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# Assessment of Diversity and CSR of a Model Urban Green Cover of Mangalore City

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## Abstract

**The extant green cover in a 138 years old St Aloysius College campus in the city of Mangalore, Karnataka, India, was used as a model to study tree diversity and carbon sequestering rate, using a non-destructive biostatistics based method. The campus was found to constitute a highly diverse tree flora with a Shannon diversity index of 4.07. A total of 169 different tree species were found in the green cover of the campus, having an average population size of 9.98 per species and covering 4.67 ha of the total area of the campus with 361.03 trees/ha of the entire green cover. Five tree species, namely *Polyanthia longifolia, Cocos nucifera, Tectona grandis, Terminalia catapa* and *Areca catechu* dominated the area. Using allometric equations, the total green cover in the campus area was found to have total biomass of 4594.6 kg, which has sequestered 8431.1 kg of carbon at a Carbon Sequestration Rate (CSR) 84.31 kg of carbon per year. *Olea europaea* and *Phoenix dactylifera,* with the highest CSR of 0.09 and 0.08, respectively, were found to have the highest sequestered carbon with 12.54 kg and 11.19 kg of carbon.**

***Keywords: Diversity index; GPS mapping; Biomass estimation; Tree diversity; Carbon sequestration***

**Abbreviations:** AGB: Above Ground Biomass; BGB: Below Ground Biomass; CSR: Carbon Sequestration Rate; GBH: The girth of the tree is measured at breast height; TB: Total Biomass; WD: Wood Density

## Introduction

The green cover of a city is an intangible aspect usually considered for aesthetics and as a process of beautification. Still, it's crucial functions to the ecosystem are always neglected and undervalued, which has led to the destruction of most of the city's green cover in favor of utilizing the urban land for further development, 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 as they continue to grow [1]. Carbon sequestration and fixing carbon by trees during photosynthesis act as a sink and play a crucial role in absorbing 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 $CO_2$ (a major greenhouse gas) removal, the cities have turned into urban heat islands, making them unliveable [2].

The urban green cover often tends to be characterized by high levels of diversity and microhabitat heterogeneity, with large proportions of exotic species and constitute critical biodiversity hotspots. Thus, the destruction of green cover impacts the distribution of biodiversity for multiple taxa (Cornelis and Hermy). Despite its importance and significance, a limited number of

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studies on the urban green cover diversity and carbon sequestration potential have been conducted in the cities of India. According to Nagendra and Gopal, 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. Hence a model study was conducted for a 138 years old campus of St Aloysius college in the city of Mangalore Karnataka, India, to assess the tree diversity and its carbon sequestering rate using a non-destructive biostatistics based method. This study will provide us with a small scale insight into the potential of small urban green cover with diverse flora as effective carbon sinks [3,4].

## Materials and Methods

**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 Simpsons dominance index (Simpson), Shannon diversity and evenness indices were calculated using PAST (v3.17) statistical software [5-8].

**Valuation of Carbon Sequestration Rate (CSR) of the tree cover in the campus:** In the current study, a non-destructive method for carbon estimation is employed, which has been demonstrated in other research studies conducted in India. Trees were sampled with respect to their approximate height and girth in meters. Using allometric equations and conversion factors from the research literature, the biomass of the tree species was calculated [9,10]. As biomass estimations are species specific and hence the current study used the most suitable model developed by brown. The Above Ground Biomass (AGB) was calculated by using the Eq. (1)

$$\hat{Y} = \exp\{-2.4090 + 0.9522\, In\,(T_{bv})\}$$

$$T_{bv} = S \times D^2 \times H$$

Where $T_{bv}$ is Tree bio volume (2), S is the wood density of respective tree species, D is tree diameter (measured by dividing the tree girth at breast height with 3.14) and H is the height of tree species. Wood density (S) of each tree species is used from the global wood density database. The standard average density of 0.6 gm/cm$^3$ is applied wherever S value is not available 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 [11,12].

$$BGB = ABG \times 0.26$$

A factor of 0.8 is multiplied to open grown urban trees to calculate the Total Biomass (TB),

$$TB = (AGB + BGB)\ \mathrm{X}\ 0.8$$

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

$$CC = TB/2$$

To determine the weight of Carbon Sequestered (CS) in a tree was multiplying CC to 3.67 (ratio of the atomic weight of $CO_2$ to C),

$$CS = CC \times 3.67$$

The CSR was calculated as 1% of standing biomass.

## Results 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 constituting more than 169 different tree species having an average population size of 9.98 per species. The details of the mapped trees species and their distribution are shown in Figure 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 [13-18].

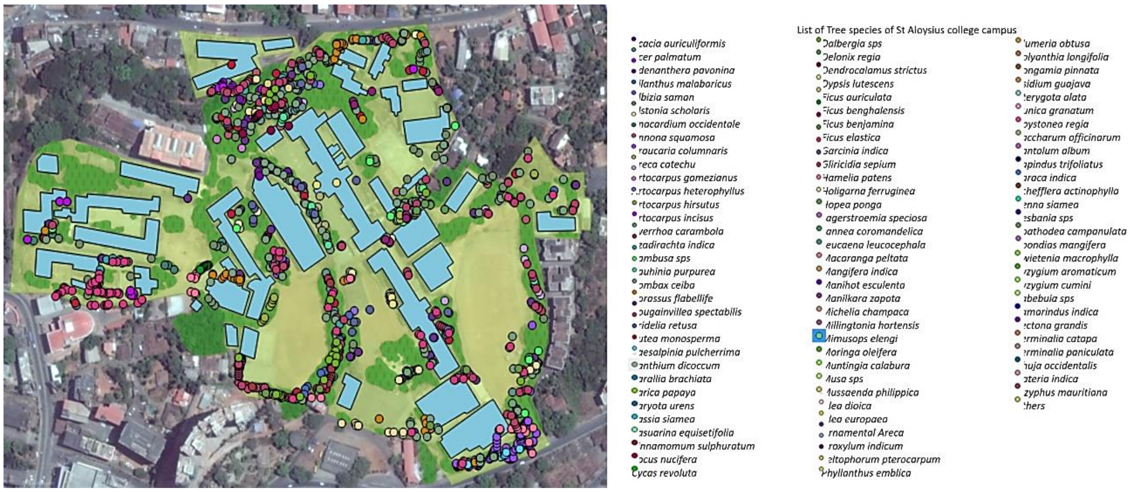


FIG. 1. **Distribution of the extant tree species present in the campus are shown as coloured dots representing each species. The blue colour blocks are concrete structures within the campus while the green region depicts the green cover.**

To place this into context, the study of Salish found 491.09 trees/ha in the core southern regions of Western Ghats in Karnataka, which constituted 234 different trees species. The density of 361.03 trees/ha found in the current study is understandably lower than the density (491.09 trees/ha) of trees in the Western Ghats, as the current study area is in the center of an urban city of Mangalore. Nonetheless, this is significantly higher than studies conducted in urban parks and campuses in Bangalore, IIT Madras, North Maharashtra university and Pune city [19,20].

Although, tree species diversity of the campus was high, indicated by a high Shannon diversity index of 4.07, a Simpson's dominance index of 0.97 revealed that a few representative species dominated the area numerically. This was also found to be in concord with the values found from the Evenness index of 0.35. The Gini Coefficient (GC) for the area of study was found to be 0.71, which also indicated more towards inequality in the wealth of distribution of the tree species on the campus. The information of all the tree species with the total number of trees per species present in the study area is given in Table 1.

TABLE 1. **Total amount of Carbon sequestered and Carbon sequestration rate per annum of every tree species present in the study area.**

| 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 | 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 | 0.4 | 9.6 | 2.5 | 9.7 | 4.9 | 17.8 | 8.9 | 0.12 | 0.06 |
| 4 | *Ailanthus triphysa* | 12 | 0.3 | 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 | 10.4 | 40.33 | 20.2 | 74 | 5.29 | 0.5 | 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 | 16.2 | 8.1 | 29.7 | 1.98 | 0.2 | 0.01 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | *Areca catechu* | 80 | 0.88 | 79.5 | 20.7 | 80.1 | 40.1 | 147 | 1.84 | 1 | 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 | 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 | 0.6 | 5.4 | 1.4 | 5.4 | 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 | 0.6 | 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 | 6.27 | 0.47 | 0.04 |
| 19 | *Bombax ceiba* | 1 | 0.35 | 3.8 | 1 | 3.83 | 1.9 | 7 | 7.03 | 0.05 | 0.05 |
| 20 | *Borassus flabellifer* | 16 | 0.87 | 55.5 | 14.4 | 55.99 | 28 | 102.7 | 6.42 | 0.7 | 0.04 |
| 21 | *Bougainvillea glabra* | 11 | 0.56 | 15.8 | 4.1 | 15.87 | 7.9 | 29.1 | 2.65 | 0.2 | 0.02 |
| 22 | *Bridelia retusa* | 1 | 0.5 | 3.6 | 0.9 | 3.59 | 1.8 | 6.6 | 6.6 | 0.04 | 0.04 |
| 23 | *Butea monosperma* | 1 | 0.56 | 3.7 | 1 | 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 | 1 | 4.03 | 2 | 7.4 | 7.4 | 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 | 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 | 0.8 | 3.03 | 1.5 | 5.6 | 2.78 | 0.04 | 0.02 |
| 31 | *Casuarina equisetifolia* | 4 | 0.96 | 14 | 3.6 | 14.09 | 7 | 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 | 0.5 | 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 | 0.5 | 339.7 | 88.3 | 342.42 | 171.2 | 628.3 | 4.87 | 4.28 | 0.03 |
| 36 | *Coreopsis lanceolata* | 1 | 0.6 | 1 | 0.3 | 1.03 | 0.5 | 1.9 | 1.88 | 0.01 | 0.01 |
| 37 | *Cycas revoluta* | 9 | 0.5 | 15 | 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 | 0.7 | 191 | 49.7 | 192.53 | 96.3 | 353.3 | 6.93 | 2.41 | 0.05 |
| 40 | *Dendrocalamus strictus* | 9 | 0.6 | 13.9 | 3.6 | 13.97 | 7 | 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 | 10.9 | 2.73 | 0.07 | 0.02 |
| 43 | *Ficus benghalensis* | 8 | 0.59 | 38.5 | 10 | 38.81 | 19.4 | 71.2 | 8.9 | 0.49 | 0.06 |
| 44 | *Ficus carica* | 5 | 0.52 | 7.6 | 2 | 7.62 | 3.8 | 14 | 2.8 | 0.1 | 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 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 50 | *Gliricidia sepium* | 3 | 0.74 | 5 | 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 | 0.6 | 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 | 5.2 | 2.6 | 9.5 | 9.55 | 0.07 | 0.07 |
| 54 | *Hopea ponga* | 4 | 0.6 | 13.4 | 3.5 | 13.52 | 6.8 | 24.8 | 6.2 | 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 | 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 | 0.6 | 190.6 | 49.6 | 192.13 | 96.1 | 352.6 | 9.04 | 2.4 | 0.06 |
| 59 | *Magnolia champaca* | 2 | 0.6 | 2 | 0.5 | 2.05 | 1 | 3.8 | 1.88 | 0.03 | 0.01 |
| 60 | *Mangifera indica* | 54 | 0.68 | 159 | 41.3 | 160.28 | 80.1 | 294.1 | 5.45 | 2 | 0.04 |
| 61 | *Manihot esculenta* | 1 | 0.48 | 0.7 | 0.2 | 0.7 | 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 | 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 | 0.3 | 17.4 | 4.5 | 17.55 | 8.8 | 32.2 | 1.69 | 0.22 | 0.01 |
| 68 | *Musa paradisica* | 14 | 0.5 | 15.7 | 4.1 | 15.85 | 7.9 | 29.1 | 2.08 | 0.2 | 0.01 |
| 69 | *Olea dioica* | 2 | 0.75 | 2 | 0.5 | 1.97 | 1 | 3.6 | 1.81 | 0.02 | 0.01 |
| 70 | *Olea europaea* | 7 | 0.7 | 47.5 | 12.3 | 47.84 | 23.9 | 87.8 | 12.54 | 0.6 | 0.09 |
| 71 | *Ornamental Areca* | 16 | 0.6 | 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 | 0.6 | 108 | 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 | 9.2 | 4.6 | 16.9 | 2.82 | 0.12 | 0.02 |
| 76 | *Plumeria alba* | 2 | 0.8 | 2.7 | 0.7 | 2.72 | 1.4 | 5 | 2.49 | 0.03 | 0.02 |
| 77 | *Polyanthia longifolia* | 157 | 0.6 | 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 | 123.1 | 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 | 0.6 | 4.3 | 1.1 | 4.37 | 2.2 | 8 | 4.01 | 0.05 | 0.03 |
| 83 | *Saccharum officinarum* | 2 | 0.6 | 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 | 77.2 | 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 | 0.2 | 0.96 | 0.5 | 1.8 | 1.76 | 0.01 | 0.01 |
| 87 | *Saraca indica* | 10 | 0.8 | 31.9 | 8.3 | 32.17 | 16.1 | 59 | 5.9 | 0.4 | 0.04 |
| 88 | *Schefflera actinophylla* | 1 | 0.41 | 1.9 | 0.5 | 1.88 | 0.9 | 3.4 | 3.44 | 0.02 | 0.02 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 89 | *Senna siamea* | 29 | 0.87 | 103.4 | 26.9 | 104.18 | 52.1 | 191.2 | 6.59 | 1.3 | 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 | 150.4 | 5.18 | 1.02 | 0.04 |
| 92 | *Spondias mombin* | 1 | 0.37 | 3.9 | 1 | 3.92 | 2 | 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 | 0.7 | 0.8 | 0.2 | 0.82 | 0.4 | 1.5 | 1.51 | 0.01 | 0.01 |
| 95 | *Syzygium cumini* | 7 | 0.76 | 32 | 8.3 | 32.28 | 16.1 | 59.2 | 8.46 | 0.4 | 0.06 |
| 96 | *Tabebuia rosea* | 26 | 0.52 | 25.9 | 6.7 | 26.06 | 13 | 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 catapa* | 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 | 3.8 | 3.8 | 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 | 3.83 | 1.9 | 7 | 3.51 | 0.05 | 0.02 |
| 104 | Unidentified species | 177 | 0.6 | 542.8 | 141.1 | 547.1 | 273.6 | 1004 | 5.7 | 5.5 | 0.03 |
| | Total | 1686 | | | | 4594.6 | 2297.3 | 8431.1 | | 84.31 | |

Note: Total number of unidentified species is 177 which include 67 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.

Five tree species, namely *Polyanthia longifolia* (157), *Cocos nucifera* (129), *Tectona grandis* (125), *Terminalia catapa* (93), and *Areca catechu* (80), dominated the tree population in the area (Figure 2). These trees were fairly distributed throughout the entire 4.67 ha of green cover in the campus. These tree species have been reported to dominate similar geographic regions such as Karwar in the state of Karnataka, which resemble an evergreen and semi evergreen forest type and are found on the western belt of the Western Ghats in the State of Karnataka. This indicates that even though the majority of the 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 has been undisturbed and retained with indigenous tree species [21-24].

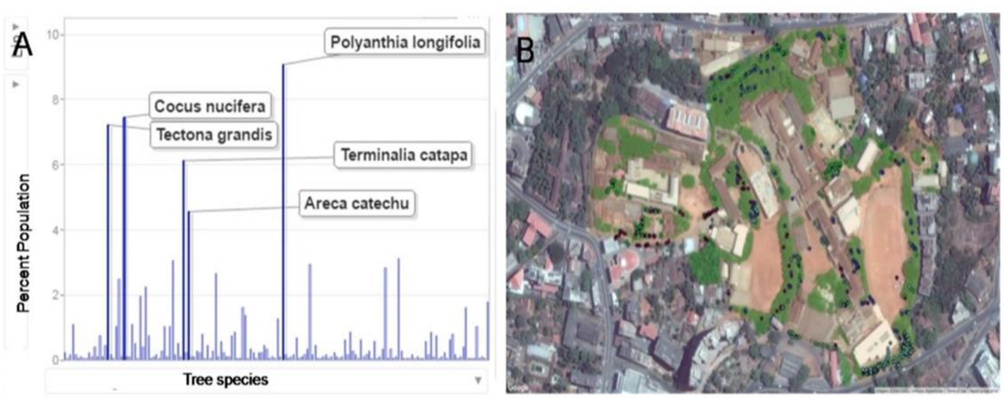


FIG. 2. **(A). The five numerically dominant tree species of the campus; (B) showing the distribution of the dominant species throughout the green zones of the campus.**

**CSR of the tree cover in the campus**

The entire tree cover constituting 1686 trees in the campus was found to have total biomass of 5494.6 kg, which has sequestered 8431.1 kg of $CO_2$, leading to a carbon content of 2297.3 kg. The CSR for the calculated biomass of green cover was found to be 84.31 kg of carbon per year. The amount of carbon sequestered by each individual tree species is also given in Table 1. Three tree species which 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, respectively, with CSR of 6.97, 4.28 and 2.97 kg/annum respectively. *Tectona grandis* (1022.6 kg) and *Cocos nucifera* (628.3 kg) also 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 found to have 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 very less in numbers in the study area and contributed lowly to the total carbon sequestrated, these trees, along with *Moringa oleifera, Butea monosperma, Tamarindus indica* and *Bombax ceiba* have been reported to be major contributors to carbon sequestration in other educational campus and parks in India. These species with high wood density are important, and even though these are less in numbers as these trees can sequester a significant amount of carbon per tree.

The trees within the campus are 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 (>10 m in height) of the campus sequestered maximum carbon of around 60% (5130 kg) compared to the medium and small trees, which sequestered 30% (2153.9 kg) and 10% (1147.1 kg) of carbon from 8431.1 kg of total carbon sequestered by the tree cover in the entire campus. It was also noted that large trees with bigger girth sequestered more carbon as compared to those with less. The amount of carbon sequestered decreased with the decrease in tree girth as the trees with girth more than 75 m in diameter sequestered 2829.5 kg of carbon, followed by 50 m (2585.9 kg), 25 m (2050.4 kg) and 10 m (965.3 kg) in diameter. Das and Mukherjee and Sahu also found a positive correlation between GBH and carbon storage potential. This is also in alignment with the findings of Nowak and Crane. It indicates the high amount of carbon sequestered for biomass growth by the larger trees with high girth compared to those with low girth. In urban green zones, as per the results of Prabha, the higher the biomass and higher the occurrence of a particular species, the higher is the capacity of the green zone to sequester $CO_2$. Such kind of green zones with large trees with high growth rates and long life cycles within urban cities not only act as carbon sinks and $O_2$ sources but also help retain the micro environmental conditions of the areas by mitigating the increased amount of $CO_2$ in the surrounding.

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 | 165.3 | 1.65 |
| | 25 | 74 | 117.5 | 268.1 | 983.8 | 9.84 |
| | 50 | 23 | 69 | 192.4 | 706 | 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 approximate diameter for trees with girth less than 50 cm is taken as 10 cm, girth with range 50-100 cm is taken as | | | | | | |

25 cm, girth with range 100-200 cm is taken as 50 and above 200 cm is taken as 75 cm. Similarly trees are categorized approximately to their heights; with height less than 15 is taken as 3 m, 15-30 as 6 m and greater than 30 as 10 m. Weight is measured in Kg.

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. Additionally, increasing levels of atmospheric temperature due to elevated amounts of $CO_2$ and other ‘‘greenhouse’’ gases is a major issue. Ill managed and unplanned removal of green zones along with high fossil fuel emissions has severely affected $CO_2$ source/sink dynamics. In terms of atmospheric carbon reduction, trees in urban areas are major carbon sinks and store large amounts of carbon in organic form.

A practical solution for reviving and revitalizing the city is by reducing the rate of deforestation for city services which leads to the release of stored carbon and utilizing the extant green cover for its ecological services. Growing and conserving more extant indigenous trees within the cities will control the carbon level of the atmosphere. As development and urbanization is indispensable, an effort has to be made to plan and develop sustainably with minimal damage to the existing green cover and plant more indigenous trees for maintaining the ecological character and the extant biodiversity of the region. Urban spaces utilized for the development of concrete structures after deforestation can be compensated by afforestation measures within the cities. Barren and fallow spaces in the cities should be utilized 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. These exercises, when conducted using local youth and college students, will ensure awareness among the masses as well as large scale projects can be take up to result in better and informed decision making.

## Conclusion

The study of an urban educational campus 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 major carbon sinks and also help in conserving the extant regional biodiversity. This diverse tree flora was able to sequester 8431.1 kg of $CO_2$, leading to a carbon sink of 2297.3 kg of carbon. While the tree species such as *Polyanthia longifolia*, *Cocos nucifera*, *Tectona grandis*, *Terminalia catapa* 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. But these numerically limited species are known to have high sequestration potential and CSR, and hence care and appropriate management of such trees should be considered while taking any decisions towards land utilization of the area. The study elucidates the role of educational campuses in urban centers as effective carbon sinks and also 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 campi can be developed for green cover enhancement in urban environments.

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