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Carbon Stock Estimation of Compensatory Afforestation Plantation Work in Balod District of Chhattisgarh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper encapsulates the findings of carbon stock assessment of compensatory afforestation work done in Balod District of Chhattisgarh. Under the State CAMPA (Compensatory Afforestation Fund Management and Planning Authority) scheme, the afforestation project aims to enhance the local environment, create employment opportunities for the villagers of Armarikala, and provide fodder for nearby farmers' cattle. This initiative not only address the ecological impact of the power transmission line construction but also align with sustainable development goals by providing socio-

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economic benefits to the local community. The study aimed to quantify the biomass and carbon sequestration potential of diverse tree species in the Compensatory Afforestation Plantation Work in Balod District of Chhattisgarh. The carbon stock data highlights the significance of different tree species, with Terminalia arjuna emerging as a major contributor, sequestering 3,814.2 kg followed by Dalbergia sissoo with 2616.7 kg of carbon in the surveyed area. The carbon stock assessment in Balod District of Chhattisgarh demonstrates the significant ecological and socio-economic benefits of the compensatory afforestation project under the State CAMPA scheme. The findings underscore the project's alignment with sustainable development goals, enhancing both environmental health and local livelihoods.

Keywords: Carbon stock assessment; biomass; CAMPA; plantation; ecosystem services.

1. INTRODUCTION

CAMPA is emerging as the largest sustainable source of funding for afforestation activities in the country. There is growing importance of independent evaluations, to assess what is working and what is not, so as to improve the programme in future. The vegetation offers a diverse array of ecological services and benefits to communities, significantly enhancing human health and environmental quality. Furthermore, it mitigates the elevated ambient air temperatures prevalent due to the prevalence of heat-absorbing materials [1]. Despite an increased number of studies on carbon stock estimates, little information is available for tropical and subtropical forests, although they constitute a significant proportion of global forest cover [2].

Anthropogenic activities precipitate a rise in atmospheric carbon dioxide levels, with limited information available concerning its sinks. The assessment of carbon biomass within tropical regions has attracted significant attention from REDD+ initiatives, which aim to mitigate emissions from deforestation and forest degradation while augmenting carbon stocks [3]. Carbon stocks in the forests of Reducing Emissions from Deforestation and Forest Degradation (REDD+) participating countries have to be estimated and monitored to determine accurate financial incentives and compensation [4]. The Kyoto Conference identified the need to establish an accurate inventory of carbon stocks in forests [5].

The most accurate method involves direct measurement of biomass, it can be time-consuming and expensive. Remote sensing and modelling offer efficient means to estimate carbon stocks over larger areas, facilitating comprehensive assessments of ecosystems. Estimating carbon stocks in different ecosystems, such as forests, wetlands, soils, and agricultural lands, presents unique challenges [6-10]. Each ecosystem requires specific considerations, and diverse methods are employed to address these challenges. Accurate carbon stock data is foundational for environmental policies, emission reduction targets, resource allocation, and monitoring climate change mitigation initiatives. Transparent and reliable estimates will foster international cooperation in addressing climate change challenges, aligning with the goals outlined in the Paris Agreement (2015). Conversely, underestimation of carbon stocks risks the development of ineffective policies, highlighting the importance of precise estimation [11].

Under the State CAMPA (Compensatory Afforestation Fund Management and Planning Authority) scheme, the afforestation project aims to enhance the local environment, create employment opportunities for the villagers of Armarikala, and provide fodder for nearby farmers' cattle. The careful execution of compensatory afforestation, coupled with protective measures, promises a positive impact on the environment, employment generation, and the overall well-being of the communities involved. Estimating carbon stock and biomass in afforestation projects is crucial for understanding their ecological and socio-economic impacts. Accurate carbon stock measurements are vital for several reasons. Primarily, forests serve as significant carbon sinks, absorbing carbon dioxide from the atmosphere and storing it in biomass and soil, thus playing a key role in mitigating climate change [12,13]. Reliable carbon stock data also aids policymakers in formulating and monitoring environmental policies and commitments under international agreements such as the Paris Agreement [14]. Biomass estimation is equally important as Higher biomass often correlates with greater biodiversity and better habitat quality, making biomass estimation a useful proxy for evaluating the ecological value of afforestation efforts [15]. Keeping this in consideration the present research aims to evaluate the effectiveness of the afforestation project under the State CAMPA (Compensatory Afforestation Fund Management and Planning Authority) scheme, focusing on specific objectives of this study as;

1. To quantify the biomass accumulated by the newly planted trees in the afforestation project area.
2. To estimate the amount of carbon sequestered, contributing to carbon stock and mitigating climate change.

2. METHODOLOGY

In present research the data collected on tree biomass from sample plots within the afforestation site under CAMPA. Allometric equations, which relate tree dimensions (like diameter and height) to biomass, to estimate above ground biomass (AGB) has been used [16].

2.1 Plantation Information

In the context of the construction of the Jagdalpur power transmission line, approximately 81.984 hectares of forest land in the Gurur Subordinate Assistant Circle was affected. To compensate for this loss, a compensatory afforestation initiative is set to take place in the revenue land located at the village of Armarikala, within the Gram Panchayat Armarikala. The allocated area spans 30.52 hectares, with a workable afforestation area of 30 hectares. The Compensatory Irrigated Plantation Project undertaken in 2020-21 in the Armarikala village in Khasra no. 580-641 and 642 of Balod Forest Range, Durg Circle, Chhattisgarh, aimed at ecological restoration and sustainable afforestation. Over a sprawling 30 hectares of land, a meticulous planting strategy was implemented, involving the insertion of 30,835 plants. These plants, strategically spaced at intervals of (3x3) meters, included a diverse array of tree species contributing to the region's biodiversity and ecological balance (Fig. 1). Scientifically classified, the plantation featured species such as *Syzygium cumini* (Jamun), *Terminalia arjuna* (Arjun), *Azadirachta indica* (Neem), *Dalbergia sissoo* (Sissoo), *Mitragyna parvifolia* (Mundi), *Adina cordifolia* (Haldu), *Pongamia pinnata* (Pongamia), *Phyllanthus emblica* (Amla), and *Psidium guajava* (Guava).

2.2 Plot Design and Sampling Strategy

To avoid bias and ensure proper representation of the entire 30-hectare area, a stratified random sampling approach was implemented. The plantation was divided into 30 equal subplots of .1 hectares each.

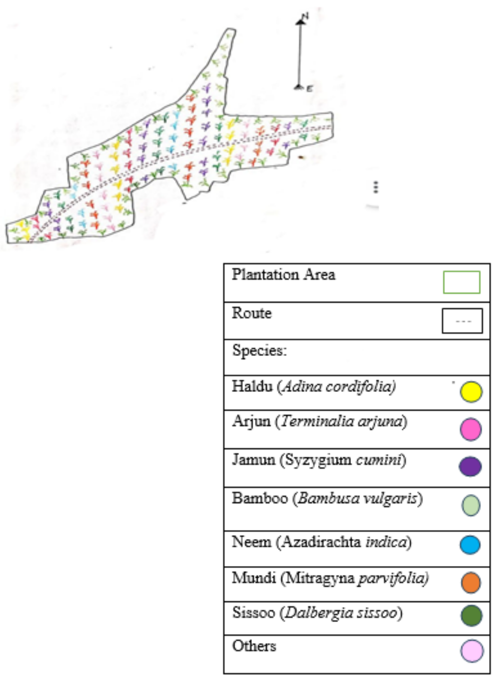

Fig. 1. Plantation Map

2.3 Data Collection

Within each sample plot, data was collected for 100 individual trees, encompassing all tree species present and a total of 3000 plants samples are collected. The following measurements were recorded for each tree:

Collar girth: Measured from the base of the plants i.e., 2 inch above the ground.

Height: Measured using ocular technique. G^ (2)

2.4 Carbon Stock Calculation

In spite of the large number of studies carried out so far, still major knowledge gaps remain in estimating carbon stock of vegetation, commonly accomplished from in situ measured biophysical parameters of individual plants. At present, diameter at breast height (DBH) is commonly used [17-20]. The method used is volume estimation by quarter girth by using this the volume of each tree was subsequently calculated using appropriate species-specific wood density to calculate biomass of the plants and to calculate the carbon stock 47% of the total biomass of above ground and 27% of above ground biomass was taken to calculate the below ground carbon stock. The total carbon stock of the plantation was calculated by summing the carbon stock values of each individual species. The quarter girth formula is commonly used for estimating the volume of standing trees. It is a simple and quick method that involves measuring the tree's circumference at collar girth (G) and then applying a formula to estimate the tree's volume. The formula is as follows:

The collar girth is typically measured a few inches above the ground, often at the root flare or collar of the tree. The formula with collar girth (G) used is;

$$V = \frac{G^2 * H}{4\pi}$$

Where:

V is the volume of the tree,

π is a mathematical constant (approximately 3.14159),

G is the collar girth of the tree (circumference divided by π),

H is the height of the tree.

Four years is a young age for these species. Wood density typically increases with age, so expect values significantly lower than mature trees. Even within the same species, individual trees can have differing wood densities due to genetics and microsite conditions. For finding biomass in the study area, volume of each species multiplied with their wood density and for enumerating carbon stock, 47 % total biomass is calculated which gives carbon sequestered from every species present.

Total Biomass = Above Ground Biomass + Below Ground Biomass

2.5 Data Analysis

The collected data was analyzed using appropriate statistical tools to determine various parameters, including; Mean of tree volume and biomass for each species and the entire plantation, Carbon stock per hectare and for the entire plantation, Carbon sequestration potential of the plantation. The employed methodology uses a stratified random sampling which ensures a representative sample of the entire plantation, reducing bias. However, the methodology also has limitations. Limited sampling intensity is one of them as while 30 samples provide good coverage, even higher sampling density could further improve accuracy. Overall, the methodology used provides a robust and reliable approach for estimating the carbon stock of the mixed plantation.

3. RESULTS

The investigation aimed to quantify the carbon sequestration potential of diverse tree species in the given land area. Through comprehensive field surveys, data collection, and analysis, assessment of the distribution of carbon stocks across various components, such as aboveground biomass, belowground biomass has been done. Table 1 represents a comprehensive overview of the tree species number planted and distribution in the surveyed area, showcasing both the variety and abundance of the local flora. The dominant species, constituting a significant portion of the total population, include *Terminalia arjuna* (Arjun) and *Dalbergia sissoo* (Sissoo), accounting for 28% and 26% of the total species, respectively. These two species together make up more than half of the entire tree population. Following closely are *Syzygium cumini* (Jamun) and *Adina cordifolia (*Haldu), each contributing 9% and 6% to the overall species composition. *Azadirachta indica* (Neem) and *Mitragyna pervifolia* (Mundi) also play notable roles, comprising 3% and 18%, respectively, of the total tree population. *Bambusa vulgaris* (Bamboo) 4% and Other

Species, which represent various trees not specified in the listed categories, contribute 6%.

Fig. 2 exhibits a significant survival rate of 85% of *Azadirachta indica* (Neem), underscoring its capacity to endure environmental stressors. *Adina cordifolia* (Haldu) and *Mitragyna parvifolia* (Mundi) demonstrate even higher survival rates of 90% and 98%, respectively, indicating their robust resilience within the local ecosystem. *Bambusa vulgaris* (Bamboo) and other uncategorized species show survival rates of 80% and 93%, respectively, reflecting a broad spectrum of species with varying adaptive capabilities. These survival metrics are vital for assessing species performance in the surveyed area, thereby informing conservation and management initiatives.

As evident from Fig. 3 *Dalbergia sissoo and Syzygium cumini* showing the maximum average height in plantation area. The species examined include *Terminalia arjuna*, with an average height of 2 meters and a girth of 0.17 meters; *Azadirachta indica*, standing at an average height of 1.39 meters and a girth of 0.114 meters; *Dalbergia sissoo*, reaching an average height of 2.1 meters and a girth of 0.125 meters; *Adina cordifolia*, displaying an average height of 1.66 meters and a girth of 0.126 meters; *Mitragyna parvifolia*, recording an average height of 1.43 meters and a girth of 0.178 meters; and *Syzygium cumini*, presenting an average height of 2.11 meters and a girth of 0.121 meters. Additionally, a category labelled "Other" was included, indicating an average height of 1.24 meters and a girth of 0.09 meters.

Table 1. Information of Species Planted

S. No.	Name of species	Number of Plants
1.	*Terminalia arjuna* (Arjun)	8488
2.	*Dalbergia sissoo* (Sissoo)	8000
3.	*Syzygium cumini* (Jamun)	2820
4.	*Azadirachta indica* (Neem)	835
5.	*Adina cordifolia* (Haldu)	1900
6.	*Mitragyna pervifolia* (Mundi)	5500
7.	*Bambusa vulgaris* (Bamboo)	1292
8.	Other Species	2000
9.	Total	30,835

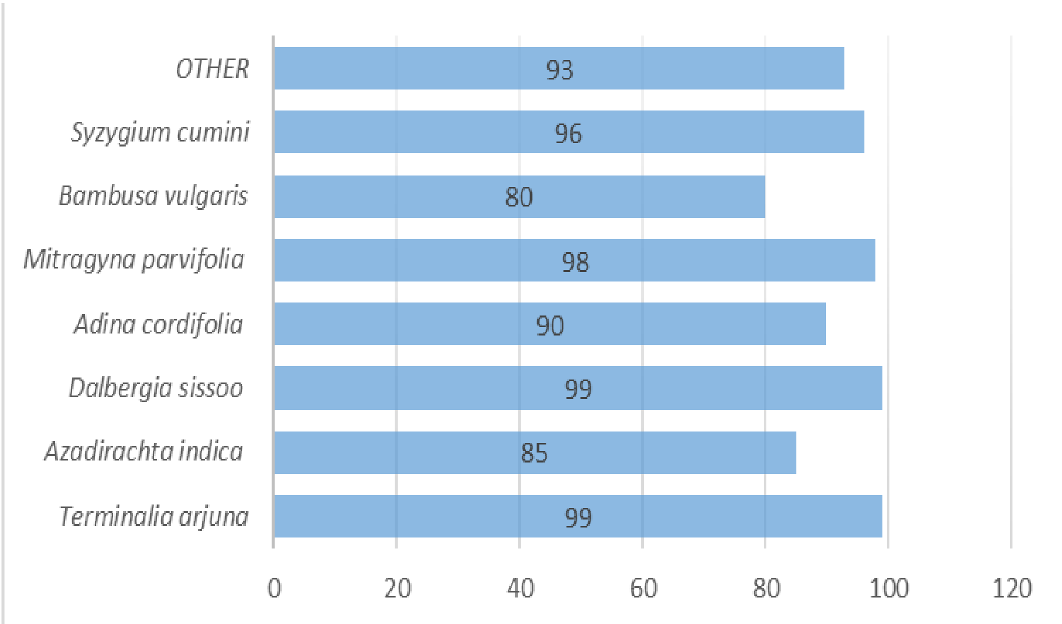

Fig. 2. Depicting Survival Rate of Plantation in Percentage (%)

Based on the wood density (Table 2), Table 3 details the volume of different tree species in a mixed plantation across a 30-hectare area. *Terminalia arjuna* stands out with the highest volume of 10.65 m3, emphasizing its significant contribution to the overall biomass and spatial occupancy within the plantation. *Dalbergia sissoo* follows closely with a volume of 8.73 m3, indicating its substantial presence and potential for biomass accumulation. *Mitragyna parvifolia* and *Syzygium cumini* contribute volumes of 9 m3 and 5.4 m3, respectively, showcasing their considerable presence in the mixed plantation. *Azadirachta indica* and *Adina cordifolia* exhibit volumes of 2.79 m3 and 3.6 m3, respectively, suggesting a comparatively smaller but still noteworthy contribution. *Madhuca longifolia*, with a volume of 0.6 m3, represents a smaller spatial footprint. The category labelled "Other" collectively contributes a volume of 3 m3, encapsulating various unlisted species. In comparison, the data underscores the varying sizes and contributions of each species, providing valuable insights into the ecological composition and distribution of volume within the mixed plantation. *Terminalia arjuna* and *Dalbergia sissoo* emerge as key contributors, while the "Other" category represents the combined volume of additional species that collectively shape the overall composition of the plantation.

3.1 Biomass

In the mixed plantation encompassing 30 hectares, the diverse array of tree species makes distinct contributions to the overall ecosystem, as elucidated by the data (Table 4), *Terminalia arjuna* emerges as a key player, boasting a remarkable above-ground biomass of 6390 kg per 30 hectares, accompanied by a substantial below-ground biomass of 1725.3 kg. This results in a comprehensive total biomass of 8115.3 kg, underscoring its significance in the mixed plantation. *Azadirachta indica* contributes moderately with an above-ground biomass of 1325.25 kg and a below-ground biomass of 357.8175 kg, resulting in a total biomass of 1683.0675 kg per 30 hectares. *Dalbergia sissoo* stands out with significant growth, showcasing an above-ground biomass of 4383.25 kg and a below-ground biomass of 1183.4775 kg. This sums up to a total biomass of 5566.7275 kg, emphasizing its substantial role in shaping the biomass dynamics. *Adina cordifolia*, with an above-ground biomass of 2070 kg and a below-ground biomass of 558.9 kg, contributes to the mixed plantation, resulting in a total biomass of 2628.9 kg per 30 hectares. *Mitragyna parvifolia* significantly contributes, presenting a substantial above-ground biomass of 4725 kg and a below-ground biomass of 1275.75 kg, totalling 6000.75 kg. *Sygium cumini* showcases noteworthy.

Table 2. Showing Species Specific Wood Density

S. No.	Species	Wood density
1	*Terminalia arjuna (Arjuna)*	500-700 kg/m³ (around 60-70% of mature density)
2	*Azadirachta indica (Neem)*	400-550 kg/m³ (around 60-70% of mature density)
3	*Dalbergia sissoo (Sissoo)*	450-600 kg/m³ (around 60-70% of mature density)
4	*Adina cordifolia (Haldu)*	500-650 kg/m³ (around 60-70% of mature density)
5	*Mitragyna parvifolia (Mundi)*	450-600 kg/m³ (around 60-70% of mature density)
6	*Madhuca longifolia*	420-630 kg/m³ (around 60-70% of mature density)

Table 3. Volume of Plantation

Scientific name	Volume/30Ha (m3)
Terminalia arjuna	10.65
Azadirachta indica	2.79
Dalbergia sissoo	8.73
Mitragyna parvifolia	9
Adina cordifolia	3.6
Madhuca longifolia	0.6
Syzygium cumini	5.4
Other	3

Table 4. Total Biomass

Name of species	Above ground Biomass/ 30 Hectare (Kg)	Below ground biomass/30Hectare	Total biomass/30 Hectare
Terminalia arjuna	6390	1725.3	8115.3
Azadirachta indica	1325.25	357.8175	1683.0675
Dalbergia sissoo	4383.25	1183.4775	5566.7275
Adina cordifolia	2070	558.9	2628.9
Mitragyna parvifolia	4725	1275.75	6000.75
Syzygium cumini	3186	860.22	4046.22
Madhuca longifolia	315	85.05	400.05
Other	1500	405	195
Total			30346.3

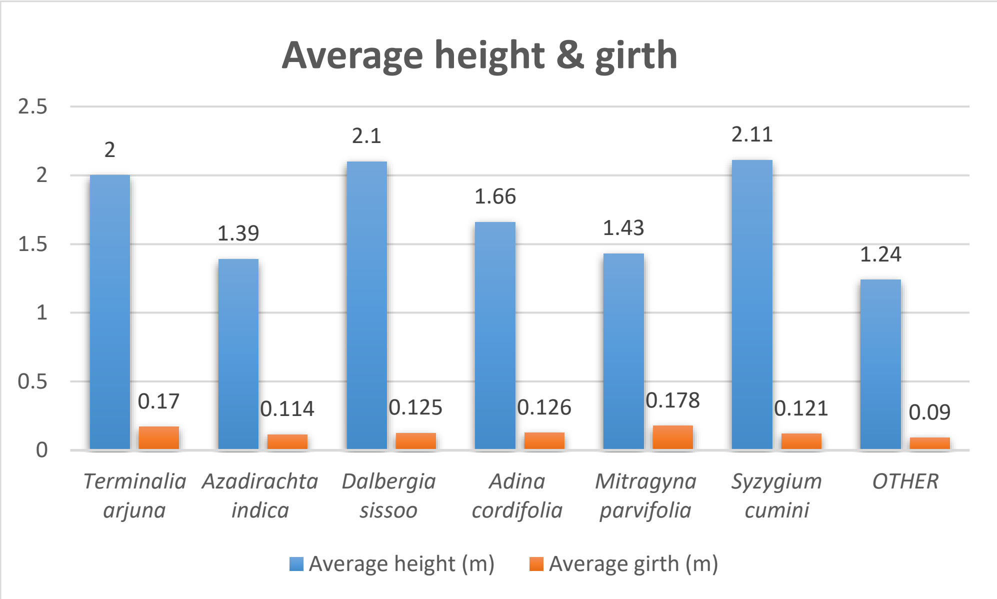

Fig. 3. Average Height and Average Girth of Plantation

growth, contributing an above-ground biomass of 3186 kg and a below-ground biomass of 860.22 kg, resulting in a total biomass of 4046.22 kg. *Madhuca longifolia*, with a relatively lower above-ground biomass of 315 kg, adds value with a below-ground biomass of 85.05 kg, totalling 400.05 kg. The "OTHER" category, representing various unlisted species, collectively contributes 1500 kg of above-ground biomass, 405 kg of below-ground biomass, totalling 1905 kg (Share of different species in percentage shown at Fig. 4). Together, these tree species form a diverse and ecologically rich mixed plantation, each playing a unique and vital role in shaping the overall biomass dynamics, carbon sequestration potential, and ecological health of the ecosystem

3.2 Carbon Stock

Table 5 provides a comprehensive overview of carbon stock of different tree species within a mixed plantation covering a 30-hectare area. *Terminalia arjuna* emerges as a major carbon stock, contributing significantly with 3814.2 kg of carbon stock. Following closely, Dalbergia sissoo plays a substantial role with 2616.7 kg of carbon stock, showcasing its importance in mitigating carbon emissions. *Mitragyna parvifolia* and *Syzygium cumini* also contribute notably having 2820 kg and 1902 kg of carbon stock, respectively, reflecting their positive impact on carbon sequestration within the ecosystem. *Azadirachta indica* and *Adina cordifolia* contribute 791 kg and 1235.6 kg of carbon, respectively, representing additional contributors to the overall carbon sequestration efforts. *Madhuca longifolia*, with a carbon stock of 188 kg, and the category labelled "OTHER," which collectively sequesters 895 kg of carbon, contribute smaller but still significant amounts to the overall carbon storage in the mixed plantation.

Table 5. Carbon Stock

Name of species	Carbon Stock /30Ha (kg)
Terminalia arjuna	3814.2
Azadirachta indica	791
Dalbergia sissoo	2616.7
Adina cordifolia	1235.6
Mitragyna parvifolia	2820
Syzygium cumini	1902
Madhuca longifolia	188
Other	895
Total	14262.5

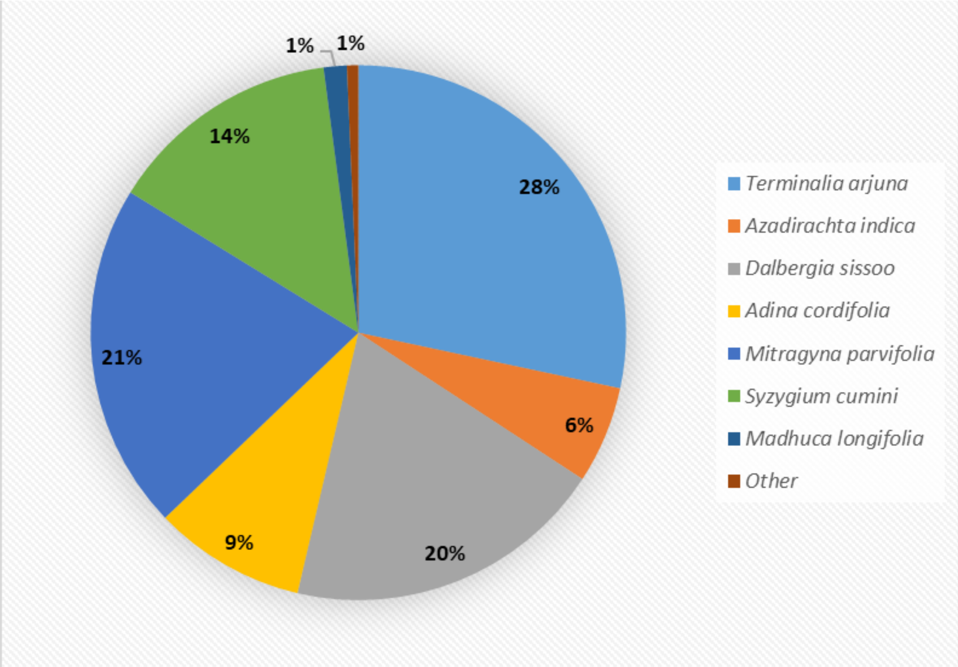

Fig. 4. Share of Different Tree Species in Total Biomass/30 Hectare

4. DISCUSSION

The diversity in species distribution highlights the richness of the local ecosystem, with each species contributing uniquely to its ecological functions. The data indicates a well-balanced and varied tree composition, reflecting a harmonious coexistence among species. This information is essential for comprehending the region's ecological dynamics and supports the development of targeted conservation and management strategies aimed at preserving the health and biodiversity of the local forest. The total count of 30,835 trees offers a robust quantitative basis for future ecological assessments and monitoring efforts. The provided Graph details the survival rates and the number of species survived for various tree species in the surveyed area, offering valuable insights into the resilience and health of the local tree population. *Terminalia arjuna* (Arjun) and *Dalbergia sissoo* (Sissoo) exhibit remarkable survival rates of 99%, underscoring their robustness and adaptability to the prevailing environmental conditions. *Syzygium cumini* (Jamun) follows closely with a commendable 96% survival rate, contributing significantly to the overall biodiversity.

The notably high survival rates of species such as *Terminalia arjuna* (Arjun) and *Dalbergia sissoo* (Sissoo) highlight their potential for sustained growth, whereas the observed variability among other species emphasizes the necessity for species-specific conservation strategies. *Terminalia arjuna* emerges as a major carbon sequester, contributing significantly with 3814.2 kg of carbon sequestered along with boasting a remarkable above-ground biomass of 6390 kg per 30 hectares. The findings shed light on the ecological significance of mixed species plantations in enhancing carbon stock, providing valuable insights for sustainable land management practices and climate change mitigation strategies. Carbon stock estimation project conducted in the mixed plantation of the State CAMPA project in Chhattisgarh provides valuable insights into the carbon stock potential of diverse tree species. The afforestation initiative, covering 30 hectares in Amerikala village, is a commendable effort towards ecological restoration in response to the environmental impact of the Jagdalpur power transmission line construction. In the meticulous planting strategy of 2020-21, 30,835 plants were strategically placed. This afforestation initiative holds significant environmental importance, as each of these species serves various ecological functions. For instance, Neem (Azadirachta *indica*) is well-known for its medicinal properties, while Arjun (*Terminalia arjuna*) contributes to soil health and water conservation. Additionally, the inclusion of diverse species ensures a resilient and sustainable ecosystem, promoting wildlife habitat and fostering a healthier environment for local communities. The Compensatory Irrigated Plantation Project in Chhattisgarh stands as a commendable effort towards mitigating environmental degradation, enhancing biodiversity, and fostering long-term ecological sustainability in the region. These measurements provide valuable insights into the morphological characteristics of each species, enhancing our understanding of their growth patterns and potential ecological roles. This dataset establishes a baseline for continuous monitoring and adaptive management, enabling stakeholders to make informed decisions to maintain the long-term health and sustainability of the local tree population. The data can be instrumental in informing conservation efforts, urban planning, and sustainable forestry practices [21]. The data underscores the varying capacities of different tree species to sequester carbon, providing valuable insights into their roles in mitigating climate change and emphasizing the importance of maintaining a diverse and well-managed mixed plantation for enhanced carbon stock.

5. CONCLUSION

The study focused on estimating carbon stocks across various components, providing a comprehensive overview of the carbon stock potential of the mixed plantation. The data, including survival rates, volume distribution, and biomass calculations, underscores the ecological richness and varied contributions of each tree species. *Terminalia arjuna* and *Dalbergia sissoo* stand out as key contributors to both biomass and carbon stock, showcasing their robustness and significant role in shaping the ecosystem. The total biomass of 30,346.3 kg per 30 hectares represents a substantial carbon reservoir. The plantation sequesters 14,262.5 kg of carbon, highlighting its role in mitigating climate change by capturing and storing carbon dioxide. High survival rates for key species indicate their resilience, providing a foundation for sustained growth and long-term carbon stock. Volume distribution data reveals *Terminalia arjuna* dominance in spatial occupancy. The carbon stock data further reinforces the significance of different tree species, with *Terminalia arjuna* emerging as a major contributor, sequestering 3,814.2 kg of carbon. In the context of environmental policies, these findings provide a foundation for decision-making. Accurate carbon stock estimates are crucial for setting emission reduction targets and monitoring climate change mitigation progress [22]. The transparent data generated through this study will contribute to informed policy development and effective implementation of afforestation projects.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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