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Research Article

A study on two important environmental services of urban trees to disseminate the economic importance of trees to student community

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Abstract: Trees provide innumerable ecosystem services in human-dominated urban environment. Forest disturbances as well as biomass enrichments are tightly linked with atmospheric carbon dioxide concentration. All trees ≥5 cm diameter at breast height (dbh) were inventoried from a one hectare area of the Cooum river bank (CRB), Chennai Metropolitan city (CMC), India. Both above and below ground biomass were estimated by widely accepted regression equations with DBH and wood density as inputs. A total of 710 trees belonged to 22 families, 41 genera and 47 species were recorded. Trees accumulated 86.02 Mg dry biomass and 43.01 Mg C in a hectare. Members of Mimosaceae dominated the CRB with 231 individuals. *Tamarindus indica* contributed more (11.744 Mg; 13.7%) to biomass. As to the families Ceasalpiniaceae, Mimosaceae and Papilionaceae altogether contributed 55.61 Mg (64.64%) to total biomass. Tree diameter class 31-45 cm contributed more (35.15 Mg; 40.86%) to total biomass. On average each tree achieved 0.47 ± 0.1 cm dbh growth yr^{-1}. In a year one hectare urban forest sequestered 3999.91 kg biomass and 1999.95 kg C. The data obtained through this study can be useful to educate the importance of urban trees to higher secondary school students and local community people in Chennai city.
Keywords: biomass storage; carbon storage, carbon dioxide absorption; higher secondary school students; human intervention; urban forest

INTRODUCTION

Urban forests and trees do numerable ecosystem services to urban environments. They reduce urban heat island (UHI) effects [1, 2]; pollution [3]; CO_2 concentration [4, 5]. By their autotrophic nature, they sequester carbon (C) thereby they act as carbon sink [7-9]. Furthermore, they also offer an opportunity for conducting research, which can useful for a more comprehensive understanding of urban ecosystems in general [10].

To date, a very limited data has been made available on biomass storage and carbon sequestration potential of trees growing on the Cooum river bank (CRB) in Chennai metropolitan city (CMC), India. A major proportion of higher secondary school students and local community people have lesser knowledge on urban trees and its importance. Thus, the primary objective of this study was to determine C stockpile and sequestration potential of trees on CRB. Further, the data obtained through this study can be useful to educate the importance of urban trees to higher secondary school students and local community people in Chennai city.

METHODS

Study area

This study was conducted in a highly polluted, urbanized Cooum river bank, Chennai Metropolitan City, India. Chennai is one among the four metropolis of the Indian sub-continent and the capital city of a southern state, Tamil Nadu. The city feels tropical dissymmetric climate, receives bulk of the rain-fall during north-east monsoon (September-December). Mean temperature and rainfall are 24-37 °C and 1300 mm. Area of the city is 174 km^2 and the human population is around five million [11]. East part of the city is bounded by the sea, Bay of Bengal; and remaining three sides are surrounded by land, Thiruvallur and Kanchipuran districts. Soil type of the river bed is alluvium; depth of the soil varies from 10 to 20 m thickness and is mostly granular in texture [12].

Field survey

One hundred 10m × 10m plots (Total area = 1 ha) were randomly laid across both northern (50 plots) as well as southern bank (50 plots) of the river. The tree survey was conducted during the month of January on 2011 and 2012. All trees ≥5 cm diameter at breast height (dbh) were measured, and tagged with consecutively numbered metal tags for further monitoring and re-assessments. For multi-stemmed individuals, the bole girth was measured separately, basal area calculated and summed. All inventoried species were identified to species level with the help of regional floras and checklist [13-15].

Above and below ground biomass

Above ground biomass was quantified by regression formula of Chave et al., [16]; $[(AGB)_{est} = p \times \exp(-0.667 + 1.784 \text{ LN (D)} + 0.207(\text{LN (D)})^2 - 0.0281(\text{LN (D)})^3)]$; where, -0.667, 1.784, 0.207 and -

0.028 are constants; D = trunk diameter at breast height (cm); LN = Natural logarithm; *p* = oven-dry wood specific gravity/wood density (g cm^{-3}). The tree allometric relationship is viable, reliably estimate AGB in tropical dry forests around the world. Data on tree wood density data was retrieved from *Global wood density database* [17]. Below ground biomass (BGB) was calculated by regression equation of Cairns et al. [18]; BBD = Exp [-1.0587 + 0.8836 × LN (ABD)] Where, -1.0587, 0.8836 are constants; BBD is below ground biomass density (dry t ha^{-1}); LN = Natural logarithm; ABD = above ground biomass density (dry Mg ha^{-1}).

Quantification of C and CO_2 sequestration

Carbon sequestration values were converted to CO_2 by multiplying with 3.67, the ratio of molecular weights of CO_2 to C (as in [5]). Biomass values were multiplied by 0.50 to get carbon storage value of trees (as in [7]). Stem diameter growth, biomass accumulation yr^{-1} were directly estimated by the difference between survey *x* and *x+1*. C sequestration potential was estimated by the difference of C storage of trees between year *x* and *x+1*.

RESULTS

Tree diversity and forest stand

A total of 47 species belonged to 41 genera and 22 families were inventoried from one hectare area of CRB (Table 1). *Muntingia calabura* and *Prosopis juliflora* were dominated the CRB with 139, 137 individuals, respectively, followed by *Ricinus communis* (99) and *Leucaena leucocephala* (72), (Table 2). As to the families, Mimosaceae was dominated with 8 species followed by Caesalpiniaceae (7), Moraceae (4), Bignoniaceae and Myrtaceae (3 each), Anacardiaceae, Annonaceae, Meliaceae, Papilionaceae and Sapotaceae (2 species each), whereas 12 families which include Apocynaceae, Arecaceae and Bombacaceae etc. were represented by just single species (Table 3). Tree stand density and basal area were 710 stem ha^{-1} and 15.10 m^2, respectively.

Biomass and carbon storage

According to the first survey, study area stored 86.018 Mg biomass in its trees (AGB = 63.66 Mg; BGB = 22.36). Cumulatively, top five species (*Tamarindus indica*, *Prosopis juliflora*, *Pongamia pinnata*, *Albizia saman* and *Peltophorum pterocarpum*) with 197 individuals contributed 45.50 Mg (49.4%) to the total biomass (Table 2). As to the families, Caesalpiniaceae accumulated high biomass 22.06 Mg (25.64%) followed by Mimosaceae (21.91; 25.47%) and Papilionaceae (11.64; 13.53%), (Table 3). Small diameter classes 0-7 cm dbh and 8-15 dominated the CRB; they represented by 223 and 295 individuals, respectively. As to the total biomass, the dbh class 31-45 cm contributed a large amount (35.15 Mg; 40.86%) followed by 16-30 (34.48 Mg; 40.1%) and 8-15 cm dbh (15.30 Mg; 17.79%), (Fig. 1). Large (45+ cm) trees stored approximately 160 times more C (1225 ± 105.93 kg/tree) when compared to low diameter class (7.56 ± 0.32 kg/tree). Evergreen species contributed more (50.295 Mg; 58.47%) to total biomass than deciduous species (35.722 Mg; 41.53%). Native trees accumulated more biomass (52.24 Mg; 60.74%) compared to introduced trees (33.78; 39.26%). Carbon stored in a tree ranged from a low of 3.78 ± 0.16 (0-7 dbh) to a high of 612.6 ± 52.96 C kg/tree (45+ dbh).

Stem horizontal growth

On an average, each tree attained 0.47 ± 0.1 cm dbh growth yr^{-1}. Large trees achieved more growth (0.68 ± 0.2 cm dbh) than small trees (0.48 ± 0.1 cm dbh).

Biomass and carbon sequestration

In a year, inventoried trees accumulated 3999.91 kg biomass ha^{-1}. On an average, each tree accumulated 5.63 kg biomass yr^{-1}. Biomass accumulation/tree/year ranged from 1.4 to 18.41 kg, respectively for small (0-7 cm dbh), and large (31-45 cm dbh) trees (Table 4).

Trees sequestered 1999.95 kg C yr^{-1} ha^{-1}. Each tree sequestered 2.82 kg C yr^{-1}. C sequestration ranged from 0.7 ± 0.02 to 9.21 ± 0.86 kg/tree/year. Roughly, large trees (45+ dbh) sequestered 10 times more C yr^{-1} than small trees (Table 4).

Table 1. Summary of tree inventory (≥5 cm dbh) on Cooum river bank, Chennai, India

Variable	Value
Species richness	47
Number of genera	41
Number of families	22
Tree density (no. ha^{-1})	710
Stand basal area (m^2 ha^{-1})	15.10
Biomass storage (Mg ha^{-1})	86.02
Carbon storage (Mg ha^{-1})	43.01

Table 2. Binomial, family, density, physiognomy, status and biomass storage of trees in Cooum river bank, Chennai, India

Binomial	Family	Density	Physiognomy	Status	Biomass storage, Mg (%)
Muntingia calabura	Elaeocarpaceae	139	Evergreen	Introduced	1.648 (1.92)
Prosopis juliflora	Mimosaceae	137	Evergreen	Introduced	10.119 (11.8)
Ricinus communis	Euphorbiaceae	99	Evergreen	Native	0.373 (0.43)
Leucaena leucocephala	Mimosaceae	72	Deciduous	Introduced	1.484 (1.73)
Pongamia pinnata	Papilionaceae	26	Deciduous	Native	8.204 (9.54)
Azadirachta indica	Meliaceae	24	Deciduous	Native	4.087 (4.75)
Thespesia populnea	Malvaceae	19	Evergreen	Native	0.814 (0.95)
Erythrina variegate	Papilionaceae	14	Deciduous	Native	3.430 (3.99)
Cordia obliqua	Boraginaceae	13	Evergreen	Native	1.257 (1.46)
Peltophorum pterocarpum	Caesalpiniaceae	13	Evergreen	Native	5.838 (6.69)
Albizia saman	Mimosaceae	12	Deciduous	Introduced	6.597 (7.67)
Guazuma ulmifolia	Sterculiaceae	11	Evergreen	Introduced	3.059 (3.56)
Ficus hispida	Moraceae	10	Evergreen	Native	0.255 (0.3)
Cassia fistula	Caesalpiniaceae	10	Deciduous	Native	0.926 (1.08)
Annona squamosa	Annonaceae	9	Evergreen	Introduced	0.363 (0.42)
Tamarindus indica	Caesalpiniaceae	9	Evergreen	Native	11.744 (13.7)
Morinda coreia	Rubiaceae	8	Evergreen	Native	0.780 (0.91)
Delonix regia	Caesalpiniaceae	7	Deciduous	Introduced	1.763 (2.05)
Terminalia catappa	Combretaceae	6	Deciduous	Native	2.250 (2.62)
Ficus religiosa	Moraceae	6	Deciduous	Native	2.465 (2.87)
Polyalthia longifolia	Annonaceae	5	Evergreen	Introduced	1.905 (2.22)
Caesalpinia coriaria	Caesalpiniaceae	4	Evergreen	Introduced	0.999 (1.16)
Moringa pterygosperma	Moringaceae	4	Deciduous	Native	0.096 (0.11)
Spathodea companulata	Bignoniaceae	4	Deciduous	Introduced	1.312 (1.53)
Lannea coromandelica	Anacardiaceae	3	Deciduous	Native	0.792 (0.92)
Psidium guajava	Myrtaceae	3	Evergreen	Introduced	0.171 (0.2)
Acacia auriculiformis	Mimosaceae	3	Evergreen	Introduced	0.285 (0.33)
Melia azedarach	Meliaceae	3	Deciduous	Native	0.306 (0.36)
Ziziphus mauritiana	Rhamnaceae	3	Evergreen	Native	0.231 (0.27)
Cassia roxburghii	Caesalpiniaceae	3	Evergreen	Native	0.183 (0.21)
Ficus racemosa	Moraceae	3	Evergreen	Native	0.363 (0.42)
Tabebuia rosea	Bignoniaceae	3	Evergreen	Introduced	1.083 (1.26)
Adenanthera pavonina	Mimosaceae	3	Deciduous	Native	2.090 (2.43)
Bombax ceiba	Bombacaceae	3	Deciduous	Native	0.905 (1.05)
Mangifera indica	Anacardiaceae	2	Evergreen	Native	1.091 (1.27)
Manilkara zapota	Sapotaceae	2	Evergreen	Introduced	0.078 (0.09)
Cassia siamea	Caesalpiniaceae	2	Evergreen	Native	0.605 (0.7)
Albizia lebbeck	Mimosaceae	2	Deciduous	Native	0.761 (0.89)
Ficus benghalensis	Moraceae	2	Evergreen	Native	1.018 (1.18)
Millingtonia hortensis	Bignoniaceae	2	Evergreen	Introduced	1.329 (1.54)
Wrightia tinctoria	Apocynaceae	1	Deciduous	Native	0.032 (0.04)
Pithecellobium dulce	Mimosaceae	1	Deciduous	Introduced	0.055 (0.06)
Madhuca longifolia	Sapotaceae	1	Deciduous	Native	0.163 (0.19)
Feronia elephantum	Rutaceae	1	Evergreen	Native	0.281 (0.33)
Enterolobium cyclocarpum	Mimosaceae	1	Deciduous	Introduced	0.520 (0.61)
Syzygium cumini	Myrtaceae	1	Evergreen	Native	0.899 (1.05)
Eucalyptus globulus	Myrtaceae	1	Evergreen	Introduced	1.002 (1.17)
	Total	710	-	-	86.018 (100)

Table 3. Contribution of families to total biomass in Cooum river bank, Chennai Metropolitan city, India

Family	Density	Biomass (Mg)	Contribution to total biomass (%)
Caesalpiniaceae	48	22.058	25.64
Mimosaceae	231	21.913	25.47
Papilionaceae	39	11.635	13.53
Meliaceae	27	4.394	5.11
Moraceae	21	4.102	4.77
Bignoniaceae	9	3.724	4.33
Sterculiaceae	11	3.059	3.56
Annonaceae	14	2.268	2.64
Combretaceae	6	2.25	2.62
Myrtaceae	5	2.072	2.41
Anacardiaceae	5	1.883	2.19
Elaeocarpaceae	139	1.648	1.91
Boraginaceae	13	1.257	1.46
Bombacaceae	3	0.905	1.05
Malvaceae	19	0.814	0.95
Rubiaceae	8	0.78	0.91
Euphorbiaceae	100	0.373	0.42
Rutaceae	1	0.281	0.33
Sapotaceae	3	0.241	0.28
Rhamnaceae	3	0.231	0.27
Moringaceae	3	0.096	0.11
Apocynaceae	1	0.032	0.04
Total	710	86.018	100

Table 4. Biomass, carbon storage and sequestration of trees in Cooum River bank, Chennai Metropolitan city, India

DBH	Density	Biomass storage (Mean ± SE)	Carbon storage (Mean ± SE)	Carbon sequestration yr^{-1} (Mean± SE)
0-7	223	7.56 ± 0.32	3.78 ± 0.16	0.7 ± 0.01
8-15	295	41.49 ± 1.57	20.74 ± 0.79	2.14 ± 0.07
16-30	138	249.88 ± 12.89	124.94 ± 6.44	5.07 ± 0.20
31-45	52	676.09 ± 48.87	338.04 ± 29.43	9.21 ± 0.86
45+	2	1225.2 ± 105.92	612.6 ± 52.96	8.22 ± 0.33
Mean		121.15	60.57	2.82
Total (Mg ha^{-1})		86.018	43.01	1.99

Table 5. Carbon storage (Mg ha^{-1}) in Cooum river bank and other urban forests of the world

Country	City	Carbon storage Mg ha^{-1} (mean)	Reference
India	Chennai	43.09	Present study
China	Beijing	45.39	[23]
Germany	Liepig	11.00	[26]
India	Pune	54.87	[33]
Korea	4 cities	11.9	[31]
Nepal	Riverine forests	80.47	[36]
Taiwan	Chiayi	13.5	[32]
USA	Shorewood	22.80	[24]
USA	Michigan	40.5	[28]
USA	Los Angeles	10.38	[22]
USA	Oakland	11.00	[29]
USA	3 cities	99.33	[34]
USA	All cities	66.69	[35]
USA	10 cities	21.07	[30]
USA	48 cities	25.10	[27, 30]

Table 6. Money value of carbon storage and sequestration services of trees

DBH classes	C storage (tree/year) as on January 2012	Value ($)	C sequestration (tree/yr)	Value ($)
0-7	3.78	0.25	0.7	0.05
8-15	20.74	1.37	2.14	0.14
16-30	124.94	8.25	5.07	0.33
31-45	338.04	22.31	9.21	0.61
45+	612.6	40.43	8.22	0.54

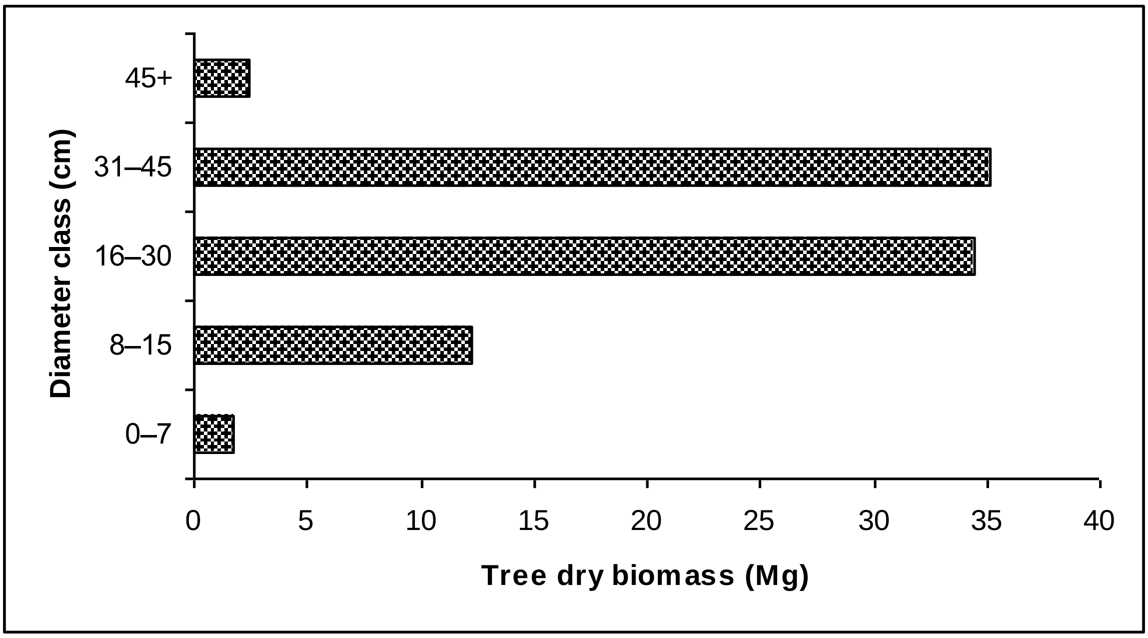

Fig. 1. Contribution of DBH classes to total dry biomass in Cooum river bank, Chennai, India.

DISCUSSION

Tree density

Tree density ha^{-1} is two to five folds higher than those of urban forests of Oakland (111.9 trees ha^{-1}; [19]); Modesto, California (61; [20]); ten cities of USA (mean=147, range, 36 to 276; [7]); Sacramento, USA (73; [21]), Los Angeles (49; [22]); and Beijing, China (79 trees ha^{-1}; [23]).

Existence of more number of small trees (<45 cm dbh; 708 trees) could be reasoned for high stem density on CRB. Relatively smaller diameter trees such as *Leucaena leucophloea*, *Muntingia calabura*, *Prosopis juliflora*, *Ricinus communis* were abundant and growing luxuriantly on CRB, altogether they have represented by 448 (63.10%) individuals. Furthermore, researchers of other countries studied entire urban forests; we have studied only a small portion of urban forest on CRB. More studies with large study areas are needed to reveal the real picture of the CRB. Approximately, 27% of trees had ≥15 cm dbh in our study area; it is less when compared to other urban forests of the world, such as Oakland, California (39%; [19]); Shorewood, Wisconsin (33%; [24]); and Los Angeles of USA (60%; [22]). However, studied forest of Chennai is superior to urban forests of Chicago, Cook and DuPage Counties of USA (23%), [25].

Carbon storage

C storage (43.09 Mg C ha^{-1}) is greater than those reported from many urban forests of the world, such as Germany [26]; Oakland, Shorewood, Michigan, Los Angeles and several cities of the USA [22, 24, 27, 28, 29, 30]; Korea [31]; and Taiwan [32], **(Table 5).** Also lesser than many urban forests such as Pune, India [33]; Beijing, China [23]; Cook and DuPage counties, and Chicago of USA [34]; cities of the USA [35]; and, riverine forests of Nepal [36] **(Table 4)**. Less C storage in CRB could be due to the presence of large number of small trees (≤15 cm dbh) and absence of large trees (50+ cm dbh).

Stem radial growth

Our findings pertaining to mean stem growth (dbh cm)/tree/year is not agreed with the results of Jo and McPherson [4]; deVries [37] and Nowak [25] they estimated 1.1, 0.61, 0.90 cm dbh growth yr^{-1} respectively for urban trees of USA, central park of New Jersey; and three cities of USA. Presence of more large trees in those forests could be contributed to high dbh growth yr^{-1}. However, trees of CRB attained more growth yr^{-1} than urban trees of Indiana and Illinois of USA, 0.38 cm dbh growth yr^{-1} [38].

Carbon sequestration

Carbon sequestration potential kg ha^{-1} yr^{-1} (1999 kg) is superior than those of four cities of Korea (530 to 800 Mg; [31]); Chiayi city of Taiwan (0.71 Mg; [32]); Michigan, USA (810 kg; [28]); Los Angeles, USA (642 kg; [22]); ten cities of USA (mean=747.5 kg C ha^{-1} yr^{-1}, range 210-1230 kg C ha^{-1} yr^{-1}; [7]), and as well as 48 cities of USA (mean=800 kg C ha^{-1} [27, 30]. However, low when compared to the Beijing's urban forest (2310 kg C ha^{-1} yr^{-1}; range 2610 to 6970 kg C ha^{-1} yr^{-1}; Yang et al., 2005); and riverine forests of Nepal (3210 kg [36]. In this study, an individual tree sequestered approximately 40 to 60% less C than urban trees of three USA cities. Nowak [34] estimated a low of 1.0 kg (0-7 cm dbh) to a high of 92.7 kg (77+ cm dbh) of C sequestration/tree/year for urban trees. Higher stem radial growth yr^{-1} and occurrence of many large trees in urban forests of the USA could have contributed to more biomass and carbon sequestration. The money values of two environmental services namely carbon storage and sequestration have been provided in **Table 6**. The carbon storage value of trees in study site is about 2800 $ (66 $/tonne carbon) whereas annual carbon sequestration potential of trees is approximately 150 $. With this simple calculation one can easily imagine the value of trees which are growing on the Cooum river bank in Chennai city. This study provides the money value of just two environmental services, with studies on all environmental services of trees (such as pollination, water percolation, conservation of soil, maintenance of water quality etc.) one can easily understand the real value of trees.

CONCLUSIONS

This study sheds light on understudied urban forests in Chennai Metropolitan City, India. Tree density is greater as well as lower than in urban forests elsewhere. Whereas, tree dry biomass storage, C storage and sequestration are comparable to other urban forest around the world. Conservation of trees on the CRB is important to protect associated faunal communities, they may play unique ecosystem services such as pollination, seed dispersal etc. The data obtained on carbon storage and sequestration of trees can be useful to educate the economic importance of trees to higher secondary school students and local community people in Chennai metropolitan city, India.

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