces the size of the land carbon sink and sources and thus may reduce these climate feedback effects.

Few scientists have documented a comparative analysis of carbon stocks in different land-use systems. Mangalassery et al., (2014) in a study in Kachchh region of Gujarat, have reported higher tree carbon stocks in silvipastoral (a mix ecosystem of trees and grasses) systems than homogenous ecosystems of trees or pastures. Srivastava et. al. (2015), have compared soil nitrogen and their effects soil carbon in different ecosystems in similar climatic zone of tropical deciduous forests of Uttar Pradesh, India. No other similar studies have been found in the region of western India. This motivated us to explore the area for a more detailed comparison of different ecosystems on total ecosystem carbon stocks. We have tried to calculate carbon stocks in five different pools viz., trees, shrubs and herbs, litter and soil of in 5 different land-use systems of dry tropical region of Gandhinagar, Gujarat using allometric equations for tree biomass and
actual dry and fresh weights for the rest. We have then tried to compare and contrast the obtained results and predicted the reasons for them.

5.2. Materials and Methods

5.2.1. Sampling and estimation of aboveground and belowground biomass of trees

The study was carried out in the 18 sites of 5 different land use systems as mentioned in previous chapter (Fig 3.1). A total of 20 plots of 0.1 ha (31.62 m * 31.62 m) each were laid randomly across all the land use types. All the trees ≥ 10 cm GBH lying within the sample plot were measured using a measuring tape. The above-ground biomass was estimated using equation given by Chave et al. (2005) for the trees.

\[
AGB = \rho \exp(-0.667 + 1.784 \times \ln D) + 0.207 \times (\ln D)^2 - 0.0281 \times (\ln D)^3
\]

Using the regression equation of Cairns et al., (1997) the belowground biomass (BGB) was estimated as follows:

\[
BGB = \exp\{-1.059 + 0.884 \times \ln (AGB) + 0.284\}
\]

5.2.2. Detritus (deadwood and forest floor litter) biomass

In each sample plot, biomass of standing dead trees, fallen trees and stumps were estimated following the procedure of Ravindranath and Ostwald (2008). Forest floor litter was collected randomly from 10 (1 m x 1 m) quadrates in each plot, and their fresh weights were obtained in the field following which, the representative samples were taken in triplicates to the laboratory where they were oven-dried at 65°C till a constant dry weight was obtained. Forest floor litter C density was obtained by multiplying the dry mass with the corresponding C concentration.

5.2.3. Total ecosystem biomass and carbon

AGB, BGB, understory and detritus biomass (DB) were added to get the total ecosystem biomass (TEB). The total C was computed by using the following formula
Carbon (C Mg/ha) = Biomass (Mg/ha) x Carbon %.

The C percentage for live tree biomass, dead wood and litter was taken as 45% for broad-leaved trees (Negi et al., 2003; Manhas et al., 2006). The total ecosystem C was taken as the sum of SOC (as given in next chapter) and biomass C of all the pools (tree, understory and detritus).

5.2.4. Statistical analysis

Statistical analysis was performed using SPSS Software package (20.0; SPSS, Chicago, IL). ANOVA was performed to test for significant differences in the biomass and C stocks of the different ecosystem components among forest types. Simple linear and exponential regression was used to obtain the relationship between basal area and biomass.

5.3. Results
5.3.1. Tree (above and belowground) biomass

Land-use class wise contribution to above-ground and below-ground biomass and carbon. Land-use classes showed significant difference in biomass and carbon stocks with huge standard error representing the difference between sites as well.

**Table 5.1** Top Species contributing to above-ground carbon (kg) in different land-use classes

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Vegetation</th>
<th>Scrub</th>
<th>Rural</th>
<th>Urban</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azadirachta indica</td>
<td>4424.51</td>
<td>8769.30</td>
<td>7435.81</td>
<td>8025.08</td>
<td>5052.25</td>
<td>33706.95</td>
</tr>
<tr>
<td>Prosopis juliflora</td>
<td>0.00</td>
<td>4545.58</td>
<td>816.93</td>
<td>738.41</td>
<td>2421.15</td>
<td>8522.07</td>
</tr>
<tr>
<td>Vachellia nilotica</td>
<td>6261.98</td>
<td>1056.36</td>
<td>5474.35</td>
<td>578.18</td>
<td>2274.37</td>
<td>15645.24</td>
</tr>
<tr>
<td>Vachellia tortilis</td>
<td>2401.05</td>
<td>1420.15</td>
<td>2644.30</td>
<td>0.00</td>
<td>1926.18</td>
<td>8391.68</td>
</tr>
<tr>
<td>Senegalia senegal</td>
<td>2554.22</td>
<td>975.12</td>
<td>188.17</td>
<td>0.00</td>
<td>279.66</td>
<td>3997.16</td>
</tr>
<tr>
<td>Holoptelia integrifolia</td>
<td>2130.69</td>
<td>234.83</td>
<td>856.53</td>
<td>0.00</td>
<td>218.82</td>
<td>3440.87</td>
</tr>
</tbody>
</table>
The Graph (Figure 5.1) showed AGB of vegetation showing minimum deviation ranging between 150 and 200 Mg/ha between 160 and 190 Mg/ha.

*Azadirachta indica* was the largest contributor of AGB in whole Gandhinagar district followed by *Prosopis juliflora* and *Vachellia nilotica* (Table 5.1).
Figure 5.1 Mean AGB and BGB (Mg/ha) in different land use classes with Standard error
5.3.2. Variation of above ground carbon stocks and no. of trees with girth sizes in different land use classes

Vegetation class showed maximum biomass in girth class 91-120 cm followed by 61-90 cm indicating secondary forests. Scrub, rural, others and urban classes showed maximum biomass in above 61-90 girth classes. The number of individuals was highest in 61-90 cm girth class in vegetation, scrub and rural. While in others and urban class, it was maximum in 31-60 cm girth class (Figure 5.2).
The two most prominent relations between girth classes and aboveground carbon were observed in vegetation and urban classes, both of which showed direct proportional relationship. Rural and Others class showed maximum above ground carbon in 61-90 cm girth while rest of the land use classes showed maximum carbon in individuals having diameter above 150 cm. Most of the classes showed peaking stem density at 61-90 cm girth class except urban which showed maximum individuals in 31-60 cm girth class (Figure 5.2). Carbon stocks varied hugely in land use classes being the most (78.53 ± 5.69 Mg/ha) in vegetation areas and the least (21.65 ±7.29 Mg/ha) in others class.

5.3.3. Total Ecosystem Carbon stock across the five land-use classes

The total ecosystem carbon stocks were calculated for the five land-use classes and the carbon stocks showed an expected response to increasing level of disturbance (Table 5.2). Vegetation class showed maximum carbon stocks while ‘others’ class showed minimum carbon stocks. The tree carbon was highest in vegetation while maximum understory carbon was found in rural class. Litter and soil organic carbon also showed highest values in vegetation class and lowest in ‘others’ class. The understory carbon was surprisingly
higher in others class than urban class contrary to the other carbon pools and overall ecosystem carbon stocks.

Table 5.2 Total Ecosystem carbon stocks (Mg C/ha) across five land-use classes

<table>
<thead>
<tr>
<th>Land-use class</th>
<th>Vegetation</th>
<th>Scrub</th>
<th>Rural</th>
<th>Urban</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>78.53</td>
<td>57.96</td>
<td>44.10</td>
<td>43.79</td>
<td>21.65</td>
</tr>
<tr>
<td>Understory</td>
<td>0.77</td>
<td>0.59</td>
<td>0.98</td>
<td>0.25</td>
<td>0.48</td>
</tr>
<tr>
<td>Litter</td>
<td>0.46</td>
<td>0.39</td>
<td>0.30</td>
<td>0.30</td>
<td>0.26</td>
</tr>
<tr>
<td>Soil</td>
<td>21.46</td>
<td>21.08</td>
<td>21</td>
<td>20.66</td>
<td>19.72</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>101.22</strong></td>
<td><strong>80.02</strong></td>
<td><strong>66.38</strong></td>
<td><strong>65.00</strong></td>
<td><strong>42.11</strong></td>
</tr>
</tbody>
</table>

With increasing pace of land use change, it becomes important to quantify the carbon stocks to account impacts of changing landscapes on ecosystem service of net primary production. Several characteristics of forest composition and structure such as stand age, species composition and forest type, size class of trees, along with climatic and topographic factors like site conditions, rainfall pattern, edaphic factors and elevation (Peichl and Arain, 2006; Gairola et al., 2011) cause changes in forest biomass. Conversion of forest lands to agriculture, human settlements, pastures, industries and other human activities are factors affecting biomass in different ecosystems. Under the policy of REDD+, it has become important to account for carbon stocks in forests as well as trees outside forests.

5.4. Discussion

Maximum account of biomass in 91-120 cm girth class in areas under vegetation showed the forests are not primary growth forests. This is also indicated by low tree count in 121-150 and above 150 cm size classes. Maximum number of trees are seen in 61-90 cm and 31-60 cm girth classes indicating plantations and maintenance of vegetation cover. Though, it cannot be concluded as there is no quantitative data on grazing and other disturbance factors in the forest.
In the scrub class, the disturbance seen in less as more biomass is seen in higher stem size class. The biomass is seen to be directly proportional to the stem size class in the scrub areas. Though, there are more trees in 61-90 cm girth class and almost equal number of trees in 31-60 to 91-120 cm girth class. The total number of individuals in the scrub areas were the least (80).

In the rural and others areas, the disturbance is higher due to less management of green cover. The ‘others’ class showed least above-ground carbon stocks while the rural and urban classes showed subsequently higher carbon stocks. The urban areas show relatively higher number of trees than rural or others class because of managed ecosystem. However, most of the biomass comes from fewer numbers of species due to monoculture plantations in urban areas.

Some of the industrial areas like Thermal Power Plant belonging to others class showed high invasion of *Prosopis juliflora* making a complete *Prosopis* forest. This was due to deliberate plantation of *Prosopis* in those areas. However, invasion by *Prosopis juliflora* is also seen in urban and rural areas.

The mean aboveground carbon in vegetation areas is 78.53 ± 5.69 tonnes/ha which is near about the average estimate (81 tonnes/ha) given by FAO State of World Forest Report 2015 (Köhl et al., 2015).

By applying anova for comparing the estimates of stem density, basal area and biomass among land use classes, it was found that stem density (number of individuals) did not vary significantly among classes. Basal area differed significantly (F=5.022, 4) at 95% and biomass or carbon stocks varied significantly (F=7.63, 4) at 99%. More number of sites needs to be analyzed for biomass and basal area to conclusively determine the difference between carbon stocks of different land use classes.

Also, vegetation biomass should include understory and litter to give actual picture of total carbon stocks of ecosystems in different land classes. Data on seedlings and saplings will give the picture of regeneration in different land use classes which is very much required to give the accurate picture of carbon stocks.
Nevertheless, trees are the most dominant carbon pools of tropical terrestrial ecosystems. Hence, the study included all woody stems larger than 10 cm in size class. In mix-aged forests, large trees often contribute a significant proportion of aboveground biomass and the carbon density of the site although only a few may be present (Lutz et al., 2012). Large trees have deep roots, which transfer carbon into the lowest layers of the forest soil. In this study, large trees were dominant in reserve forest areas and scrub areas. This shows that the plantations are still young in other managed ecosystems and need to be cared for till they grow sufficiently old. One of the observed causes seem to be trees harvested for fire wood and other purposes like timber and new plantations after regular intervals. Within each land use, mean similarities were low, ranging 25–31%. Mean pairwise dissimilarities between land uses were relatively high, ranging 73–81%. This suggests that variations in species composition and diversity are to a great extent influenced by land-use and anthropogenic disturbances (Nagendra, Sudhira, et al., 2013).

The relatively low woody species diversity and richness in this savanna indicates woodland degradation, fragmentation and local species loss resulting from unsustainable harvesting for charcoal, and short interval shifting cultivation.

Urban areas are very diverse and include many different land use classes within themselves like gardens and lawns, sports grounds, urban forests, trees along roadsides, commercial and residential areas and roads. To account for all the overall picture of urban carbon stocks these land use classes need to be studied in detail.