found dissimilarity with *C. tenuis*, *C. kokangensis*, *C. membranosa* and *C. hainanensis* in having two whorls of carpels compared to single whorls in our fossil. As *C. oeningensis* was found similar to our fossil in the presence of a single whorl of five carpels alternating with sepal and size range of sepal length and width, we have described the present fossil under the same specific epithet.

Flowers are the ideal source of phylogenetic information and hold a key position in reproductive biology, perhaps facilitating angiosperm diversification through their influence on speciation and extinction rates[17]. The present fossil evidences provide a glimpse of the abundance of flowering plants in tropical regions of the Indian subcontinent during the early Palaeogene time when a major diversification of angiosperms took place.

1. Cui, D. F. *et al.*, A Jurassic flower bud from China, *Geol. Soc. Spec. Publ., London*, 2022, 521.
2. Singh, H. *et al.*, Flowers of Apocynaceae in amber from the early Eocene of India. *Am. J. Bot.*, 2021, **108**(5), 1–10.
3. Hazra, T. *et al.*, First fossil legume flower of papilionoid affinity from India. *J. Geol. Soc. India*, 2021, **97**, 267–270.
4. Srivastava, R. *et al.*, *Pterospermumocarpon*, a new malvalean fruit from the Sindhudurg Formation (Miocene) of Maharashtra, India, and its phytogeographical significance. *J. Earth Syst. Sci.*, 2012, **121**, 183–193.
5. Reback, R. G. *et al.*, Fruits of Euphorbiaceae from the Late Cretaceous Deccan intertrappean beds of India. *Int. J. Plant Sci.*, 2021, **183**(2), 128–138.
6. Smith, S. Y. *et al.*, Fossil fruits and seeds of Zingiberales from the Late Cretaceous–early Cenozoic Deccan Intertrappean beds of India. *Int. J. Plant Sci.*, 2021, **182**(2), 91–108.
7. Ramteke, D. D. *et al.*, *Singpuria*, a new genus of Eudicot flower from the latest Cretaceous Deccan Intertrappean Beds of India. *Acta Palaeobot.*, 2020, **60**(2), 323–332.
8. Manchester, S. R. *et al.*, Morphology and anatomy of the angiosperm fruit *Baccatocarpon*, incertae sedis, from the Maastrichtian Deccan Intertrappean Beds of India. *Acta Palaeobot.*, 2019, **59**(2), 241–250.
9. Shukla, A. and Mehrotra, R. C., Early Eocene plant megafossil assemblage of western India: paleoclimatic and paleobiogeographic implications. *Rev. Palaeobot. Palynol.*, 2018, **258**, 123–132.
10. Agnihotri, P. *et al.*, First fossil record of a nymph (Ephemeroptera, Teloganellidae) from the Indian subcontinent. *Zootaxa*, 2020, **4838**(1), 137–142.
11. Wang, Y. F. and Manchester, S. R., *Chaneya*, a new genus of winged fruit from the Tertiary of North America and eastern Asia. *Int. J. Plant Sci.*, 2000, **161**, 167–178.
12. Traverse, A., Why one 'does' paleopalynology and why it works. In *Paleopalynology*, Springer, Berlin, Dordrecht, 2007, 2nd edn, pp. 45–813; doi:10.1007/978-1-4020-5610-9.
13. Ramanujam, C. G. K., Palynology of the Neogene Warkalli beds of Kerala state in South India. *J. Palaeontol. Soc. India*, 1987, **32**, 26–46.
14. Wodehouse, R. P., The oil shales of the Eocene Green River formation. *Bull. Tor. Bot. Club*, 1933, **60**, 480–524.
15. Assis, A. C. *et al.*, Pollen morphology of selected species of Anacardiaceae and its taxonomic significance. *Rodriguésia*, 2021, **72**, e01422020.
16. Feng, X. X. and Jin, J. H., First record of extinct fruit genus *Chaneya* in low-latitude tropic of South China. *Sci. China Earth Sci.*, 2012, **55**, 728–732.
17. Sauquet, H. *et al.*, The ancestral flower of angiosperms and its early diversification. *Nat. Commun.*, 2017, **8**, 16047.

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Biomass, carbon stock and sequestration of predominant tree species of Vikarabad Natural Forest lands, Telangana, India

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A study was conducted during 2019–20 to document the predominant tree species, biomass, carbon stock and sequestration of undisturbed natural forest lands (40 years) across the 18 mandals of the Vikarabad district (3386 sq. km area with 109,325 population) of Telangana state. Results revealed that the predominant tree species consisted of *Eucalyptus grandis*, *Tectona grandis*, *Azadirachta indica* and *Ficus benghalensis*. The highest total biomass, carbon stock and sequestration were registered with *Eucalyptus grandis* (179.08, 89.54 and 328.62 tonne ha^{-1} respectively) followed by *Ficus benghalensis* (140.66, 70.33 and 258.10 tonne ha^{-1} respectively) and *Tamarindus indica* (51.60, 25.80 and 94.68 tonne ha^{-1} respectively) and minimum with *Pongamia pinnata* (0.31, 0.15 and 0.57 tonne ha^{-1} respectively). Deviation in volume, carbon stock and sequestration was due to the variation in height, girth and biomass of individual tree species. The results identified the potent tree species with high C stocks and sequestration for regions with similar climates and useful for environmental education to the people for climate change mitigation.

Keywords: Biomass, carbon stock, forest lands, predominant tree species, sequestration, undisturbed forest lands.

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BIODIVERSITY and its nexus with the carbon cycle are the current research interests for mitigating climate change[1]. Forest vegetation constitutes a major terrestrial carbon pool to mitigate carbon. Hence, well-managed forests increase the resilience of ecosystem services, as trees absorb and store large quantities of carbon[2]. REDD and REDD+ mechanisms enable countries that avoid forest loss by compensating financial rewards through quantified carbon estimates and quantifying carbon benefits[3]. Evidence of climate change linked to human-induced changes in the soil carbon pool[4], increase in greenhouse gas concentration[5] and carbon cycle[6] are well documented.

Trees with a longer life cycle over field crops absorb larger amounts of CO_2 during assimilation and protect the planet from hazards like global warming[7]. Stored carbon in their biomass is released into the atmosphere after death[8]. Hence, the added soil organic carbon (SOC) becomes a crucial part of the food chain and is directly proportional to the quantity of biomass[9].

Tree species vary in their ability to produce biomass and carbon sequestration. Local, regional and national carbon inventories of source and sink of carbon estimation are indispensable to assess carbon sequestration. They play a key role in reducing atmospheric CO_2 accumulation apart from developing systems/markets for national and international carbon credit/emission trading. Studies on tree species are crucial in the present scenario of climate change and to generate significant findings on identifying potential tree species with high carbon sequestration[10]. They also extend advantage over carbon offset apart from the generation of valuable information on suitable species for the promotion of urban greenery in newly emerging cities and to meet the needs of the wood industries in specific regions.

Vikarabad is one of the newly formed districts of Telangana, India, from the erstwhile Rangareddy district. The geographical area of this district is 3386 sq. km. It is located between 17°20′ and 11.15°N lat. and 77°54′ and 17.45′E long., characterized by dry deciduous forest spread over an area of 43,397 ha^{-1}. Vikarabad district shares boundaries with other districts in the state, viz. Sangareddy, Rangareddy, Narayanpet, Mahbubnagar and the state of Karnataka[11]. The mean annual temperature varies from 22°C to 32°C and the mean summer (April–June) temperature from 32°C to 46°C, rising to a maximum of 48°C in May, while the mean winter (December–February) temperature varies from 12°C to 26°C. The mean annual rainfall of the study area varies from 500 to 1000 mm. The objective of the study was to identify the predominant tree species of undisturbed natural forest lands of Vikarabad district, Telangana, their biomass, carbon stock and CO_2 sequestration.

The present study was carried out during 2019–20 in undisturbed forest lands (40 years) across the 18 mandals of Vikarabad district, Telangana, viz. Pargi, Pudur, Doma, Kulkacherla, Kodangal, Doulatabad, Bomraspet, Basheerabad, Vikarabad, Marpalle, Momipet, Nawabpet, Kotepally, Tandur, Yelal, Bantwaram, Dharur and Peddemul (Figure 1). The latitude, longitude and altitude of the study area range from 16°90′–18°03′N, 77°15′N–78°08′E and 430–700 m msl respectively.

Tree species observed in the study area were identified based on visual characteristics, viz. morphological features (leaf, stem, flower and pod/fruit shape, colour, orientation, arrangement and other botanical aspects like branching,

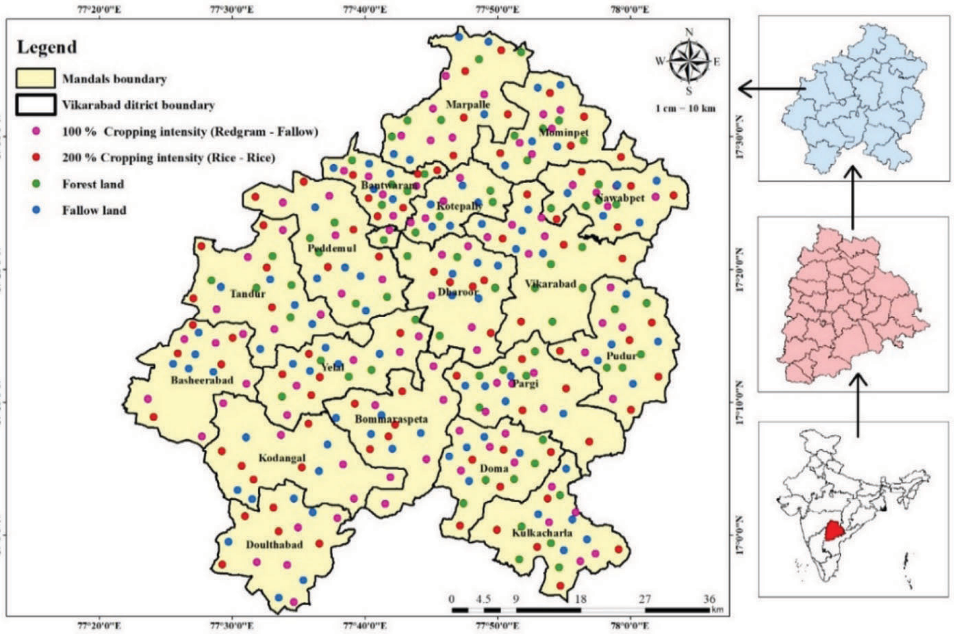

Figure 1. Land-use pattern and distribution of natural forest lands across Vikarabad district, Telangana, India.

Table 1. Predominant tree species of undisturbed natural forest lands of Vikarabad district, Telangana, India and growth parameters

Botanical name of tree species	Vernacular name	Family	Total number of trees	Average height (m)	Average girth (m)
Eucalyptus grandis	Mysore Gum/Neelgiri	Myrtaceae	120	33.0	1.50
Tectona grandis	Teak/Teku	Lamiaceae	85	16.5	0.60
Azadirachta indica	Neem/Vepa	Meliaceae	62	8.5	0.90
Ficus benghalensis	Banayan/Marrichettu	Moraceae	42	24.0	2.70
Mangifera indica	Mango/Mamidi	Anacardiaceae	33	12.3	1.40
Acacia nilotica	Babool/Nalla tumma	Fabaceae	30	13.5	0.95
Tamarindus indica	Imli/Chinta	Fabaceae	20	27.0	2.00
Madhuca longifolia	Mahua/Ippa	Sapotaceae	20	9.0	0.73
Pongamia pinnata	Karanj/kanuga	Fabaceae	10	6.0	0.52
Butea monosperma	Palas/Moduga	Fabaceae	12	11.0	0.93
Syzygium cumini	Jamun/Neredu	Myrtaceae	7	25.0	1.90
Dalbergia latifolia	Sisham/Sissoo	Fabaceae	6	12.0	1.21
	–	–	447	–	–

bark and crown). Tree age varied from 20–25 years (*Tectona grandis*, *Dalbergia latifolia*, *Madhuca longifolia*, *Pongamia pinnata* and *Butea monosperma*) to 35–40 years (*Ficus benghalensis*, *Azadirachta indica*, *Tamarindus indica*, *Acacia nilotica*, *Mangifera indica*, *Eucalyptus grandis* and *Syzygium cumini*). A grid size of 20 m × 20 m (average of five locations) in each mandal was taken as the standard to get the information on all tree growth parameters. The average of all standard grids (90 grids) across the 18 mandals in the undisturbed forest lands was finally transformed to a hectare basis.

Girth at breast height is one of the most important parameters representing the volume or weight of a tree converted to biomass per unit area. A random plot sampling method was used for measurement of girth. A grid size of 20 m × 20 m was selected for tree biomass estimation. All trees (species-wise) within each 20 m × 20 m plot (average of 5 locations) in each mandal were measured for their diameter at breast height (DBH), i.e. 1.3 m above ground[12].

The height of the tree is the most important parameter for calculating its volume or weight. It was recorded using an altimeter from the base to the tip of ten trees.

Tree biomass was estimated using the non-destructive method. Above-ground biomass (AGB) of tree species (entire shoot, branches, leaves, fruits and flowers) was calculated using tree height, DBH, volume and wood density.

$$V = \pi \times r^2 \times h,$$

where V is the volume of the tree (cm^3 or m^3), r the radius of the tree at 1.3 m above the ground = DBH/2 and h is the height of the tree (cm or m).

$$\text{AGB (kg tree}^{-1}) = \text{volume (m}^3) \times \text{wood density (kg m}^{-3}).$$

Standard wood density values were obtained for each tree species from global wood density data base[13].

Below ground biomass (BGB) includes all the biomass of live roots, excluding fine roots having <2 mm diameter. BGB was calculated by multiplying AGB by taking 0.26 as the root-to-shoot ratio[14].

$$\text{BGB (kg tree}^{-1}) = \text{AGB} \times 0.26.$$

Total biomass of the tree is the sum of AGB and BGM and was calculated using the following formula[9].

$$\text{Total biomass (kg tree}^{-1}) = \text{AGB (kg tree}^{-1}) + \text{BGB (kg tree}^{-1}).$$

Carbon storage of the tree was estimated as follows[15]:

$$\text{Carbon (kg tree}^{-1}) = 0.5 \times \text{total biomass (kg tree}^{-1}),$$

where 0.5 is a default conversion factor as 50% of its biomass is considered as carbon.

Carbon dioxide sequestration (kg $tree^{-1}$) was estimated as follows[15]

$$\text{Carbon dioxide sequestered (kg tree}^{-1}) = 3.67 \times \text{carbon (kg tree}^{-1}),$$

where 3.67 is the factor for CO_2 sequestration in trees (ratio of atomic weight of CO_2/atomic weight of carbon (44/12)).

An overview of the dataset revealed that 12 tree species were distributed across the 18 mandals of natural forest lands of Vikarabad district, Telangana (Table 1). The predominant tree species consisted of *E. grandis*, *T. grandis*, *A. indica*, *F. benghalensis* and *M. indica* as the area is characterized by dry, hot and humid climatic conditions. Overall, the tree species belonged to eight families. Fabaceae constituted the major family, including five tree species, viz. *A. nilotica*, *T. indica*, *P. pinnata*, *B. monosperma* and *D. latifolia*. The prevailing microclimatic variations, soil type, soil moisture and different tree based products used for culinary and medicinal purpose in a particular region alter species richness, structure, composition,

Table 2. Volume, wood density and biomass of tree species of undisturbed natural forest lands of Vikarabad district, Telangana

Tree species Botanical name	Growth parameters							
	Volume (m^3)	Wood density (kg m^{-3})	Above ground biomass (AGB, kg $tree^{-1}$)	Below ground biomass (BGB, kg $tree^{-1}$)	Total biomass (kg $tree^{-1}$)	Density base AGB (tonne ha^{-1})	Density base BGB (tonne ha^{-1})	Density base total biomass (tonne ha^{-1})
Eucalyptus grandis	1.88	630	1184.40	307.94	1492.34	142.12	36.95	179.08
Tectona grandis	0.15	550	82.50	21.45	103.95	7.013	1.823	8.84
Azadirachta indica	0.17	690	117.30	30.50	147.80	7.273	1.891	9.16
Ficus benghalensis	4.43	600	2658.00	691.08	3349.08	111.63	29.02	140.66
Mangifera indica	0.61	590	359.90	93.57	453.47	11.87	3.08	14.97
Acacia nilotica	0.30	600	180.00	46.80	226.80	5.40	1.404	6.80
Tamarindus indica	2.73	750	2047.50	532.35	2579.85	40.95	10.64	51.60
Madhuca longifolia	0.12	480	57.60	14.98	72.58	1.15	0.300	1.45
Pongamia pinnata	0.04	620	24.80	6.45	31.25	0.24	0.06	0.31
Butea monosperma	0.24	480	115.20	29.95	145.15	1.38	0.35	1.74
Syzygium cumini	2.28	510	1162.80	302.33	1465.13	8.140	2.116	10.26
Dalbergia latifolia	0.44	620	272.80	70.93	343.73	1.637	0.426	2.062

density, growth and survival rate of the tree species in their habitat[16,17].

The growth parameters (tree height, girth and volume) varied largely among the tree species (Table 1). Tree height ranged between 6 m and 33 m across the tree species in the study area. Maximum tree height was registered with *E. grandis* (33 m) followed by *T. indica* (27 m), *S. cumini* (25 m) and *F. benghalensis* (24 m). Minimum tree height was recorded with *P. pinnata* (6 m).

The girth of the tree species ranged from a minimum of 0.52 m to maximum of 2.70 m; maximum with *F. benghalensis* (2.70 m) followed by *T. indica* (2.00 m), *S. cumini* (1.90 m) and *E. grandis* (1.50 m), and minimum with *P. pinnata* (0.52 m).

The volume across different tree species ranged from 0.04 to a maximum of 4.43 m^3 (Table 2). The highest volume was registered with *F. benghalensis* (4.43 m^3), *T. indica* (2.73 m^3), *S. cumini* (2.28 m^3) and *E. grandis* (1.88 m^3), and the lowest was with *P. pinnata* (0.04 m^3). Data on wood density indicated the highest value with *T. indica* (750 kg m^3), followed by *A. indica* (690 kg m^3), *E. grandis* (630 kg m^3), *P. pinnata* and *D. latifolia* (620 kg m^3), and lowest wood density with *M. latifolia* and *B. monosperma* (480 kg m^3). Tree volume depends on girth and tree height. Higher volume was registered due to greater girth and height of tamarind, eucalyptus and neem species over other tree species. The growth pattern of individual tree species, biotic factors and microclimate are also the major determinants for this variation. Similar results on the heterogeneity of tree volume due to diameter and height among different tree species have been reported[16].

Biomass production of individual tree species, viz. above ground, below ground and total biomass, was the highest for *F. benghalensis* (2658.00, 691.08 and 3349.08 kg $tree^{-1}$ respectively), followed by *T. Indica* (2047.50, 532.35 and 2579.85 kg $tree^{-1}$ respectively), *E. grandis* (1184.40, 307.94 and 1492.34 kg $tree^{-1}$ respectively). *P. pinnata* had the lowest AGB, BGB and total biomass of 24.80, 6.45 and 31.25 kg $tree^{-1}$ respectively. A perusal of the total biomass on a density basis indicated that the highest value (179.08 tonne) was registered by *E. grandis* followed by *F. benghalensis* (140.66 tonne) and *T. indica* (51.60 tonne) due to the occurrence of a higher number of these trees across the study areas.

On the other hand, higher AGB registered with *F. benghalensis*, *T. indica* and *E. grandis* could be ascribed to the greater girth and wood density associated with these tree species. Higher total biomass is due to the cumulative effect of greater AGB and BGB. Similar findings on larger tree diameter contribution towards greater biomass have been documented[18]. Lower AGB might be due to the lower girth and wood density as evident from the data. These results are in line with Terakunpisut *et al.*[19].

Carbon stock and sequestration potential varied with trees across the study area (Tables 3 and 4). An overview of species-wise data indicated the highest carbon stock as well as sequestration potential with *F. benghalensis* (1.67 and 6.14 tonne $tree^{-1}$ respectively), followed by *T. Indica* (1.28 and 4.73 tonne $tree^{-1}$ respectively), *E. grandis* (0.74 and 2.73 tonne $tree^{-1}$ respectively) and *S. cumini* (0.73 and 2.68 tonne $tree^{-1}$ respectively). Higher C stock and sequestration potential recorded with these tree species is due to higher biomass accumulation (AGB and BGB) in comparison to the other species. Long-living and fast-growing trees like *F. benghalensis*, *T. indica* and *E. grandis* are efficient reservoirs for the storage of CO_2 and have better C sequestration[20], and carbon in the tree biomass increases with DBH, basal area and height[21,22]. Similar findings on high carbon storage in large tree species and high DBH like Ficus to an extent of 1000 times over small stature trees were earlier documented[23–25].

The amount of carbon and CO_2 sequestration on a density basis was the highest for *E. grandis* (89.54 and 328.62 tonne ha^{-1} respectively), *F. benghalensis* (70.33 and 258.10 tonne ha^{-1} respectively) and *T. indica* (25.80 and 94.68 tonne ha^{-1} respectively). This was mainly due to the higher density of

Table 3. Carbon stock (tonne) of predominant tree species of undisturbed natural forest lands of Vikarabad district, Telangana

Tree species	Carbon stock $tree^{-1}$ (tonne)			Density based carbon stock (tonne ha^{-1})		
Botanical name	Above ground	Below ground	Total	Above ground	Below ground	Total
Eucalyptus grandis	0.59	0.15	0.74	71.06	18.48	89.54
Tectona grandis	0.04	0.01	0.05	3.51	0.909	4.42
Azadirachta indica	0.05	0.01	0.07	3.63	0.94	4.58
Ficus benghalensis	1.329	0.34	1.67	55.81	14.51	70.33
Mangifera indica	0.180	0.04	0.22	5.94	1.54	7.48
Acacia nilotica	0.09	0.023	0.11	2.70	0.70	3.40
Tamarindus indica	1.02	0.26	1.28	20.47	5.32	25.80
Madhuca longifolia	0.02	0.008	0.03	0.57	0.15	0.72
Pongamia pinnata	0.01	0.003	0.01	0.12	0.03	0.15
Butea monosperma	0.05	0.015	0.07	0.69	0.18	0.87
Syzygium cumini	0.58	0.15	0.73	4.06	1.05	5.12
Dalbergia latifolia	0.13	0.03	0.17	0.81	0.21	1.03

Table 4. Carbon sequestration (tonne) of predominant tree species of undisturbed natural forest lands of Vikarabad district, Telangana

Tree species	Carbon sequestration $tree^{-1}$ (tonne)			Density-based carbon sequestration (tonne ha^{-1})		
Botanical name	Above ground	Below ground	Total	Above ground	Below ground	Total
Eucalyptus grandis	2.17	0.56	2.73	260.80	67.82	328.62
Tectona grandis	0.15	0.03	0.19	12.88	3.33	16.22
Azadirachta indica	0.21	0.05	0.27	13.35	3.48	16.83
Ficus benghalensis	4.87	1.26	6.14	204.85	53.25	258.10
Mangifera indica	0.66	0.17	0.83	21.79	5.66	27.46
Acacia nilotica	0.33	0.08	0.41	9.90	2.57	12.48
Tamarindus indica	3.75	0.97	4.73	75.14	19.53	94.68
Madhuca longifolia	0.10	0.02	0.13	2.11	0.55	2.66
Pongamia pinnata	0.04	0.01	0.05	0.45	0.11	0.57
Butea monosperma	0.21	0.05	0.26	2.53	0.66	3.19
Syzygium cumini	2.13	0.55	2.68	14.93	3.88	18.82
Dalbergia latifolia	0.50	0.13	0.63	3.00	0.78	3.78

E. grandis. Factors like the age of the forest stand[26], tree density[27], diversity and basal area[28] influence biomass and total vegetation carbon. There is a positive and strong correlation between carbon sequestration basal area, type of species and tree density[29,30].

Carbon density of 34 mg C ha^{-1} has been reported for Indian forests[31], 64.35 mg ha^{-1} for dry deciduous forests of Andhra Pradesh[32] and 99.44 mg ha^{-1} for tropical deciduous forests of India[33]. The estimates from the present study are in the range of dry deciduous forests. Trees in dry deciduous forests generally have a lower height-to-diameter ratio, produce leaves with lower specific leaf area and have higher wood density and thick bark than those in wet habitat forests on account of less rainfall[34].

The present study in undisturbed forest lands across the 18 mandals of Telangana's newly formed Vikarabad district revealed distribution of 12 tree species belonging to 8 families. The predominant ones were *E. grandis*, *T. grandis*, *A. indica* and *F. benghalensis*. The highest density-based total biomass, carbon stock and sequestration were registered with *E. grandis* (179.08, 89.54 and 328.62 tonne ha^{-1} respectively) followed by *F. benghalensis* (140.66, 70.32 and 258.10 tonne ha^{-1} respectively) and *T. indica* (51.59, 25.80 and 94.68 tonne ha^{-1} respectively). This study provides baseline information and insights into tree species, biomass, carbon stock and sequestration potential. It helps mitigate climate change through environment education and for planting tree species with high biomass and carbon sequestration in other regions with homogenous climatic and topographic conditions as that of Vikarabad.

1. Midgley, G. F., Bond, W. J., Kapos, V., Ravilious, C., Scharlemann, J. P. and Woodward, F. I., Terrestrial carbon stocks and biodiversity:key knowledge gaps and some policy implications. *Curr. Opin. Environ. Sustain*, 2010, **4**, 264–270.
2. UN FAO, Durban declaration: 2050, Vision for forests and forestry. Food and Agriculture Organization of the United Nations, Rome, Italy; www.fao.org/fileadmin/user-upload/wfc2015.
3. Hans, F. X., Plodinec, M. J., Su, Y., Monts, D. L. and Li, Z., Terrestrial carbon pools in southeast and south-central United States. *Clim. Change*, 2007, **84**, 191–202.
4. Lal, R., Soil carbon sequestration impacts on global climate change and food security. *Science*, 2004, **304**, 1623–1627.

5. IPCC, Synthesis Report, Contributions of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2014, p. 151.
6. Hussain, T., Devi, H. S. and Sarma, K. K., Above ground biomass and carbon stock mapping using NDVI and ecological studies of woody trees of Jeypore Reserve Forest, Assam, India. *Indian For.,* 2019, **145**(7), 614–618.
7. Montagnini, F. and Nair, P. K. R., Carbon sequestration: an underexploited environmental benefit of agroforestry aystems. *Agrofo. Syst.*, 2004, **61**(1), 281–295.
8. Vishnu, R. and Patil, S., Sequestration and storage of carbon by trees in and around university campus of Aurangabad city in Maharashtra, India. *Int. Res. J. Eng. Technol*., 2017, **1**(4), 598–602.
9. Suryawanshi, M. N., Patel, A. R., Kale, T. S. and Patil, P. R., Carbon sequestration potential of tree species in the environment of North Maharashtra University Campus, Jalgaon (MS) India. *BioSci. Discov.*, 2014, **5**(2), 175–179.
10. Vieilledent, G. *et al.*, A universal approach to estimate biomass and carbon stock in tropical forests using generic allometric models. *Ecol. Appl.*, 2012, **22**(2), 572–583.
11. Directorate of Economics and Statistics, Government of Telangana, 2019–20; www.ecostat.telangana.gov.in
12. MacDicken, K. G., *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects*, Winrock International Institute for Agricultural Development, Nairobi, Kenya, 1997.
13. Pandya, I. Y., Salvi, H., Chahar, O. and Vaghela, N., Quantitative analysis on carbon storage of 25 valuable tree species of Gujarat, incredible India. *Indian J. Sci. Res*., 2013, **4**(1), 137.
14. Cairns, M. A., Brown, S., Helmer, E. H. and Baumgardner, G. A., Root biomass allocation in the world's upland forests. *Oecologia*, 1997, **111**, 1–11.
15. Nguyen, V. L., Estimation of biomass for calculating carbon storage and CO_2 sequestration using remote sensing technology in Yok Don National Park, Central Highlands of Vietnam. *J. Viet. Environ.*, 2012, **3**(1), 14–18.
16. Durai, S. J. and Somaiah, S., Soil carbon stock assessment in the tropical dry deciduous forest of the Sathanur reserve forest of Eastern Ghats, India. *J. Sustain For.*, 2017, **36**(4), 358–374.
17. Padmakumar, B. *et al.*, Tree biomass and carbon density estimation in the tropical dry forest of Southern Western Ghats, India. *IForest*, 2018, **11**(4), 534–541.
18. Srinivas, K. and Somaiah Sundarapandian, P., Biomass and carbon stocks of trees in tropical dry forest of East Godavari region, Andhra Pradesh, India. *Geol. Ecol. Landsc.*, 2018, **3**(2), 114–122.
19. Terakunpisut, J., Gerasene, N. and Raukawa, N., Carbon sequestration potential in aboveground biomass of thongphaphum national forest, Thailand. *Appl. Ecol. Environ. Res*., 2007, **5**, 93–102.
20. Potadar Vishnu, R. and Satish, S., Sequestration and storage of carbon by trees in and around University campus of Aurangabad city in Maharashtra, India. *Int. Res. J. Eng. Technol.*, 2017, **4**(1), 598–602.
21. Hui, D., Wang, J., Le, X., Shen, W. and Ren, H., Influences of biotic and abiotic factors on the relationship between tree productivity and biomass in China. *For. Ecol. Manage.*, 2012, **264**, 72–80.
22. Pragasan, L. A., Carbon stock assessment in the vegetation of the Chitteri Reserve Forest of the Eastern Ghats in India based on non-destructive method using tree inventory data. *J. Earth Sci. Climate Change*, 2014, **S11**, 1–6; doi:10.4172/2157-7617.511-001.
23. Kirby, K. R. and Potvin, C., Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. *For. Ecol. Manage.*, 2007, **2–3**, 208–221.
24. Nagendra, H., Assessing relatedness and redundancy of forest monitoring and change indicators. *J. Environ. Manage.*, 2012, **95**, 108–113.
25. Srinivasarao, D., Prayaga Murthy, P. and Aniel Kumar, O., Plant biodiversity and phytosociological studies on tree species diversity of Khammam District, Telangana State, India. *Plant J. Pharm. Sci. Res.*, 2015, **7**(8), 518–522.
26. Kohl, M., Neupane, P. R. and Lotfifiomran, N., The impact of tree age on biomass growth and carbon accumulation capacity: a retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname. *PLoS ONE*, 2017, **12**(8), e0181187; doi:10.1371/journal.pone.0181187.
27. Garcia-Vega, D. and Newbold, T., Assessing the effects of and use on biodiversity in the world's drylands and Mediterranean environments. *Biodivers. Conserv.*, 2020, **29**, 393–408.
28. Joshi, R. K. and Dhyani, S., Biomass, carbon density and diversity of tree species in tropical dry deciduous forests in Central India. *Acta Ecol. Sin.*, 2019, **39**(4), 289–299.
29. Salunkhe, O. and Khare, P. K., Aboveground biomass and carbon stock of tropical deciduous forest ecosystems of Madhya Pradesh, India. *Int. J. Ecol. Environ. Sci*., 2017, **42**(S), 75–81.
30. Tamang, M., Chettri, R., Vineeta, Shukla, G., Shukla, J. A., Kumar, A. and Kumar, M., Stand structure, biomass and carbon storage in *Gmelina arborea* plantation at agricultural landscape in foothills of eastern Himalayas. *Land*, 2021, **10**, 387; doi:10.3390/land10040387.
31. Haripriya, G. S., Estimates of biomass in Indian forests. *Biomass Bioenerg.*, 2000, **19**, 245–258.
32. Prasad, V. K., Kant, Y. and Badarinath, K. V. S., Quantifying short-term carbon dynamics from land use changes using satellite data – a case study from Rampa Forests (Eastern Ghats) India. *Geocarto. Int*., 2000, **15**(2), 71–78.
33. Singh, L., Yadav, D. K., Pagare, P., Gosh, L. and Thakur, B. S., Impact of land use changes on species structure, biomass and carbon storage in tropical deciduous forest and converted forest. *Int. J. Ecol. Environ. Sci.*, 2009, **35**(1), 113–119.
34. Jayashree, R., Chengappa, S. K., Siddarth, J. M., Nandita, N., Anand, M. O. and Mahesh, S., Functional traits of trees from dry deciduous 'Forests' of southern India suggest seasonal drought and fire are important drivers. *Front. Ecol Evol.*, 2019, **29**; https://doi.org/10.3389/fevo.2019.00008.

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