Tree Diversity and Carbon Sequestration Potential Assessment of Urban Landscapes : A Case Study in Bengaluru City

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Abstract

Utilizing available land efficiently in the cities helps in climate stabilization through carbon sequestration and conserves biodiversity, apart from providing many other ecosystem benefits. This study investigates the diversity and carbon sequestration in trees that are grown in different landscapes of cities such as residential area, avenue trees, parks, industrial area and around lakes in one of the wards of Bengaluru city. In the present study, 44 tree species belonging to 23 families were recorded among the different landscapes mentioned. Among the five landscapes studied, the highest tree population is noticed among the avenue trees. *Pongamia pinnata* is the most dominant tree species. The residential area had the highest tree biomass and Parks had the lowest biomass assessed from the top ten dominant trees that constituted about 82 per cent of the population. Total carbon sequestered by the trees from the study area is 505 tons and total CO_2 sequestered is 1852 tons. The total amount of carbon stocked in five landscapes varied from 155 tons km^{-1} in the industrial area, followed by avenue trees (143 tons km^{-1}) and least was found around the lakes (26 tons km^{-1}). Thus, maintaining trees in urban areas help in conserving biodiversity and ameliorating climate.

Keywords: Tree diversity, Landscape, Biomass, Carbon stock

Cities are the hubs of economic growth and development. Urban areas contribute close to half of India's gross domestic product today, but rapid urbanization is a major driver of global change, driving land use change, habitat loss, biodiversity loss and epicentres of climate change and pollution. Deteriorating quality of urban ecosystems is a major concern of urban planners. Environmental problems such as air and water contamination and pollution are widespread in urban areas which currently account for 78 per cent of global carbon emissions and 60 per cent of water for domestic use (Shivanand *et al.* 2010). It is therefore essential to take steps to redesign the urban ecosystems to address these environmental problems and to sustain clean air, water and other ecosystem services needed for healthy urban living. In the urbanization process, built-up areas replace the vegetation cover and also increase vehicle movement. These activities are likely to increase the release of pollutants and greenhouse gases resulting in increased atmospheric temperature, decreased air quality and increased levels of stress for trees and humans (Saini, 2017). Trees absorb carbon from the atmosphere through photosynthesis (Francesco Ferrini, 2011), extracting carbon dioxide from the air, separating the carbon atom from the oxygen atoms and returning oxygen to the atmosphere. In doing so, trees retain a tremendous amount of carbon in their structures which increases periodically with time. Conservation and restoration of urban green spaces comprising of 'urban trees' is therefore an important approach to improve the environmental quality of urban areas.

Urban tree includes trees in gardens, parks and along the streets, roads, canal, residential area *etc.,* which contribute to green space in the city. These spaces provide a variety of ecosystem services such as improving air quality, buffering noise pollution, biodiversity conservation, mitigating the Urban Heat Island effect, microclimate regulation, stabilization of soil, ground water recharge, prevention of soil erosion and carbon sequestration. Tree canopies provide a cooling effect directly by shading the ground surface and indirectly through transpiration (Scott *et al*. 1999). Studies conducted by several scientists have claimed that urban green spaces can play a very important role in limiting the city's carbon footprint. The vegetation and soil of a green space cannot only sequester carbon, directly contributing to a reduction in atmospheric CO_2 concentration, but also affect the carbon balance indirectly, through their effects on the urban energy balance and thus on CO_2 emissions related to energy use. Urban trees perform important ecological functions in cities by sequestering carbon and reducing automobile pollution. The net carbon emissions that can be reduced by urban tree planting can be up to 18 kg CO_2 per year per tree, equal to the benefits provided by 3 to 5 forest trees of similar size and health (Francesco Ferrini, 2011).

Urban trees face an array of man-made and natural stresses that may lead to the degradation of urban forests and reduce their life spans compared to trees in rural areas or natural stands. Although estimates vary, life spans of trees in downtown areas are often less. One of the important stressors of urban trees is air pollution, which has a negative impact on tree health. Air pollution reduces plant growth and the extent of growth reduction depends on the plant species, concentration and distribution of pollutants and climatic factors. In this background present study is an attempt to assess the diversity of tree species among the different landscapes the urban areas and their contribution towards ameliorating the urban environment and conservation of biodiversity.

Material and Methods

In order to study the above factors on a pilot basis the study was conducted in five different landscapes of Ward number four (Yelahanka New town), Bengaluru, Karnataka. In this region of Bengaluru city five different landscapes namely; Avenue Trees, Residential Area, Industrial area, Lake and Parks were studied. An area of two kilometre stretch of each of the landscapes were sampled while in case of lake, the entire lake was assessed and three parks were enumerated which covers a length of two kilometres. Trees present in these landscapes were identified to their species level and carbon stocks were assessed.

1. Calculation of Alpha Diversity Index

Shannon Alpha Diversity index $H = -\sum (P_i * \ln P_i)$

Where,

P_i is the proportion of individuals found in species i ($P_i = n_i /N$)

N is the total number of individuals in the community

2. Calculation of Beta Diversity Index

Jaccard β diversity $C_j = j/ (a+b-j)$

Where,

j is the number of species found in both the sites.

a is the number of species in site A.

b is the numbers of species found in site B.

3. Biomass of the Tree (kg)

Standing tree biomass is estimated using the height and girth of the tree to derive trunk volume.

Above ground biomass (dry biomass) = Volume X Specific wood density (Bandana and Sanjay, 2014).

Volume = $\pi r^2 h$

For getting the value of radius from the girth of the tree

$C = 2\pi r$ or $r = C / 2\pi$

Where,

C = circumference of the tree trunk

h = The height of tree is measured with the help of Blume-Leiss Altimeter.

The estimated volume of the trunk is converted into biomass of individual tree by multiplying with the wood density of tree species.

4. Carbon content in the biomass (kg)

Standing Biomass × 0.45 (Pearson *et al.,* 2005).

5. CO_2 content of the Biomass

$CO_2 = (12 + (16×2)) / 12 = 44 / 12 = 3.67$.

One molecule of carbon = 3.67 molecules of CO_2 or 1 ton of carbon = 3.67 ton of CO_2

6. Single factor ANOVA is used to know the significant differences of Carbon stock in each species at different landscapes.

Results and Discussion

The present study is conducted in the urban landscapes of north Bengaluru. Tree diversity in Industrial area, Avenue Trees, Residential Area, Lake and Parks is presented in Table 1. There were 44 tree species found in the study area belonging to 23 different families. Out of the 44 species highest numbers of species were found in Parks (40) followed by industrial area (27), road sides (25) and along Lakes (18) and the least number of species (16) were found in residential area (Fig. 1). The numbers of trees found in different landscapes are 206, 336, 378, 143 and 291 km^{-1} in Industrial area, lake, avenue trees, Residential area and Parks respectively (Table 1). Trees planted as avenue trees recorded the highest number of trees.

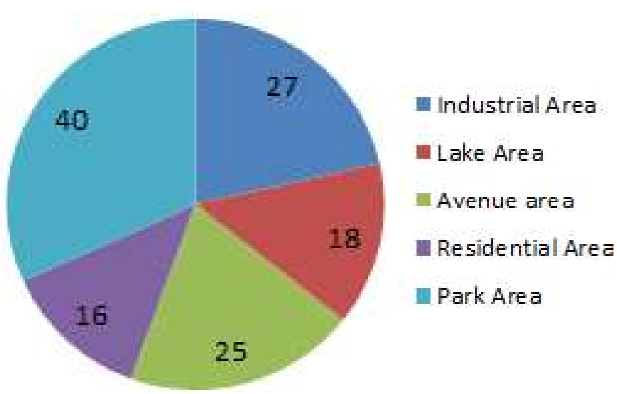

Fig. 1 : Distribution of total tree species (S= 44) in five landscapes studied

Out of 206 trees in Industrial area, the highest number of trees belonged to *S. companulata* (51) followed by *P. pinnata* (47), *P. pterocarpum* (16) and *G. robusta* (10) and one each from *A. scholaris*, *C. lanceolatus*, *D. sissoo* and *F. benghalensis* species were noticed. In case of lakes, a total of 336 trees came from only 18 different trees species among which 114 trees were of *H. Lagenicaulis* and 110 trees belonged to *P. pinnata* while least number is found that of *F. benghalensis*. Similarly in road side planted trees, the highest numbers of trees found were that of *P. pinnata* (163) followed by *P. pterocarpum* (48), *B. purpurea* (40), *S. mahagoni* (28) and *M. champaca* (24). Residential area had least number of trees compared to all other landscapes, in which the highest number of trees found were of *B. purpurea* (24) and *T. rosea* (24) followed by *P. pinnata* (23), *P. pterocarpum* (17) and *C. guianensis* (16) and least number were seen in the species *A. indica* (1), *M. calabura* (1), *T. argentea* (1) and *T. catappa* (1). Similarly in the parks, out of the total 291 trees recorded the highest number of trees were that of *P. pinnata* (27) followed by *G. robusta* (26), *D. Regia* (21), *A. indica* (19) and *L. flosreginae* (19). The least number of trees found were *A. columnaris* (1), *F. religiosa* (1), *A. lebbeck* (2), *F. benghalensis* (2) and *S. saman* (2). Among the five landscapes studied, 30 per cent of the tree population was found among the avenue trees, 25 per cent were found in the lake ecosystem, 21 per cent in the parks, 15 per cent in industrial area and 10 per cent in residential area. The type of species as well as the tree density varied across the landscapes. *P. pinnata* is found to be most dominant species which constitutes about 27 per cent of the total population from all the five landscapes studied. This could be due to the following reasons; *P. pinnata* is leguminous in nature that has ability to assimilate assimilate atmospheric nitrogen and thus it helps in not only reducing the nutrient deficiency but also help in reducing the NO2 emission (which is a greenhouse gas) that comes from inorganic fertilizer application (Usharani et al. 2019). Higher population is indicative of higher survival rate and therefore suggests that it has higher stress tolerance (Arjunan et al. 1994). The

TABLE 1

List of tree species and their distribution in five urban landscapes

Name of the species	Family	Number of Individuals per kilometre					
		Industrial Area	Lake	Avenue Trees	Residential Area	Parks	Total
Albizia lebbeck	Fabaceae	3	-	4	-	2	9
Alstonia scholaris	Apocynaceae	1	-	-	-	7	8
Anthocephalus cadamba	Rubiaceae	-	-	1	-	-	1
Araucaria columnaris	Araucariaceae	-	-	-	-	1	1
Artocarpus heterophyllus	Moraceae	-	5	3	-	6	14
Azadirachta indica	Meliaceae	3	-	3	1	19	26
Bauhinia purpurea	Fabaceae	7	5	40	24	15	91
Bixa orellana	Bixaceae	-	-	-	-	6	6
Callistemon lanceolatus	Myrtaceae	1	-	2	-	5	8
Cassia spectabilis	Fabaceae	5	-	-	2	-	7
Cocos nucifera	Aracaceae	0	6	6	-	4	16
Couroupita guianensis	Lecythidaceae	1	-	-	16	5	22
Dalbergia sissoo	Fabaceae	1	-	-	-	5	6
Delonix regia	Fabaceae	2	-	1	-	21	24
Eucalyptus globulus	Myrtaceae	-	12	-	-	-	12
Ficus benghalensis	Moraceae	1	1	-	-	2	4
Ficus racemosa	Moraceae	-	5	2	-	3	10
Ficus religiosa	Moraceae	-	2	-	-	1	3
Grevillea robusta	Proteaceae	10	-	2	-	26	38
Hyophorbe lagenicaulis	Aracaceae	-	114	-	-	3	117
Jacaranda mimosifolia	Bignoniaceae	-	-	1	2	9	12
Kigelia pinnata	Bignoniaceae	1	2	-	-	12	15
Lagerstroemia flosreginae	Lythraceae	9	-	-	-	19	28
Mangifera indica	Anacardiaceae	-	-	3	-	4	7
Michelia champaca	Magnoliaceae	3	3	24	13	7	50
Millingtonia hortensis	Bignoniaceae	1	-	2	-	5	8
Muntingia calabura	Muntingiaceae	7	3	0	1	5	16
Peltophorum pterocarpum	Caesalpiniaceae	16	3	48	17	7	91
Phyllanthus emblica	Phyllanthaceae	-	-	-	-	3	3
Plumeria alba	Apocynaceae	3	48	-	-	4	55
Polyalthia longifolia	Annonaceae	-	-	3	-	11	14
Pongamia pinnata	Fabaceae	47	110	163	23	27	370
Samanea saman	Fabaceae	1	-	3	2	2	8
Santalum album	Santalaceae	-	-	-	-	3	3
Saraca asoca	Fabaceae	6	-	5	-	5	16
Schefflera actinophylla	Araliaceae	-	-	-	-	5	5
Spathodea campanulata	Bignoniaceae	51	-	2	4	7	64
Swietenia mahagoni	Meliaceae	5	3	28	5	5	46
Syzygium cumini	Myrtaceae	5	6	-	-	4	15
Tabebuia argentea	Bignoniaceae	-	-	1	1	-	2
Tabebuia rosea	Bignoniaceae	4	2	11	24	5	46
Tectona grandis	Lamiaceae	4	-	1	-	-	5
Terminalia catappa	Combretaceae	-	6	-	1	3	10
Thespesia populnea	Malvaceae	8	-	19	7	8	42
Total		206	336	378	143	291	1354

morphological features of P. pinnata such as moderate height, medium size leaflet, lush green canopy (Bohre *et al.* 2014), make them suitable for growing in the cities across the landscapes and also it is easy to manage. Availability of planting material is also another factor. *P. pinnate* is the preferred tree species to increase the production of tree born oil seeds to promote the bio-fuel manufacturing.

For assessing the diversity of tree species present in different land use systems of the city, Shannon alpha diversity index was used to know the richness and evenness of the trees. Typical values of Shannon index vary between 1.5 and 3.5 in most ecological studies. The index values in the present study varied from 1.81 in lake to 3.35 in parks (Table 2). The diversity values depend on both the number of individuals present as well as the number of species. Higher the index, more diverse is the species in the habitats. Hence tree planting in the available lands in the city has helped in conserving biodiversity. From the alpha diversity index, it is observed that the diversity of trees in roadside as well as Residential area did not differ much, while the diversity of the trees in parks was found to be highest.

TABLE 2

Shannon alpha diversity index

Land Use System	Diversity Index
Industrial Area	2.54
Lake	1.81
Avenue Trees	2.06
Residential Area	2.29
Parks	3.35

Jaccard beta diversity index between Industrial Area and Lake were found to be 0.28 which suggest that there is about 28 per cent similarity between these two landscapes while a value of 0.48 between Industrial Area and avenue landscapes indicates about 48 per cent similar species or 52 per cent of the species are unique to these two landscapes. In between Avenue Trees and Lake about 26 per cent similarity is seen, likewise in Residential Area and Industrial area 54 per cent of the species were unique. Lake and Residential area have a similarity of up to 29 per cent whereas Residential and Road side trees have a similarity up to 35 per cent. Diversity index between Industrial Area and Park were found to be 0.58 which suggests 58 per cent similarity. Similarly between the lake and park landscapes 57 per cent species were unique. In between Park and Avenue Trees, 53 per cent similar species are seen and in between Park and Residential area 67 per cent species were unique to these two ecosystems (Table 3). This is quite obvious because trees planted in these landscapes are deliberately planted with specific purposes. The trees on the road side are planted mainly with the intention of providing shade and to absorb the pollutants, while in the parks and on the lake bunds are for improving aesthetic value. Higher diversity could help in higher convectional rains in turn contribute in maintaining microclimatic conditions and reduce temperature and the pollution caused due to vehicular movement (Doddabasawa, 2017 and Vailshery *et al.* 2013).

Tree biomass of the ten dominant species in the Industrial area is 309.22 t km^{-1} out of 378.85 t km^{-1} total biomass of trees present in this landscape per kilometre length. The contribution of top ten tree species to total tree biomass in this landscape was 82 per cent. In case of Lake, 72 per cent (35.92 t km^{-1}) of tree biomass is from top ten species present in the ecosystem. Similarly, the ten dominant species in Avenues contain 290.58 t km^{-1} biomass out of the total 320.99 t km^{-1} and in Residential area, 99 per cent (133.01 t km^{-1}) of tree biomass is from top

TABLE 3

Jaccard Beta Diversity Index in different urban landscapes

Land Use System	Industrial Area	Lake	Avenue Trees	Resi-dential Area	Parks
Industrial Area	–	–	–	–	–
Lake	0.28	–	–	–	–
Avenue Trees	0.48	0.26	–	–	–
Residential Area	0.46	0.29	0.35	–	–
Parks	0.58	0.43	0.53	0.33	–

TABLE 4

Biomass contribution of dominant ten tree species in five landscapes

Industrial Area		Allalasandra Lake		Avenue Trees		Residential Area		Park	
Species	Biomass (tons)	Species	Biomass (tons)	Species	Biomass (tons)	Species	Biomass (tons)	Species	Biomass (tons)
Spathodea campanulata	232.94 (75.3%)	*Hyophorbe lagenicaulis*	6.08 (16.93%)	*Pongamia pinnata*	71.62 (24.65%)	*Bauhinia purpurea*	15.54 (11.69%)	*Grevillea robusta*	25.89 (16.47%)
Pongamia pinnata	15.61 (5.05%)	*Pongamia pinnata*	1.65 (4.58%)	*Peltophorum pterocarpum*	101.84 (35.05%)	*Tabebuia rosea*	32.65 (24.55%)	*Delonix regia*	25.74 (16.37%)
Peltophorum pterocarpum	31.97 (10.34%)	*Plumeria alba*	2.60 (7.23%)	*Bauhinia purpurea*	6.43 (2.21%)	*Pongamia pinnata*	6.22 (4.67%)	*Pongamia pinnata*	20.53 (13.06%)
Grevillea robusta	4.90 (1.58%)	*Eucalyptus globulus*	14.82 (41.29%)	*Swietenia mahagoni*	43.31 (14.91%)	*Peltophorum pterocarpum*	19.76 (14.86%)	*Lagerstroemia flosreginae*	3.00 (1.91%)
Lagerstroemia flosreginae	0.46 (0.15%)	*Terminalia catappa*	1.76 (4.91%)	*Michelia champaca*	6.21 (2.14%)	*Couroupita guianensis*	31.38 (23.59%)	*Bauhinia purpurea*	3.65 (2.32%)
Thespesia populnea	3.53 (1.14%)	*Michelia champaca*	2.11 (5.88%)	*Thespesia populnea*	2.69 (0.93%)	*Michelia champaca*	2.71 (2.04%)	*Azadirachta indica*	11.67 (7.42%)
Bauhinia purpurea	15.74 (5.09%)	*Coccos nucifera*	3.40 (9.47%)	*Tabebuia rosea*	32.49 (11.18%)	*Thespesia populnea*	1.43 (1.07%)	*Spathodea campanulata*	2.76 (1.75%)
Muntingia calabura	0.44 (0.14%)	*Bauhinia purpurea*	0.90 (2.50%)	*Cocos nucifera*	4.97 (1.71%)	*Swietenia mahagoni*	6.00 (4.51%)	*Swietenia mahagoni*	12.59 (8.01%)
Saraca asoca	0.51 (0.17%)	*Michelia champaca*	1.24 (3.46%)	*Saraca asoca*	0.31 (0.11%)	*Spathodea campanulata*	17.13 (12.88%)	*Jacaranda mimosifolia*	18.46 (11.74%)
Syzygium cumini	3.12 (1.01%)	*Ficus racemosa*	1.37 (3.81%)	*Albizia lebbeck*	20.70 (7.12)	*Samanea saman*	0.19 (0.15%)	*Peltophorum pterocarpum*	32.95 (20.96%)
Total	309.22 (82%)		35.919 (72%)		290.585 (90%)		133.013 (99%)		157.208 (57%)
Total biomass in each land scape from all species (kg)	378.857		50.385		320.999		134.273		271.525

ten species present in the ecosystem. Similarly in the park 157.21 t km^{-1} of biomass found in top ten tree species out of (271.52 t km^{-1}) accounting for 57 per cent of biomass from top ten species (Table 4).

Residential area had the highest tree biomass from top ten dominant trees upto 99 per cent. This could be because of presence of greater wood size, higher girth class and older trees. Higher biomass will be contributed by the higher girth class individuals (Hareesh and Nagarajaiah, 2019). Park showed the lowest percent of biomass may be because parks are man-made ecosystem and it is mainly focused on growing trees for ornamental, recreational and aesthetic valve. Park had lesser old trees when compared to other landscapes as most of the trees are newly planted and had smaller girth class. The tree size (DBH and Height) in urban parks established in more recent years is less as compared to old parks in Bangalore (Harini and Diya, 2011). Assessment of biomass provides information on the structure and functional attributes of trees. Bigger the size and structure greater will be the biomass. With approximately 50 per cent of dry biomass comprises of carbon (Montagu *et al*. 2005), biomass assessments illustrate the amount of carbon that may be sequestered by trees. Biomass is an important indicator in carbon sequestration therefore estimating the biomass in trees is the first step in carbon accounting.

The mean carbon accumulated in industrial area is highest in *S. campanulata* (104.82 tons) followed by *P. pterocarpum* (14.38 tons), *B. purpurea* (7.08 tons) and the least values were found in *C. lanceolatus* (0.009 tons) followed by *P. alba* (0.11 tons), *D. regia* (0.12 tons). In case of Lake landscape, the mean carbon stock was found to be highest *E. globulus* (6.67 tons) followed by *F. benghalensis* (4.41 tons), *F. religiosa* (2.73 tons) and the least was found in *M. calabura* (0.022 tons) followed by *T. rosea* (0.11 tons), *S. mahagoni* (0.12 tons). The mean carbon accumulated in road side trees were found highest in *P. pterocarpum* (45.82 tons) followed by *P. pinnata* (32.22 tons), *S. mahagoni* (19.49 tons) and the least mean carbon stock found in *T. argentea* (0.029 tons) and *C. lanceolatus* (0.033 tons). In case of residential area, the mean carbon stock was found highest in *T. rosea* (14.69 tons) followed by *C. guianensis* (14.12 tons), *P. pterocarpum* (8.89 tons) and least was found in *T. argentea* (0.0062 tons) and *C. spectabilis* (0.032 tons). Similarly in case of park ecosystem, the mean carbon stock was found to be highest in *S. campanulata* (15.67 tons) followed by *G. robusta* (11.65 tons), *D. regia* (11.58 tons) and least was in *H. lagenicaulis* (0.0093 tons), *P. alba* (0.11tons) and *S. asoca* (0.11 tons) (Table 5).

In order to quantify the carbon stocks among the tree species, the total amount of carbon sequestered from each species was computed which varied as follows. Out of the total amount of 505 tons, *S. companulata* contributed 132 tons; this could be due to higher Diameter at Breast Height and height and higher density of trees, followed by *P. pterocarpum* (73 tons), *P. pinnata* (52 tons). Among the species, the least carbon accumulated species was found to be *T. argentea* (0.03 tons) followed by *P. emblica* (1.29 tons), *S. album* (0.08 tons).

The total amount of carbon stocked in five land scapes varied from 155 tons km^{-1} in industrial area, followed by 143 tons km^{-1} in avenue trees, 121 tons km^{-1} in parks, 61 tons km^{-1} in residential area and the least of 26 tons km^{-1} was found in the trees around the lake. From these five ecosystems, a total of 505 tons of carbon is stored in the standing biomass of trees which is equal to 1852 tons of carbon dioxide sequestered from atmosphere over years (Fig. 2).

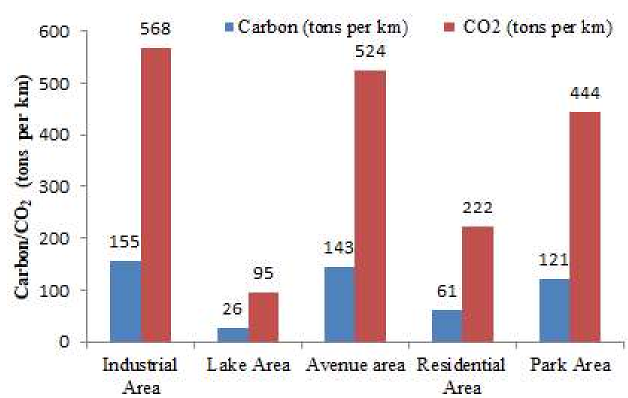

Fig. 2 : Total Carbon stocks and CO_2 in the biomass of standing trees in five landscapes

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TABLE 5

Carbon stock present in each species present in different landscapes

Name of the species	Carbon stock (tons km^{-1})					Total	Mean
	Industrial Area	Allalasandra Lake	Avenue Trees	Residential Area	Parks		
Albizia lebbeck	0.40	-	9.31	-	1.66	11.38	2.274 [c]
Alstonia scholaris	0.49	-	-	-	2.98	3.48	0.694 [c]
Anthocephalus cadamba	-	-	1.91	-	0.22	2.13	0.426 [c]
Araucaria columnaris	-	-	-	-	1.44	1.44	0.288 [c]
Artocarpus heterophyllus	-	0.48	0.24	-	0.64	1.37	0.272 [c]
Azadirachta indica	0.14	-	0.17	0.011	0.39	0.72	0.142 [c]
Bauhinia purpurea	7.08	0.41	2.89	6.99	1.62	18.99	3.798 [bc]
Bixa orellana	-	-	-	-	0.15	0.15	0.03 [c]
Callistemon lanceolatus	0.0097	-	0.033	-	0.27	0.32	0.063 [c]
Cassia spectabilis	0.24	-	-	0.032	-	0.27	0.054 [c]
Cocos nucifera	-	1.52	2.23	-	2.53	6.31	1.256 [c]
Couroupita guianensis	1.12	-	-	14.12	7.34	22.59	4.516 [bc]
Dalbergia sissoo	0.96	-	-	-	4.18	5.14	1.028 [c]
Delonix regia	0.12	-	0.24	-	11.58	11.94	2.388 [c]
Eucalyptus globulus	-	6.67	-	-	-	6.67	1.334 [c]
Ficus benghalensis	2.35	4.41	-	-	6.43	13.19	2.638 [c]
Ficus racemosa	-	0.61	1.82	-	3.89	6.33	1.264 [c]
Ficus religiosa	-	2.73	-	-	2.32	5.05	1.01 [c]
Grevillea robusta	2.21	-	0.65	-	11.65	14.50	2.902 [c]
Hyophorbe lagenicaulis	-	2.73	-	-	0.0093	2.74	0.548 [c]
Jacaranda mimosifolia	-	-	0.13	0.32	8.31	8.76	1.752 [c]
Kigelia pinnata	1.51	0.41	-	-	4.31	6.21	1.246 [c]
Lagerstroemia flosreginae	0.21	-	-	-	1.35	1.55	0.312 [c]
Mangifera indica	-	-	0.12	-	0.44	0.56	0.112 [c]
Michelia champaca	0.37	0.59	2.79	1.21	0.88	5.83	1.168 [c]
Millingtonia hortensis	0.59	-	0.55	-	1.15	2.31	0.458 [c]
Muntingia calabura	0.19	0.022	-	0.01	0.12	0.33	0.064 [c]
Peltophorum pterocarpum	14.38	1.35	45.82	8.89	3.07	73.54	14.702 [b]
Phyllanthus emblica	-	-	-	-	0.05	0.05	0.01 [c]
Plumeria alba	0.11	1.16	-	-	0.11	1.39	0.276 [c]
Polyalthia longifolia	-	-	0.33	-	1.08	1.429	0.282 [c]
Pongamia pinnata	7.02	0.74	32.22	2.79	9.24	52.03	10.402 [bc]
Samanea saman	3.69	-	1.31	0.086	6.58	11.67	2.333 [c]
Santalum album	-	-	-	-	0.08	0.08	0.016 [c]
Saraca asoca	0.23	-	0.13	-	0.11	0.48	0.094 [c]
Schefflera actinophylla	-	-	-	-	0.41	0.41	0.082 [c]
Spathodea campanulata	104.82	-	4.25	7.71	15.67	132.45	26.49 [a]
Swietenia mahagoni	1.65	0.12	19.49	2.71	5.66	29.63	5.926 [bc]
Syzygium cumini	1.41	0.94	-	-	1.54	3.89	0.778 [c]
Tabebuia argentea	-	-	0.029	0.0062	-	0.035	0.007 [c]
Tabebuia rosea	0.47	0.11	14.62	14.69	0.32	30.22	6.042 [bc]
Tectona grandis	1.33	-	0.17	-	-	1.509	0.3 [c]
Terminalia catappa	-	0.79	0	0.35	0.24	1.39	0.276 [c]
Thespesia populnea	1.58	-	1.21	0.64	0.68	4.12	0.822 [c]
Total	154.77	25.78	142.75	60.59	120.85	504.74	
SEM = 3.52							
CD = 9.83							

Note: Alphabets in superscript indicate the significant differences

Industrial area contributed highest towards carbon sequestration compared to all other landscapes because of better growth noticed. The tree species *S. campanulata* contributed more biomass which resulted in more sequestration of carbon and also the presence of more number of trees. *S. campanulata* is often grown as ornamental and a fast-growing tree, even in unfavourable conditions makes the tree survive. Hence, the tree has the ability to survive in Industrial area. Similarly road side planted trees contributed the highest carbon sequestration next to Industrial area, in which *P. pterocarpum* contributed more among other species. It is a large tree that has a dense spreading crown and the flower retains the bright yellow colour even when fallen and also as they dry. So this tree species may be used as a shade tree in addition to its use as an ornamental avenue tree. Therefore, the *P. pterocarpum* trees in road side had bigger size and was good in number which helped in removing of carbon from the atmosphere in the avenue landscape.

The least amount of carbon sequestered from the Lake landscape could be due to low tree diversity and also the presence of less number of larger sized trees. Trees that can be planted in this environment should have ability to tolerate high soil moisture content and even flooding and such characters are generally present in all trees. This could be the reason for less diversity of tree species here (Stoffberg *et al*. 2010).

Urban regions characterized with high human and vehicular density emanate higher GHG's creating heat islands. A city where land is the most constraining input for tree planting should be utilized very diligently. Hence, the landscapes such as roadsides, parks, lake bunds, residential areas and industrial areas should be effectively utilized to grow plants. This approach is one of the most economical way of ameliorating climate as well as conserving biodiversity apart from deriving many other ecosystem benefits.

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