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Assessment of carbon storage and sequestration for mitigating climate change in urban forests

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ABSTRACT

Background: Urban forests can contribute to climate change mitigation by lowering atmospheric carbon dioxide (CO_2) concentrations, thereby enhancing ecosystem resilience in urban area. Quantifying the carbon storage and sequestration capacities of urban forests is crucial for assessing their actual and potential roles. Interest in carbon quantification is growing; however, empirical evidence from densely populated urban forests remains limited. This study presents a case study on the quantification of carbon storage and sequestration by the Kemayoran Urban Forest, an urban forest in the city center with high population density and environmental pressure**. Methods:** Quantitative methods were employed to estimate carbon storage and sequestration using a non-destructive method based on allometric equations. Data collection was conducted through direct field surveys with established plot samples. **Findings:** This study recorded 267 tree individuals, comprising 36 species across 32 genera and 19 families. The total carbon storage was 74.83 tons C ha^{-1}, with total carbon sequestration amounting to 274.62 tons CO_2 ha^{-1}. However, this carbon assessment was limited to above-ground biomass estimates and did not include below-ground carbon stocks. **Conclusion:** The results indicate that the Kemayoran Urban Forest has substantial carbon storage and sequestration capacity despite being managed in an urban setting characterized by high population density and environmental pressures. **Novelty/Originality of this article:** This study provides empirical evidence of the carbon storage and sequestration capacity of a densely populated urban forest using a standardized non-destructive allometric approach. The findings establish baseline carbon data that support urban forest management and climate change mitigation planning.

KEYWORDS: carbon sequestration; carbon storage; climate change mitigation; Kemayoran urban forest; urban forest.

1. Introduction

Rapid urbanization has increased in carbon dioxide emissions caused by human activity in urban areas over the past few decades (Tang et al., 2016). The number of people living in urban areas now accounts for more than half of the world's population, and this proportion is projected to continue rising (United Nations, 2018a). Although urbanization has been regarded as a sign of human progress and improved quality of life, it has also generated adverse environmental impacts (Butt et al., 2017; Wang et al., 2019; Behera et al., 2022; Li et al., 2026). Globally, the average surface air temperature increased by 0.5 °C during the the twentieth century, and is projected to rise by 1.5–4.5 °C by 2100 (Tang et al., 2016). Although cities occupy only approximately 3% of the Earth's land area, they are home to a substantial proportion of the global population (Habtamu, 2022; Luqman et al., 2023). Currently, about 55% of the world's population lives in cities, and this proportion is

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projected to increase to 60% by 2030, with nearly 90% of future urban population growth occurring in Asia and Africa (United Nations, 2018b). Consequently, increasing urban populations have intensified the demand for housing, food, water, transportation, electricity, cooling, heating, and other urban services, resulting in higher fossil fuel consumption and atmospheric carbon emissions (Dangulla et al., 2021). This trend has been accompanied by increasing energy consumption and environmental emissions driven by infrastructure, housing, and transportation development (Li et al., 2022), as well as land-use change, habitat degradation, biodiversity loss, increased pollution, and climate change (Abhilash & Devakumar, 2023; Genete & Bogale, 2022). Consequently, urban areas account for approximately 70–80% of global energy consumption and produce more than 70–75% of global greenhouse gas or carbon emissions (Elmqvist et al., 2019; Zhou et al., 2025), with developing countries experiencing particularly significant increases in carbon emissions and climate change impacts (Zhang et al., 2016). These conditions create substantial environmental pressures while simultaneously highlighting opportunities for climate change mitigation and pressure reduction in urban areas.

Cities' anthropogenic carbon dioxide (CO_2) emissions can be offset by conserving or increasing the amount of carbon stored in urban areas. Combating climate change and achieving net-zero emissions depend on effective carbon sequestration through forests as carbon sinks (Li et al., 2026). Forestry projectsare widely recognized as an effective method for reducing atmospheric greenhouse gas concentrations. Forests are capable of absorbing approximately one-quarter of the global atmospheric carbon emitted annually through atmospheric greenhouse gas concentrationsconcentrations (Poudyal, 2021). Given the increasing carbon emissions from urban areas, improving the capacity of urban forests to store and sequester carbon has become an important climate mitigation strategy. By mitigating the urban heat island effect, boosting biodiversity, and acting as effective nature-based solutions to maximize climate benefits, urban green spaces can directly reduce climate change and deliver indirect benefits (Pan et al., 2023; Zhao et al., 2022). In the context of climate change, urban forests are regarded as nature-based solutions capable of mitigating climate impacts by lowering atmospheric CO_2 through absorption and emission reduction. They perform functions such as urban climate regulation, air purification, and carbon sequestration (Feng et al., 2024; Nowak & Crane, 2002). In essence, urban forests influence the urban carbon cycle through net CO_2 exchange by acting as sinks for atmospheric CO_2 and sequestering carbon through photosynthesis, storing it in the form of above- and below-ground biomass (e.g., branches or roots) as well as soil organic matter (Dusenge et al., 2019; Nowak et al., 2013). CO_2 uptake by urban vegetation contributes to the reduction of atmospheric carbon dioxide, which plays a crucial role in the terrestrial carbon cycle and sustainable development (Zhang et al., 2022; Zhuang et al., 2022). The presence of urban forests can contribute to the provision of ecosystem services, influence the sustainability of urban ecosystems, and improve urban residents' quality of life (Turner-Skoff & Cavender, 2019).

Given the various environmental challenges facing urban areas, estimating the carbon storage and sequestration capacity of urban vegetation and positioning cities as hubs for climate change mitigation and enhanced carbon sequestration are crucial (Zhou et al., 2025; Zhuang et al., 2022). Urban forests can act as carbon sinks and reservoirs (Joshi & Chandra Garkoti, 2025). Understanding the role of conservation and enhanced carbon storage in urban forests can help offset rising CO_2 emissions in expanding urban agglomerations (Ariluoma et al., 2021; Nowak & Crane, 2002). Many studies have shown that measuring the carbon storage and sequestration of urban vegetation is essential for assessing its present and future contribution to lowering atmospheric CO_2 (Trlica et al., 2020). Since the 1990s, researchers have evaluated the carbon storage of urban vegetation in major U.S. cities through field investigations, remote sensing, and modeling studies (Lin et al., 2022). The total carbon sequestration by urban vegetation in the United States is estimated at 25.6 Tg C yr^{-1} (1 Tg = 10^{12} kg), representing roughly 2% of urban anthropogenic CO_2 emissions (Hardiman et al., 2017; Nowak et al., 2013). In Korean cities, urban trees and shrubs absorb

3.2–6.2 Gg C yr^{-1} (1 Gg = 10^9 g), which offsets approximatelyapproximately 0.5%–2.2% of the total annual urban CO_2 emissions (Jo, 2002).

According to the findings of this study, urban vegetation's carbon storage and sequestration differ markedly among various cities and countries (Xie et al., 2025). The observed effect is probably attributable to alterations in abiotic and biotic variables, including green space area, species composition, stand density, and age structure, in addition to local site conditions. Given the rapid pace of urbanization and changes in urban forest land, conducting research on the carbon storage and sequestration capacity of urban forests is crucial.

Although research on the carbon storage and sequestration capacity of urban forests has increased in recent years, no such assessment has been conducted in the Kemayoran urban forest. This represents an important knowledge gap because the Kemayoran urban forest is located in Jakarta, the province with the highest population density in Indonesia, reaching 16,155 people per square kilometer (Central Statistics Agency, 2025). Increasing urbanization in Jakarta has been associated with higher urban energy consumption; for example, a 1% increase in urbanization is estimated to increase transportation energy consumption by 4.5% (Sodri & Garniwa, 2016). Moreover, North Jakarta, where the Kemayoran urban forest is located, is more vulnerability than other cities to coastal threats, pollutant concentrations, and meteorological factors such as surface temperature, wind speed, and humidity (Kurniawan et al., 2025; Nerem et al., 2018). Furthermore, North Jakarta continues to develop as an economic hub, resulting in increasing energy demand and declining environmental quality (Putra & Marfai, 2021; Saidi et al., 2017). Therefore, this study is expected to provide the first empirical assessment of urban forest ecosystem services in terms of carbon storage and sequestration to inform urban environmental management and climate change mitigation planning.

Given this background, this study was conducted to answer the following research questions: (1) What is the Kemayoran urban forest's carbon storage capacity?; (2) What is the Kemayoran urban forest's carbon sequestration capacity?; and (3) How does the Kemayoran urban forest contribute to climate change mitigation through carbon storage and sequestration?. The results of this study are expected to help assess the actual and potential role of urban forests in reducing atmospheric CO_2 and assist decision-makers and the public in understanding the role of urban forests in reducing atmospheric CO_2 and developing better management plans (Liu & Li, 2012). Additionally, the findings can serve as a basis for maintaining the ecosystem services provided by vegetation in urban forests and provide information for sustainable urban development.

2. Methods

2.1 Study area

This study was conducted in the Kemayoran Urban Forest, located on Jl. H Benyamin Sueb, East Pademangan Village, Pademangan Subdistrict, North Jakarta City, DKI Jakarta Province, Indonesia, as shown in Figure 1. The Kemayoran Urban Forest was designated as a 4.6 ha conservation urban forest in 2002. According to its designation, the urban forest serves multiple functions, including improving the quality of the urban living environment through greening, regulating water management, controlling air pollution, providing habitats for flora and fauna, supporting recreation and public health, conserving genetic resources, promoting tourism, facilitating education and outreach, and enhancing urban aesthetics.

The study area is located in North Jakarta, a coastal region characterized by low-lying terrain with elevations ranging from 0 to 10 m above sea level. These environmental conditions influence soil and vegetation characteristics, which may subsequently affect carbon storage and sequestration capacity. The presence of Kemayoran urban forest as part of Jakarta's urban green infrastructure provides important ecosystem services, particularly carbon sequestration, while offering an appropriate setting for evaluating the role of urban forests in climate change mitigation.

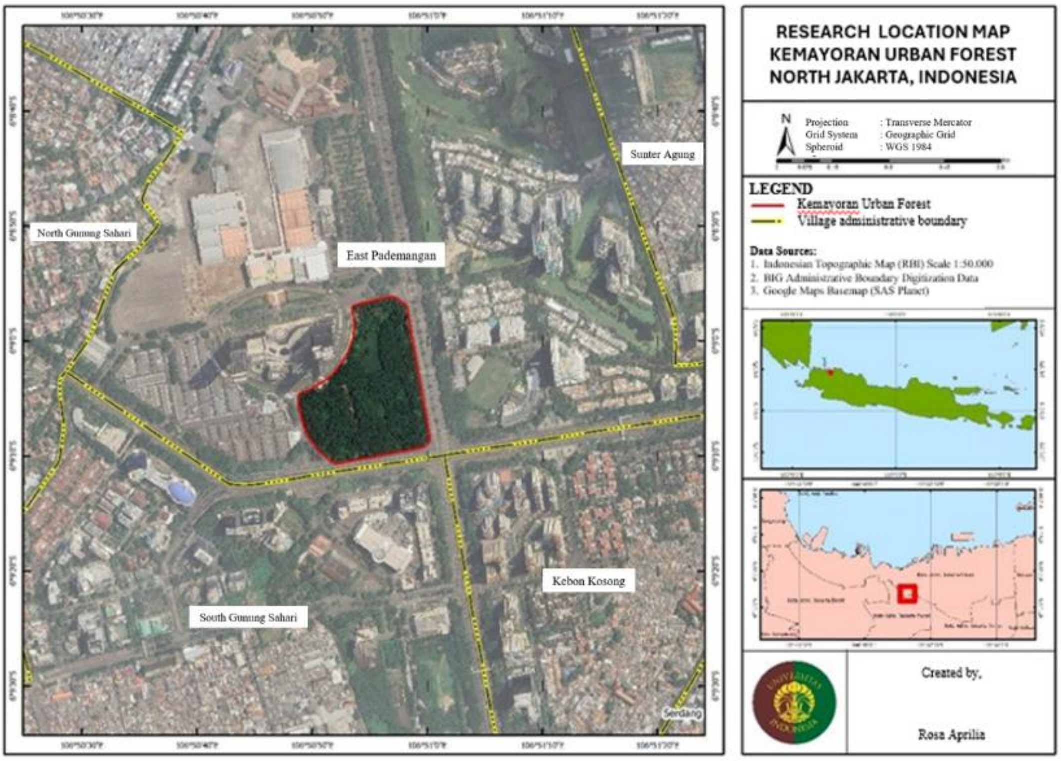

Fig. 1. Research location

2.2 Data collection

To estimate vegetation carbon storage, a stand inventory was conducted to collect data on vegetation structure and composition. The study employed observation plots measuring 20 × 20 m (0.04 ha). Based on the total vegetated area of the Kemayoran Urban Forest (4.6 ha), a total of 115 potential plots were identified. A 10% sampling intensity was adopted considering the relatively small size of the study area, resulting in a required sample size of 11.5 plots, which was rounded up to 12 observation plots. The sample plots were subsequently selected using purposive sampling to ensure the representativeness of stand structure variation, species composition, and vegetation conditions within the Kemayoran Urban Forest. A sampling intensity of 10% was adopted considering the relatively small size of the study area. Based on these calculations, 11.5 sample plots were required, which were then rounded up to 12 observation plots. The 12 sample plots were selected purposively to represent different vegetation densities, dominant species, canopy conditions, and spatial distribution across the Kemayoran Urban Forest. The selection criteria were established before field sampling to ensure representative coverage of the study area.

Vegetation parameters included vegetation type, number of individuals, diameter at breast height (DBH), and tree height. We estimated biomass and carbon storage using tree height and DBH measurements. Tree height was measured using a height meter, and DBH was measured using a measuring tape at a height of 1.3 m above ground level (Dalponte et al., 2018). Additionally, the counting of individuals and identification of vegetation types were conducted during the field inventory of the sample plots. Field measurements of DBH and tree height were used to estimate above-ground biomass using allometric equations, which were then converted into carbon storage and carbon sequestration values. These estimates were calculated using a non-destructive method based on allometric equations, as has been done in various studies on urban forests (Sanogo et al., 2021; Yuen et al., 2016). The allometric approach allows the estimation of biomass and carbon stocks based on vegetation structural parameters, such as stem diameter and tree height, without disrupting the area's ecological functions (Montès, 2009). The specific allometric equation used in this study, together with the criteria for selecting the equation for the recorded tree species.

2.3 Estimation of biomass, carbon storage, and carbon sequestration

Carbon stock and carbon sequestration in urban forests are estimated by calculating the biomass of above-ground vegetation. These calculations are based on several parameters, including DBH, tree height, and wood density values for each vegetation type. The allometric equations developed by Chave et al. (2014) was selected because it is widely applied and validated for estimating above-ground biomass in tropical forests using DBH, tree height, and wood density in Eq. 1, where, AGB = above-ground biomass (kg), ρ = wood density (g/cm^3), D = diameter at breast height (cm), and h = tree height (m). To enhance the quality of AGB estimates, AGB calculations are performed using three predictors—diameter, height, and wood density (Nam et al., 2016). This model with three predictors provides more accurate estimates of biomass and carbon storage in tropical regions than other equations that only use diameter or diameter and height. The aboveground carbon of each tree was determined by applying species-specific wood density values. Wood density or specific gravity values for tree species typically range from 0.27 to 0.76 g/cm^3, with fast-growing trees having lower wood density (Yeboah et al., 2014). When species-specific wood density data were unavailable, a default value of 0.6 g/cm^3 was applied to the corresponding tree species (Ravindranath & Ostwald, 2008).

$$AGB = 0.0559 \times \rho \times D^2 \times h \qquad \text{(Eq. 1)}$$

Vegetation carbon storageis calculated using a conversion factor to convert biomass values into carbon content. Following the IPCC (2006) guidelines, a default carbon fraction of 0.5 was applied to convert above-ground biomass into carbon storage (Habib & Al-Ghamdi, 2021; Hutyra et al., 2011; Mackey et al., 2020). This is also consistent with Watson's (2009) finding that the appropriate default value is 0.5 when local values are unavailable and when applied to various urban forest types. The formula for calculating the carbon stock in Eq. 2, where, C = Carbon storage (kg C), AGB = Above-ground biomass (kg) in tons of carbon per hectare (ton C ha^{-1}) to enable comparison with values reported in other studies.

$$C = 0.5 \times AGB \qquad \text{(Eq. 2)}$$

The potential for carbon sequestration is calculated by multiplying the total carbon storage by a conversion factor and the amount of CO_2 equivalent (CO_2e) represented by the estimated carbon storage was calculated by multiplying the carbon storage by 3.67, which represents the molecular weight ratio of CO_2 to carbon, as shown in Equation 3. This factor translates greenhouse gas values into an equivalent of 3.67. Figure3.67 represents the molecular weight ratio of CO_2 to carbon. This means that every Mg of carbon stored in vegetation is equivalent to 3.67 Mg of CO_2 (Ivando et al., 2019). The equation in Eq. 3. Where, CO_2e = Carbon dioxide equivalent (tons CO_2 ha^{-1}), C = Amount of carbon storage (tons C ha^{-1}).

$$CO_2e = C \times 3.67 \qquad \text{(Eq. 3)}$$

3. Results and Discussion

3.1 Vegetation composition and structure

The results of this study recorded 267 vegetation individuals in the Kemayoran urban forest, comprising 36 species across 32 genera and 19 families, across 12 sample plots and the recorded vegetation composition indicates moderate species diversity, which may enhance ecosystem stability and carbon storage potential in the Kemayoran Urban Forest. The most common genera were Ficus and Fabaceae. The dominant species included mahoni (*Swietenia macrophylla)* with 38 individuals, trembesi (*Samanea saman)* with 35 individuals, sengon buto (*Enterolobium cyclocarpum)* with 23 individuals, ketapang (*Terminalia catappa)* with 22 individuals, kapuk randu (*Ceiba pentandra)* with 18 individuals, flamboyan (*Delonix regia)* with 17 individuals, kenitu (*Chrysophyllum cainito)* with 14 individuals, matoa (*Pometia pinnata)* with 12 individuals, mindi (*Melia azedarach)* with 11 individuals, and johar (*Senna siamea)* with 8 individuals. Conversely, mangga (*Acacia mangium)*, benda (*Artocarpus elasticus)*, longan (*Dimocarpus longan)*, bisbul (*Diospyros discolor)*, and angsana (*Pterocarpus indicus)* were found only once at the study site. Figure 2 shows the distribution of the 10 most common vegetation species. As noted by Malunguja et al. (2025), species composition is essential for determining carbon sequestration capacity.

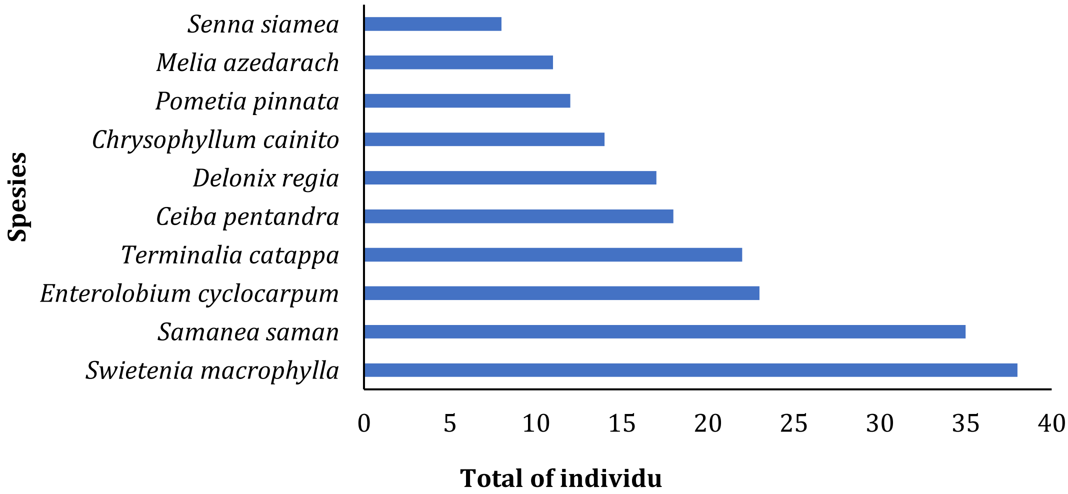

Fig. 2. Distribution of the top 10 vegetation types

Beyond species-level abundance, the vegetation composition was further examined based on the relative contribution of species, genera, and families. Most of species account for less than 8% of the total, except for mahogany (*Swietenia macrophylla*) at 14%, trembesi (*Samanea saman*) at 13%, and sengon buto (*Enterolobium cyclocarpum*) at 9%. The percentage of genus diversity is less than 9%, and the percentage of family diversity is less than 12%, except for the Fabaceae family at 22%. In accordance with the 10-20-30 rule, vegetation composition should not exceed 10% for a single species, 20% for a single genus, and 30% for a single family to ensure maximum protection against plant pest and disease outbreaks. Vegetation evenness at the species, genus, and family levels is a key factor in maintaining the health of urban forests and providing a variety of ecosystem services to residents in urban areas (Ratti et al., 2021). Urban forests with high vegetation diversity are capable of providing a wider range of ecosystem services to the surrounding area (Brockerhoff et al., 2017) and are considered to have the ability to effectively maintain ecosystem function and stability (Shen et al., 2022). Vegetation evenness is also significantly associated with the social benefits of urban nature—specifically the psychological benefits for urban residents—which increase with greater species diversity in urban forests (Fuller et al., 2007). Overall, the observed vegetation composition was broadly consistent with the 10-20-30 rule, although *Swietenia macrophylla* slightly exceeds the recommended 10% threshold for a single species. indicating a relatively balanced species, genera, and families composition that may enhance the ecological resilience of the Kemayoran urban forest.

Figure 3 shows the DBH distribution. The dominant DBH class in the Kemayoran urban forest is 10–20 cm, comprising 88 individuals (33%). The subsequent diameter classes, from largest to smallest, are: < 10 cm (59 individuals, 22%), 10-20 cm (88 individuals, 33%), 21–30 cm (42 individuals, 16%), 31–40 cm (29 individuals, 11%), 41–50 cm (26 individuals, 10%), diameter 51–60 cm (18 individuals, 7%), diameter 61–70 cm (3 individuals, 1%), and diameter > 71 cm (3 individuals, 1%). The observed DBH distribution indicates that the Kemayoran urban forest consists predominantly of trees in the 10–20 cm diameter class, while only a small proportion of trees exceed 60 cm DBH. Given that previous studies have demonstrated that larger-diameter trees contribute significantly to biomass production and are positively correlated with carbon storage and sequestration (Malunguja et al., 2025), the presence of these large-diameter individuals may substantially enhance the overall carbon storage capacity of the Kemayoran urban forest despite their relatively low abundance.

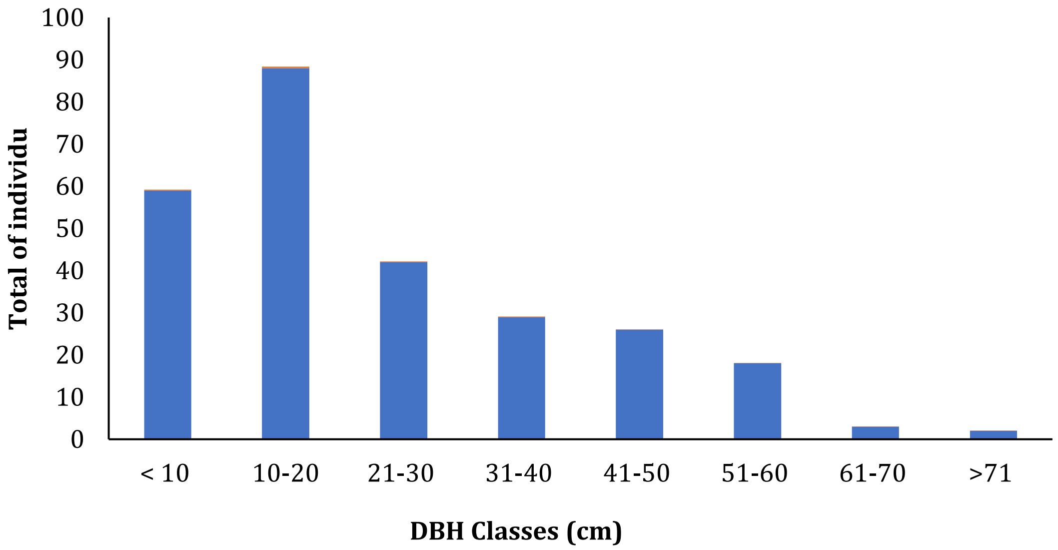

Fig. 3. Distribution of the DBH classes

The five largest recorded DBH values belonged totrembesi (*Samenea saman*) at 74.0 cm, sengon buto (*Enterolobium cyclocarpum*) at 73.0 cm, beringin (*Ficus benjamina*) at 66.7 cm, sengon buto (*Enterolobium cyclocarpum*) at 64.0 cm, and sengon buto (Enterolobium cyclocarpum) at 63.0 cm. The five individual trees with the smallest diameter classes were akasia (*Acacia mangium*) at 1.56 cm, sapodilla (*Manilkara zapota*) at 1.6 cm, kersen (*Muntingia calabura*) at 2.3 cm, sapodilla (*Manilkara zapota*) at 2.3 cm, and tanjung (*Mimusops elengi*) at 2.4 cm.

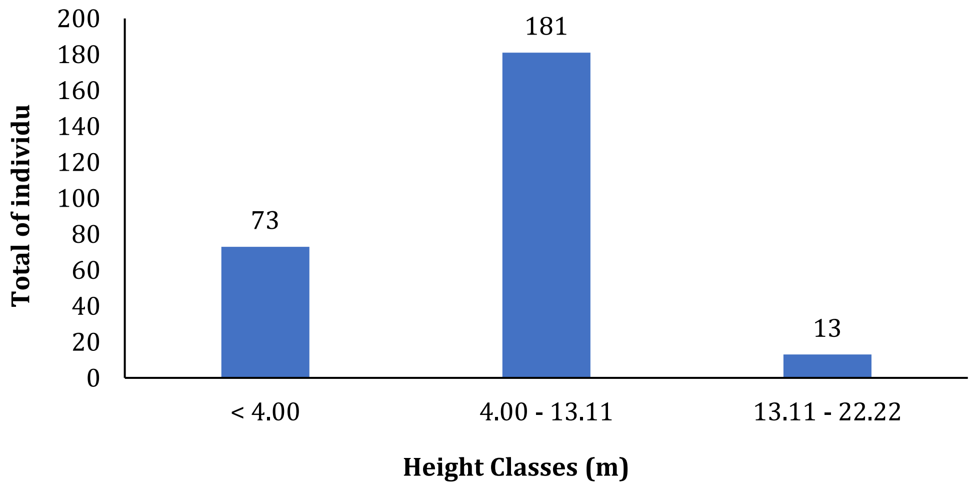

Fig. 4. Distribution of height classes

Figure 4 shows the distribution of vegetation height in the Kemayoran urban forest when classified by height class. The vegetation in Kemayoran urban forest is dominated by the tall class in the range of 4.00–13.11 m, comprising 181 individuals (68%), followed by the tall class < 4.00 m, comprising 73 individuals (27%), and the tall class in the range of 13.11–22.22 m, comprising 13 individuals (5%). The five individual trees with the greatest height are trembesi (*Samanea saman*) at 17.5 m, ilat-ilatan (*Ficus callosa*) at 17.3 m, kapuk (*Ceiba pentandra*) at 17.0 m, ilat-ilatan (*Ficus callosa*) at 17.0 m, and flamboyan (*Delonix regia)* at 16.0 m. TheVegetations with the lowest height, at 1.5 m, were sapodilla (*Manilkara zapota*) and saga (*Adenanthera pavonine*), while species measuring 1.6 m include matoa (*Pometia pinnata),* sengon buto (*Enterolobium cyclocarpum*), and kenitu (*Chrysophyllum caimito).*

3.2 Carbon storage and sequestration

Biomass refers to the total amount of living material above ground on a tree and is expressed in units of dry weight per unit area, whereas carbon storage refers toto the total weight of carbon stored within an ecosystem at a specific time, including plant biomass, dead vegetation, and soil carbon (Ahmad et al., 2023). The results of the calculations for carbon storage and sequestration values in the Kemayoran urban forest are shown in Table 1. The estimated carbon storage of 74.83 tons C ha^{-1} indicates that the Kemayoran Urban Forest contributes to urban carbon mitigation. This value can be compared with carbon storage capacities reported in other urban forests to evaluate its relative contribution. The calculated AGB for the 12 sample plots was 71,838.03 kg or 71.84 tons, while the AGB per hectare was 149.66 tons ha^{-1}. The total carbon storage was estimated by applying carbon fraction of 0.5 to the above-ground biomass, following IPCC guidelines is 35.91 tons, and the carbon stock per hectare is 74.83 tons C ha^{-1}. The CO_2 equivalent absorbed, or carbon sequestration,was calculated by multiplying the total carbon storage by a correction factor of 3.67, resulting in 274.62 tons of CO_2 ha^{-1}. Based on the estimated carbon stock, the Kemayoran Urban Forest stores approximately 344.22 tons of carbon, equivalent to 1,262.25 tons of CO_2. This value represents the CO_2 equivalent of stored carbon rather than annual carbon sequestration. The carbon stock values for each observation plot ranged from 1.79 to 12.33 tons of carbon per hectare, indicating variations in vegetation conditions among the plots in the Kemayoran urban forest, particularly in terms of the number of individuals and vegetation size, which influence biomass accumulation and carbon stock.

Table 1. Carbon storage and sequestration calculations

Category	Unit	Value
AGB in the sample plot	Ton	71.84
AGB per hectare	Ton ha^{-1}	149.66
Carbon storage	Ton C	35.91
Carbon storage per hectare	Ton C Ha^{-1}	74.83
Carbon sequestration per hectare	Ton CO_2 Ha^{-1}	274.62
Total carbon storage(4.6 ha)	Ton C	344.22
Total carbon sequestration(4.6 ha)	Ton CO_2	1,263.25

Figure 5 shows the aboveground biomass content distribution based on the class of breast-height diameter. Although the small diameter class has the highest number of individuals, its estimated biomass content is low; conversely, the large diameter class has a low number of individuals and a high above-ground biomass content. The 51–60 cm breast-height diameter class, with 19 individuals, has the highest estimated biomass content of 20,459.43 kg. Conversely, the 10–20 cm breast-height diameter class, which has the highest number of individuals (88 individuals), has an estimated above-ground biomass of only 4,359.98 kg. These findings are consistent with Moussa et al. (2020) study, who reported that although urban green spaces contain relatively few large-diameter trees, these individuals contribute largely to total biomass and carbon stocks. Similarly, the present study found that the 51–60 cm DBH class, despite comprising only 19 individuals, accounted for the highest above-ground biomass. This finding suggests that tree size has a greater influence on biomass accumulation than tree abundance, highlighting the importance of conserving mature trees to maximize carbon storage in urban forests.

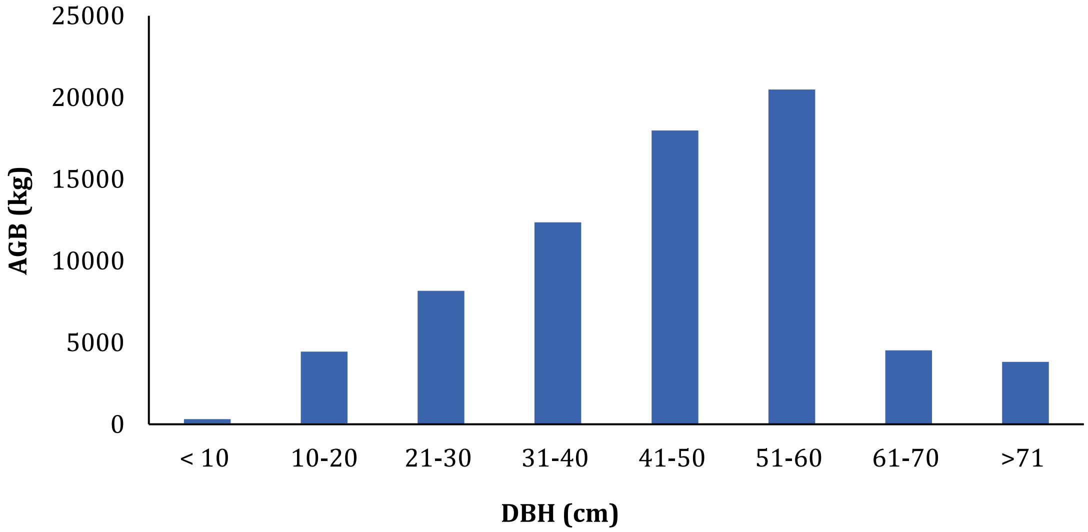

Fig. 5. AGB distribution based on DBH classes

In the Kemayoran Urban Forest, the higher biomass contribution from larger trees explains the observed carbon storage pattern, where trees with larger DBH classes contribute more significantly to total carbon storage despite having fewer individuals. According to Lestari & Martuti (2024), vegetation biomass values are positively correlated with carbon storage values. Carbon storage values in a given zone increase as biomass values in that zone rise; thus, an increase in biomass leads to an increase in the potential for stored carbon. This aligns with the findings of Samsoedin et al. (2016) and Santoso et al. (2021), who stated that any increase in biomass is accompanied by an increase in carbon storage and vice versa. Carbon storage also increases with vegetation age due to changes in tree dimensions, specifically breast-height diameter and height (Kohl et al., 2017). An increase in breast-height diameter in vegetation leads to a corresponding increase in carbon storage, which increasesincreases as more CO_2 is absorbed by the vegetation.

Stem biomass accounts for the largest proportion compared to biomass in other parts of the vegetation (Putri & Wulandari, 2015). The dominance of stem biomass explains why larger trees contribute substantially to carbon storage, as stem diameter is a major factor influencing above-ground biomass estimation.. Most of the carbon serves as fuel for the plant's life processes, while some is incorporated into the plant's structure through cellulose. Cellulose is a long-chain linear sugar molecule composed of carbon; thus, the higher the cellulose content, the higher the carbon content. The larger the tree's diameter, the greater the potential for cellulose and other wood-constituent compounds. Meanwhile, the biomass of a stand increases as plants absorb CO_2 from the atmosphere and convert it into organic compounds through photosynthesis; these photosynthetic products are then used by the plants to grow horizontally and vertically, resulting in increased tree diameter and height (Syam'ani et al., 2012). Horizontal growth occurs due to the activity of lateral meristems, which produce secondary vascular tissue and periderm, leading to an increase in tree diameter.

Compared with the results of several studies on other urban forests, such as the Banda Aceh urban forest, the Tinjomoyo urban forest in Semarang, the Bungkirit urban forest, and the Mayasih Kuningan urban forest, the values for biomass, carbon storage, and CO_2 absorption in the Kemayoran urban forest per hectare are higher, at 149.66 tons ha^{-1}, 74.83 tons C ha^{-1}, and 274.62 tons CO_2 ha^{-1}. The higher carbon storage observed in the Kemayoran Urban Forest compared with other urban forests may be related to differences in tree size distribution, species composition, stand structure, and local environmental conditions. The biomass value in the Banda Aceh urban forest, covering an area of 8.71 ha spread across

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various urban areas, is 110.79 tons ha^{-1}, with a total carbon stock of 55.40 tons ha^{-1} and CO_2 absorption of 203.36 tons CO_2 ha^{-1} (Irvianty et al., 2023). The Banda Aceh urban forest consists of 39 species belonging to 20 families, with an average diamater ranging from 19.47 to 29.94 cm. The number of tree individuals in the Tinjomoyo urban forest area in Semarang is 367, with a total biomass value of 125.5 tons ha^{-1}, total carbon stock of 57.72 tons ha^{-1}, and total carbon sequestration of 211.8 tons CO_2 ha^{-1} (Lestari & Martuti, 2024). A total of 420 individuals were found in the Bungkirit urban forest, with the 15.0-29.9 cm diameter class being the most dominant. These individuals had a total carbon stock of 24.97 tons C ha^{-1} (Lestari et al., 2021). In the Mayasih urban forest was 246 individuals were found, with a dominant class 15.0-29,9 m, holding a carbon stock of 8.24 tons C ha^{-1} (Lestari et al., 2021).

Conversely, the carbon stock storage value in the Kemayoran urban forest is lower than that in the UI Urban Forest. The results of the study by Febiriyanti et al. (2021), indicate that the UI urban forest consists of 641 individuals belonging to 57 tree species and 28 families, with dominant vegetation species including *Acacia mangiun, Falcataria moluccana, Microcos tomentosa,* and *Macaranga tanarius.* The total biomass and carbon storage in the UI urban forest are 972.03 tons Ha^{-1} and 486.01 tons C Ha^{-1}, respectively. The detailed carbon storage value per hectare for each zone (West Wallace, East Wallace, and natural vegetation) at 138.62 tons C ha^{-1}, 162.75 tons C ha^{-1}, and 182.64 tons C ha^{-1} , respectively. The Fabaceae family, which exhibits rapid growth diameter, accounts for the highest proportion of carbon stock in these urban forests.

In comparison, other research findings on urban forests in other countries—specifically, a study in the Bengaluru urban forest in India—identified 44 tree species belonging to 23 families, with accumulated carbon storage of 505 tons and a total of 1,852 tons of CO_2 absorbed (Abhilash & Devakumar, 2023). Uttaruk et al. (2024) studied the forested area of Rajamangala University of Technology Isan, Surin Campus, Thailand, and identified 85 plant species with an average biomass of 231.81 tons per hectare and carbon storage of 108.94 tons of carbon per hectare. The total biomass and carbon stock in the Puducherry Urban Forest in India were 278.11 tons ha^{-1} and 139.1 tons C ha^{-1} (Khadanga & Jayakumar, 2018), and the biomass value in the green open space of the Northern Nigeria Urban Forest is 98.48 tons with a total carbon storage of 49.23 tons C ha^{-1} (Dangulla et al., 2021).

Differences in biomass, carbon storage, and carbon sequestration between the Kemayoran urban forest and several other urban forests indicate that the number of individual plants in the forest does not solely determine the carbon capacity of urban forests. Variations in vegetation structure and composition and environmental conditions at each location are believed to influence biomass levels. According to Nandi & Jashimuddin (2026), carbon storage in urban forests varies significantly across different land-use zones, reflecting the influence of stand structure and species composition on carbon sequestration. Carbon density is related to structural attributes, such as tree size and cross-sectional area. Liu & Li (2012) recommended increasing the structural diversity of urban carbon stocks by planting mixed, multi-layered vegetation. Increasing the diversity of stand structure can be achieved through selective logging systems, while enrichment planting can be used to enhance the diversity of woody vegetation species (Tetemke et al., 2021). Other studies have revealed that forest type, age structure, site conditions, and the level of urban forest management significantly influence urban forest carbon density, which can be reflected through vegetation species diversity and stand spatial structure indices (Rodrigues, 2023; Wang et al., 2021). Vegetation diversity is a key factor influencing the stability, productivity, and storage and sequestration of urban forest carbon (Ahmad et al., 2021). Species diversity contributes to enhancing carbon accumulation capacity because species with different growth characteristics can complement each other in using resources for carbon sequestration (Agbelade & Onyekwelu, 2020). Moreover, disturbed forests have lower species diversity and structural complexity, indicating lower carbon stocks (van der Sande et al., 2017).

A larger stand diameter correlates positively with biomass and carbon storage (Moussa et al., 2020). This is because biomass is also present in the stem; thus, the biomass value also tends to increase as the diameter at breast height of a stand increases (Effendi, 2012). This is consistent with the present findings, where the presence of several large-diameter trees, although relatively low in abundance, contributed to the above-ground biomass and carbon storage of the Kemayoran Urban Forest. Therefore, maintaining existing large trees and supporting the growth of mature trees are important management considerations for maintaining above-ground carbon storage.

Abiotic factors also play important roles in biomass accumulation and carbon sequestration by influencing plant physiological processes. Sunlight is essential for photosynthesis and affects plant growth characteristics, including height, leaf size, and stem development (Uthbah et al., 2017). Temperature also regulates photosynthetic activity and plant productivity, although excessively high temperatures may reduce photosynthetic efficiency (Liu, 2020). In addition, humidity and soil moisture contribute to maintaining suitable conditions for plant growth, while soil fertility and pH influence nutrient availability required for biomass production (Lestari & Martuti, 2024; Azurianti et al., 2022). These environmental factors have been widely recognized as contributing to carbon accumulation in vegetation (Arfina et al., 2020). However, because they were not measured in the present study, their influence on carbon storage and sequestration in the Kemayoran urban forest could not be directly evaluated and should therefore be explored in future research.

The present study showed that the carbon storage and sequestration capacity of the Kemayoran urban forest is closely associated with aboveground biomass, which is primarily determined by vegetation structure and composition, including tree size, stand density, and species diversity. The dominance of medium-sized trees, together with the presence of several large-diameter individuals, contributed to the estimated biomass and carbon storage observed in this study. These findings suggest that maintaining diverse vegetation structure and promoting the growth of mature trees are important strategies for enhancing the carbon sequestration potential of urban forests. However, the biomass, carbon storage, and carbon sequestration estimates presented in this study are subject to uncertainties associated with the use of allometric equations. These uncertainties arise from sampling intensity, variation in vegetation structure and species composition among plots, and the assumptions underlying the selected allometric model. Therefore, the estimated values should be interpreted as approximations of the carbon storage and sequestration capacity of the Kemayoran urban forest rather than absolute values.

The management practices and health conditions of urban forest vegetation also influence carbon storage and sequestration capacity. In the Kemayoran Urban Forest, management practices such as vegetation maintenance, pruning activities, and species management may influence tree growth and biomass accumulation, which ultimately affect carbon storage capacity. In terms of vegetation health, trees under high environmental stress—such as high temperatures and drought—tend to experience a decline in their photosynthetic capacity and carbon uptake; conversely, well-maintained trees exhibit higher carbon uptake capacity (Zhao et al., 2023).

Urban population density is negatively correlated with carbon sequestration capacity due to urban development, which increases impervious surfaces and reduces vegetation cover in urban forests. Considering the characteristics of the study area, this issue is particularly relevant to the Kemayoran urban forest, which is located in Jakarta, the most densely populated province in Indonesia. As highlighted in the Introduction, North Jakarta also experiences multiple environmental pressures, including coastal vulnerability and declining environmental quality associated with rapid urban development. Previous studies have similarly reported that urban expansion, increasing impervious surfaces, and rising temperatures reduce the carbon storage capacity of urban forests (Ma et al.,2024; Guo et al., 2024). Despite these challenges, the present study demonstrates that the Kemayoran urban forest continues to provide substantial carbon storage and sequestration, highlighting its important role as an urban carbon sink and emphasizing the need to conserve and effectively manage existing urban forests as part of climate change mitigation strategies in highly urbanized metropolitan areas.

3.3 Policy implication

This study demonstrates that the Kemayoran urban forest provides measurable carbon storage and sequestration despite being located in a highly urbanized area. Therefore, appropriate urban forest management is essential to maintain and further enhance these ecosystem services. large-diameter trees contributed substantially to biomass accumulation and carbon storage, conservation of mature trees should become a priority in urban forest management. Complementary strategies such as enrichment planting and increasing species diversity can further improve long-term carbon sequestration capacity. Human activities have a dual impact: they reduce the carbon sequestration capacity of urban green spaces and urban forests in densely populated urban areas due to socioeconomic pressures, while landscape connectivity and the extent of green spaces can enhance carbon sequestration capacity in urban environments (Zhou et al., 2025). The relatively small area of urban forests limits the total carbon contribution, but research results indicate the potential of urban forests as carbon sinks and absorbers to provide climate change mitigation benefits. According to various studies, several approaches can be taken to enhance the potential capacity for carbon storage and sequestration, thereby improving urban forest ecosystem services and strengthening climate resilience in urban environments. Li et al. (2024) recommended enhancing forest carbon sequestration capacity by adjusting vegetation spatial structure and species diversity as a viable approach to addressing climate change. In line with this, Liu & Li (2012) recommend creating multiple layers of trees, shrubs, and grasses in urban forests, as well as a mix of various vegetation types of different ages.

Ariluoma et al. (2024) stated that favorable growth conditions and optimal maintenance are two key factors that can influence the carbon storage and sequestration capacity of urban vegetation through landscape design and management, specifically regarding the above-ground growth space and root zones. The aboveground growth space plays a crucial role in enabling vegetation to store carbon in the aboveground parts of plants, while root space—specifically root size—influences the size of the aboveground plant parts, thereby determining the plant's carbon absorption capacity. The selection of appropriate local vegetation species and the expansion of vegetation planting play a vital role in enhancing carbon storage and sequestration by urban vegetation (Xie et al., 2025). For instance, planting fast-growing native species can increase the carbon storage and sequestration capacity of urban forest vegetation. Rehman et al. (2025) also revealed that native species are generally more effective at providing better ecosystem services and supporting regional biodiversity conservation than non-native species and have high potential for reducing carbon emissions.

4. Conclusions

The study's findings highlight the role of urban forests as carbon storage systems that contributeto climate change mitigation in in urban environments. Based on direct measurements in sample plots, the 4.6 hectare Kemayoran Urban Forest yielded 267 individuals representing 36 species across 32 genera and 19 families, with an above-ground biomass of 71.84 tons. Calculations and analysis yielded an estimated carbon storage value of 74.83 tons C ha^{-1} and a total carbon absorption of 274.62 tons CO_2 ha^{-1}. The results indicate that stand characteristics, particularly tree diameter, height, and vegetation structure, influence biomass accumulation and carbon storage potential in the Kemayoran Urban Forest.. Urban forest management strategies aimed at climate change mitigation are necessary to enhance the carbon storage and sequestration potential of these urban forests. Management strategies should prioritize the conservation of existing large-diameter trees, maintenance of vegetation diversity, and development of structurally complex urban forests to enhance long-term carbon storage.

The findings of the study provide insights for decision-makers and the public to better understand the role of urban forests in reducing atmospheric CO_2 and developing more effective urban forest management plans. Although limited in area, the Kemayoran Urban Forest demonstrates meaningful carbon storage potential and provides ecosystem services that support urban climate mitigation. Policy makers, urban planners, and urban forest managers must consider the benefits of urban forests in combatingcombating climate change and promoting sustainable development. Developing and integrating urban forest management practices for climate change mitigation into urban planning will create cities that are more resilient, sustainable, and livable. This study also has limitations in that carbon calculations were limited to above-ground biomass estimates and were conducted at a single study site with specific vegetation characteristics and management conditions. Therefore, the reported carbon storage values represent above-ground carbon stocks and should not be interpreted as total ecosystem carbon storage.

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Author Contribution

Conceptualization, R.A., Y.M.W., and S.S.T.; Methodology, R.A., Y.M.W., and S.S.T.; Validation, R.A., Y.M.W., and S.S.T.; Formal Analysis, R.A.; Investigation, R.A.; Resources, R.A.; Data Curation, R.A.; Writing – Original Draft Preparation, R.A.; Writing – Review & Editing, Y.M.W., and S.S.T.,; Visualization, R.A.

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During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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