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Standing Tree Biomass and Carbon Stocks of Trees Outside Forest (Pragati Sudhaama), Hyderabad, Telangana, India

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ABSTRACT
The carbon sequestration potential of the Trees outside Forests, owned by Pragati Sudhaama, has been analyzed which extend over 2500 acres in Proddatur village, Hyderabad, Telangana. The study area comprises three sites, viz., Pragati Green Meadows (1000 acres), Pragati Green Heights (700 acres) and Pragati Green Valley (800 acres). This study employed a non-destructive sampling method and examined 361 native and exotic tree species, comprising 1,56,818 individuals. This study evaluated a total biomass of 89,493.79 t (1,64,071.94 t CO_2e) for trees with a girth above 10 cm, comprising 1,25,041 individuals. Ten tree species account for 70% of the total biomass viz., *Azadirachta indica* with 5,928 individuals (20,645.98 t biomass), *Tectona grandis* with 9,561 (12,422.67 t), *Mangifera indica* with 39,184 (10,469.33 t), *Swietenia macrophylla* with 12,802 (8,506.48 t), *Phyllanthus emblica* with 3,145 (3,160.98 t), *Pongamia pinnata* with 1,886 (1,993.12 t), *Manilkara zapota* with 6,265 (1,900.55 t), *Syzygium cumini* with 1,593 (1,527.10 t), *Ficus religiosa* with 524 (1,462.07 t), *Ficus benjamina* with 2,405 (1,291.42 t). The tallest species are *Eucalyptus globulus*, *Pterygota alata*, and *Holoptelea integrifolia,* with 16 m, and the highest girth in *Ficus benghalensis* (4 m).

Key words: Standing biomass, TOF, Carbon sequestration Potential, Block plantattion

INTRODUCTION

In the present climate change scenario, carbon sequestration studies play a significant role in understanding the role of trees in reducing carbon dioxide emissions in the atmosphere. Climate change is one of humanity's most important issues (Akintunde-Alo et al. 2024). Increased atmospheric levels of carbon dioxide and the ability of the terrestrial biosphere to sequester and store atmospheric carbon dioxide have been recognized as an effective and low-cost method of mitigating carbon emissions (Srinivasa Rao et al. 2012).

Over the past 150 years, land use changes have been responsible for 33% of global carbon emissions; plantations play a crucial role in land rehabilitation, soil and water conservation, carbon sequestration, and socioeconomic benefits; thus, the potential carbon stock in plantations should be assessed to understand their role in mitigating climate change, particularly in regions where natural forests have been converted into plantation areas (Dabi et al. 2021). Reduction in carbon dioxide concentrations in the atmosphere can be achieved by reducing the demand for energy, altering the usage of energy, or increasing the rates of removal of CO2 through carbon sequestration, which can decrease the atmospheric carbon dioxide naturally (Sharma et al. 2021). Understanding carbon stocks in natural forests or plantations is critical for forest management to minimize climate change, biodiversity loss, and settling conflicts over multiple landuses (Akintunde-Alo et al. 2024). Apart from forest ecosystems, trees outside forests also have great potential in the sequestration of atmospheric carbon (Ramanjaneyulu et al. 2021).

Trees Outside Forests (TOF) are the trees that are neither categorized as 'forest' nor 'other wooded land' irrespective of their patch size (Anonymous 2010, Ramanjaneyulu et al. 2021) and include agricultural land (including meadows and pastures), built-on land (including settlements and infrastructure) and barren land (including dunes and rocky outcroppings), orchards and plantations. TOF are classified into linear, scattered and block categories. As the obligations from international conventions have also made it necessary to conduct TOF assessment, particularly the United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention on Biological Diversity (UN CBD) have urged keeping up to date information on tree resources within and outside forests (Beckschafer et al. 2017).

Manasa et al. (2016) reported that the establishment of plantations to mitigate increased CO_2 in the atmosphere is one of the key options for reducing global warming, as trees are important sinks for atmospheric carbon dioxide and 50 percent of their standing biomass is carbon itself; efforts have been made to calculate the amount of CO_2 sequestered by planted trees with specific silvicultural treatments. In tropical countries, there is increasing interest in establishing mixed native species plantations for various sustainability objectives. When diversified species are established, they balance the impacts of ecological disturbance and climate change by providing localities with more resilient forests (Anbarashan et al. 2019). India has pledged to reduce total projected carbon emissions by up to 1 billion tons by 2030, apart from other ambitious climate change targets agreed in the COP26 summit in Glasgow, 2021; according to the Fourth Assessment Report of the Intergovernmental Panel on Climatic Change (IPCC), scanty information is available concerning the biomass, carbon stock/sequestration potential of both natural forests and trees outside forests at national and regional levels (Panwar et al. 2022).

The rate of carbon sequestration by the plantations has also become an important concern in considering its effects and calculating carbon credits during climate change negotiations (Dabi et al. 2021). The plantation can be a good substitute for obtaining higher biomass in addition to its ecological services, but it cannot be as biologically rich as a natural forest (Manoj Kumar et al. 2018). Repeated sampling of a plantation over the long term is likely to yield more accurate biomass or carbon accumulation (Semwal et al. 2013). The conversion of arable land to forests also implies a change from shorter to longer carbon residence time (Rytter et al. 2012).

Fast-growing tree species are considered a viable way to reduce atmospheric carbon because they can sequester carbon for a long time (Chauhan et al. 2019). Sharma et al. (2020) estimated the carbon stock in *Pinus roxburghii* plantations. They observed that the tree DBH, height, basal area, and biomass were the determining variables for forest cover, positively affecting the forest carbon stock. In contrast, tree density does not affect forest carbon stock. In India, exotics like *Acacia mangium* Willd. and moderately fast-growing native trees like *Gmelina arborea* (Swamy and Sunil 2005) are important due to their enormous growth potential and capacity to produce large amounts of biomass (Rocha et al. 2017).

Our earlier research estimated standing biomass and carbon stocks in diversified ecosystems in Andhra Pradesh. This includes, carbon stocks of Nallamalais (Srinivasa Rao et al. 2013, Srinivasa Rao and Rao 2015), carbon stocks across forest types of southern Andhra Pradesh (Priyadarsini and Rao 2013) carbon stocks of TOF Kurnool District (Rao et al. 2013, Ramesh et al. 2015), carbon stocks of *Croton scabiosus* (Salamma et al. 2016), carbon stocks of TOF of Anantapuramu District (Ramesh et al. 2016, Kavitha et al. 2016, 2017), carbon stocks of TOF in Prakasam District (Dabbara et al. 2022). The present study analyzed the carbon sequestration potential of Pragati Sudhaama, a TOF site located near Hyderabad, India.

MATERIAL AND METHODS

Study area

The study was conducted at Pragati Sudhaama Estates, situated near Proddatur Village in the Ranga Reddy district of Telangana. The plantations were established in 1999 and cover 2500 acres (1000 ha). The study area comprises three sites: Site -I (Green Meadows), spanning 1000 acres, located at 17°232 173 N and 78°102 523 E; Site -II (Green Heights), spanning 700 acres, situated at 17°222 433 N and 78°112 053 E; and Site -III (Green Valley), spanning 800 acres, positioned at 17°222 063 N and 78°132 243 E. (Fig. 1). The soil in the region is predominately red, and the area experiences a tropical, semi-arid climate with average daily temperatures ranging from 26 to 38°C and an average annual rainfall of 833 mm.

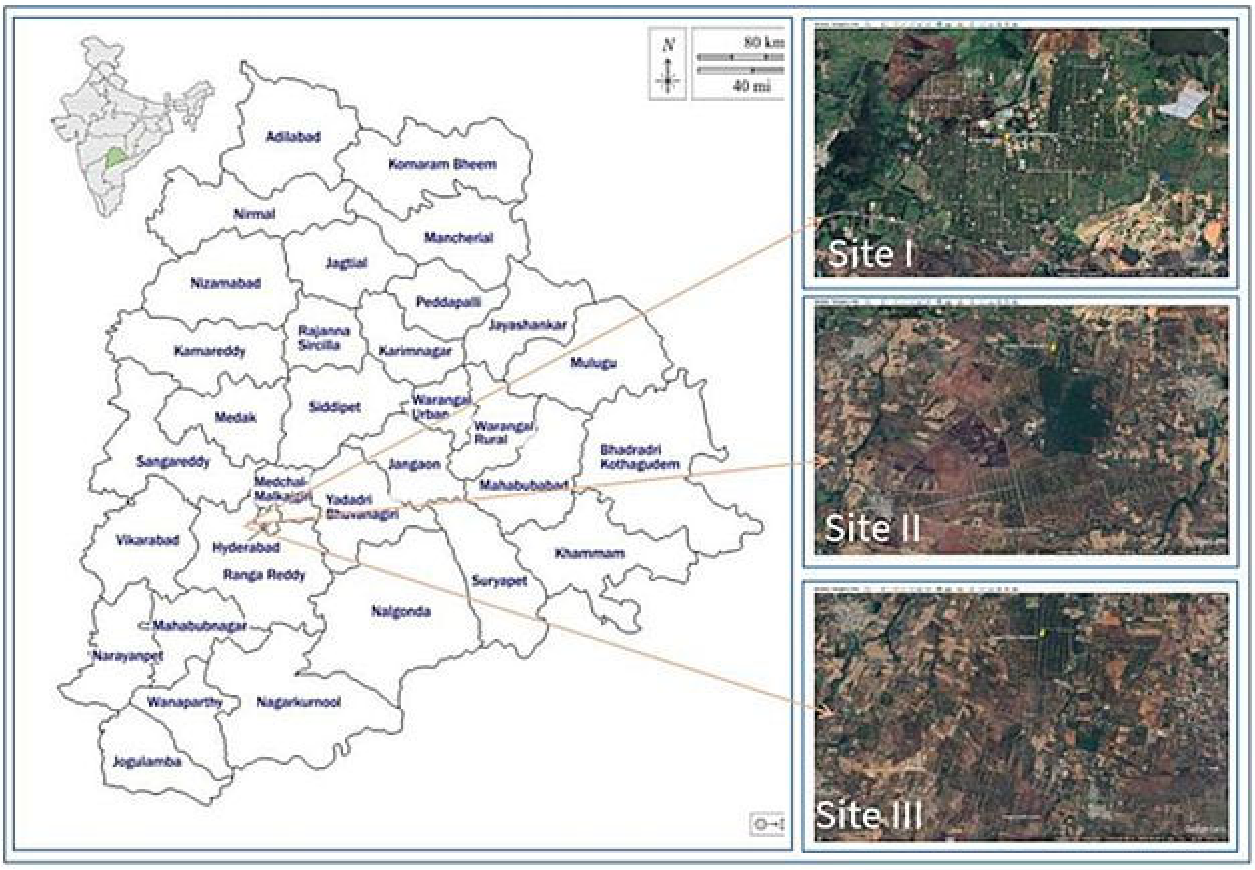

Figure 1. Satellite images of study area Site I- Pragati Green Meadows (PGM), Site II-Pragati Green Heights (PGH), Site III- Pragati Green Valley (PGV)

Exploration, Documentation and Calculation

Field explorations were held for a period of two years (2022-2024). Tree height (m) and girth at breast height (cm) of each tree in the study area were recorded using a hypsometer and a measuring tape, respectively, from 2022 to 2024 in Microsoft Excel. Representative specimens of tree species were collected, and herbarium was prepared following standard methods and identified using standard references (Bose et al. 1998, Pullaiah 2015, Reddy et al. 2021). The nomenclature was updated following Anonymous (2025b), and species under different threat categories were identified following IUCN protocols (Anonymous 2025a).

Species-wise biomass was estimated using a non-destructive method. Specific gravity (wood density) values of different species available from earlier works (Reyes et al. 1992, D'Souza et al. 1996, Anonymous 1996, Kanawjia et al. 2013, Saravanan, 2016, Pati et al. 2022, 2025) were used. Trees were grouped into eight height classes, viz., 0.1-2, 2.1-4, 4.1-6, 6.1-8, 8.1-10, 10.1-12, 12.1-14, and 14.1-16 m, and eight GBH classes, viz., 10-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, and 351-400 cm girth at breast height. Above-ground biomass (AGB) was calculated using the tree volume and wood density. Below-ground biomass (BGB) was calculated using above-ground biomass and a default conversion factor of 0.26. The biomass values were converted to tonnes of above-ground carbon (AGC) and below-ground carbon content using a conversion factor of 0.5 (half of the biomass). The quantum of carbon dioxide was estimated using the formula:

$$\text{Quantum of } CO_2 = (\text{Quantum of carbon} \times 44)/12$$

where 44 is the molecular weight of CO_2, 12 is the atomic weight of carbon.

RESULTS AND DISCUSSION

In the present study, a total of 1,56,818 individual trees belonging to 361 species, including native (182 species), exotic (174 species) and hybrids (6),

Table 1. Categorical details of the study area

Variables	Site-I (PGM)	Site-II (PGH)	Site-III (PGV)	TOTAL
Number of species	340	149	125	361
Genera	229	121	99	239
Families	66	38	37	66
Number of individuals (>10 cm girth)	49,327	43,345	32,369	1,25,041
Biomass (t)	49,794.85	19,337.76	20,361.18	89,493.79
Carbon (t)	24,897.42	96,68.88	10,180.59	44,746.89
CO_2e (t)	91,290.56	35,452.56	37,328.83	16,4071.95

PGM: Pragati Green Meadow, PGH: Pragati Green Heights, PGV: Pragati Green Valley

representing 239 genera and 66 families, were within the study area. Site-I accounted for 63,790 individual trees belonging to 340 species representing 66 families, and the most prominent family is Fabaceae with 64 species, followed by Malvaceae (22), Arecaceae and Moraceae (21 each), and Bignoniaceae (15). Site-II has 53,874 individuals belonging to 149 species from 39 families and the most prominent family is Fabaceae with 35 species, followed by Arecaceae (12), Bignoniaceae (10), Malvaceae (8), and Moraceae (7). Site-III recorded 39,154 individuals belonging to 125 species from 37 families, and the most prominent family is Fabaceae with 27 species, followed by Malvaceae (9), Moraceae and Arecaceae with six species each. Of the 361 taxa, 9 are gymnosperms representing four families; 352 are angiosperms representing 62 families. Endemic and threatened native species encountered are *Commiphora wightii* (Arn.) Bhandari (Critically Endangered), *Pterocarpus santalinus* L.f. and *Tectona grandis* L.f. (Endangered), *Chloroxylon swietenia* DC., *Dalbergia latifolia* Roxb., *Mesua ferrea* L., *Santalum album* L., *Saraca asoca* (Roxb.) W.J.de Wilde and *Vateria indica L.* (Vulnerable). Endemic and threatened exotic species include *Amherstia nobilis* Wall. and *Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Sweet (Extinct in the Wild), *Araucaria araucana* (Molina) K.Koch, *Coffea arabica* L., *Guaiacum officinale* L. and *Swietenia macrophylla* King (Endangered), *Adonidia merrillii* (Becc.) Becc., *Cinnamomum verum* J.Presl., *Handroanthus chrysanthus* (Jacq.) S.O.Grose, *Jacaranda mimosifolia* D.Don and *Khaya senegalensis* (Desr.) A.Juss. (Vulnerable).

The total biomass recorded from the study area is 89,493.78 t and 1,64,071.94 t of CO_2e of trees with a girth above 10 cm, comprising 1,25,041 individuals. The total biomass of site-I is 49,794.85 t, site-II is 19,337.76 t, and site-III is 20,361.18 t. The CO_2e values are 91,290.56 t for site-I, 35,452.56 t for site-II, and 37,328.83 t for site-III. Among the sites studied, the highest biomass and CO_2e are recorded for site-I (Table 1). Individuals with a diameter of less than 10 cm have biomass of 139.10 t.

Sixty-nine species attained biomass greater than 100 t (Table 2). Ten species, *Azadirachta indica* A. Juss. (20,645.98 t), *Tectona grandis* L.f. (12,422.67 t), *Mangifera indica* L. (10,469.33 t), *Swietenia macrophylla* King (8,506.48 t), *Phyllanthus emblica* L. (3,160.98 t), *Pongamia pinnata* (L.) Pierre (1,993.12 t), *Manilkara zapota* (L.) P. Royen (1900.55 t), *Syzygium cumini* (L.) Skeels (1,527.10 t), *Ficus religiosa* L. (1,462.07 t) and *F. benjamina* L. (1,291.42 t) together contributed 70% of the total biomass across the study area, i.e., 63,379.71 t of biomass (Fig. 2). Even though the number of individuals in *Azadirachta indica* (5,928) is less than those of *M. indica* (39,184), *S. macrophylla* (12,802), and *T. grandis* (9,561), the biomass is higher because of their height and girth values.

In the study area, 37 species are native, such as *Azadirachta indica* (Meliaceae), *Buchanania lanzan* Spreng. (Anacardiaceae), *Butea monosperma* (Lam.) Kuntze (Fabaceae), *Diospyros chloroxylon* Roxb. (Ebenaceae), *D. melanoxylon* Roxb. (Ebenaceae), *Morinda pubescens* Sm. (Rubiaceae), *Naringi crenulata* (Roxb.) Nicolson (Rutaceae), *Semecarpus anacardium* L.f. (Anacardiaceae), *Soymida febrifuga* (Roxb.) A.Juss. (Meliaceae), *Schrebera*

Table 2. Species attaining biomass greater than 100 t in the study area

Name of the species	Family	Biomass (t)	Carbon (t)	CO2e (t)
Azadirachta indica A.Juss.	Meliaceae	20,645.98	10,322.99	37,850.97
Tectona grandis L.f.	Lamiaceae	12,422.67	6,211.33	22,774.89
Mangifera indica L.	Anacardiaceae	10,469.33	5,234.67	19,193.78
Swietenia macrophylla King	Meliaceae	8,506.48	4,253.24	15,595.22
Phyllanthus emblica L.	Phyllanthaceae	3,160.98	1,580.49	5,795.12
Pongamia pinnata (L.) Pierre	Fabaceae	1,993.12	996.56	3,654.06
Manilkara zapota (L.) P.Royen	Sapotaceae	1,900.55	950.28	3,484.35
Syzygium cumini (L.) Skeels	Myrtaceae	1,527.10	763.55	2,799.68
Ficus religiosa L.	Moraceae	1,462.07	731.03	2,680.46
Ficus benjamina L.	Moraceae	1,291.42	645.71	2,367.61
Jacaranda mimosifolia D.Don	Bignoniaceae	1,246.80	623.40	2,285.81
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	1,059.43	529.72	1,942.29
Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	1,037.18	518.59	1,901.49
Roystonea regia (Kunth) O.F.Cook	Arecaceae	935.78	467.89	1,715.59
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	Fabaceae	923.59	461.79	1,693.25
Tabebuia rosea (Bertol.) DC.	Bignoniaceae	891.22	445.61	1,633.90
Tamarindus indica L.	Fabaceae	735.67	367.84	1,348.73
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae	570.95	285.48	1,046.74
Albizia procera (Roxb.) Benth.	Fabaceae	568.40	284.20	1,042.07
Grevillea robusta A.Cunn. ex R.Br.	Proteaceae	558.19	279.09	1,023.34
Madhuca longifolia var. *latifolia* (Roxb.) A.Chev.	Sapotaceae	557.27	278.63	1,021.65
Butea monosperma (Lam.) Kuntze	Fabaceae	509.89	254.94	934.79
Kigelia africana (Lam.) Benth.	Bignoniaceae	503.94	251.97	923.90
Mimusops elengi L.	Sapotaceae	500.97	250.49	918.45
Sterculia foetida L.	Malvaceae	492.55	246.27	903.01
Dalbergia sissoo Roxb. ex DC.	Fabaceae	464.64	232.32	851.84
Wodyetia bifurcata A.K.Irvine	Arecaceae	457.25	228.63	838.30
Leucaena leucocephala (Lam.) de Wit	Fabaceae	412.70	206.35	756.61
Bauhinia purpurea L.	Fabaceae	411.24	205.62	753.94
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	394.34	197.17	722.96
Khaya senegalensis (Desr.) A.Juss.	Meliaceae	383.31	191.65	702.73
Millingtonia hortensis L.f.	Bignoniaceae	380.18	190.09	696.99
Gliricidia sepium (Jacq.) Kunth	Fabaceae	372.35	186.17	682.64
Cocos nucifera L.	Arecaceae	369.12	184.56	676.72
Dalbergia latifolia Roxb.	Fabaceae	369.12	184.56	676.72
Putranjiva roxburghii Wall.	Putranjivaceae	356.51	178.25	653.59
Spathodea campanulata P.Beauv.	Bignoniaceae	350.30	175.15	642.22
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	333.02	166.51	610.54
Ficus benghalensis L.	Moraceae	324.41	162.21	594.75
Acacia auriculiformis A.Cunn. ex Benth.	Fabaceae	322.11	161.05	590.53
Wrightia tinctoria (Roxb.) R.Br.	Apocynaceae	301.25	150.62	552.29
Soymida febrifuga (Roxb.) A.Juss.	Meliaceae	300.56	150.28	551.03
Plumeria alba L.	Apocynaceae	275.97	137.98	505.94
Phoenix sylvestris (L.) Roxb.	Arecaceae	267.54	133.77	490.49
Santalum album L.	Santalaceae	249.38	124.69	457.20
Tabebuia aurea Benth. & Hook.f. ex S.Moore	Bignoniaceae	242.39	121.19	444.38
Millettia peguensis Ali	Fabaceae	239.93	119.97	439.87
Alstonia scholaris (L.) R. Br.	Apocynaceae	231.87	115.93	425.09
Pterospermum acerifolium (L.) Willd.	Malvaceae	205.64	102.82	377.01

Name of the species	Family	Biomass (t)	Carbon (t)	CO2e (t)
Caryota mitis Lour.	Arecaceae	204.03	102.01	374.05
Madhuca longifolia (L.) J.F.Macbr.	Sapotaceae	202.46	101.23	371.17
Plumeria rubra L.	Apocynaceae	196.74	98.37	360.69
Melia dubia Cav.	Meliaceae	166.12	83.06	304.56
Albizia lebbeck (L.) Benth.	Fabaceae	158.28	79.14	290.18
Corymbia citriodora (Hook.) K.D.Hill & L.A.S.Johnson	Myrtaceae	149.74	74.87	274.52
Ficus racemosa L.	Moraceae	146.24	73.12	268.12
Borassus flabellifer L.	Arecaceae	136.65	68.32	250.52
Buchanania lanzan Spreng.	Anacardiaceae	134.37	67.19	246.35
Bombax ceiba L.	Malvaceae	126.31	63.16	231.57
Chrysalidocarpus lutescens H.Wendl.	Arecaceae	123.14	61.57	225.76
Artocarpus heterophyllus Lam.	Moraceae	122.31	61.15	224.23
Crescentia cujete L.	Bignoniaceae	121.37	60.69	222.52
Aegle marmelos (L.) Correa	Rutaceae	120.15	60.07	220.27
Dendrocalamus strictus (Roxb.) Nees	Poaceae	116.49	58.24	213.56
Eucalyptus globulus Labill.	Myrtaceae	108.67	54.33	199.22
Cordia dichotoma G.Forst.	Boraginaceae	107.27	53.64	196.67
Filicium decipiens (Wight & Arn.) Thwaites	Sapindaceae	104.42	52.21	191.44
Bauhinia blakeana Dunn	Fabaceae	103.08	51.54	188.98
Pterocarpus marsupium Roxb.	Fabaceae	102.31	51.16	187.58

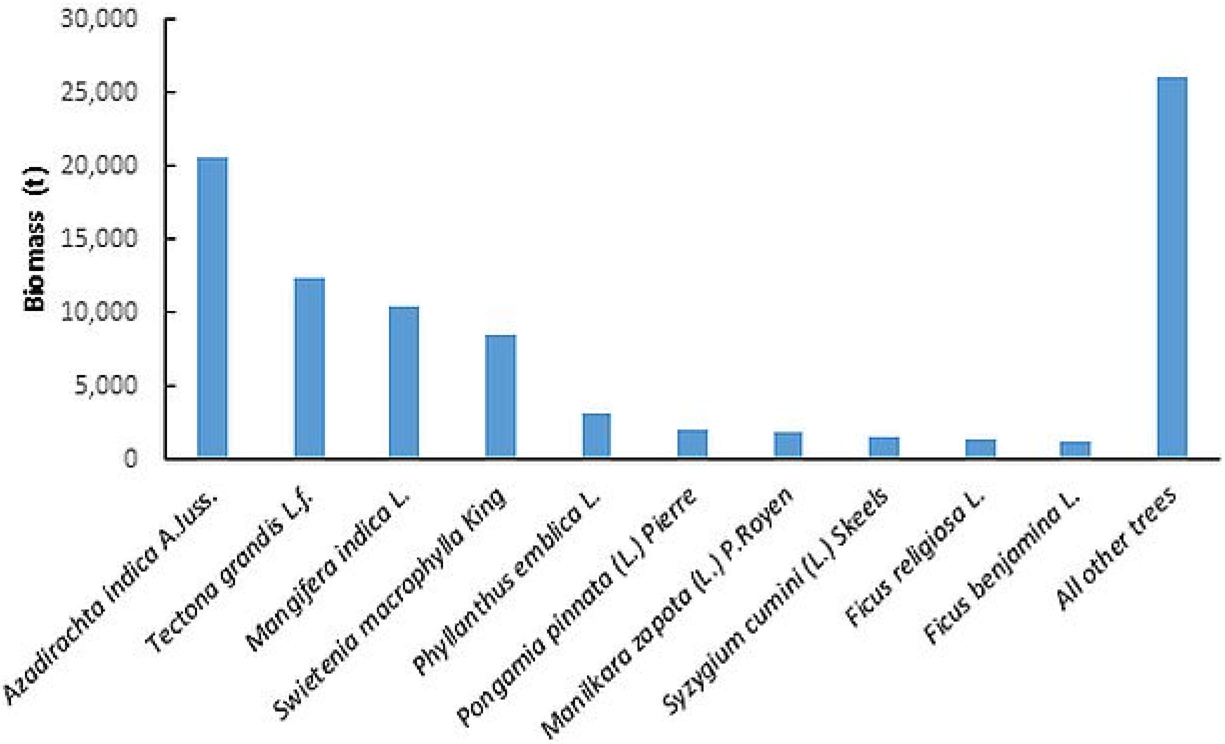

Figure 2. Biomass of top ten species and all other species together

swietenioides Roxb. (Oleaceae) and *Tamarindus indica* L. (Fabaceae).

The height class of 2.1-4 m had the highest number of individuals (62,716), while the least were found in the 14.1-16 m height class (Table 3). The tallest species recorded are *Eucalyptus globulus* Labill, *Pterygota alata* (Roxb.) R.Br., *Holoptelea integrifolia* (Roxb.) Planch. (16 m), *Khaya senegalensis* (Desr.) A.Juss., *Melia dubia* Cav., *Prosopis cineraria* (L.) Druce (15 m).

Girth class distribution pattern is important in understanding changes occurring in a plantation and

Table 3. Height class (HC) wise total number of individuals (TNI) across the study area

Height classes (m)	Height (m)	TNI
HC- I	0.1-2 m	380
HC- II	2.1-4 m	62716
HC- III	4.1-6 m	34870
HC- IV	6.1-8 m	21354
HC- V	8.1-10 m	4955
HC- VI	10.1-12 m	717
HC- VII	12.1-14 m	43
HC- VIII	14.1-16 m	6

appreciating differences in the structural pattern. GC -I constitute most individuals (1,08,247) compared to other girth classes (Table 4). The largest GBH (Girth at breast height) is recorded for *Ficus benghalensis* L. (400 cm), followed by *Adansonia digitata* L. (390 cm), *Ficus religiosa* L. (315 cm), *Madhuca longifolia* var. *latifolia* (Roxb.) A. Chev. (305 cm) and *Azadirachta indica* A. Juss. (275 m).

For the successful implementation of reforestation projects, it is necessary to have proper knowledge regarding species survival and growth rates in varied environmental conditions. Tree biomass depends on various factors like the type of species, girth class, density, age and locality. In our study, it is observed that the survival rate is about 75% and it is greater in indigenous species than exotics and a fast growth rate is observed among indigenous species like *Azadirachta indica, Ficus benghalensis, Ficus benjamina,* etc.

The native tree species attained greater girth and accumulated more biomass than certain exotics, even though they attained more height, viz., *Eucalyptus globulus* Labill (16 m), *Khaya senegalensis* (Desr.)

Table 4. Girth class (GC) wise total number of individuals (TNI) across the study area

Girth Classes	Diameter (cm)	TNI
GC - I	10 - 50 cm	108247
GC - II	51 - 100 cm	14967
GC - III	101 - 150 cm	1424
GC - IV	151 - 200 cm	313
GC - V	201 - 250 cm	70
GC - VI	251 - 300 cm	13
GC - VII	301 - 350 cm	4
GC - VIII	351 - 400 cm	3

A.Juss. (15 m). Similar results were observed by Jharia and Yadav (2018), who reported that a natural stand reflects the role of large trees in carbon capture and storage. In contrast, our results are lower than those Rocha et al. (2017) reported on mono plantation of *Acacia mangium* Willd. This is attributed to the varied age of the plantation, the type of plantation, various species, environmental conditions, and the density of the plantation. At the global and regional scale, potential forest biomass production and carbon density are determined mainly by climatic conditions, primarily temperature and water availability (Swamy and Sunil 2005, Omoro et al. 2013). According to Manasa et al. (2016), spacing strongly influences biomass production; closer spacing led to greater biomass production and greater crown diameter.

CONCLUSIONS

Pragati Sudhaama, the study area is highly diversified with 361 species and has a great potential as a carbon sink with a cumulative biomass of 89,493.79 t. Few dominant species have contributed substantially to the total biomass, including *Azadirachta indica*, *Tectona grandis*, *Mangifera indica*, *Swietenia macrophylla*, and *Phyllanthus emblica*. It is observed that plantations help in carbon sequestration, and this varies across the species and girth classes. Our study revealed that diversified species in plantations contribute more to carbon sequestration than monocultures. Trees Outside Forests, apart from forests, play a significant role in carbon sequestration. It is necessary to understand the influence of spacing and response of species in terms of attaining girth and height, which impacts biomass accumulation. These findings highlight the importance of TOF in mitigating climate change while providing ecological and socioeconomic benefits. Long-term monitoring and including diverse native species can enhance the carbon sequestration potential and biodiversity value of such plantations. This work will be of immense use for future annual monitoring of carbon stocks.

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