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RESEARCH ARTICLE

Assessment of carbon sequestration rate and tree diversity in a model urban green cover study using a college campus in Mangalore city

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Abstract

The extant green cover in a 140-year-old St Aloysius College campus in Mangalore, Karnataka, India, was used as a model to study tree diversity and carbon-sequestering rate (CSR), using a non-destructive biostatistics-based method. The results of the study indicated that the campus constituted a highly diverse tree flora with a Shannon Diversity index of 4.07. A total of 169 different tree species were found on the campus with an average population size of 9.98 per species. The green cover of 4.67 ha of the total area of the campus had a tree density of 361.03 trees/ha. Five tree species, namely *Polyanthia longifolia*, *Cocos nucifera*, *Tectona grandis*, *Terminalia catappa*, and *Areca catechu*, dominated the area. Using allometric equations, the total green cover in the campus area with biomass of 4594.6 Kg, which sequestered 8431.1 Kg of carbon at a carbon sequestration rate of 84.31 Kg per year was deduced. *Olea europaea* and *Phoenix dactylifera*, with the highest CSR of 0.09 and 0.08, respectively, were the most effective in sequestering 12.54 Kg and 11.19 Kg of carbon. The highest amount of Carbon sequestered (CS) per tree was in *Olea europaea* (12.54 Kg) and *Phoenix dactylifera* (11.19 Kg), followed by *Acacia auriculiformis* (10.44 Kg), and *Adenanthera pavonina* (10.08 Kg). It was observed that the amount of carbon sequestered decreased with the decrease in tree girth.

Keywords

biomass estimation; carbon sequestration; diversity index; GPS mapping; tree diversity.

Introduction

The green cover of a city is an intangible aspect usually considered for aesthetics and as a process of beautification. However, its crucial functions to the ecosystem are always neglected and undervalued. This has led to the destruction of most of the city's green cover, favouring concrete urban land development projects, and causing severe environmental concerns. Trees, through carbon sequestration, take up a considerable amount of CO_2 from the atmosphere and store the carbon in their biomass (1) as they continue to grow. Carbon sequestration and fixing carbon by trees during photosynthesis act as a sink and absorb atmospheric CO_2. This process is a natural mechanism for removing carbon from the atmosphere by storing it in the biosphere. With depleting green cover acting as sinks for CO_2 removal, the cities have turned into urban heat islands, making them uninhabitable.

High levels of diversity and microhabitat heterogeneity often characterize the urban green cover, with large proportions of exotic species (2,3), that constitute critical biodiversity hotspots (4-6). Thus, the destruction of green cover impacts the distribution of biodiversity for multiple taxa (4). Despite its importance and significance, a limited number of studies on the urban green cover diversity and carbon sequestration potential have been conducted in Indian cities in the last decade (7-17). According to Nagendra and Gopal (9), inadequate data has resulted in inefficient urban planning and a lack of conservation. The study of plant diversity in development projects is essential for effective conservation strategies and Management plans (18). Hence a model study was conducted for a 140-year-old campus of St Aloysius College in Mangalore Karnataka, India, to assess the tree diversity and its carbon-sequestering rate using a non-destructive biostatistics-based method. This study will provide a small-scale insight into the effectiveness of an urban green cover with diverse flora as an effective carbon sink in growing cities.

Materials and methods

2.1. Data Collection and Analysis

The tree flora of St Aloysius College (12.873067N 74.845914E) campus of 14.97 ha in Mangalore was mapped using a handheld GARMEN Global Positioning System (GPS). The number of trees per species was also noted for the diversity study. The diversity indices such as the Simpsons Dominance Index (19), Shannon diversity (20), and evenness indices (21) were calculated using PAST (v3.17) statistical software.

2.2. Valuation of Carbon Sequestration Rate (CSR) of the tree cover on the campus

In the current study, a non-destructive method for carbon estimation is employed, as demonstrated in other research studies conducted in India (8,22,23). Trees were sampled for their approximate height and girth in meters. Using allometric equations and conversion factors from the research literature (24-26), the biomass of the tree species was calculated. As biomass estimations are species-specific (9), the current study used the most suitable model developed by Brown et al., (26). The Above Ground Biomass (AGB) was calculated by using the Eq. (1)

$$\hat{Y}=\exp\{-2.4090+0.9522 \ln (T_{bv})\} \quad \ldots \quad (1)$$

$$T_{bv}= S \times D^2 \times H \quad \ldots \quad (2)$$

Where T_{bv} is Tree bio-volume (2), S is the wood density of individual tree species, D is tree diameter (measured by dividing the tree circumference at breast height with 3.14), and H is the height of species. The wood density (S) of each tree species is used from the global wood density database (27). The standard average density of 0.6gm/cm3 is applied wherever the S value is unavailable for a tree species. The Below Ground Biomass (BGB) was calculated by multiplying the AGB by a factor of 0.26 as the root-to-shoot ratio (28).

$$BGB=ABG\times0.26 \quad \ldots \quad (3)$$

A factor of 0.8 is multiplied by open-grown urban trees to calculate the total Biomass (TB) (24),

$$TB=(AGB+BGB)\ X\ 0.8 \quad \ldots \quad (4)$$

As per Pearson et al. (29), for any plant species, 50% of its biomass is considered as carbon content (CC), hence,

$$CC=TB/2 \quad \ldots \quad (5)$$

To determine the weight of carbon sequestered (CS) in a tree multiplying CC by 3.67 (ratio of the atomic weight of CO_2 to C),

$$CS=CC\times3.67 \quad \ldots \quad (6)$$

The CSR was calculated as 1% of standing biomass.

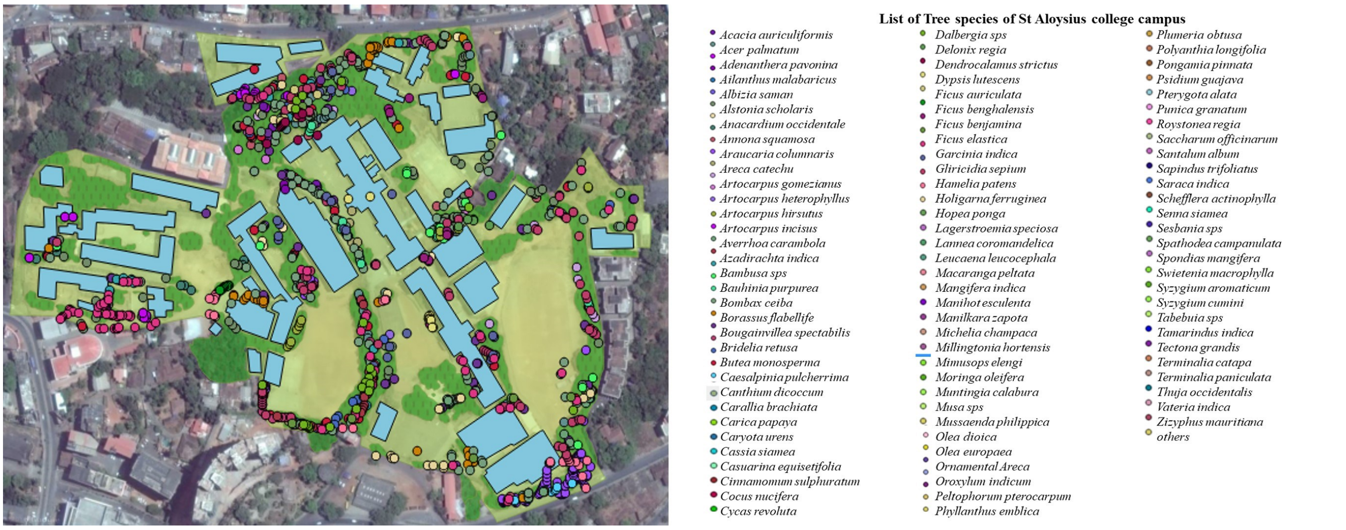

Fig. 1. Distribution of the extant tree species present on the campus are shown as coloured dots representing each species. The blu e co lour b locks are conc rete structures within t he campus, while the green region depicts the green cover.

Result and Discussion

Tree species composition and diversity of the tree cover in the study area

Although small in area (14.97 ha), we found a highly diverse tree flora on the campus, constituting more than 169 different tree species having an average population size of 9.98 per species. The details of the mapped tree species and their distribution are shown in Fig. 1. These include a significant number of trees that stand to a total of 1686, covering 4.67 ha of the total area of the campus, i.e., equivalent to 361.03 trees/ha of the total green cover and 112.62 trees/ha of the total campus.

To place this into context, the study of Sathish et al. (30) found 491.09 trees/ha in the undisturbed core forests of Southern regions of the Western Ghats in Karnataka, which constituted 234 different tree species. The density of 361.03 trees/ha found in the current study is lower than the density (491.09 trees/ha) of trees in the Western Ghats, as the present study area is in the heart of an urban city of Mangalore (575001). Nonetheless, this is significantly higher than studies conducted in urban parks and campuses in Bangalore (7,9), IIT Madras (31), North Maharashtra University (11), and Pune City (32).

The tree species diversity of the campus was high as indicated by a high Shannon diversity index of 4.07. However, a high Simpson's dominance index of 0.97 indicates that a few representative species among the diverse tree flora dominated the area. It was also in concord with the values from the Evenness index of 0.35. The Gini coefficient (GC) for the area of study was 0.71, which indicates inequality in the wealth of distribution of the tree species on the campus. The information of all the tree species present in the study area is given in Table 1.

Five tree species, namely *Polyanthia longifolia* (157), *Cocos nucifera* (129), *Tectona grandis* (125), *Terminalia catappa (*93), and *Areca catechu* (80), dominated the tree population in the area (Fig. 2A). These trees were distributed throughout the entire 4.67 ha of green cover in the campus (Fig. 2B). These tree species have been reported to dominate similar geographic regions such as Karwar in the State of Karnataka (33), which resemble an evergreen and semi-evergreen forest type of the western belt of the Western Ghats in the State of Karnataka. The study indicates that a large area (10.3 ha out of 14.97 ha) within the campus has been taken up for development and other activities. The extant tree cover of the campus is largely undisturbed and has retained its indigenous tree species population.

CSR of the tree cover on the campus

The entire tree cover constituting 1686 trees on the campus was found to have a total biomass of 5494.6 Kg, which has sequestered 8431.1 Kg of CO_2, leading to a carbon content of 2297.3 Kg (Table 1). The CSR for the calculated biomass of green cover was 84.31 Kg of carbon per year. The amount of carbon sequestered by each tree species is given in Table 1. Three tree species that dominated the area numerically, namely, *Tectona grandis*, *Cocos nucifera*, and *Polyanthia longifolia*, were also able to sequester the highest amount of carbon with a carbon content of 278.6, 171.2, and 118.9 Kg, at CSR of 6.97, 4.28 and 2.97 Kg/annum respectively. Among these *Tectona grandis* (1022.6 kg) and *Cocos nucifera* (628.3 Kg) sequestered the highest amount of CO_2. But it was noted that the highest amount of CS/tree was found in *Olea europaea* (12.54 Kg), followed by *Phoenix dactylifera* (11.19 Kg), *Acacia auriculiformis* (10.44 Kg), and *Adenanthera pavonina* (10.08 Kg). *Olea europaea* and *Phoenix dactylifera* were also the highest CSR/tree with 0.09 and 0.08 Kg/annum, respectively. It is also to be noted that although trees such as *Olea europaea*, *Phoenix dactylifera*, *Acacia auriculiformis*, and *Adenanthera pavonina* are significantly less in numbers in the study area and contributed lowly to the total carbon sequestrated, The tree species, *Moringa oleifera, Butea monosperma*, *Tamarindus indica*, and *Bombax ceiba* are reported to be significant contributors to carbon sequestration in other educational campus and parks in India (11, 34, 35). The species with high wood density (27) are essential, and even though they are fewer in number, they can sequester a significantly higher amount of carbon per tree as compared to the others.

The trees within the campus were categorized into three categories based on their sizes. The amount of carbon sequestered by trees in each size category is explained in Table 2. Tall trees (>10m in height) sequestered maximum carbon of around 60% (5130Kg) compared to the medium and small trees, which sequestered 30% (2153.9 Kg) and 10% (1147.1 Kg) of carbon from of total carbon sequestered (8431.1Kg) (Fig.3). It was also noted that large trees with bigger girth sequestered more carbon than those with less. The amount of carbon sequestered decreased with the decrease in tree girth as the trees with girth more than 75m in diameter sequestered 2829.5 Kg of carbon, followed by 50m (2585.9Kg), 25m (2050.4Kg), and 10m (965.3Kg) in diameter. Das and Mukherjee (12) and Sahu et al. (16) also found a positive correlation between GBH and carbon storage potential. This also aligned with the findings of Nowak and Crane (36). It indicates the high amount of carbon sequestered for biomass growth by the larger trees with increased girth than those with low girth. In urban green zones, as per the results of Prabha et al.

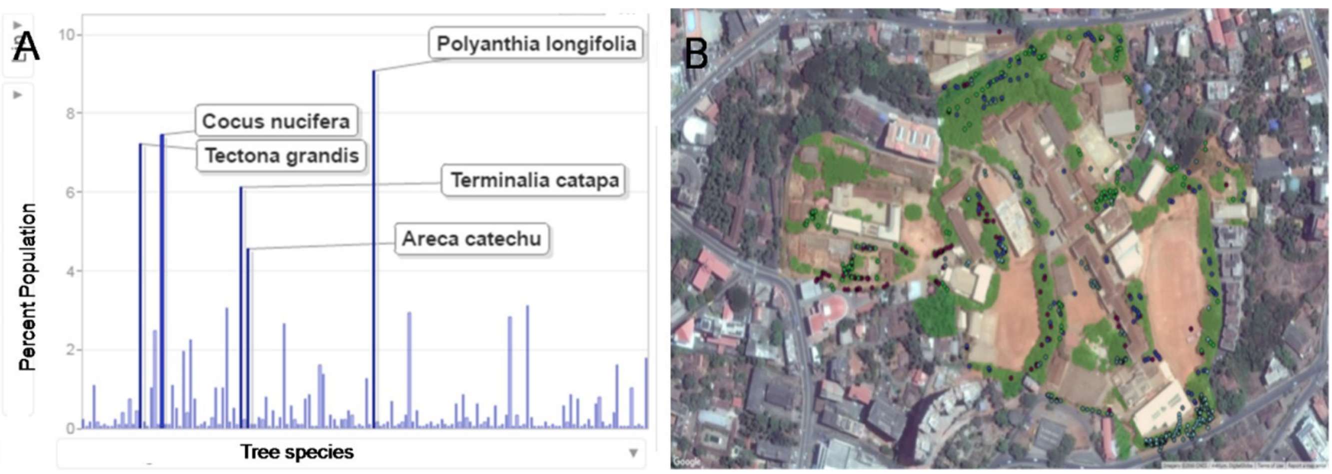

Fig. 2. (A) Five species of dominant tree species on the campus, (B) showing the distribution of the dominant species in the green zones of the campus.

Table 1. The total amount of carbon sequestered and Carbon sequestration rate per annum of every tree species present in the study a rea.

Sr. No.	Tree species	N	S (g/cm^3)	AGB	BGB	TB	CC	CS	CS /tree	CSR	CSR /tree
1	*Acacia auriculiformis*	15	0.68	84.7	22.0	85.35	42.7	156.6	10.44	1.07	0.07
2	*Adenanthera pavonina*	2	0.88	10.9	2.8	10.99	5.5	20.2	10.08	0.14	0.07
3	*Ailanthus malabaricus*	2	0.40	9.6	2.5	9.70	4.9	17.8	8.90	0.12	0.06
4	*Ailanthus triphysa*	12	0.30	20.8	5.4	20.98	10.5	38.5	3.21	0.26	0.02
5	*Alstonia scholaris*	19	0.44	70.6	18.4	71.18	35.6	130.6	6.87	0.89	0.05
6	*Anacardium occidentale*	14	0.47	40.0	10.4	40.33	20.2	74.0	5.29	0.50	0.04
7	*Annona squamosa*	4	0.73	3.3	0.9	3.35	1.7	6.1	1.53	0.04	0.01
8	*Araucaria columnaris*	15	0.43	16.1	4.2	16.20	8.1	29.7	1.98	0.20	0.01
9	*Areca catechu*	80	0.88	79.5	20.7	80.10	40.1	147.0	1.84	1.00	0.01
10	*Artocarpus gomezianus*	4	0.58	16.9	4.4	17.08	8.5	31.3	7.83	0.21	0.05
11	*Artocarpus heterophyllus*	47	0.44	112.0	29.1	112.94	56.5	207.2	4.41	1.41	0.03
12	*Artocarpus hirsutus*	13	0.52	41.6	10.8	41.89	20.9	76.9	5.91	0.52	0.04
13	*Artocarpus incisus*	1	0.32	0.8	0.2	0.79	0.4	1.5	1.45	0.01	0.01
14	*Averrhoa carambola*	7	0.60	5.4	1.4	5.40	2.7	9.9	1.42	0.07	0.01
15	*Azadirachta indica*	11	0.66	46.8	12.2	47.19	23.6	86.6	7.87	0.59	0.05
16	*Bambusa vulgaris*	9	0.52	13.1	3.4	13.17	6.6	24.2	2.69	0.16	0.02
17	*Bambusa arundinacea*	3	0.60	2.3	0.6	2.31	1.2	4.2	1.42	0.03	0.01
18	*Bauhinia purpurea*	11	0.72	37.3	9.7	37.62	18.8	69.0	6.27	0.47	0.04
19	*Bombax ceiba*	1	0.35	3.8	1.0	3.83	1.9	7.0	7.03	0.05	0.05
20	*Borassus flabellifer*	16	0.87	55.5	14.4	55.99	28.0	102.7	6.42	0.70	0.04
21	*Bougainvillea glabra*	11	0.56	15.8	4.1	15.87	7.9	29.1	2.65	0.20	0.02
22	*Bridelia retusa*	1	0.50	3.6	0.9	3.59	1.8	6.6	6.60	0.04	0.04
23	*Butea monosperma*	1	0.56	3.7	1.0	3.77	1.9	6.9	6.91	0.05	0.05
24	*Caesalpinia pulcherrima*	1	0.84	0.9	0.2	0.89	0.4	1.6	1.63	0.01	0.01
25	*Canthium dicoccum*	1	0.75	2.9	0.8	2.96	1.5	5.4	5.43	0.04	0.04
26	*Carallia brachiata*	1	0.66	4.0	1.0	4.03	2.0	7.4	7.40	0.05	0.05
27	*Carica papaya*	18	0.86	28.9	7.5	29.11	14.6	53.4	2.97	0.36	0.02
28	*Caryota urens*	43	0.48	146.7	38.2	147.91	74.0	271.4	6.31	1.85	0.04
29	*Cassia siamea*	4	0.86	12.7	3.3	12.85	6.4	23.6	5.89	0.16	0.04
30	*Cassia fistula*	2	0.52	3.0	0.8	3.03	1.5	5.6	2.78	0.04	0.02
31	*Casuarina equisetifolia*	4	0.96	14.0	3.6	14.09	7.0	25.9	6.46	0.18	0.04
32	*Cinnamomum sulphuratum*	1	0.65	4.9	1.3	4.94	2.5	9.1	9.07	0.06	0.06
33	*Cinnamomum verum*	7	0.50	12.1	3.1	12.18	6.1	22.4	3.19	0.15	0.02
34	*Clerodendrum inerme*	1	0.54	0.7	0.2	0.74	0.4	1.4	1.36	0.01	0.01
35	*Cocos nucifera*	129	0.50	339.7	88.3	342.42	171.2	628.3	4.87	4.28	0.03
36	*Coreopsis lanceolata*	1	0.60	1.0	0.3	1.03	0.5	1.9	1.88	0.01	0.01
37	*Cycas revoluta*	9	0.50	15.0	3.9	15.08	7.5	27.7	3.08	0.19	0.02
38	*Dalbergia latifolia*	5	0.77	22.3	5.8	22.48	11.2	41.3	8.25	0.28	0.06
39	*Delonix regia*	51	0.70	191.0	49.7	192.53	96.3	353.3	6.93	2.41	0.05
40	*Dendrocalamus strictus*	9	0.60	13.9	3.6	13.97	7.0	25.6	2.85	0.17	0.02
41	*Dypsis lutescens*	34	0.52	24.5	6.4	24.72	12.4	45.4	1.33	0.31	0.01
42	*Ficus auriculata*	4	0.47	5.9	1.5	5.95	3.0	10.9	2.73	0.07	0.02
43	*Ficus benghalensis*	8	0.59	38.5	10.0	38.81	19.4	71.2	8.90	0.49	0.06
44	*Ficus carica*	5	0.52	7.6	2.0	7.62	3.8	14.0	2.80	0.10	0.02
45	*Ficus benjamina*	8	0.49	8.5	2.2	8.53	4.3	15.7	1.96	0.11	0.01
46	*Ficus religiosa*	2	0.44	7.3	1.9	7.35	3.7	13.5	6.74	0.09	0.05
48	*Ficus elastica*	4	0.68	6.5	1.7	6.58	3.3	12.1	3.02	0.08	0.02
49	*Garcinia indica*	1	0.75	3.2	0.8	3.19	1.6	5.9	5.86	0.04	0.04
50	*Gliricidia sepium*	3	0.74	5.0	1.3	5.02	2.5	9.2	3.07	0.06	0.02
51	*Gmelina arborea*	1	0.34	1.7	0.4	1.73	0.9	3.2	3.17	0.02	0.02
52	*Hamelia patens*	4	0.60	3.1	0.8	3.09	1.5	5.7	1.42	0.04	0.01
53	*Holigarna arnottiana*	1	0.33	5.2	1.3	5.20	2.6	9.5	9.55	0.07	0.07
54	*Hopea ponga*	4	0.60	13.4	3.5	13.52	6.8	24.8	6.20	0.17	0.04
55	*Lagerstroemia speciosa*	5	0.64	14.2	3.7	14.36	7.2	26.4	5.27	0.18	0.04
56	*Lannea coromandelica*	1	0.34	3.8	1.0	3.78	1.9	6.9	6.94	0.05	0.05

57	*Leucaena leucocephala*	6	0.52	25.5	6.6	25.75	12.9	47.2	7.87	0.32	0.05
58	*Macaranga peltata*	39	0.60	190.6	49.6	192.13	96.1	352.6	9.04	2.40	0.06
59	*Magnolia champaca*	2	0.60	2.0	0.5	2.05	1.0	3.8	1.88	0.03	0.01
60	*Mangifera indica*	54	0.68	159.0	41.3	160.28	80.1	294.1	5.45	2.00	0.04
61	*Manihot esculenta*	1	0.48	0.7	0.2	0.70	0.4	1.3	1.29	0.01	0.01
62	*Manilkara zapota*	15	0.81	34.4	8.9	34.68	17.3	63.6	4.24	0.43	0.03
63	*Michelia champaca*	3	0.67	8.4	2.2	8.48	4.2	15.6	5.19	0.11	0.04
64	*Millingtonia hortensis*	1	0.64	4.9	1.3	4.91	2.5	9.0	9.02	0.06	0.06
65	*Mimusops elengi*	2	0.96	6.7	1.7	6.74	3.4	12.4	6.19	0.08	0.04
66	*Moringa oleifera*	3	0.26	2.8	0.7	2.83	1.4	5.2	1.73	0.04	0.01
67	*Muntingia calabura*	19	0.30	17.4	4.5	17.55	8.8	32.2	1.69	0.22	0.01
68	*Musa paradisica*	14	0.50	15.7	4.1	15.85	7.9	29.1	2.08	0.20	0.01
69	*Olea dioica*	2	0.75	2.0	0.5	1.97	1.0	3.6	1.81	0.02	0.01
70	*Olea europaea*	7	0.70	47.5	12.3	47.84	23.9	87.8	12.54	0.60	0.09
71	*Ornamental Areca*	16	0.60	12.2	3.9	12.34	6.2	22.6	1.42	0.15	0.01
72	*Oroxylum indicum*	1	0.48	2.4	0.6	2.46	1.2	4.5	4.52	0.03	0.03
73	*Peltophorum pterocarpum*	36	0.60	108.0	28.1	108.87	54.4	199.8	5.55	1.36	0.04
74	*Phoenix dactylifera*	2	0.48	12.1	3.2	12.19	6.1	22.4	11.19	0.15	0.08
75	*Phyllanthus emblica*	6	0.68	9.1	2.4	9.20	4.6	16.9	2.82	0.12	0.02
76	*Plumeria alba*	2	0.80	2.7	0.7	2.72	1.4	5.0	2.49	0.03	0.02
77	*Polyanthia longifolia*	157	0.60	235.9	61.3	237.76	118.9	436.3	2.78	2.97	0.02
78	*Pongamia pinnata*	24	0.64	122.1	31.8	123.10	61.5	225.9	9.41	1.54	0.06
79	*Psidium guajava*	4	0.63	3.1	0.8	3.15	1.6	5.8	1.44	0.04	0.01
80	*Pterygota alata*	5	0.48	26.6	6.9	26.85	13.4	49.3	9.85	0.34	0.07
81	*Punica granatum*	2	0.77	1.7	0.4	1.71	0.9	3.1	1.57	0.02	0.01
82	*Roystonea regia*	2	0.60	4.3	1.1	4.37	2.2	8.0	4.01	0.05	0.03
83	*Saccharum officinarum*	2	0.60	1.5	0.4	1.54	0.8	2.8	1.42	0.02	0.01
84	*Samanea saman*	20	0.52	76.6	19.9	77.20	38.6	141.7	7.08	0.97	0.05
85	*Santalum album*	1	0.52	2.5	0.7	2.55	1.3	4.7	4.67	0.03	0.03
86	*Sapindus trifoliatus*	1	1.02	1.0	0.2	0.96	0.5	1.8	1.76	0.01	0.01
87	*Saraca indica*	10	0.80	31.9	8.3	32.17	16.1	59.0	5.90	0.40	0.04
88	*Schefflera actinophylla*	1	0.41	1.9	0.5	1.88	0.9	3.4	3.44	0.02	0.02
89	*Senna siamea*	29	0.87	103.4	26.9	104.18	52.1	191.2	6.59	1.30	0.04
90	*Sesbania grandifolia*	11	0.51	46.9	12.2	47.26	23.6	86.7	7.88	0.59	0.05
91	*Spathodea campanulata*	29	0.64	81.3	21.1	81.94	41.0	150.4	5.18	1.02	0.04
92	*Spondias mombin*	1	0.37	3.9	1.0	3.92	2.0	7.2	7.19	0.05	0.05
93	*Swietenia macrophylla*	22	0.49	93.1	24.2	93.81	46.9	172.1	7.82	1.17	0.05
94	*Syzygium aromaticum*	1	0.70	0.8	0.2	0.82	0.4	1.5	1.51	0.01	0.01
95	*Syzygium cumini*	7	0.76	32.0	8.3	32.28	16.1	59.2	8.46	0.40	0.06
96	*Tabebuia rosea*	26	0.52	25.9	6.7	26.06	13.0	47.8	1.84	0.33	0.01
97	*Tamarindus indica*	2	1.28	10.1	2.6	10.19	5.1	18.7	9.35	0.13	0.06
98	*Tectona grandis*	125	0.72	552.9	143.8	557.29	278.6	1022.6	8.18	6.97	0.06
99	*Terminalia catappa*	93	0.52	150.2	39.1	151.45	75.7	277.9	2.99	1.89	0.02
100	*Terminalia paniculata*	15	0.75	75.6	19.7	76.24	38.1	139.9	9.33	0.95	0.06
101	*Thuja occidentalis*	1	0.53	2.1	0.5	2.07	1.0	3.8	3.80	0.03	0.03
102	*Vateria indica*	14	0.48	9.8	2.5	9.85	4.9	18.1	1.29	0.12	0.01
103	*Ziziphus mauritiana*	2	0.76	3.8	1.0	3.83	1.9	7.0	3.51	0.05	0.02
104	*Unidentified Species*	177	0.60	542.8	141.1	547.1	273.6	1004.0	5.7	5.5	0.03
	Total	**1686**				**4594.6**	**2297.3**	**8431.1**		**84.31**	

Note: Total number of unidentified species is 67 which includes 177 different unidentified species. N: Number of trees; S: Wood density in g/cm^3; AGB; above-ground biomass in Kg; BGB: below-ground biomass in Kg; TB: total biomass in Kg; CC: carbon content; CS: Carbon sequestered; CSR: Carbon sequestration rate. All the mass measurements are in Kg.

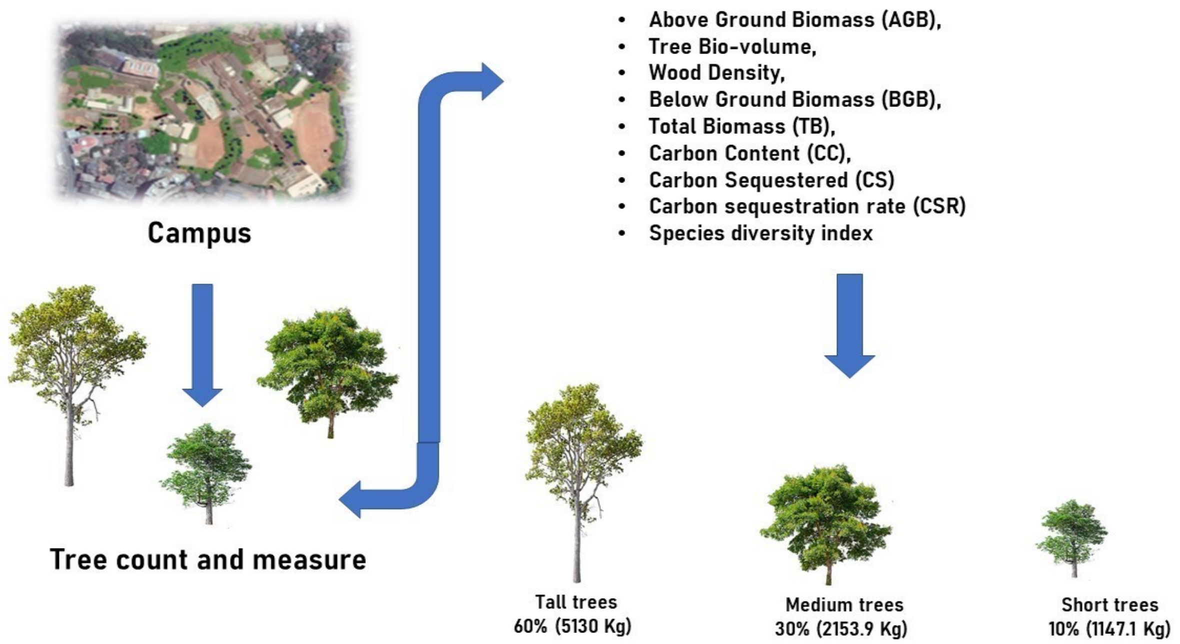

Fig. 3. Graphical abstract of assessment of carbon sequestration and tree diversity study

Table 2. Total biomass, carbon sequestered and Carbon sequestration rate of Tree categories based on height and girth for the entire tree cover in the study area.

Tree categories	Girth	N	TB	CC	CS	CSR
Small trees (3 m average)	10	517	401.6	45.0	165.3	1.65
	25	74	117.5	268.1	983.8	9.84
	50	23	69.0	192.4	706.0	7.06
	75	9	37.0	81.4	298.8	2.99
Medium height (6 m average)	10	89	90.1	17.2	63.0	0.63
	25	248	536.1	231.9	851.0	8.51
	50	99	384.7	477.7	1753.3	17.53
	75	30	162.9	671.0	2462.7	24.63
Tall trees (10 m average)	10	27	34.3	200.8	737.0	7.37
	25	171	463.8	58.7	215.6	2.16
	50	200	955.5	34.5	126.6	1.27
	75	199	1342.1	18.5	67.9	0.68
Total		**1686**	**4594.6**	**2297.3**	**8431.1**	**84.31**

Note: N: Number of trees; TB: Total biomass in Kg; CC: Carbon content; CS: Carbon sequestered; CSR: Carbon sequestration rate. For ease of calculation, the approximate diameter for trees with a girth less than 50cm is taken as 10cm, girth with a range of 50 - 100 cm is taken as 25cm, and girth with a range of 100-200 cm is taken as 50 and above 200 cm is taken as 75cm. Similarly, trees are categorized approximately to their heights, with height less than 15' is taken as 3m, 15'-30' as 6m, and greater than 30' as 10m. Weight is measured in Kg.

(37), the higher the biomass and higher the occurrence of a particular species, the higher the green zone's capacity to sequester CO_2. Such green zones with large trees with high growth rates and long-life cycles within urban cities, act as carbon sinks and O_2 sources, that help retain the micro-environmental conditions of the areas by mitigating the increased amount of CO_2 in the surroundings.

Urban areas have exhibited considerable climatic variations due to the destruction of such green zones, unplanned urbanization, high levels of fossil fuel combustion, and deforestation (38-40). Additionally, there is a significant increase in atmospheric temperature due to elevated CO_2 and other "greenhouse" gases which is further aggravated by ill-managed and unplanned removal of green zones severely affecting CO_2 source/sink dynamics (37). In terms of atmospheric carbon reduction, trees in urban areas are major carbon sinks and store large amounts of carbon in organic form (41).

A practical solution for reviving and revitalizing the city is by reducing the rate of deforestation and implementing afforestation strategies for carbon sequestration services (42) and utilizing the extant green cover for its ecosystem services. Growing and conserving more extant indigenous trees within the cities will reduce atmospheric carbon dioxide through carbon sequestration and control the atmospheric carbon level (43). As development and urbanization are indispensable, an effort has to be made to plan and develop sustainably with minimal damage to the existing green cover. Various studies at local and global levels indicate diverse management strategies, the extent of plant biodiversity, and carbon sequestration contributions. It is dependent on the type of ecological settings, area sizes, preferences, and purposes (44). Efforts should also be made to undertake plantation and afforestation of indigenous trees to maintain the ecological character and the extant biodiversity of the region. The majority of the trees in the study area resembled that of the extant biodiversity. This not only helps in climate change adaptation and mitigation, nutrient cycling, soil and water conservation, but also pollination, food and nutrient availability, and habitat improvement, for the extant fauna that depend on the indigenous flora. Furthermore, Afforestation measures within the cities can compensate for urban spaces utilized to develop concrete structures after deforestation. Barren and fallow areas in the cities should be used for planting fruit-bearing or other indigenous forest trees, which will also ensure benefits from the tree produce, thereby leading to conservation efforts of green spaces. When conducted using local youth and college students, these exercises will ensure awareness among the masses, and large-scale projects can be taken up for community education programs. This exercise with better conservation efforts will help city planners in informed decision-making and better urban planning.

Conclusion

An urban educational campus study revealed a highly diverse tree flora with more than 169 different tree species. Such high diversity in educational campuses with extant tree flora can help the urban cities, as they act as significant carbon sinks and also help in conserving the extant regional biodiversity. This diverse tree flora sequesters 8431.1 Kg of CO_2, leading to a carbon sink of 2297.3 Kg of carbon (Fig 3). While tree species such as *Polyanthia longifolia*, *Cocos nucifera*, *Tectona grandis*, *Terminalia catappa*, and *Areca catechu* dominated the area, other species, namely *Olea europaea*, *Phoenix dactylifera*, *Acacia auriculiformis*, *Adenanthera pavonina*, *Moringa oleifera*, *Butea monosperma*, *Tamarindus indica*, and *Bombax ceiba* were found to be low in numbers. However, these numerically limited species are known to have high sequestration potential and CSR. Hence, care and appropriate management of such trees should be considered while making any decisions about land utilization of the area. The study elucidates the role of educational campuses in urban centres as effective carbon sinks. Also, it demonstrates that non-destructive biostatistics-based methods can help appropriately evaluate the carbon sequestration rate of extant tree flora. With appropriate planning and implementation, similar models of campuses can be developed for green cover enhancement in urban environments.

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Authors' contributions

All authors contributed to the study's conception and design. SH provided the intellectual input, resources and guidance for the research carried out. SM and SS executed the field survey. SM performed the data analysis, manuscript preparation and prepared all figures and tables. The first draft of the manuscript was written by SM and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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