RESEARCH ARTICLE

Contribution of Street Trees to Carbon Sequestration: A Case Study from Varanasi, India

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Abstract

Street trees are a valuable resource for a city, because of the lower ambient temperatures, mitigate urban heat island effects, reduce runoff of rainwater and the abundance of aerial particulate matter, add visual appeal to the urban landscape and store and sequester a significant amount of carbon from the ambient CO_2. We quantified carbon storage and sequestration by street trees in the campus of Banaras Hindu University located within a highly crowded city of India. Street trees in the BHU campus account for 9.8×10^7 kg stem biomass and stored 4.6×10^7 kg carbon in the stems. By interpolating the electricity resource unit values campus street trees stored 7.3×10^7 KWH energy. These trees, of course, have to be properly managed for maintaining their vigor and function.

Keywords: Biomass, Carbon sequestration, Carbon stored, Climate change, Urban trees.

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Introduction

Growing urbanization is a major contributor to global environmental change and can extensively alter regional carbon dynamics (Pataki *et al*., 2006; McHale *et al*., 2009). For example, during recent decades unprecedented population growth and urbanization have occurred in India. Between 2001 and 2011, the total population in India increased by 17.64%. And "from 5161 classified towns and 384 urban agglomerations in 2001, India's urban centers grew to 7935 classified towns and 475 urban agglomerations in 2011, making India the second largest urban system in the world" (Majumdar and Selvan, 2018). Urban areas in the conterminous United States have increased from 2.5% of the U.S. land area (19.5 million ha) in 1990 to 3.1% (24.0 million ha) in 2000 (Nowak *et al*., 2013). If the growth patterns of the 1990s continue, urban land is projected to reach 8.1% by 2050. Notwithstanding the adverse effects of urbanization, urban trees are a valuable resource for a city, because they lower ambient temperatures (Ngo and Lum, 2018), mitigate urban heat island effects (Aniello *et al*., 1995; Solecki *et al*., 2005), reduce runoff of rainwater (Mitchell, 2014) and the abundance of aerial particulate matter (Ngo and Lum, 2018), and add visual appeal to the urban landscape (Zhang *et al*., 2007). City trees also reduce energy consumption by the inhabitants (Akbari, 2002; McPherson and Simpson, 2003). In addition to the above benefits, trees in urban area, or those in the peri-urban areas also store and sequester remarkable amounts of carbon as biomass from the atmospheric carbon dioxide (Majumdar and Selvan, 2018; Ngo and Lum, 2018), and thus influence local climate, carbon cycles, and energy use (Nowak *et al*., 2013). Therefore, urban trees provide a tremendous amount of cultural ecosystem services. In fact, carbon storage and sequestration are identified among the four key ecosystem services contributing to sustainable development goals (Wood *et al*., 2018). Street trees do reduce the demand for air-conditioners.

Thus according to Singh *et al*. (2018), "Trees comprise the natural capital assets for cities as they provide immense benefits and ecosystem services for the wellbeing of city dwellers". Limited data have been extrapolated to provide national estimates of carbon storage and sequestration, for example, Nowak (1993) national carbon storage by urban trees 350–750 million tonnes based on carbon data of Oakland city and tree cover data from various U.S cities. In a later assessment which included data from a second city, Nowak (1994) estimated 600–900 million tonnes national carbon storage, and in a more recent analysis Nowak *et al*. (2001) of data derived from advanced very high-resolution radiometer (AVHRR) for urban tree cover in ten cities estimated the national carbon storage by urban forest at 700 million tonnes.

In India, however, a limited number of studies on street trees (Sudha and Ravindranath, 2000; Nagendra and Gopal, 2011) exclusively on carbon estimation, sequestration are on record (Majumdar and Selvan, 2018). Mazumdar and Selvan (2018) have pointed out the potential of such studies for urban forest and trees available in various University Campuses. Chavan and Rasal (2010) have also estimated carbon stock in selected tree species grown in the university campus at Aurangabad. Most of such studies suffer from the fact that they lack direct measurement of urban tree volume and biomass (McPherson and Simpson, 2001; Pataki *et al*., 2006).

In the present study, we report the estimates of biomass and sequestered carbon in the street trees of the Banaras Hindu University campus located within a highly crowded city of India. This should be taken as a preliminary report.

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Study Area

The campus of the Banaras Hindu University is located in the upper gangetic plain, at latitude 25.267878"N and longitude 82.990494"E. It has totaled about 5.3 km^2 geographical area. The total length of streets planted with trees on both sides is 30.8 km (Anil Kumar Singh, Professor of Horticulture, BHU, personal communication). The trees were basically selected to provide shade to pedestrians and for producing edible flowers (*Madhuca longifolia*), fruits (*Mangifera indica, Syzygium cumini*, and *Tamarindus indica*) and rarely for the economic value of timber (*Tectona grandis*). These streets connect various university departments, playgrounds and residential areas and thus are a significant part of the green infrastructure, attracting thousands of people from outside of the campus for a morning walk (Fig. 1). The soil is inceptisol (alluvial). The flora of BHU campus comprises 574 species belonging to 426 genera and 111 families of angiosperm (Dubey, 2004).

Methods

A reconnaissance survey was made of all the streets of the university, and it was visually noted that five species dominated the population of street trees, these are *Syzygium cumini, Mangifera indica, Madhuca longifolia, Tamarindus indica*, and *Tectona grandis*. Subsequently, five streets were randomly selected, each planted with one of the five species. A 100 m stretch of each chosen street was selected randomly, and 10 trees of each species in this stretch were measured for height and DBH (Diameter at breast height).

Height of each tree was measured by holding a meter stick perpendicular to the ground as described by Brower and Zar (1998). The diameter of each tree was measured at breast height (1.3 m) (DBH) using a dendrometer (Chaturvedi *et al*., 2010). The stem biomass (dry weight) of each tree was measured by using, DBH, height and wood density. The expression given by Chaturvedi *et al*. (2010), as below, was followed:

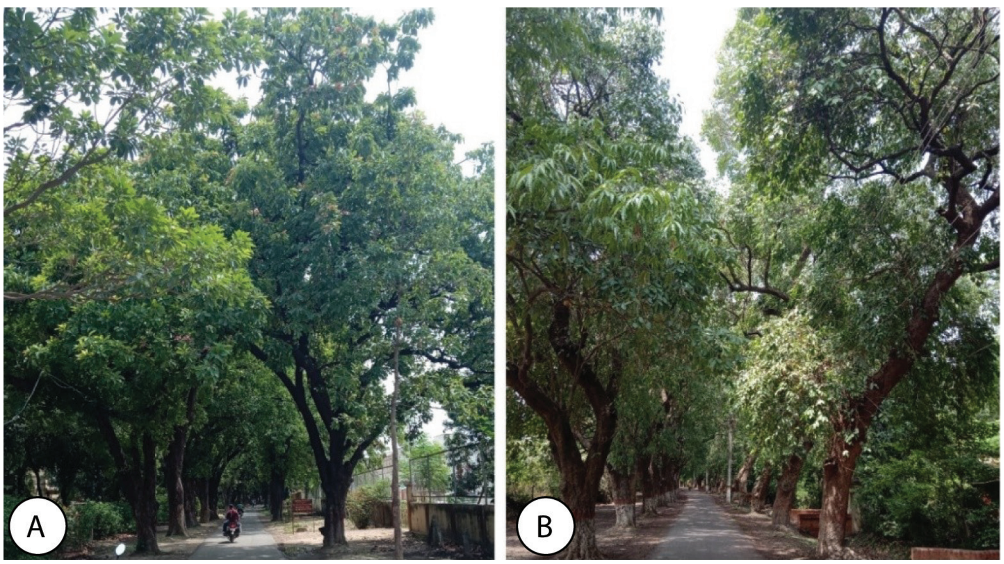
Stem Biomass (B, Kg tree^{-1}) = $0.5(\pi/4)\ \rho\ D^2\ H$

Where, 0.5 is the assumed form factor, defined as the ratio of stem volume to the volume of a cylinder with the H (m) and DBH (cm) of tree and ρ is the specific gravity.

Carbon stored in the biomass was estimated by multiplying the biomass value with 0.47 (Singh and Singh, 1991). Energy stored in the biomass was calculated by multiplying the biomass value as detailed in the website <0.75http://wiki.gekgasifier.com/w/page/6123680/Biomass%20to%20Woodgas%20to%20BTU%20to%20HP%20to%20KW%20to%20MPG%20conversion%20rules (accessed on 29/06/2018)>.

Result and discussion

The height of the trees of *Syzygium cumini, Mangifera indica*, *Madhuca longifolia*, *Tamarindus indica*, *Tectona grandis*, ranged, respectively, from 15–21, 19–27, 12–21, 10–20, 17–22 m (Table 1).



Figs 1A and B: Street planted with (A) *Madhuca longifolia* (B) *Syzygium cumini*

Table 1: Tree dimensions, biomass, carbon, and the energy equivalent of stored biomass

No. of trees in 100 m stretch	*Mean DBH (cm)*	*Mean height (m)*	*Mean biomass (kg)*	*Mean carbon (kg)*	*Mean stored energy (kwh)*	*Mean height (m)/ Mean DBH (cm)*
Syzygium cumini						
4	117.85	21.65	90875.64	42711.55	68156.73	18.50
1	113.1	20.97	81068.85	38102.36	60801.64	18.56
6	105.34	19.74	66200.94	31114.44	49650.71	18.80
3	97.5	19.01	54616.23	25669.63	40962.17	19.60
8	82.7	18.12	37454.12	17603.44	28090.59	22.10
2	76.04	17.29	30214.10	14200.62	22660.57	22.75
2	70.46	16.65	24982.16	11741.61	18736.62	23.79
5	68.64	13.1	18653.32	8767.06	13989.99	19.26

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No. of trees in 100 m	*Mean DBH (cm)*	*Mean height (m)*	*Mean biomass (kg)*	*Mean carbon (kg)*	*Mean stored energy (kwh)*	*Mean height (m)/ Mean DBH (cm)*
4	64.57	12.9	16254.80	7639.76	12191.10	20.16
3	60.25	11.38	12484.95	5867.93	9363.71	18.97
Overall mean	856.45	170.81	432805.11	203418.4	324603.8	
Mangifera indica						
3	100.31	27.3	57143.47	26857.43	42857.61	27.3
1	92.02	25.65	45182.20	21235.63	33886.65	27.88
5	89.17	24.85	41103.56	19318.67	30827.67	27.92
2	88.21	24.2	39171.17	18410.45	29378.38	27.5
6	86.62	22.78	35555.40	16711.04	26666.55	26.48
4	84.39	22	32592.69	15318.56	24444.52	26.19
2	79.61	21.12	27844.84	13087.07	20883.63	26.73
2	71.65	20.86	22277.28	10470.32	16707.96	29.38
1	66.87	23.85	22185.36	10427.12	16639.02	36.13
1	63.69	19.67	16598.25	7801.18	12448.69	31.22
Overall mean	822.54	232.28	339654.23	159637.49	254740.68	
Madhuca longifolia						
2	96.81	20.36	61414.61	28864.87	46060.96	21.2
1	90.76	19.97	52944.46	24883.90	39708.35	22.18
4	86.94	19.06	46367.71	21792.83	34775.79	22.16
2	81.21	17.74	37655.30	17697.99	28241.48	21.9
1	78.66	15.76	31384.67	14750.80	23538.50	20.2
1	76.43	14.75	27731.49	13033.80	20798.62	19.4
3	74.84	14	25237.66	11861.70	18928.25	18.91
1	72.92	13.9	23788.20	11180.46	17841.15	19.3
2	71.01	13.3	21584.61	10144.77	16188.46	18.73
1	68.78	12.5	19032.15	8945.11	14274.11	18.38
Overall mean	798.36	161.34	347140.88	163156.22	260355.66	
Tamarindus indica						
2	102.86	19.63	56247.35	26436.26	42185.51	19.24
3	100.31	18.56	50577.25	23771.31	37932.94	18.56
1	92.35	16.8	38803.58	18237.68	29102.69	18.26
2	89.17	15.4	33162.48	15586.37	24871.86	17.3
1	85.98	12.24	24505.58	11517.62	18379.19	14.4
2	71.35	13.4	18474.87	8683.19	13856.16	18.87
2	70.06	13	17281.14	8122.14	12960.85	18.57
1	65.28	12.87	14853.46	6981.13	11140.09	19.8
2	63.69	16.16	17753.03	8343.93	13314.78	25.65
1	54.77	10.4	8449.04	3971.05	6336.78	19.25
Overall mean	795.82	148.46	280107.8	131650.67	210080.85	
Tectona grandis						
2	97.13	22.3	45416.53	21345.77	34062.40	22.98
1	92.35	21.18	38994.39	18327.36	29245.79	23.02
3	85.98	21	33513.25	15751.23	25134.94	24.7
2	82.8	20.7	30636.09	14398.96	22977.07	25.24

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No. of trees in 100 m	*Mean DBH (cm)*	*Mean height (m)*	*Mean biomass (kg)*	*Mean carbon (kg)*	*Mean stored energy (kwh)*	*Mean height (m)/ Mean DBH (cm)*
1	76.43	20.2	25473.08	11972.35	19104.81	26.57
2	73.24	19	22001.52	10340.71	16501.14	26.02
1	60.5	18.78	14839.14	6974.40	11129.35	31.3
2	52.54	18.5	11024.38	5181.46	8268.29	35.57
1	50.95	18.2	10199.11	4793.58	7649.33	36.4
1	47.77	17.85	8793.28	4132.84	6594.96	37.97
Overall mean	719.69	197.71	240890.77	113218.66	18066.81	

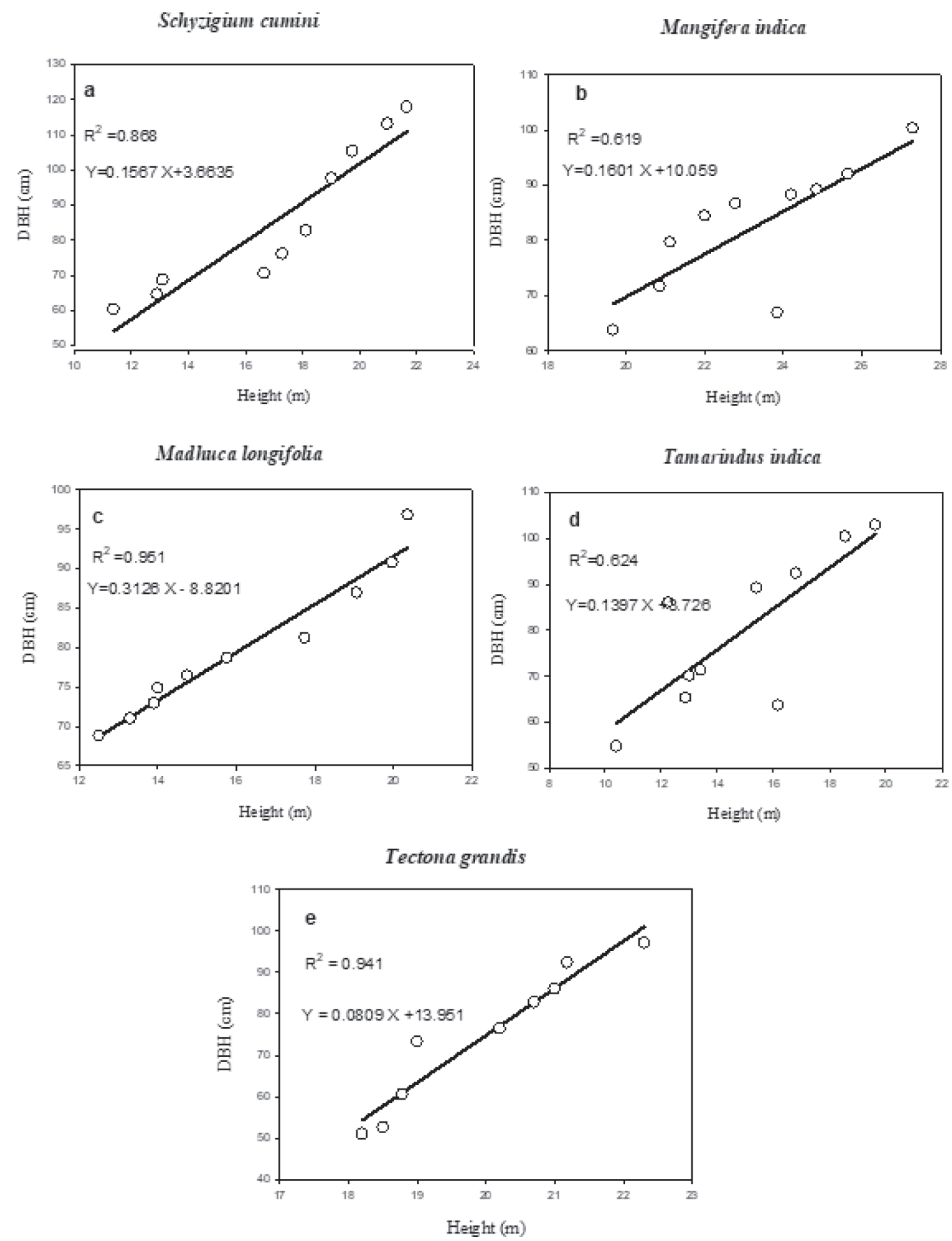

Fig. 2: Relationship between height and DBH of sampled trees (a) *Syzygium cumini*, (b) *Mangifera indica*, (c) *Madhuca longifolia*, (d) *Tamarindus indica,* (e) *Tectona grandis*

The tallest species, on the basis of mean values, was *Mangifera indica* followed by the *Tectona grandis*, *Syzygium cumini, Madhuca longifolia, Tamarindus indica*. In urban plantation of *Chamaecyparis obtusa* in Nagoya University, the height varied from 10-27 m, while in the natural forest the maximum height varied from 20-30 m (Sumida *et al*., 2013). Chaturvedi *et al.* (2011) measured a height of 40 species growing in a nearby natural forest. Mean height across all species, sites and individuals was 6.58 m. This compares with 17 m mean height of the present five street trees.

The DBH of *Syzygium cumini, Mangifera indica*. *Madhuca longifolia, Tamarindus indica, Tectona grandis*, ranged, respectively, from 60–117, 63–100, 68–96, 54–102, 47–97 cm. The DBH of Syzygium was maximum followed by *Mangifera indica, Madhuca longifolia, Tamarindus indica, Tectona grandis*. In the urban street trees, the DBH ranged from 47-117 cm, but in the case of the natural forest, the DBH ranged only from 9 to <12.7 cm (Chaturvedi *et al*., 2011). In this study, tree height and DBH were positively related with each other in each of the four species and so were height and biomass (Figs 2 and 3). In other words, stem biomass can be predicted just from height data.

The average biomass (per tree) of *Syzygium cumini, Mangifera indica, Madhuca longifolia, Tamarindus indica, Tectona grandis* was 1.1×10^4, 1.2×10^4, 1.9×10^4, 1.6×10^4, 1.5×10^4 kg tree^{-1} (Table 1). The average biomass was highest in *Madhuca longifolia* followed by*, Tamarindus indica, Tectona grandis, Mangifera indica, Syzygium cumini*. Kumar *et al*. (1998) have studied the biomass production of

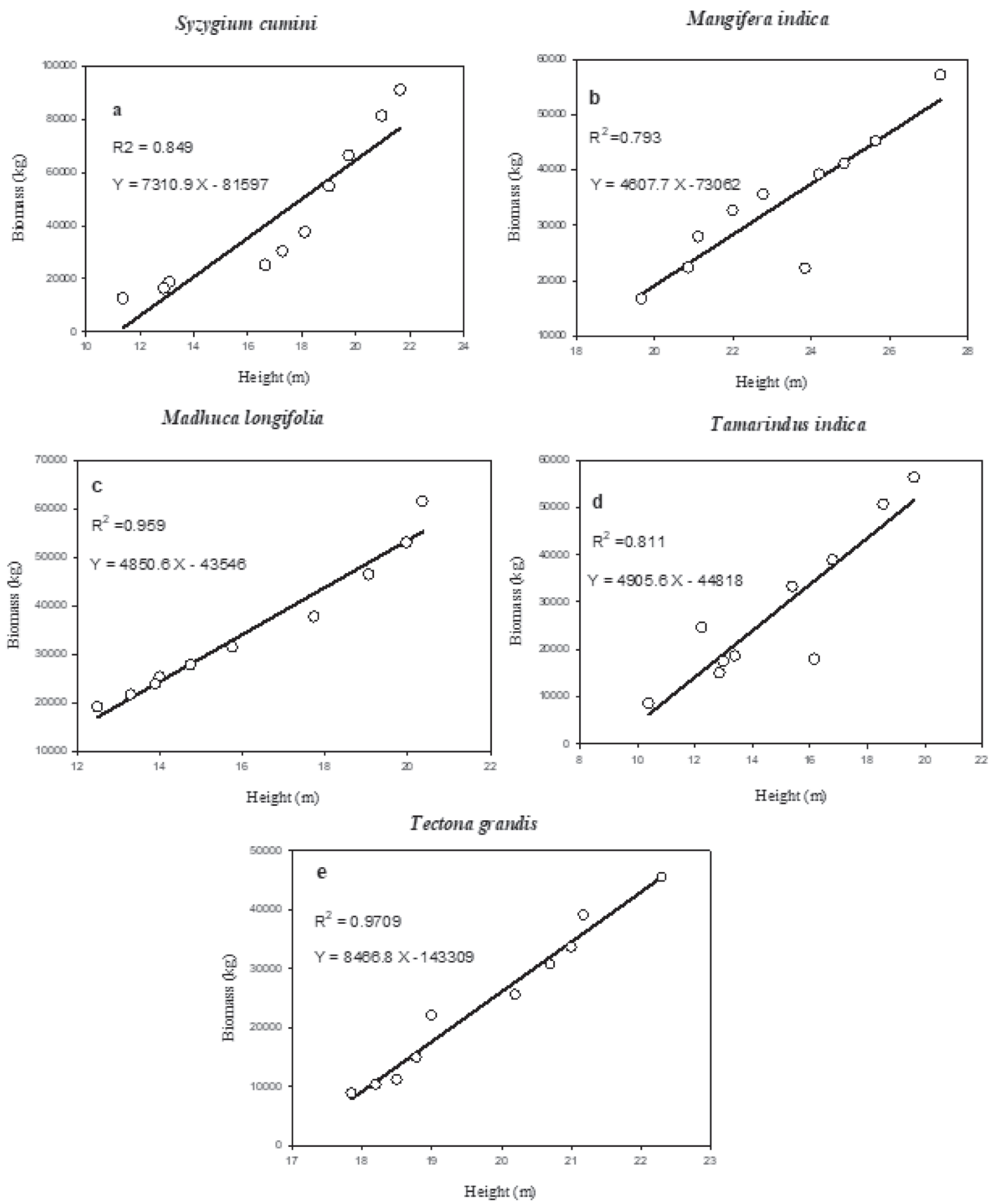

Fig. 3: Relationship between height and biomass of sampled trees (a) *Syzygium cumini*, (b) *Mangifera indica*, (c) *Madhuca longifolia*, (d) *Tamarindus indica*, (e) *Tectona grandis*

nine fast-growing multipurpose tree species planted in experimental plots at the Livestock Research Station, Thiruvazhamkunnu in Kerala and found that the biomass varied strongly across species with maximum biomass in *Acacia auriculiformis* (height 17.84 m, 8.8 years old) and minimum in *Casuarina equisetifolia* (height 8.24 m, 5 years old). Majumdar and Selvan (2018) recorded maximum biomass of 525.05 Mg from 468 individuals in diameter class 41-50 cm and least biomass of 17.46 Mg from 268 individuals in diameter class <10cm. Evidently greater the diameter greater the biomass.

The highest amount of carbon in the street trees of BHU was stored (kg) per tree by *Madhuca longifolia*, i.e. 9.0×10^3 followed by *Tamarindus indica* (7.7×10^3), *Tectona grandis* (7.0×10^3), *Mangifera indica* (5.9×10^3), *Syzygium cumini* (5.3×10^3).

Mir *et al*. (2017) have reported on the above ground biomass and carbon density of plantations of *Tectona grandis* and *Madhuca longifolia* in the deciduous forest region of Uttar Pradesh. *Tectona grandis* is reported to accumulate 5.6×10^2 kg per tree biomass and store 2.5×10^2 kg carbon per tree. These values compare with 1.5×10^5 and 7.0×10^3 observed for the same species by us growing as a street tree. Similarly, the aboveground biomass and stored carbon per tree of *Madhuca longifolia* estimated by Mir *et al*. (2017) were 6.8×10^2 and 3.0×10^2 kg compared to our values of 1.9×10^4 and 9.0×10^3.

By interpolating electricity resource unit value the highest amount of energy was stored (KWH) per tree by *Madhuca longifolia*, i.e. (1.4×10^4) followed by *Tamarindus indica* (1.2×10^4), *Tectona grandis* (1.1×10^4), *Mangifera indica* (9.4×10^3), *Syzygium cumini* (8.5×10^3).

Thus, compared to the trees occurring in the deciduous forest on nutrient-poor ultisol the street trees of BHU campus occurring on nutrient-rich inceptisol are larger and accumulate greater amounts of carbon. The nutrient status of ultisol and inceptisol is described by Lal *et al*. (2001). It is evident that per km length of the road inside the campus of BHU has stored 3.2×10^6 kg stem biomass, 1.5×10^6 kg carbon in the tree stems and 2.4×10^6 KWH stored energy. Taking 30.8 km total length of the streets of the campus, total carbon stored is 4.6×10^7 kg and the total energy stored is 7.3×10^7 KWH.

These trees, of course, have to be properly managed for maintaining their vigor and function. According to O'Sullivan *et al*. (2017), retaining mature trees and planting additional ones to replace the too-old ones would enhance biodiversity, pollution and climate regulation, carbon storage, and stormwater management. Davies *et al.* (2017) have advocated a proactive ecosystem services approach with adequate funding for managing the green infrastructure.

Hopefully, campuses of other institutions and residential areas of Varanasi will try to emulate the example of BHU.

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