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Research Article

Estimation of urban tree biomass in Pachaiyappa's College, Chennai, India

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Abstract: A quantitative study was conducted in Pachaiyappa's College to estimate dry biomass of trees. In total, two hectares were studied to estimate tree biomass. All trees with diameter at breast height (dbh) ≥5 cm were measured and recorded. An available linear log-transformed region-specific regression equation was used to estimate above ground biomass (AGB) of trees in study plots. A total of 74 species spread in 63 genera and 31 families were recorded from a two hectare plot. Collectively, 552 trees (≥5 cm dbh; mean tree density 226 trees ha^{-1}) were inventoried from study area. Basal area (BA) of tree stand is 56.13 m^2 (28.07 m^2 ha). This study estimated 263.72 Mg tree dry biomass from two hectares. As on January 2014, each tree stored 238.88 kg C in trees. This study is an initial step towards the understanding of ecosystem services and roles of urban forests in Chennai metropolitan city (CMC).
Keywords: Chennai metropolitan city; Institutional forest; Tamil Nadu; Tree biomass; urban forest.

INTRODUCTION

Urban forests and trees are getting more importance in developing countries. They are the vital components in urban biodiversity and play a major role in the abatement of global warming. Green house gases exhausted from fossil-fuels is one of the major contributors to surface temperature increase across the globe [1-3]. It has been shown that annually 2.6 billion Mg of carbon is accumulating in the atmosphere [4]. The current CO_2 concentration (400 ppm) is twice as high as it was only in eighteen thousand years ago, and 30% higher than pre-industrial concentration [5]. Trees with their autotrophic nature absorb CO_2, using it for metabolism and store excess in their organs as biomass [6]. They store approximately 90% of all biomass carbon on earth (*c*. 500 Giga ton C), this amount is not so different in size from sum of C in the atmosphere. Thus, atmospheric C content is highly sensitive to forest disturbances as well as forest biomass enrichments [7]. As emphasized by Moulton and Richards [8], Nowak [9,10] trees are the relatively inexpensive option that can significantly reduce CO_2 concentration and substantially purify the air in urban environment. To disseminate the importance of urban forests and trees many researchers did invaluable works across the globe. For instance, works of McPherson et al. [11] shed lights on the importance of urban trees in C sequestration in USA. Chen and Jim [12] and Yang et al. [13] researched on China's urban environments, reported their values. McPherson and Simpson [14] valued the ecosystem services provided by urban trees (53.17 to 83.38 US dollars/tree/year) in two cities at California, USA. To date very limited data are available for urban trees and forests in CMC, thus the primary objective of this study was to estimate biomass storage of trees in an institutional forest in CMC.

METHODS

Study area

Chennai Metropolitan city is 34th largest city in the world with the human population of approximately 450 0000 [15]. CMC is one among the four mega-cities of the Indian subcontinent, and the capital city of Tamil Nadu state. The city is experiencing tropical dissymmetric climate and receiving bulk of the rainfall during north-east monsoon (September-December). Mean temperature and rainfall were 24-37 °C and 1300 mm [16]. East-side of the city is bounded by the Bay of Bengal and remaining three sides are bordered with Thiruvallur and Kanchipuram districts. CMC is endowed with rich plant diversity (1039 species) which include both native as well as introduced species. Pachaiyappa's College (PC) situated in heart of the city and endowed with good plant diversity [17, 18]. PC was established in the year 1842, the leading institutions for higher learning in south India. Strict rules and regulations are framed and strictly followed to protect plant lives in PC. Collection of plant materials both living and dead and cutting of trees are banned in PC. The forest type of this region is known as tropical dry evergreen forests (TDEF), at present very less amount of land is under TDEF (Governor's bungalow, Guindy National park, Theosophical society and Indian institute of science campus). Urbanization has reduced most of the native forest areas, however left some remnants here and there

in CMC [18]. Chennai is the least green covered metropolitan city (21%) in India and has very less, 0.46 m^2 green cover/city dweller, it is very less as per WHO norms, it suggests 9.0 m^2 green cover for each city dwellers [19].

Field survey

A two hectare (200m × 100m) plot was established in PC. The plot was sub-divided into 10m × 10m workable sub-plots for tree inventories. All trees with diameter at breast height (dbh) ≥5 cm were measured and recorded. All recorded trees were marked with yellow paint. For multi-stemmed trees, stem diameter was measured individually, basal area (BA) calculated and summed. Tree measurements were undertaken during August 2013 to February 2014.

Estimation of basal area

Basal area (BA) is the area of stem measured at 137 cm above the ground.

i.e., Basal area of stem = Diameter at breast height (dbh) / π (3.14).

Regression equations and estimation of aboveground biomass

An available linear log-transformed region-specific regression equation was used to estimate above ground biomass (AGB) of trees in study plots [18, 19]. AGB_{dry} = exp (1.9724*LN (DBH) – 1.0717); where, AGB_{dry} is aboveground dry biomass of tree (kg); DBH is stem diameter at breast height (cm); LN is natural logarithm; 1.9724 and 1.0717 are constants. The researchers developed the allometric formula by destructing healthy trees (DBH range 4.45 to 178.7 cm). They followed the guidelines of Pearson et al. [20] to develop regression equation. In the present study DBH of trees ranged from 5 to 176 cm. The coefficient of determination (r^2) of allometric equation is high i.e. 0.98. Biomass values were multiplied by 0.50 to get carbon storage value of trees [21, 22].

RESULTS

Tree stand

A total of 74 species spread in 63 genera and 31 families were recorded from a two hectare plot. Collectively, 552 trees (≥5 cm dbh; mean tree density 226 trees ha^{-1}) were inventoried from study area (Table 1). *Polyalthia longifolia* was the most represented species with 141 individuals, followed by *Azadirachta indica* (83) and *Peltophorum pterocarpum* (56). While a red-listed tree *Guaiacum officinale*, and south Indian soapnut tree *Sapindus emarginatus* represented by just single individual in PC. Study plot dominated by native species. Evergreen trees are also abundant in PC.

Basal area

Basal area (BA) of tree stand is 56.13 m^2 (28.07 m^2 ha). Basal area of individual tree species ranged from 28.74 (=0.003 m^2) (*Guaiacum officinale*) to 169953.3 cm^2 (=16.99 m^2) (*Albizia saman*) (Table 2). Likewise, BA of individual family varied from 28.74 (=0.003 m^2) (Zygophyllaceae) to 175585.0 cm^2 (=17.55 m^2) (Mimosaceae) in study area (Table 3). The mean BA of trees in study area is 1016.97 cm^2 (=0.1 m^2).

Biomass

This study estimated 263.72 Mg tree dry biomass from two hectares. In a hectare PC stored 131.86 Mg biomass in trees. *A. saman* had more biomass 75707.31 kg followed by *A. Indica* (50203.26 kg) and *Peltophorum pterocarpum* (29476.07 kg) (Table 4).

The percent contribution of individual species to total biomass ranged from a minimum of 0.004% (11.92 kg; *Guaiacum officinale* and *Mangifera indica*) to a maximum of 28.71% (75707.31 kg; *A. saman*). On average, each tree stored 477.76 kg AGB in study plots. Members of the family Mimosaceae stocked a large amount of biomass (80064.68 kg) followed by Meliaceae (50203.25 kg) and Caesalpiniaceae (45779.52 kg). While the families Zygophyllaceae, Ochnaceae and Lythraceae stored least amounts of biomass, 11.92, 16.99 and 19.29 kg respectively in study area (Table 5).

Contribution of families to forest biomass

The members of the family Mimosaceae contributed a higher proportion (80064.68 kg, 30.36%) followed by Meliaceae (50203.26 kg, 19.04%) and Caesalpiniaceae (45779.52 kg, 17.36%) to total biomass.

Carbon storage

As on January 2014, each tree stored 238.88 kg C in trees. Smaller trees (0-7 cm dbh) stored 3.8 to 5.58 kg C, while large trees accumulated, 1655.10 to 2774.60 kg C. Approximately, larger trees stored 500 to 700 times more C than low diameter class.

Table 1. Binomial, family and vernacular name (Tamil) of trees recorded in Pachaiyappa's College campus, Chennai

S. no.	Botanical Name	Family	Vernacular (Tamil)
1.	*Acacia auriculiformis*	Mimosaceae	Pencil maram
2.	*Achras sapota*	Sapotaceae	Sappottaa
3.	*Aegle marmelos*	Rutaceae	Vilvam
4.	*Alangium salviifolium*	Cornaceae	Azhinjil
5.	*Albizia lebbeck*	Mimosaceae	Vaagai
6.	*Albizia saman*	Mimosaceae	Thoongu-moonchi maram
7.	*Azadirachta indica*	Meliaceae	Vaeppa maram
8.	*Bassia latifolia*	Sapotaceae	Iluppai
9.	*Bauhinia recemosa*	Caesalpiniaceae	Thiruvaatchi
10.	*Bauhinia variegate*	Caesalpiniaceae	Mandhaarai
11.	*Bombax malabarica*	Bombacaceae	Ilavampanchu
12.	*Caesalpinia coriaria*	Caesalpiniaceae	Kodivelam
13.	*Caesalpinia pulcherrima*	Caesalpiniaceae	Mayirkondrai
14.	*Calophyllum inophyllum*	Clusiaceae	Punnai
15.	*Cassia biflora*	Caesalpiniaceae	-
16.	*Cassia fistula*	Caesalpiniaceae	Sarakkondrai
17.	*Cassia roxburgii*	Caesalpiniaceae	Karunkondrai
18.	*Cassine glauca*	Celasraceae	Eeerkolli
19.	*Casuarina equisetifolia*	Casuarinaceae	Savukku
20.	*Citrus aurantifolia*	Rutaceae	Elumicchai
21.	*Citrus medica*	Rutaceae	Naarththankaay
22.	*Coccoloba uvifera*	Polygonaceae	Kadalthiratchai
23.	*Cordia oblique*	Boraginaceae	Mookkusali pazham
24.	*Cordia sebestena*	Boraginaceae	-
25.	*Crescentia cujete*	Bignoniaceae	Thiruvottukaay maram
26.	*Dalbergia spp.*	Papilionaceae	-
27.	*Delonix regia*	Caesalpiniaceae	Senkondrai
28.	*Diospyros peregrine*	Ebenaceae	Malai sappotta
29.	*Eucalyptus spp.*	Myrtaceae	Thaila maram
30.	*Feronia elephantum*	Rutaceae	Vilaa
31.	*Ficus elastic*	Moraceae	Indhiya rubber maram
32.	*Ficus religiosa*	Moraceae	Arasa maram
33.	*Filicium dicipiens*	Sapindaceae	Perani maram
34.	*Gliricidia sepium*	Papilionaceae	-
35.	*Gmelina arborea*	Verbenaceae	Kumizha maram
36.	*Guaiacum officinale*	Zygophyllaceae	-
37.	*Guazuma ulmifolia*	Sterculiaceae	Thenkaay maram
38.	*Ixora pavetta*	Rubiaceae	Korivi maram
39.	*Jatropha curcas*	Euphorbiaceae	Kaattaamanakku
40.	*Kigelia africana*	Bignoniaceae	Marachcurai
41.	*Lannea coromandelica*	Anacardiaceae	Udhiya maram
42.	*Lawsonia inermis*	Lawsonia inermis	Marudhaani
43.	*Leucaena leucocephala*	Mimosaceae	Thagara maram
44.	*Markhamia stipulate*	Bignoniaceae	-
45.	*Millingtonia hotensis*	Bignoniaceae	Maramalli
46.	*Mimusops elengi*	Sapotaceae	Magizha maram
47.	*Mangifera indica*	Anacardiaceae	Maamaram
48.	*Morinda tinctoria*	Rubiaceae	Manjanaththi
49.	*Moringa oleifera*	Moringaceae	Murungai
50.	*Morus indica*	Moraceae	Musumusukkai
51.	*Murraya koenigii*	Rutaceae	Karivaeppilai
52.	*Ochna serrata*	Ochnaceae	Serundhi
53.	*Pheltophorum pterocarpum*	Caesalpiniaceae	Manjal kondrai
54.	*Phyllanthus acidus*	Euphorbiaceae	Nelli maram

55.	*Phyllanthus emblica*	Euphorbiaceae	Malai nelli
56.	*Pisonia alba*	Nyctaginaceae	Latchakotta keerai
57.	*Polyalthia longifolia*	Annonaceae	Nettilingam
58.	*Pongamia pinnata*	Papilionaceae	Punga maram
59.	*Premna latifolia*	Verbenaceae	Munnai
60.	*Psidium guajava*	Myrtaceae	Koyyaa maram
61.	*Pterospermum canascens*	Sterculiaceae	Sempulavu
62.	*Sapindus emarginatus*	Sapindaceae	Soppukaay
63.	*Saraca asoca*	Caesalpiniaceae	Asoka maram
64.	*Spathodea campanulata*	Bignoniaceae	-
65.	*Sterculia foetida*	Sterculiaceae	-
66.	*Syzygium cumini*	Myrtaceae	Naaval
67.	*Tabebuia rosea*	Bignoniaceae	-
68.	*Tamarindus indica*	Caesalpiniaceae	Puliyamaram
69.	*Tecoma stans*	Bignoniaceae	Sornapatti
70.	*Tectona grandis*	Verbenaceae	Thekku
71.	*Terminalia catapa*	Combretaceae	Maattu vaadhumai
72.	*Thespesia populnea*	Malvaceae	Poovarasu
73.	*Vitex altissima*	Verbenaceae	Mayilaadi
74.	*Vitex negundo*	Verbenaceae	Nochchi

Table 2. Basal area (cm^2) of species' recorded in Pachaiyappa's College, Chennai, India

S.no	Botanical Name	Basal area (cm^2)
1	*Acacia auriculiformis*	911.62
2	*Achras sapota*	60.90
3	*Aegle marmelos*	161.22
4	*Alangium salviifolium*	346.81
5	*Albizia lebbeck*	3680.33
6	*Albizia saman*	169953.3
7	*Azadirachta indica*	100195.3
8	*Bassia latifolia*	882.24
9	*Bauhinia recemosa*	118.01
10	*Bauhinia variegata*	787.85
11	*Bombax malabarica*	8389.88
12	*Caesalpinia coriaria*	6070.09
13	*Caesalpinia pulcherrima*	32.88
14	*Calophyllum inophyllum*	30.97
15	*Cassia biflora*	161.22
16	*Cassia fistula*	790.44
17	*Cassia roxburghii*	3136.96
18	*Cassine glauca*	1146.49
19	*Casuarina equasitifolia*	2488.67
20	*Citrus aurantifolia*	103.34
21	*Citrus medica*	417.19
22	*Coccoloba uvifera*	127.38
23	*Cordia obliqua*	1227.18
24	*Cordia sebestena*	70.38
25	*Crescentia cujete*	513.77
26	*Dalbergia spp.*	4973.24
27	*Delonix regia*	21373.89
28	*Diospyros peregrina*	114.96
29	*Eucalyptus spp.*	8368.63
30	*Feronia elephantum*	1118.01
31	*Ficus elastic*	1277.22
32	*Ficus religiosa*	29477.57
33	*Filicium dicipiens*	1550.39
34	*Gliricidia sepium*	286.62

35	*Gmelina arborea*	175.87
36	*Guaiacum officinale*	28.74
37	*Guazuma ulmifolia*	20895.6
38	*Ixora pavetta*	191.16
39	*Jatropha curcas*	297.21
40	*Kigelia africana*	447.85
41	*Lannea coromandelica*	1214.35
42	*Lawsonia inermis*	40.49
43	*Leucaena leucocephala*	1039.72
44	*Markhamia stipulata*	330.97
45	*Millingtonia hotensis*	4942.63
46	*Mimusops elengi*	990.28
47	*Mangifera indica*	28.74
48	*Morinda tinctoria*	2105.81
49	*Moringa oleifera*	129.69
50	*Morus indica*	43.96
51	*Murraya koenigii*	111.41
52	*Ochna serrata*	40.52
53	*Peltophorum pterocarpum*	52263
54	*Phyllanthus acidus*	32.64
55	*Phyllanthus emblica*	303.02
56	*Pisonia alba*	199.04
57	*Polyalthia longifolia*	61244.55
58	*Pongamia pinnata*	5589.39
59	*Premna latifolia*	775.77
60	*Psidium guajava*	157.24
61	*Pterospermum canescens*	2179.69
62	*Sapindus emarginatus*	168.47
63	*Saraca asoca*	147.21
64	*Spathodea campanulata*	7988.87
65	*Sterculia foetida*	2379.77
66	*Syzygium cumini*	281.86
67	*Tabebuia rosea*	8617.91
68	*Tamarindus indica*	2410.51
69	*Tecoma stans*	145.74
70	*Tectona grandis*	10568.14
71	*Terminalia catapa*	1903.50
72	*Thespesia populnea*	100.39
73	*Vitex altissima*	296.25
74	*Vitex negundo*	210.98
	Total (2 hectare)	**561370.00**

Table 3. Basal area (cm^2) of families recorded in Pachaiyappa's College, Chennai, India

S.no.	Family name	Basal area (cm^2)
1	Anacardiaceae	1243.09
2	Annonaceae	61244.55
3	Bignoniaceae	22987.75
4	Bombacaceae	8389.89
5	Boraginaceae	1297.57
6	Caesalpiniaceae	87386.47
7	Casuarinaceae	2485.67
8	Celastraceae	1146.49
9	Clusiaceae	30.97
10	Combretaceae	1903.50
11	Cornaceae	346.81
12	Ebenaceae	114.96

13	Euphorbiaceae	632.88
14	Lythraceae	46.49
15	Malvaceae	100.39
16	Meliaceae	100195.3
17	Mimosaceae	175585
18	Moraceae	30798.77
19	Moringaceae	129.69
20	Myrtaceae	8807.74
21	Nyctaginaceae	199.04
22	Ochnaceae	40.52
23	Papilionaceae	10849.27
24	Polygonaceae	124.38
25	Rubiaceae	2296.97
26	Rutaceae	1910.92
27	Sapindaceae	1718.86
28	Sapotaceae	1839.05
29	Sterculiaceae	25455.08
30	Verbenaceae	12027.04
31	Zygophyllaceae	28.74
	Total (2 hectare)	**561370.00**

Table 4. Biomass stored in tree species at Pachaiyappa's College, Chennai, India

S. no.	Botanical Name	Biomass
1.	*Acacia auriculiformis*	363.83
2.	*Achras sapota*	49.27
3.	*Aegle marmelos*	65.34
4.	*Alangium salviifolium*	139.08
5.	*Albizia lebbeck*	1428.64
6.	*Albizia saman*	75707.31
7.	*Azadirachta indica*	50203.26
8.	*Bassia latifolia*	612.90
9.	*Bauhinia recemosa*	48.03
10.	*Bauhinia variegate*	351.32
11.	*Bombax malabarica*	3267.01
12.	*Caesalpinia coriaria*	3779.34
13.	*Caesalpinia pulcherrima*	22.20
14.	*Calophyllum inophyllum*	23.85
15.	*Cassia biflora*	65.34
16.	*Cassia fistula*	316.32
17.	*Cassia roxburghii*	1247.60
18.	*Cassine glauca*	452.27
19.	*Casuarina equisetifolia*	989.79
20.	*Citrus aurantifolia*	115.25
21.	*Citrus medica*	535.10
22.	*Coccoloba uvifera*	51.79
23.	*Cordia oblique*	961.03
24.	*Cordia sebestena*	57.03
25.	*Crescentia cujete*	25.63
26.	*Dalbergia spp.*	1947.80
27.	*Delonix regia*	9472.31
28.	*Diospyros peregrine*	46.81
29.	*Eucalyptus spp.*	3263.49
30.	*Feronia elephantum*	441.18
31.	*Ficus elastic*	984.35
32.	*Ficus religiosa*	11352.95

33.	*Filicium dicipiens*	1465.67
34.	*Gliricidia sepium*	115.25
35.	*Gmelina arborea*	71.19
36.	*Guaiacum officinale*	11.92
37.	*Guazuma ulmifolia*	10508.66
38.	*Ixora pavetta*	77.29
39.	*Jatropha curcas*	381.93
40.	*Kigelia africana*	178.97
41.	*Lannea coromandelica*	478.65
42.	*Lawsonia inermis*	19.29
43.	*Leucaena leucocephala*	423.01
44.	*Markhamia stipulate*	133.64
45.	*Millingtonia hotensis*	2667.77
46.	*Mimusops elengi*	1007.85
47.	*Mangifera indica*	11.92
48.	*Morinda tinctoria*	831.10
49.	*Moringa oleifera*	104.16
50.	*Morus indica*	18.14
51.	*Murraya koenigii*	76.15
52.	*Ochna serrata*	16.99
53.	*Peltophorum pterocarpum*	29476.07
54.	*Phyllanthus acidus*	25.53
55.	*Phyllanthus emblica*	354.10
56.	*Pisonia alba*	80.43
57.	*Polyalthia longifolia*	26849.74
58.	*Pongamia pinnata*	2209.19
59.	*Premna latifolia*	529.59
60.	*Psidium guajava*	112.04
61.	*Pterospermum canescens*	2288.28
62.	*Sapindus emarginatus*	68.24
63.	*Saraca asoca*	59.74
64.	*Spathodea campanulata*	3109.09
65.	*Sterculia foetida*	947.59
66.	*Syzygium cumini*	113.36
67.	*Tabebuia rosea*	3306.28
68.	*Tamarindus indica*	941.2
69.	*Tecoma stans*	93.34
70.	*Tectona grandis*	4252.61
71.	*Terminalia catapa*	1631.90
72.	*Thespesia populnea*	41.29
73.	*Vitex altissima*	119.07
74.	*Vitex negundo*	85.73
	Total (2 hectare)	**263724.00**

Table 5. Biomass stored in families at Pachaiyappa's college campus, Chennai

S.no	Family name	Biomass (kg)
1	Anacardiaceae	490.58
2	Annonaceae	24869.74
3	Bignoniaceae	9849.35
4	Bombacaceae	3267.01
5	Boraginaceae	1018.07
6	Caesalpiniaceae	45779.52
7	Casuarinaceae	989.79
8	Celastraceae	452.27
9	Clusiaceae	23.85
10	Combretaceae	1631.90
11	Cornaceae	139.08

12	Ebenaceae	46.81
13	Euphorbiaceae	761.67
14	Lythraceae	19.29
15	Malvaceae	41.29
16	Meliaceae	50203.26
17	Mimosaceae	80064.68
18	Moraceae	12355.45
19	Moringaceae	104.16
20	Myrtaceae	3494.90
21	Nyctaginaceae	80.43
22	Ochnaceae	16.99
23	Papilionaceae	4272.24
24	Polygonaceae	51.79
25	Rubiaceae	908.39
26	Rutaceae	1233.04
27	Sapindaceae	1533.91
28	Sapotaceae	1670.04
29	Sterculiaceae	13744.54
30	Verbenaceae	5058.20
31	Zygophyllaceae	11.92
	Total (2 hectare)	**263724.00**

DISCUSSION

Tree density

Stem density (226 trees ha^{-1}) of present study area is greater than those of urban forests (111.9 trees ha^{-1}) of Oakland, California [23]; Modesto, California (61 trees ha^{-1}) [24]; ten USA cities (mean = 147, range, 36 to 276) [6], Sacramento, USA (73 trees ha^{-1}) [25], and Beijing, China (79 trees ha^{-1}) [13]. However, tree density recorded in this study is lesser than in urban forests of three USA cities (563 ± 77 ha^{-1}, range 332-674 ha^{-1}) [10].

Tree diameter classes

More than 70% of recorded trees were ≥ 15 cm dbh, this value is greater than those of Nowak [26], Dorney et al. [27] and Nowak [9] they reported 39%, 33% and 23% of urban trees with ≥15 cm dbh respectively from Oakland (California), Shorewood (Wisconsin), and three USA cities. In addition, large trees (77+ cm dbh) are abundant in present study than in US cities, (range 0.4 to 2.1%). Studied trees planted before *c*. 25 to 40 years.

Mean biomass and carbon storage of single tree

The mean biomass stored in a tree (477.76 kg) is notably higher than that of Yang et al. [13] they reported 162.6 kg mean biomass from urban areas of China. However, mean carbon stored in an individual tree in study area (238.88 kg) is not in-line with that of Nowak [10] who estimated approximately 20-50% more carbon per tree for urban trees in three USA cities. The differences in abundance of various tree diameter classes in urban forests have contributed to changes in mean tree biomass.

Carbon storage in a hectare

Carbon storage recorded in the study (65.93 Mg) is greater than those of urban forests in India, China, Germany and USA [6, 10, 13, 23, 27-32]. However, biomass storage of study area is lower than that of urban forests of Chicago and DuPage County, USA (128.0, 95.5 Mg C ha^{-1}) [10]. Quantity of stored biomass tends to vary with forest tree density, tree cover, stand basal area and tree diameter distributions.

Compared to present study institutional areas of US cities stored less carbon (mean, 41.0 Mg C ha^{-1}, Nowak [10]; 12.9 Mg ha^{-1}, Nowak [33]. However, institutional urban forests in Pune city stored more carbon (87.33 Mg ha^{-1}) [28] than in present study. Studies of this kind with large study areas are required to create a real picture of CMC's forests.

CONCLUSIONS

Biomass storage of the present study area is very well within the range of world's urban forests. However, compared to urban forests of some USA cities trees of CMC are less potent in terms of CO_2 absorption, O_2 production, C sequestration, and stem diameter growth yr^{-1}. Studies of this kind with large study areas are essential to reveal the actual potential of trees and urban forests in CMC. Pre-tested species selection and planting of relatively high C sequestering trees on vacant lands, river banks and parks, and nurturing, caring them to perform well could significantly reduce the CO_2 concentration, pollution and UHI effects in CMC. This study is an initial step towards the understanding of ecosystem services and roles of urban forests of CMC. CMC is the least green covered (9.5%; [34,35]) metropolitan city in India hence government authorities, urban planners, city developers and managers should allot more funds and

allocate additional space for trees to increase green spaces.

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