Jurnal Teknik Industri: Jurnal Hasil Penelitian dan Karya Ilmiah dalam Bidang Teknik Industri

Vol. 12, No. 1, 2026

Analysis of Biomass Potential and Carbon Stocks on Various Vegetation Types in Trembesi City Forest and Putroe Phang City Forest in Banda Aceh

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ABSTRACT

Urban forests play an important role in climate change mitigation by storing biomass and carbon. This study aims to analyze the potential of biomass and carbon stocks in various types of vegetation in the Trembesi City Forest and Putroe Phang City Forest in Banda Aceh. The study uses a quantitative descriptive approach through vegetation inventory, employing non-destructive sampling methods. Field data in the form of tree type, number of individuals, and trunk diameter are used to calculate biomass using allometric equations, then converted into carbon stocks. The results of the study show that the Trembesi City Forest has a higher biomass potential and carbon reserves than the Putroe Phang City Forest. This is influenced by the dominance of large-diameter, wide-headed trees, which contribute significantly to biomass accumulation. In contrast, the Putroe Phang Urban Forest has a more diverse vegetation structure, but is dominated by medium-sized trees, resulting in relatively lower biomass potential and carbon reserves. The findings of the study confirm that the size of the diameter of the tree is a major factor in determining the amount of biomass and carbon reserves. Thus, the presence of large trees in urban forests plays a strategic role in improving the area's ecological function as a carbon store and supporting the sustainability of the urban environment.

Keywords: Biomass, Carbon Reserves, Urban Forests, Vegetation, Banda Aceh.

Introduction

Global climate change has become an increasingly urgent environmental issue and demands the attention of various parties an both the international and local scales [1]. One of the main causes of climate change is the increasing concentration of greenhouse gases in the atmosphere, specifically carbon dioxide (CO_2), which is largely produced by human activities in urban areas [2], [3].

Cities, as centers of economic growth and human activity, contribute significantly to increases in carbon emissions from transportation, industry, and land-use change [4]. This condition also occurs in Banda Aceh, which is experiencing increased environmental pressure from urban development. As a coastal city, Banda Aceh is highly vulnerable to the impacts of climate change, including rising temperatures, changes in rainfall patterns, and the potential for sea-level rise. In this context, the existence of green open spaces, especially urban forests, is an important component in maintaining ecological balance [5]. Urban forests function as an environmental buffer system that is able to improve air quality, improve the microclimate, and play a role in absorbing carbon dioxide through the process of photosynthesis [6], [7]. The absorbed carbon is then stored in vegetation biomass [8]. Vegetation biomass is an important indicator in determining the capacity of an area to store carbon. The larger the biomass of a vegetation [9], the greater the potential for carbon that can be stored in plant tissue [10]. In urban ecosystems, vegetation has different abilities to absorb carbon depending on the type, structure, density, and size of the tree. Therefore, the analysis of biomass potential and carbon stocks is important in understanding the role of urban forests as nature-based solutions in climate change mitigation [11].

Previous research in the Aceh region has shown that tree size significantly affects carbon sequestration potential. Trees with large diameters tend to have a higher carbon storage capacity than small vegetation.

In line with this, studies on urban forests in Banda Aceh show that aboveground biomass can exceed 24 tons/ha, equivalent to a carbon stock of about 11 tons/ha. This indicates that green open spaces have a real contribution to carbon emission mitigation [12].

However, most previous research has focused on vegetation inventory, without directly linking it to biomass potential and carbon stocks. In fact, quantitative information on carbon stocks is essential to assess the extent to which an urban forest area is able to play a role in reducing the accumulation of CO_2 in the atmosphere [13].

In this context, two urban forest areas in Banda Aceh are important objects for study, namely the Trembesi City Forest and the Putroe Phang City Forest. These two areas have different vegetation characteristics, both in terms of type composition and tree stand structure. The Trembesi City Forest has an area of about 2.3335 hectares with a vegetation composition consisting of 31 types and 151 individual trees.

The vegetation in this area is dominated by the trembesi species (Samanea saman) with a dominance proportion of 35.10%. Meanwhile, the Putroe Phang Urban Forest has an area of about 2.4462 hectares with 23 types of vegetation and 127 individual trees. The cape type (Mimusops elengi) is the dominant vegetation in this area, with a dominance rate of 16.54%. Differences in vegetation composition can affect the amount of biomass and carbon stored in each area.

The vegetation structure in the two urban forests also shows the dominance of the tree phase, which is 70.20% in Trembesi and 77.95% in Putroe Phang. The dominance of trees over 20 cm in diameter contributes more than 95% to the total biomass, which shows the importance of the role of large trees in carbon storage [14].

Thus, biomass-based vegetation management is an important strategy in improving the ecological function of green open spaces. Analysis of biomass potential and carbon stocks also provides a scientific basis in sustainable urban spatial planning [15] . In addition, the results of this study can be used as a reference in determining priority vegetation types that have high carbon absorption capacity. In the long term, strengthening the ecological functions of urban forests can help reduce carbon emissions and increase urban environmental resilience [16].

Therefore, research on the analysis of biomass potential and carbon stocks on various types of vegetation in the Trembesi City Forest and Putroe Phang City Forest is important to support ecosystem-based climate change mitigation efforts in urban areas.

Research Methods

This study employed a quantitative descriptive approach using a field survey method to analyze vegetation composition and estimate biomass potential, carbon stocks, and carbon dioxide (CO_2) uptake in two urban forests in Banda Aceh, namely Trembesi City Forest and Putroe Phang City Forest [17]. The quantitative approach was selected to generate empirical, measurable estimates of biomass and carbon storage using biophysical tree parameters observed directly in the field [12].

Study Area

The research was conducted in two green open space areas in Banda Aceh:

1. Trembesi City Forest
2. Putroe Phang City Forest

Both sites were purposively selected due to differences in vegetation composition, stand structure, and dominant species. Trembesi City Forest covers approximately 2.3335 ha with 31 vegetation types and 151 individual trees, while Putroe Phang City Forest covers approximately 2.4462 ha with 23 vegetation types and 127 individual trees. These structural differences enable comparative analysis of biomass and carbon storage capacity.

Data Collection

Vegetation data were collected using a non-destructive sampling method, meaning that no trees were felled during the measurements. This method aligns with carbon accounting standards recommended by the IPCC (2006) and SNI 7724:2011. Observation units included vegetation at different growth stages: seedlings, saplings, poles, and trees. However, biomass and carbon stock calculations primarily focused on pole and tree stages, as these growth classes contribute most significantly to biomass accumulation.

For each recorded individual, the following parameters were measured:

1. Vegetation species

2. Number of individuals
3. Diameter at breast height (DBH)
4. Tree height

DBH was measured at 1.3 meters above ground level using a diameter tape. Tree height was measured using a tree height measurement instrument. All measurements were conducted within a total observation plot area of 0.4 ha at each site.

Biomass Estimation

Above-ground biomass (AGB) was estimated using allometric equations for tropical forests that allow biomass estimation from DBH and tree height without destructive harvesting. The general allometric model applied follows:

$$AGB=f(DBH,H,\rho) \quad (1)$$

where:

- AGB = Above-ground biomass (kg)
- DBH = Diameter at breast height (cm)
- H = Tree height (m)
- ρ = Wood density (g/cm³, when applicable)

Total biomass per plot was calculated by summing the individual tree biomass values and then converted to tons per hectare (ton/ha).

Carbon Stock and CO_2 Uptake Estimation

Carbon stock was calculated by applying a conversion factor of 0.47 to total biomass, reflecting that approximately 47% of dry biomass consists of carbon:

$$C=0.47\times AGB \quad (2)$$

The estimated CO_2 uptake potential was calculated using a molecular conversion factor of 3.67, representing the ratio of CO_2 molecular weight (44) to carbon atomic weight (12):

$$CO2=3.67\times C \quad (3)$$

Data Analysis

Quantitative analysis was conducted to determine:

1. Total above-ground biomass (kg and ton/ha)
2. Total carbon stock (kg and ton/ha)
3. Total potential CO_2 uptake

Species-level analysis was performed to determine the contribution of dominant and minor vegetation types to total biomass and carbon stocks. Additionally, biomass and carbon distribution were analyzed by tree diameter class, with particular emphasis on trees with DBH > 20 cm, to assess structural contribution to carbon storage. Finally, a comparative analysis between the Trembesi City Forest and the Putroe Phang City Forest was conducted to evaluate differences in carbon storage capacity influenced by vegetation composition, tree size distribution, and stand maturity.

Through this methodological framework, representative and scientifically robust estimates of biomass potential, carbon reserves, and CO_2 absorption capacity were obtained without damaging vegetation, thereby providing an empirical basis for assessing the ecological contribution of urban forests in climate change mitigation in Banda Aceh.

Results and Discussion

Vegetation Biomass Potential

Based on the results of tree diameter measurement (DBH) in the field and calculations using allometric equations, the value of above-ground biomass (AGB) was obtained at both research sites. Vegetation biomass reflects the amount of living organic matter stored in tree stands and is a key indicator of an area's carbon storage capacity.

The results of the study showed that both urban forests have a fairly high biomass potential despite being in urban landscapes.

The total vegetation biomass obtained in the Trembesi City Forest is:

1. 166,271.16 kg on the observation plot area (0.4 ha)
2. Equivalent to 415.68 tons/ha

This value indicates that this area has relatively mature tree stands and is dominated by large-diameter individuals. The largest biomass contribution comes from the trembesi species, which is known ecologically to have rapid growth and large heads.

Table 1. Biomass is the Dominant Type in Trembesi City Forest

Yes	Vegetation Type	Biomass (kg)
1	Trembesi	80.729,51
2	Tamarind	30.384,22
3	Ketapang Kencana	21.654,78
4	São Paulo	9.245,63
5	Guava	7.820,45

Table 2. low biomass Type in Trembesi City Forest

No	Vegetation Type	Biomass (kg)
1	This	1,80
2	Srikaya	2,35
3	Big Miss	2,99

The low biomass of these species is due to the small stem diameter and the limited number of individuals.

In the Putroe Phang City Forest, obtained:

- 133,937.03 kg total biomass
- Equivalent to 334.84 tons/ha

This value is slightly lower than that of the Trembesi City Forest, reflecting differences in stand structure and vegetation dominance.

Table 3. Biomass is the Dominant Type in Putroe Phang Urban Forest

No	Vegetation Type	Biomass (kg)
1	Trembesi	32.297,36
2	Mahoni	27.763,40
3	Pulai	16.112,32
4	Gelodokan Tiang	12.855,71
5	Tanjung	10.244,83

Table 4. lowest biomass Type in Putroe Phang Urban Forest

No	Vegetation Type	Biomass (kg)
1	Melinjo	17,32
2	Red Peacock	23,94

The high biomass in the Trembesi City Forest is strongly correlated with the dominance of trembesi trees (Samanea saman). Ecologically, trembesi is known for its rapid growth, wide crown, and high ability to accumulate biomass.

According to allometric theory, tree biomass increases exponentially with trunk diameter (Brown, 1997; Chave et al., 2014). This explains why trembesi's contribution dominates the region's total biomass. Trees with large diameters have a higher volume of wood so they store more organic material.

Recent research by Nowak et al. (2014) shows that tree species with large crowns in urban areas can increase biomass stocks by up to 40% compared to medium-sized species. This is in line with the condition of the Trembesi City Forest which is dominated by large canopy trees such as trembesi and tamarind.

In addition, a more mature stand structure reflects the growth phase of trees that have stabilized, allowing optimal biomass accumulation. Vegetation in the mature tree phase generally has a high trunk growth ratio, thereby directly increasing total biomass (Poorter et al., 2016).

In contrast, low biomass in species such as buni and srikaya is due to small diameter sizes and limited individual contributions. This is consistent with the theory that young trees allocate more energy to high growth than to the increase in wood mass.

The biomass in the Putroe Phang Urban Forest is lower than in Trembesi, reflecting the difference in vegetation composition. The dominance of species such as mahogany (Swietenia macrophylla), pulai (Alstonia scholaris), and pole wave (Polyalthia longifolia) shows more heterogeneous stand structural characteristics.

Ecologically, these species have relatively upright stem growth and narrow crowns. This condition causes biomass accumulation to be lower than broad-headed species such as trembesi. Research by Escobedo et al. (2011) shows that canopy shape and tree architecture significantly affect the biomass potential of urban forests. Trees with narrow crowns tend to store lower biomass despite having the same height.

In addition, the variation in stand age in the Putroe Phang Urban Forest led to a more even but not concentrated biomass distribution in large individuals. This is in accordance with the findings (Zhao et al., 2010) that heterogeneity in stand structure often results in lower total biomass than in stands dominated by large trees.

Potential Carbon Reserves

Carbon stocks are derived from biomass conversion, using a carbon fraction of 0.47, in accordance with national standards. The carbon stored in vegetation reflects the region's contribution to climate change mitigation.

Total carbon stocks:

1. 78,147.44 kg
2. Equivalent to 195.37 tons/ha

The main contributors to carbon stocks:

Table 5. Dominant Type of Carbon Reserves in Trembesi City Forest

Yes	Vegetation Type	Carbon Reserve (kg)
1	Trembesi	37.942,87
2	Tamarind	14.280,58
3	Ketapang Kencana	10.177,75
4	São Paulo	4.345,44
5	Guava	3.675,61

Table 6. Types with the lowest carbon reserve in Trembesi City Forest

No	Vegetation Type	Carbon Reserve (kg)
1	This	0,85
2	Srikaya	1,10
3	Big Miss	1,41

Total carbon stocks:

1. 62,950.40 kg
2. Equivalent to 157.38 tons/ha

Table 7. Dominant Type of Carbon Reserves in Putroe Phang Urban Forest

No	Vegetation Type	Carbon Reserve (kg)
1	Trembesi	15.179,76
2	Mahoni	13.048,80
3	Pulai	7.572,79
4	Gelodokan Tiang	6.042,18
5	Tanjung	4.814,07

Table 8. Types with low carbon reserves in Putroe Phang Urban Forest

No	Vegetation Type	Carbon Reserve (kg)
1	Melinjo	8,14

2	Red Peacock	11,25

The high carbon reserves in the Trembesi City Forest are a direct consequence of the dominance of trembesi biomass. According to climate change mitigation theory, large-diameter trees play an important role in atmospheric carbon sequestration (Luyssaert et al., 2018). Large trees can store significant amounts of carbon due to their dense wood networks.

Research by McPherson et al. (2016) confirms that a mature urban tree can store carbon equivalent to that of dozens of young trees. This reinforces the finding that the structure of mature stands in the Trembesi City Forest contributes to high carbon stocks.

The carbon stock in the Putroe Phang Urban Forest is lower, but it still plays an important ecological role as a carbon sink in urban areas. The dominance of species such as mahogany still makes a significant contribution because of its high wood density. According to recent research by Kanni et al. (2014), species with high wood density, although not large in diameter, still have a good carbon storage capacity. Thus, although the total carbon stock is lower than that of Trembesi, the species diversity in Putroe Phang provides long-term ecosystem stability.

Comparison of Biomass and Carbon Potential

A comparison of the two locations shows that the Trembesi City Forest has a higher biomass and carbon storage capacity.

Table 9. Biomass and Carbon Stock Recapitulation

Location	Total Biomass (kg)	Biomass (ton/ha)	Carbon Reserve (kg)	Karbon (ton/ha)
Trembesi City Forest	166.271,16	415,68	78.147,44	195,37
Putroe Phang City Forest	133.937,03	334,84	62.950,40	157,38

The difference between the two urban forests shows that stand structure is more influential than the number of species. The forest in Trembesi City, dominated by large trees, has higher biomass and carbon reserves. In contrast, the Putroe Phang Urban Forest has a more heterogeneous structure with a more dispersed carbon contribution. These findings are consistent with research by Pretzsch et al. (2014), which found that tree size has a greater influence on carbon storage than species diversity.

Contribution Distribution Based on Vegetation Size

The results of the study show that:

1. Trees with a diameter of >20 cm account for more than 95% of biomass
2. Mature stand structure plays a dominant role in carbon storage

This confirms that the tree's diameter is a major factor in determining carbon storage capacity. The largest contribution to biomass comes from trees with a diameter of>20 cm. Theoretically, the relationship between the diameter of the rod and the biomass is non-linear, where a small increase in diameter can result in a large increase in biomass [10]. Research by Stephenson indicates that large trees continue to increase carbon accumulation throughout their lives, making them a key component in climate change mitigation [18].

The results showed that Trembesi City Forest has higher biomass and carbon stock than Putroe Phang City Forest, mainly due to differences in stand structure and vegetation characteristics. Stands dominated by large-diameter, relatively mature trees show a greater capacity for carbon accumulation than areas with medium- or small-diameter tree composition. Log diameter is positively correlated with an increase in biomass due to the exponential increase in timber volume [19]. The relationship is non-linear as described in the allometric approach, where a small increase in DBH results in a significant increase in biomass [20], [21]. The contribution of trees with a DBH of > 20 cm, which accounts for more than 95% of the total biomass, is in line with global findings regarding the dominance of large diameter individuals in total carbon stocks [22].

The age structure and maturity level of the stand also strengthen the carbon storage capacity. Stands with mature tree composition and optimally developed canopies have a larger base area and biomass volume than young or heterogeneous stands [23]. Increased stand life is associated with higher carbon accumulation due to secondary growth and crown expansion [24]. Structural characteristics such as maximum diameter and base field area have been shown to explain variation in biomass rather than species richness alone [25]. Although individual density still contributes to total biomass [26].

The functional dominance of certain species reinforces biomass accumulation patterns at the community level. Wide-canopy species such as Samanea saman contribute significantly to above-ground biomass due to its wide crown architecture and large volumes of wood. An increase in the relative density of dominant species is directly correlated with an increase in community biomass [27]. The composition of species dominated by large trees also significantly affects carbon stocks and sequestration rates [28]. Narrow-canopy and medium-diameter species show a more limited contribution to total biomass, especially when they do not have structural dominance in stands [29], although functional traits such as leaf area and plant height still play a role. .

Environmental conditions and area management practices affect vegetation growth dynamics and the stability of carbon stocks. Topographic factors, soil quality, and maintenance intensity determine growth rate and long-term carbon accumulation [30]. The role of urban forests as carbon sinks in urban ecological systems is increasingly relevant given their ability to absorb CO_2 through photosynthesis and store it in biomass. Empirical evidence from various cities shows substantial carbon storage capacity, including in Banda Aceh [31]. The presence of large-diameter trees has been proven to determine the effectiveness of these functions [32].

Management implications underscore the importance of protecting mature trees and planning green open space based on quantitative biomass estimation. The i-Tree Eco model and tropical allometric approach are effective in calculating urban carbon stocks [33], while remote sensing and LiDAR technologies improve the accuracy of biomass spatial mapping [34]. This research remains limited to surface biomass, whereas root biomass and soil carbon contribute significantly to the total ecosystem carbon stock [35]. Longitudinal monitoring is needed to understand the dynamics of diameter distribution and the impact of environmental disturbances on long-term carbon storage capacity [36].

Conclusion

This study demonstrates that the Trembesi City Forest possesses greater above-ground biomass and carbon stock capacity than the Putroe Phang City Forest in Banda Aceh. The disparity is mainly due to differences in stand structure, diameter distribution, and characteristics of the dominant species. Trembesi City Forest is characterized by the prevalence of large-diameter, wide-canopy trees, particularly *Samanea saman*, which substantially contribute to total biomass accumulation. Trees with DBH > 20 cm account for more than 95% of total biomass, confirming that trunk size is the most influential variable in determining carbon storage potential. The non-linear relationship between diameter growth and biomass, as explained by allometric principles, further clarifies why areas dominated by mature trees exhibit higher carbon reserves compared to stands composed largely of medium-sized individuals.

Both urban forests function as important carbon sinks within the urban ecosystem of Banda Aceh, contributing meaningfully to climate change mitigation efforts. However, structural composition and stand maturity exert stronger influence on sequestration capacity than species richness alone. These findings highlight the strategic importance of conserving large and mature trees, integrating biomass-based assessments into urban green space planning, and prioritizing vegetation management approaches that enhance long-term ecological resilience. Comprehensive carbon accounting, including future consideration of below-ground components and longitudinal monitoring, is essential to strengthen evidence-based urban forest management policies.

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