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RESEARCH ARTICLE

Estimation of diversity, biomass and carbon sequestration potential of woody vegetation in scarce rainfall zone of Andhra Pradesh

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Abstract

This study was conducted in four districts (Anantapur, Kurnool, Nandyal and Sri Satya Sai) of Andhra Pradesh, India under the scarce rainfall zone (SRZ), where woody floral diversity plays a crucial role in storing carbon and supporting the ecosystem. We found that varying number of tree species in each district such as 34 in Anantapur, 53 in Kurnool, 56 in Nandyal and 50 in Sri Satya Sai district. The diversity of woody species was measured using the Shannon diversity index and Simpson's index. The results showed that Sri Satya Sai had the highest diversity (1.43), while Anantapur had the lowest (1.19). Simpson's index ranged from 0.94 to 0.97, indicating variations in species composition. Nandyal district had the highest above-ground biomass (AGB) 430.16 Mg ha^{-1}, below-ground biomass of 111.84 Mg ha^{-1}, total biomass density of 542.10 Mg ha^{-1} and carbon density of 271.00 Mg ha^{-1}. Effective conservation and management strategies are necessary to enhance carbon storage and protect biodiversity in semi-arid regions like Andhra Pradesh.

Keywords: Andhra Pradesh; biodiversity; biomass; carbon stock; climate change mitigation

Introduction

Forests play a crucial role in the climate system, acting as both carbon sources and sinks (1, 2). The clean development mechanism (CDM) promotes reforestation and afforestation efforts, generating certified carbon reduction (CCR) credits and highlighting their contribution to global carbon sequestration by capturing atmospheric CO_2 and storing it in biomass and soil (3, 4). However, deforestation and land-use changes release significant amounts of CO_2, contributing to climate change (5, 6). A significant portion of this increase stems from the burning of fossil fuels, contributing to approximately 64 % of the rise in atmospheric heat (7, 8). Forest ecosystems mitigate these emissions by sequestering carbon in both above-ground and below-ground plant components, facilitating long-term carbon storage (9, 10). As one of the largest contributors to carbon sequestration, forests play a fundamental role in stabilising global climate patterns (11, 12). Human activities have led to significant losses in terrestrial carbon stocks such as approximately 145 Gt C from woody biomass and soils (1850–2015) (13), 133 Gt C lost from soil carbon stocks over the 1200 years (14) and 379 Gt C of biomass lost over 10000 years (15). These losses highlight the impact of human activities on the environment and the need for sustainable management of terrestrial ecosystems. Afforestation and reforestation (A/R) provide multiple benefits, including ecosystem services (16–18) like biodiversity conservation (19), soil stabilisation (20) water cycling (21) as well as various other regulating cultural and supporting services provided by forest ecosystems (22, 23).

Forest systems enhance this process by integrating trees into landscapes, boosting carbon uptake and storage. Conventional wisdom suggests that woody ecosystems trigger competitive interactions for resources as the stand canopy development advances (24). The nutrient cycling pathway turns more efficient at this stage leading to self-nourishment through the optimal utilisation of the available nutrients (25–28). However, the variability in biomass production may be caused by species, rotation age, stand age, spacing or planting density, stand history, structural differences and climatic factors such as temperature and precipitation (29, 30). Tree biomass, often measured using Diameter at Breast Height

(DBH), is a key parameter for estimating carbon storage capacity (31, 32). Large trees are vital carbon sinks because their extensive biomass acts as a primary reservoir for atmospheric CO_2 while carbon is approximately half of the total biomass (33). Promoting sustainable forest utilisation strategies, including the use of wooden products for carbon resource utilisation, climate change mitigation, integrating renewable energy sources, development of environmental and establishing supportive land-use policy frameworks, is vital for enhancing forest carbon sequestration and ensuring the sustainable development of global forests (34, 35). This study in Andhra Pradesh reveals spatial variations in biomass, emphasising that site-specific conservation and integrating agroforestry or reforestation can enhance ecological resilience, support local livelihoods and maximise long-term carbon sequestration in water-limited landscapes.

Materials and Methods

Study area

This study was conducted in 4 districts (Anantapur, Kurnool, Nandyal and Sri Satya Sai) of Andhra Pradesh, India under the scarce rainfall zone (SRZ). Geographically, Anantapur district lies between 13°40′ to 15°15′ N latitude and 76°50′ to 78°30′ E longitude, Kurnool district between 14°54′ to 16°18′ N latitude and 76°58′ to 79°34′ E longitude, Nandyal district between 15°00′ to 16°15′ N latitude and 78°00′ to 79°30′ E longitude and Sri Sathya Sai district between 13°30′ to 14°30′ N latitude and 77°00′ to 78°30′ E longitude (Fig. 1). The region is characterised by a semi-arid climate with low and erratic rainfall, predominantly red and black soils and agriculture largely dependent on monsoon rainfall, making the farming system highly vulnerable to climatic variability. Forest cover in the region is sparse and unevenly distributed, consisting mainly of dry deciduous and scrub forests, which show significant spatial variability due to rainfall patterns Anantapur district (10205 km^2), Kurnool district (7977 km^2), Nandyal district (9681 km^2) and Sri Sathya Sai district (8925 km^2) were selected due to their pronounced susceptibility to climate change and ongoing environmental degradation (36).

Experimental details about sampling and data analysis

To evaluate biomass and carbon stock potential, a systematic field survey was conducted across selected districts of Andhra Pradesh during 2022–23. The vegetation analysis was performed using a quadrat-based random sampling method. A total of 20 quadrats (20 × 20 m; 400 m^2) were laid out at each site to ensure adequate representation of species diversity, stand structure and biomass distribution across the study area. The placement of quadrats was further guided using imagery-based trajectory lines across the landscape, which helped in systematic coverage of different vegetation patches and minimised sampling bias (37). Within each quadrat, all trees were identified and diameter at breast height (DBH, at 1.37 m) was measured. The tree height was also recorded using a Haga altimeter and species-specific wood density values were obtained from reputable sources. The aboveground biomass (AGB) was estimated using allometric equations ($AGB = 0.112(\rho D^2H)0.916$) , incorporating wood density (ρ), DBH and height (32, 38-39). Belowground biomass (BGB) was calculated as 27 % of AGB (40) and total biomass density (TBD) was derived as the sum of AGB and BGB (41). The carbon storage was estimated by assuming that 50 % of the total biomass represents carbon content, a commonly accepted coefficient in biomass studies. Accordingly, the aboveground and belowground biomass values obtained for each sampling unit were converted into carbon stock by multiplying with a factor of 0.5. Further, carbon density (expressed as t ha^{-1}) was computed for each

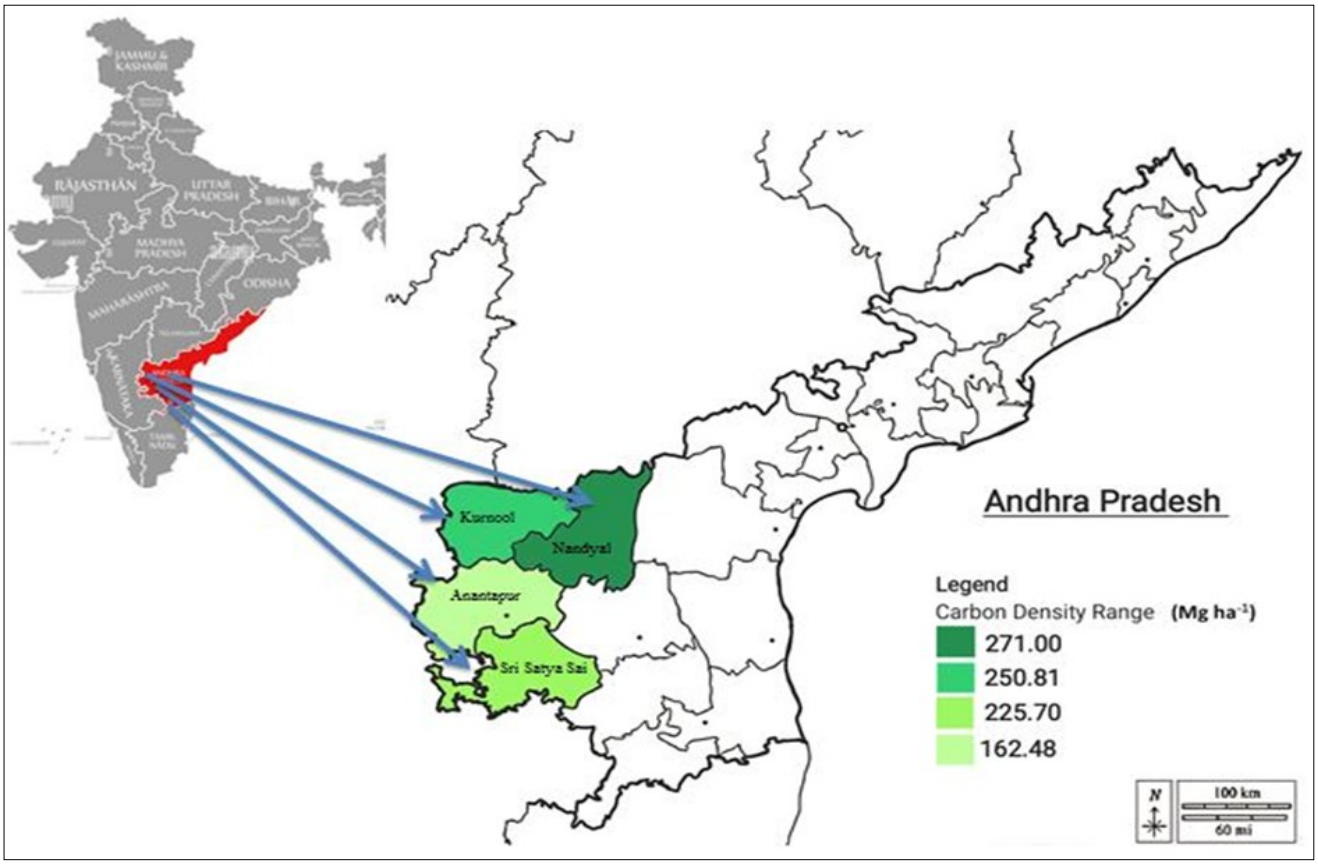


Fig. 1. Map indicating carbon density of four districts (Anantapur, Kurnool, Nandyal and Sri Satya Sai) in the of state Andhra Pradesh, India.
[Source: https://www.alamy.com/andhra-pradesh-red-highlighted-in-map-of-india-image363416972.html]

site by relating the estimated carbon stock to the corresponding area. This approach enabled a systematic comparison of carbon storage across different locations and helped in assessing the spatial variability in carbon sequestration potential. The variations in carbon density among sites reflect differences in vegetation structure, species composition, age of plantations and site-specific environmental conditions, thereby providing insights into the ecological and management factors influencing carbon accumulation (42–46). Statistical analysis of the data was carried out using one-way analysis of variance (ANOVA) to evaluate the significance of differences among the study sites. The analysis was performed separately for each parameter, including aboveground biomass, belowground biomass, total biomass and carbon density. The significance of treatment effects was tested using the *F*-test and differences among means were compared using the critical difference (CD) at the 5 % level (p-0.05) of significance.

Results and Discussion

The study aimed to assess tree species diversity, their botanical classification, basal area (BA) and DBH to understand variations in species richness across different sites.

Tree diversity and species wise carbon density in different study sites

Tree species composition varied significantly across the four study sites, reflecting differences in environmental conditions and resource availability. In Anantapur, 34 species were recorded, with Fabaceae being the most dominant family (12 species), followed by Combretaceae (4 species) and Moraceae (3 species) (Table 1). The relatively low species diversity in Anantapur can be attributed to harsh climatic conditions, poor soil fertility and extended dry periods, which limit tree establishment and growth. In Kurnool, 53 species were identified, with Fabaceae again being the most prevalent (17 species), followed by Combretaceae (5 species), while Anacardiaceae, Malvaceae and Rutaceae contributed 3 species each (Table 1). The higher species richness in Kurnool is likely due to more favourable soil and moisture conditions.

Nandyal exhibited the highest diversity among the sites, with 56 species documented. Fabaceae was again the dominant family (16 species), followed by Combretaceae (7 species) and Rubiaceae (4 species), while Anacardiaceae, Malvaceae and Rutaceae contributed 3 species each (Table 1). This high species richness may be attributed to favourable environmental conditions, including better soil moisture retention and a more heterogeneous landscape. Sri Satya Sai recorded 50 species, with Fabaceae (11 species) as the most dominant family, followed by Rubiaceae (5 species), Anacardiaceae (3 species) and Malvaceae (3 species), while other families contributed fewer than two species each.

Results indicated variations in AGB across study locations, with the highest recorded in Nandyal (430.16 Mg ha^{-1}) and the lowest in Anantapur (257.91 Mg ha^{-1}) (Table 2). The BGB was estimated as 27 % of AGB, based on the multiplier recommended (42) yielding values between 67.06 Mg ha^{-1} in Anantapur and 111.84 Mg ha^{-1} in Nandyal. Total biomass density (TBD), determined by summing AGB and BGB was highest in Nandyal (542.01 Mg ha^{-1}) and lowest in Anantapur (324.96 Mg ha^{-1}). Carbon storage was assessed by assuming 50 % of the total biomass consists of carbon (46).

The highest carbon density was observed in Nandyal (271.00 Mg C ha^{-1}), followed by Kurnool (250.81 Mg C ha^{-1}), Sri Satya Sai (225.70 Mg C ha^{-1}) and Anantapur (162.48 Mg C ha^{-1}) (Table 2). The average values across all study locations were 361.11 Mg ha^{-1} for AGB, 93.88 Mg ha^{-1} for BGB, 455.25 Mg ha^{-1} for TGB and 227.50 Mg C ha^{-1} for carbon density. Statistical evaluation revealed that the coefficient of deviation (CD) ranged between 19.12 % and 20.74 %, signifying moderate variations in biomass and carbon density among different sites (Table 2). The standard deviation (SD) was found to be highest for total biomass (90.88 Mg ha^{-1}) and lowest for BGB (19.46 Mg ha^{-1}) (Table 2). Additionally, the standard error of the mean (SEm) was 36.46 Mg ha^{-1} for AGB and 21.73 Mg ha^{-1} for carbon density. The *F*-test indicated that all assessed parameters were statistically significant, validating the study's results. The AGB ranged from 257.91 Mg ha^{-1} to 430.16 Mg ha^{-1}, which is consistent with similar findings of previous reports (47–49). Similarly, the carbon stocks in this study ranged from a minimum of 162.48 Mg ha^{-1} to 271 Mg ha^{-1}, supporting previous studies by previous researchers (50, 51). Research on floral diversity and carbon stock assessment has gained increasing prominence; however further studies are required to generate more comprehensive insights. A positive relationship between species diversity and productivity has also been reported previously (52, 53). A significant relationship was observed between diversity indices and AGB. Both species richness and the Shannon diversity index were positively correlated with AGB, whereas the Simpson index of concentration of dominance showed a negative correlation. However, these findings contrast with those of previous researchers, who reported no significant relationship between tree species diversity and above-ground biomass (54, 55). The relationship between AGB and basal area in a forest stand is intricately linked to tree architecture, as the lower trunk plays a crucial role in the tree's growth. Identifying the key species contributing to AGB and above-ground carbon stocks is essential for effective forest management. Understanding the effects of removing or conserving species from different families is vital for maintaining overall AGB and carbon stock stability (56, 57). The substantial carbon density recorded in Nandyal and Kurnool district highlights the necessity of region-specific afforestation and conservation strategies to enhance carbon storage and mitigate climate change. Promoting sustainable forest management and expanding tree cover in the semi-arid regions of Andhra Pradesh can significantly contribute to global carbon sequestration and ecosystem restoration efforts. The present study primarily focuses on estimating carbon stocks in tree biomass; however, it is acknowledged that in semi-arid ecosystems, soil organic carbon (SOC) constitutes a significant and often dominant component of the total carbon pool.

Conclusion

The study demonstrated significant spatial variation in tree species composition, biomass accumulation and carbon sequestration potential across the four study sites. Species richness and family dominance patterns clearly reflected the influence of environmental conditions, with district Nandyal exhibiting the highest diversity and biomass, while Anantapur showed comparatively lower values due to harsher semi-arid conditions. The dominance of the Fabaceae family across all sites highlights its ecological adaptability and contribution to biomass accumulation in dryland ecosystems. Biomass and carbon stock estimates followed a consistent trend, with Nandyal recording

Table 1. Species wise carbon density in four districts (Anantapur, Kurnool, Nandyal and Sri Satya Sai) of Andhra Pradesh, India

Study site	Tree species	Family	AG tree biomass density (Mg ha^{-1})	BG tree biomass density (Mg ha^{-1}) (27 % of AGB)	T biomass density (Mg ha^{-1})	Carbon density (Mg C ha^{-1}) in tree
Anantapur district site 1	*Senegalia chundra*	Fabaceae	0.47	0.12	0.60	0.30
	Vachellia nilotica	Fabaceae	0.71	0.19	0.90	0.45
	Albizia amara	Fabaceae	0.06	0.02	0.08	0.04
	Albizia julibrissin	Fabaceae	0.59	0.15	0.74	0.37
	Albizia lebbeck	Fabaceae	3.52	0.92	4.44	2.22
	Anogeissus latifolia	Combretaceae	1.66	0.43	2.10	1.05
	Azadirachta indica	Meliaceae	5.47	1.42	6.89	3.44
	Barringtonia racemosa	Lecythidaceae	0.22	0.06	0.28	0.14
	Bombax ceiba	Malvaceae	29.75	7.73	37.48	18.74
	Borassus flabellifer	Arecaceae	20.26	5.27	25.52	12.76
	Butea monosperma	Fabaceae	9.49	2.47	11.95	5.98
	Careya arborea	Lecythidaceae	0.58	0.15	0.73	0.37
	Casearia elliptica	Salicaceae	0.93	0.24	1.18	0.59
	Cassia fistula	Fabaceae	2.40	0.62	3.02	1.51
	Chloroxylon swietenia	Rutaceae	1.28	0.33	1.62	0.81
	Cochlospermum religiosum	Bixaceae	0.47	0.12	0.59	0.29
	Cordia dichotoma	Boraginaceae	0.88	0.23	1.11	0.55
	Dalbergia latifolia	Fabaceae	11.43	2.97	14.40	7.20
	Ficus benghalensis	Moraceae	41.56	10.80	52.36	26.18
	Ficus hispida	Moraceae	0.28	0.07	0.36	0.18
	Ficus religiosa	Moraceae	19.01	4.94	23.95	11.98
	Lannea coromandelica	Anacardiaceae	2.66	0.69	3.35	1.67
	Mangifera indica	Anacardiaceae	8.72	2.27	10.98	5.49
	Moringa oleifera	Moringaceae	6.04	1.57	7.61	3.80
	Phyllanthus emblica	Phyllanthaceae	0.79	0.21	1.00	0.50
	Pongamia pinnata	Fabaceae	2.13	0.56	2.69	1.34
	Saraca asoca	Fabaceae	33.52	8.72	42.24	21.12
	Cassia siamea	Fabaceae	5.84	1.52	7.35	3.68
	Tamarindus indica	Fabaceae	10.33	2.69	13.02	6.51
	Terminalia alata	Combretaceae	12.03	3.13	15.16	7.58
	Terminalia arjuna	Combretaceae	20.43	5.31	25.74	12.87
	Terminalia chebula	Combretaceae	4.02	1.05	5.06	2.53
	Wrightia tinctoria	Apocynaceae	0.15	0.04	0.19	0.10
	Ziziphus xylopyrus	Rhamnaceae	0.23	0.06	0.29	0.15
Kurnool district site 2	*Senegalia chundra*	Fabaceae	0.10	0.03	0.13	0.06
	Vachellia leucophloea	Fabaceae	6.15	1.60	7.75	3.88
	Acacia nilotica	Fabaceae	0.21	0.05	0.26	0.13
	Adina cordifolia	Rubiaceae	4.33	1.13	5.46	2.73
	Aegle marmelos	Rutaceae	0.62	0.16	0.78	0.39
	Alangium salviifolium	Cornaceae	21.20	5.51	26.71	13.36
	Albizia amara	Fabaceae	0.06	0.01	0.07	0.03
	Albizia julibrissin	Fabaceae	0.47	0.12	0.59	0.29
	Albizia lebback	Fabaceae	2.17	0.56	2.73	1.36
	Anacardium occidentale	Anacardiaceae	3.43	0.89	4.33	2.16
	Anogeissus latifolia	Combretaceae	9.70	2.52	12.22	6.11
	Azadirachta indica	Meliaceae	9.68	2.52	12.19	6.10
	Barringtonia racemosa	Lecythidaceae	0.96	0.25	1.21	0.60
	Bombax ceiba	Malvaceae	8.19	2.13	10.32	5.16
	Borassus flabellifer	Arecaceae	20.13	5.23	25.36	12.68
	Boswellia serrata	Burseraceae	27.51	7.15	34.66	17.33
	Careya arborea	Lecythidaceae	1.55	0.40	1.95	0.97
	Casearia elliptica	Salicaceae	0.38	0.10	0.48	0.24
	Cassia fistula	Fabaceae	0.41	0.11	0.51	0.26
	Chloroxylon swietenia	Rutaceae	0.59	0.15	0.74	0.37
	Citrus aurantium	Rutaceae	0.10	0.03	0.13	0.06
	Cordia dichotoma	Boraginaceae	0.53	0.14	0.67	0.33
	Dalbergia latifolia	Fabaceae	16.09	4.18	20.27	10.14
	Delonix regia	Fabaceae	1.79	0.47	2.25	1.13
	Diospyros melanoxylon	Ebenaceae	12.61	3.28	15.89	7.94
	Eucalyptus	Myrtaceae	2.50	0.65	3.15	1.58
	Ficus benghalensis	Moraceae	8.93	2.32	11.25	5.63
	Ficus religiosa	Moraceae	7.75	2.02	9.77	4.89
	Gardenia gummifera	Rubiaceae	0.43	0.11	0.54	0.27
	Grewia rotundifolia	Malvaceae	0.21	0.05	0.26	0.13
	Gyrocarpus asiaticus	Hernandiaceae	4.08	1.06	5.15	2.57
	Hardwickia binata	Fabaceae	2.01	0.52	2.53	1.27
	Lannea coromandelica	Anacardiaceae	1.03	0.27	1.30	0.65
	Mangifera indica	Anacardiaceae	1.92	0.50	2.42	1.21
	Moringa oleifera	Moringaceae	1.58	0.41	1.99	0.99
	Phyllanthus emblica	Phyllanthaceae	0.20	0.05	0.25	0.12
	Pongamia pinnata	Fabaceae	2.51	0.65	3.16	1.58
	Psidium guajava	Myrtaceae	2.52	0.66	3.18	1.59

Kurnool district site 2	*Pterocarpus marsupium*	Fabaceae	4.39	1.14	5.54	2.77
	Pterocarpus santalinus	Fabaceae	18.82	4.89	23.72	11.86
	Pterospermum xylocarpum	Malvaceae	1.72	0.45	2.17	1.08
	Saraca asoca	Fabaceae	10.97	2.85	13.83	6.91
	Shorea roxburghii	Dipterocarpaceae	5.77	1.50	7.27	3.63
	Cassia siamea	Fabaceae	2.65	0.69	3.34	1.67
	Tamarindus indica	Fabaceae	7.04	1.83	8.88	4.44
	Tectona grandis	Lamiaceae	9.46	2.46	11.92	5.96
	Terminalia arjuna	Combretaceae	21.90	5.69	27.59	13.80
	Terminalia bellirica	Combretaceae	76.89	19.99	96.88	48.44
	Terminalia chebula	Combretaceae	25.17	6.54	31.71	15.86
	Terminalia elliptica	Combretaceae	24.81	6.45	31.27	15.63
	Wrightia tinctoria	Apocynaceae	0.81	0.21	1.02	0.51
	Xylia xylocarpa	Fabaceae	2.92	0.76	3.69	1.84
	Ziziphus xylopyrus	Rhamnaceae	0.17	0.04	0.21	0.11
Nandyal district site 3	*Senegalia chundra*	Fabaceae	0.52	0.13	0.65	0.33
	Vachellia leucophloea	Fabaceae	10.89	2.83	13.72	6.86
	Vachellia nilotica	Fabaceae	4.94	1.28	6.23	3.11
	Adina cordifolia	Rubiaceae	4.45	1.16	5.60	2.80
	Aegle marmelos	Rutaceae	1.61	0.42	2.03	1.01
	Alangium salviifolium	Cornaceae	4.55	1.18	5.73	2.86
	Albizia amara	Fabaceae	0.28	0.07	0.35	0.18
	Albizia julibrissin	Fabaceae	0.65	0.17	0.82	0.41
	Albizia lebbeck	Fabaceae	14.94	3.88	18.82	9.41
	Anacardium occidentale	Anacardiaceae	1.51	0.39	1.91	0.95
	Annona squamosa	Annonaceae	0.59	0.15	0.74	0.37
	Anogeissus latifolia	Combretaceae	8.56	2.23	10.79	5.39
	Azadirachta indica	Meliaceae	21.45	5.58	27.02	13.51
	Bombax ceiba	Malvaceae	17.83	4.63	22.46	11.23
	Boswellia serrata	Burseraceae	5.83	1.52	7.35	3.67
	Butea monosperma	Fabaceae	1.85	0.48	2.33	1.16
	Cassia fistula	Fabaceae	0.98	0.26	1.24	0.62
	Chloroxylon swietenia	Rutaceae	3.01	0.78	3.79	1.89
	Citrus aurantium	Rutaceae	1.23	0.32	1.55	0.78
	Grewia rotundifolia	Malvaceae	0.29	0.08	0.37	0.19
	Gyrocarpus asiaticus	Hernandiaceae	2.80	0.73	3.52	1.76
	Hardwickia binata	Fabaceae	5.45	1.42	6.87	3.43
	Holoptelea integrifolia	Ulmaceae	1.81	0.47	2.28	1.14
	Hymenodictyon orixense	Rubiaceae	1.75	0.46	2.21	1.10
	Ixora arborea	Rubiaceae	0.15	0.04	0.19	0.10
	Lagerstroemia parviflora	Lythraceae	1.70	0.44	2.14	1.07
	Lannea coromandelica	Anacardiaceae	1.78	0.46	2.25	1.12
	Madhuca longifolia	Sapotaceae	26.05	6.77	32.82	16.41
	Mangifera indica	Anacardiaceae	40.12	10.43	50.55	25.28
	Mimusops elengi	Sapotaceae	0.85	0.22	1.07	0.53
	Morinda umbellata	Rubiaceae	1.24	0.32	1.56	0.78
	Moringa oleifera	Moringaceae	1.54	0.40	1.93	0.97
	Phyllanthus emblica	Phyllanthaceae	3.79	0.99	4.77	2.39
	Pongamia pinnata	Fabaceae	15.51	4.03	19.54	9.77
	Psidium guajava	Myrtaceae	1.08	0.28	1.36	0.68
	Pterocarpus marsupium	Fabaceae	16.92	4.40	21.33	10.66
	Pterocarpus santalinus	Fabaceae	19.95	5.19	25.14	12.57
	Pterospermum xylocarpum	Malvaceae	1.91	0.50	2.40	1.20
	Sesbania grandiflora	Fabaceae	0.33	0.09	0.42	0.21
	Shorea roxburghii	Dipterocarpaceae	12.40	3.23	15.63	7.82
	Cassia siamea	Fabaceae	9.19	2.39	11.58	5.79
	Strychnos nux-vomica	Loganiaceae	2.12	0.55	2.67	1.34
	Strychnos potatorum	Loganiaceae	1.81	0.47	2.28	1.14
	Tamarindus indica	Fabaceae	37.06	9.63	46.69	23.35
	Tectona grandis	Lamiaceae	11.30	2.94	14.24	7.12
	Terminalia alata	Combretaceae	2.68	0.70	3.38	1.69
	Terminalia arjuna	Combretaceae	31.21	8.11	39.33	19.66
	Terminalia bellirica	Combretaceae	14.12	3.67	17.79	8.89
	Terminalia chebula	Combretaceae	20.25	5.26	25.51	12.76
	Terminalia elliptica	Combretaceae	14.65	3.81	18.45	9.23
	Terminalia latifolia	Combretaceae	6.76	1.76	8.51	4.26
	Wrightia arborea	Apocynaceae	0.86	0.22	1.09	0.54
	Wrightia tinctoria	Apocynaceae	0.98	0.25	1.23	0.62
	Xylia xylocarpa	Fabaceae	8.26	2.15	10.40	5.20
	Ziziphus mauritiana	Rhamnaceae	4.81	1.25	6.06	3.03
	Ziziphus xylopyrus	Rhamnaceae	1.03	0.27	1.30	0.65

	Aegle marmelos	Rutaceae	8.37	2.18	10.55	5.27
	Alangium salviifolium	Cornaceae	7.82	2.03	9.85	4.93
	Albizia amara	Fabaceae	0.16	0.04	0.20	0.10
	Albizia lebbeck	Fabaceae	6.35	1.65	8.00	4.00
	Anacardium occidentale	Anacardiaceae	4.44	1.15	5.59	2.80
	Annona squamosa	Annonaceae	0.39	0.10	0.50	0.25
	Anogeissus latifolia	Combretaceae	7.28	1.89	9.18	4.59
	Azadirachta indica	Meliaceae	18.78	4.88	23.66	11.83
	Barringtonia racemosa	Lecythidaceae	0.68	0.18	0.85	0.43
	Bombax ceiba	Malvaceae	10.19	2.65	12.84	6.42
	Boswellia serrata	Burseraceae	6.77	1.76	8.53	4.27
	Butea monosperma	Fabaceae	5.26	1.37	6.62	3.31
	Casearia elliptica	Salicaceae	0.32	0.08	0.41	0.20
	Cassia fistula	Fabaceae	0.60	0.16	0.75	0.38
	Chloroxylon swietenia	Rutaceae	1.14	0.30	1.44	0.72
	Citrus aurantium	Rutaceae	0.51	0.13	0.64	0.32
	Cochlospermum religiosum	Bixaceae	0.56	0.14	0.70	0.35
	Cordia dichotoma	Boraginaceae	2.41	0.63	3.04	1.52
	Dalbergia latifolia	Fabaceae	28.27	7.35	35.62	17.81
	Delonix regia	Fabaceae	3.03	0.79	3.81	1.91
	Diospyros chloroxylon	Ebenaceae	5.20	1.35	6.55	3.27
	Diospyros melanoxylon	Ebenaceae	20.88	5.43	26.31	13.16
	Eucalyptus	Myrtaceae	9.76	2.54	12.30	6.15
	Ficus bengalensis	Moraceae	33.60	8.74	42.34	21.17
Sri Satya Sai district site 4	*Ficus hipsida*	Moraceae	0.53	0.14	0.67	0.33
	Ficus religiosa	Moraceae	26.51	6.89	33.40	16.70
	Gardenia resinifera	Rubiaceae	0.21	0.06	0.27	0.13
	Gardenia turgida	Rubiaceae	1.52	0.40	1.91	0.96
	Grewia rotundifolia	Malvaceae	0.60	0.16	0.76	0.38
	Hardwickia binata	Fabaceae	5.65	1.47	7.12	3.56
	Holoptelea integrifolia	Ulmaceae	4.92	1.28	6.20	3.10
	Hymenodictyon orixense	Rubiaceae	13.52	3.51	17.03	8.51
	Ixora arborea	Rubiaceae	0.33	0.09	0.42	0.21
	Mangifera indica	Anacardiaceae	11.22	2.92	14.14	7.07
	Phyllanthus emblica	Phyllanthaceae	2.33	0.60	2.93	1.47
	Psidium guajava	Myrtaceae	0.27	0.07	0.34	0.17
	Pterocarpus santalinus	Fabaceae	12.41	3.23	15.64	7.82
	Pterospermum xylocarpum	Malvaceae	5.68	1.48	7.15	3.58
	Sesbania grandiflora	Fabaceae	0.32	0.08	0.40	0.20
	Strychnos nuxvomica	Loganiaceae	3.80	0.99	4.79	2.39
	Tamarindus indica	Fabaceae	14.41	3.75	18.15	9.08
	Tectona grandis	Lamiaceae	10.60	2.76	13.36	6.68
	Terminalia alata	Combretaceae	6.85	1.78	8.63	4.31
	Terminalia arjuna	Combretaceae	7.69	2.00	9.69	4.84
	Terminalia elliptica	Combretaceae	17.25	4.48	21.73	10.87
	Terminalia latifolia	Combretaceae	6.11	1.59	7.70	3.85
	Wrightia arborea	Apocynaceae	5.29	1.38	6.67	3.34
	Wrightia tinctoria	Apocynaceae	0.80	0.21	1.01	0.50
	Xylia xylocarpa	Fabaceae	7.56	1.97	9.53	4.77
	Ziziphus mauritiana	Rhamnaceae	9.12	2.37	11.49	5.74

AG: above ground; AGB: above ground biomass; BG: below ground; C: carbon; T: total; MG HA^{-1}: megagram per hectare; MG C HA^{-1}: megagram carbon per hectar.

Table 2. Biomass and carbon density analysis across four districts (Anantapur, Kurnool, Nandyal and Sri Satya Sai) of Andhra Pradesh

Study site	AGB tree biomass density (Mg ha^{-1})	BGB tree biomass density (Mg ha^{-1})	Total Biomass density (Mg ha^{-1})	Tree C density (Mg C ha^{-1})
Anantapur	257.91	67.06	324.96	162.48
Kurnool	398.10	103.51	501.61	250.81
Nandyal	430.16	111.84	542.01	271.00
Sri Satya Sai	358.26	93.10	451.40	225.70
Mean	361.11	93.88	455.25	227.50
CD	20.18 %	20.74 %	20 %	19.12 %
SD	72.91	19.46	90.88	43.47
SE(m)	36.46	9.73	45.44	21.73
SE(d)	37.84	46.47	58.33	50.34
F-Test	S	S	S	S

AGB: above ground biomass; BGB: below ground biomass; T: total biomass; C: carbon; Mg ha^{-1}: mega gram per hectare; CD: critical difference; SE(M): standard error of the mean; SD: standard deviation; SE(D): standard error of the difference; *F*-Test: Fisher's test; S: significant.

the highest aboveground, belowground and total biomass, as well as carbon density, indicating its superior carbon sequestration potential. In contrast, Anantapur exhibited the lowest biomass and carbon stocks, emphasising the limiting effects of climatic and edaphic constraints. The statistically significant differences confirm that site-specific factors strongly influence vegetation structure and carbon dynamics. The positive relationship between species diversity indices and aboveground biomass further suggests that increased biodiversity enhances ecosystem productivity and carbon storage capacity. The study highlights the need for site-specific management strategies, including afforestation, restoration of degraded lands and promotion of native species, particularly in low-productivity areas, to strengthen ecosystem resilience and climate change mitigation potential.

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Authors' contributions

BSY and HK conceived, planned and conducted the experiment on the estimation of diversity, biomass and carbon sequestration potential of woody vegetation in the scarce rainfall zone of Andhra Pradesh. NP, UPL, GR, CJY and SK recorded the experimental data. AT and VK prepared the draft manuscript, formatted it according to journal guidelines and cross-checked the statistical analyses. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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