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Comparative Study on the Effectiveness of Carbon Sequestration and Storage on Two Median Strips in Bogor City

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Abstract. This study addresses the lack of a comprehensive evaluation of how tree morphometric characteristics influence carbon sequestration and storage in urban roadside median vegetation under increasing CO₂ emissions from the transportation sector. Focusing on two major streetscapes in Bogor City, Pajajaran Road and Kolonel Ahmad Syam Road, this research assesses ecosystem services related to annual carbon sequestration and long-term carbon storage, examines their relationships with key tree morphometric parameters, and compares carbon performance between contrasting urban road environments. The analyzed parameters include diameter at breast height (DBH), total height, canopy width, and total leaf area, which determine tree biomass accumulation and carbon dynamics. The research was conducted along 660 m median strips on each road segment. Tree morphometric data were obtained through direct field measurements and analyzed using the i-Tree Eco model to quantify carbon sequestration rates and carbon storage at individual tree and site levels. The results show that the Pajajaran Road median sequesters 4.87 tons of carbon annually and stores 51.3 tons of carbon, exceeding Kolonel Ahmad Syam Road, which sequesters 1.81 tons per year and stores 41 tons of carbon. Statistical analysis confirmed a significant difference in annual carbon sequestration between the two road segments ($p < 0.001$). Relationships between morphometric parameters and carbon sequestration varied among species. *Swietenia macrophylla*, *Cerbera manghas*, *Tabebuia aurea*, and *Plumeria alba* showed positive correlations, while *Dimocarpus longan* exhibited a negative correlation. These findings emphasize species selection and morphometric structure in enhancing roadside carbon mitigation and supporting urban median planting strategies.

Keywords: Bogor City, carbon sequestration, carbon storage, i-Tree Eco, median strip, tree morphometry

1. Introduction

Climate change is a global environmental challenge characterized by alterations in temperature and precipitation patterns, with widespread impacts on human life. A major contributing factor is the rising concentration of greenhouse gases, particularly carbon dioxide (CO₂), resulting from human activities. In urban areas, the transportation sector constitutes a significant source of air



pollution. Motorized vehicles contribute approximately 70% of air pollutants in major cities [1], and there is a direct correlation between the increasing number of vehicles and CO₂ emissions [2]. In Bogor City, the number of motorized vehicles increased by an average of 15% annually, reaching 480,100 units in 2019, which exacerbates air pollution and leads to environmental degradation [3].

Trees play a crucial role in mitigating climate change through carbon sequestration, a process in which CO₂ is absorbed from the atmosphere via photosynthesis and stored in plant biomass. This mechanism contributes significantly to reducing the greenhouse effect [4]. Carbon is stored in various components of the ecosystem, including plant organs, soil, and dead organic matter [5, 6]. The total amount of carbon sequestered and stored directly reflects the contribution of vegetation in regulating climate change [7]. The effectiveness of this process depends on species characteristics, morphometric parameters (such as stem diameter, height, crown area, and leaf area), tree health, and environmental conditions [8, 9]. Trees with greater morphometric values have been shown to possess higher carbon sequestration and storage capacities [10].

This study aims to compare the effectiveness of carbon sequestration and storage in two streetscapes in Bogor City, namely Pajajaran Road and Kolonel Ahmad Syam Road. The i-Tree Eco model is utilized to perform data-driven estimations at the individual tree level by incorporating specific tree-related variables such as species, diameter at breast height (DBH), total height, height to crown base, crown width, and other relevant parameters [11]. The analysis focuses on determining the relationship between tree morphometric characteristics (DBH, height, crown area, and leaf area) and the capacity of trees to deliver ecosystem services in the form of carbon sequestration and long-term carbon storage. The i-Tree Eco model enables the identification of complex interactions between tree morphology and environmental functions, including annual carbon sequestration performance and carbon retention over time [11].

The research was conducted on two urban streetscapes in Bogor City: the median strips of Pajajaran Road and Kolonel Ahmad Syam Road. Pajajaran Road functions as a primary arterial route in the city center, connecting multiple major roads. High traffic volume and human activity in this area have resulted in severe congestion and elevated levels of air pollution, particularly from motor vehicle emissions. In contrast, Kolonel Ahmad Syam Road serves as an alternative route with lower traffic intensity but shares similar greenway characteristics with Pajajaran Road. Both roads are lined with trees along their medians, making them suitable case studies for vegetation-based environmental assessment. To date, no comprehensive evaluation has been conducted to assess the ecological performance of roadside vegetation on these two streets, specifically in terms of carbon sequestration and storage using the i-Tree Eco model. This research is therefore essential for developing urban green streetscapes that are not only aesthetically pleasing but also effective in mitigating climate change and enhancing urban environmental quality.

2. Methods

The research began with the preparation stage, which involved creating a tree mapping map using Avenza Maps on Pajajaran Road and Kolonel Ahmad Syam Road. This was followed by data collection, processing, and analysis. The final stage was preparing recommendations for arranging median strip greenways in Bogor City. The research framework is presented in Figure 1.

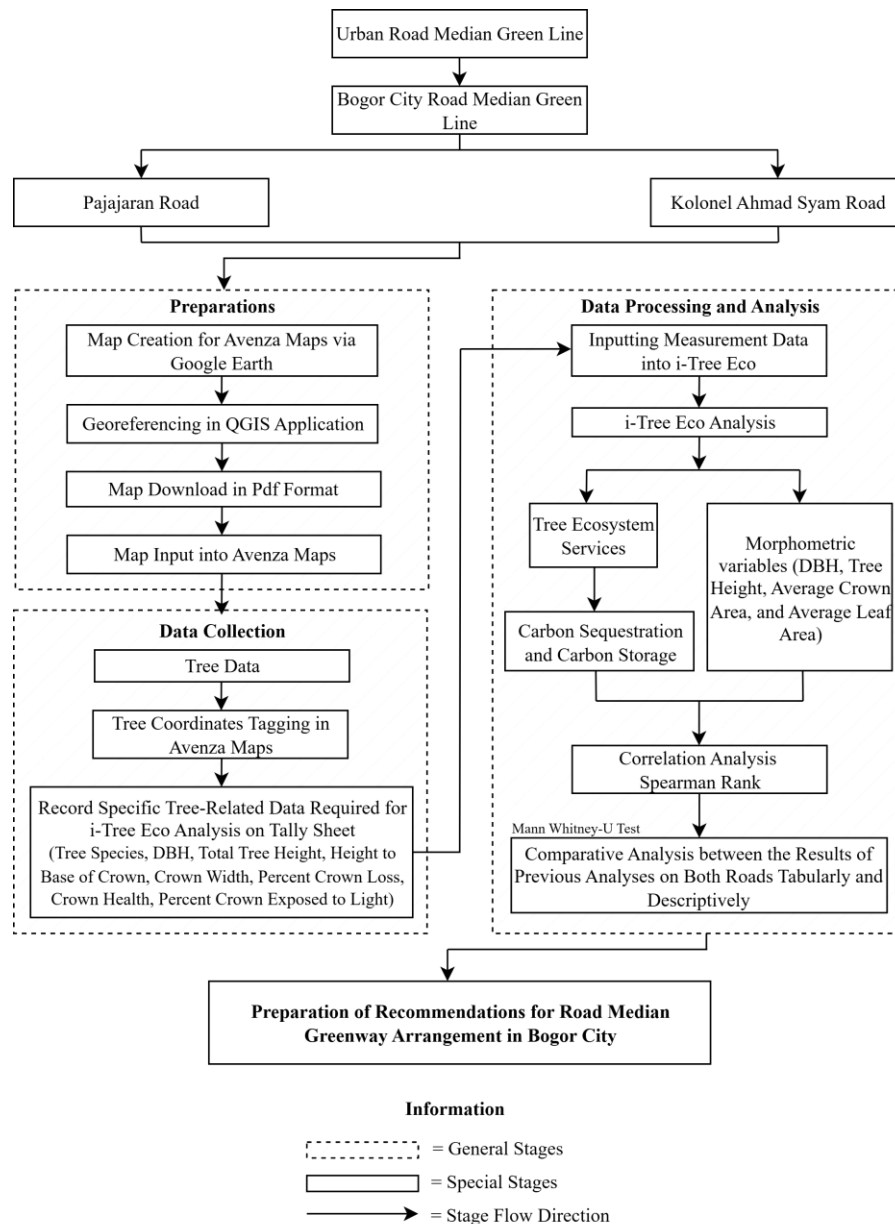


Figure 1. Diagram of the research framework

2.1 Study area and research stages

This six-month research study was conducted on two different road segments in Bogor City: Pajajaran Road (RT.02/RW.06, Baranangsiang, East Bogor Subdistrict) and Kolonel Ahmad Syam Road (RT.03/RW.01, Katulampa) (Figure 2). The same 660 meters segment length was used for each road. The research activities included preparation, field data collection, analysis, and recommendation preparation. Data were collected through field surveys and by measuring the necessary variables for data processing. Data collection was carried out through field surveys and by measuring the necessary variables for data processing.

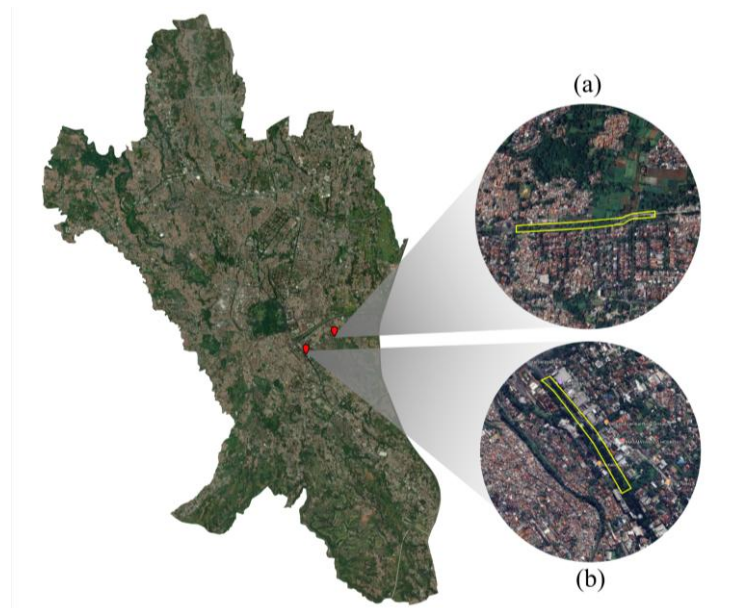


Figure 2. Research location (a) Pajajaran Road, (b) Kolonel Ahmad Syam Road

2.2 Tools and materials

Tools used in data collection include HAGA altimeter, phi band, roll meter, and digital camera. The software used consists of Google Earth, Avenza Maps, i-Tree Eco v6.0, Microsoft Excel, AutoCAD 2024, SPSS v30, and Adobe Photoshop CC 2022.

2.3 Research stages

This stage involved collecting primary and secondary data to support the research. Primary data were obtained through direct observation, field measurements, and visual documentation of trees, while secondary data were collected from literature and related agencies. The tree variables measured included species, stem diameter (DBH), total tree height, height to the base of the crown, crown width (north-south and west-east), percent crown missing, crown health, and percent of the crown exposed to light. Tree inventories were limited to trees with a DBH of at least 10 cm. An illustration of the measurement of specific tree-related variables can be seen in Figure 3.

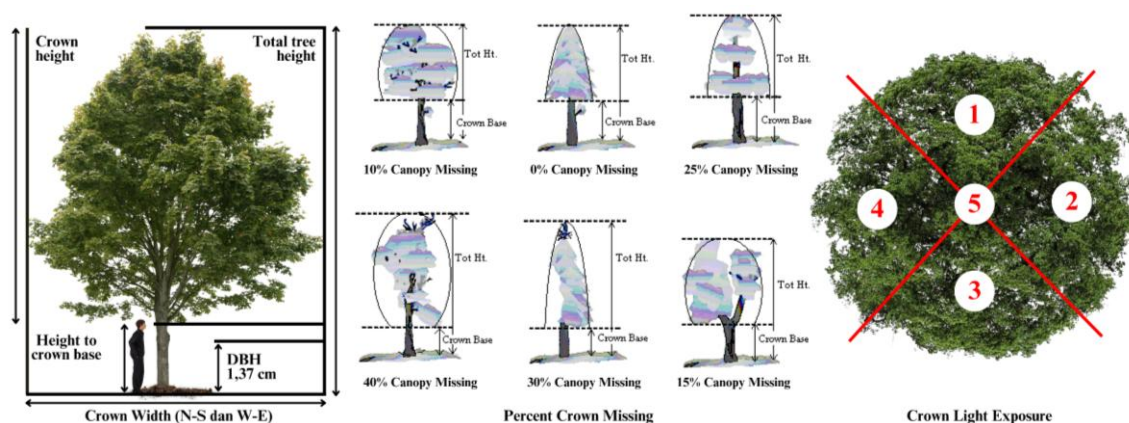


Figure 3. Illustration of measurement of tree-related specific variables

Source : Modified from *i-Tree Eco Field Guide Manual version 6.0* [11]

This data was then analyzed using the i-Tree Eco application. The research focused on tree vegetation identified with the PictureThis app. This identification was validated through references to the book *Tanaman Hias Lanskap* [12], as well as through the opinions of experts and lecturers. Identification was done through field photos taken with Android or iOS devices. A study evaluating plant identification tools reported that the application used in this study is fast, accurate, and informative, with an accuracy rate reaching up to 98%, making it suitable for supporting data collection in scientific research [13].

2.4 Data processing and analysis

Following the processing of tree data using the i-Tree Eco application, the results from both road segments were tabulated to evaluate the effectiveness of each tree species in sequestering and storing carbon. Further analysis was conducted to assess the relationship between morphometric variables (diameter at breast height, height, crown area, and leaf area) and the carbon sequestration and storage capacity in five selected tree species. These species were chosen from the top 20 carbon contributing species and included a minimum of five individuals to meet the statistical validity requirements. The analysis employed the Spearman's rank correlation method, which is appropriate for testing associative hypotheses involving ordinal data, particularly when the data sources between variables are not necessarily homogeneous [14]. The formula used for Spearman's rank correlation is as follows:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

ρ = Spearman rank correlation coefficient

d_i^2 = the difference between two paired observations

n = number of research samples

The correlation coefficient is a measurement that describes the degree of closeness of the relationship between two variables, X and Y. If the p -value is smaller than the significance level ($\alpha = 5\%$), then the relationship between the two variables is considered significant. Categories of correlation levels are usually determined subjectively, but are generally divided into the following three groups:

1. If the significance value is < 0.05 , then it is correlated
2. If the significance value is > 0.05 , then it is not correlated
3. If the significance value is $= 0.05$, it needs to be compared with the r table. If $> r$ table then correlated, but if $< r$ table then the opposite, is not correlated.

The results of the correlation analysis were interpreted based on three indicators: asterisks (*), plus and minus signs (+/-), and the numerical correlation values. The asterisk symbol (*) represents the level of statistical significance, where a higher number of asterisks indicates a smaller p -value and thus a more significant relationship. A positive sign (+) denotes a positive or unidirectional relationship, whereas a negative sign (-) indicates an inverse relationship. The interpretation of the correlation strength follows the classification guidelines proposed which are presented as follows [14, 15]:

1. Correlation value of 0.00 - 0.19, indicating no correlation
2. Correlation value of 0.20 - 0.39, indicating a weak correlation
3. Correlation value of 0.40 - 0.59, indicating a moderate correlation
4. Correlation value of 0.60 - 0.79, indicating a strong correlation
5. Correlation value of 0.80 - 1.00, indicating a very strong correlation.

After the two road segments, Pajajaran Road and Kolonel Ahmad Syam Road, were subjected to Spearman correlation analysis, the next step was a comparative test using the Mann-Whitney U statistical method to compare the sequestration and carbon storage values between the segments of Pajajaran Road and Kolonel Ahmad Syam Road.

2.5 Recommendation preparation

Based on the results of the ecological analysis, landscape recommendations were developed in the form of a planting plan and a list of recommended species. These recommendations consider the effectiveness of carbon sequestration and storage for each species on both roads and are organized in tables and 2D illustrations using AutoCAD, Photoshop, and Canva software.

3. Results and Discussion

3.1 Characteristics of Median Green Spaces and Tree Condition on Two Urban Roads in Bogor City a. Pajajaran Road

Pajajaran Road is a primary arterial corridor in Bogor City (RTRW) with a total length of 6.4 km and an average width of 24.2 m, strategically functioning as a link between Jagorawi Toll Road and the city center. The study segment is located on a 660-meter median strip that has high traffic intensity and significant ecological pressures in the form of air pollution, noise, and development density. Average daily vehicles reached 2,966.67 units for cars and 3,733.33 units for motorcycles, with the highest emissions recorded at 20,440 g/hour on national holidays [3]. However, the median greenway has relatively dense tree vegetation with ecological functions as shade, direction and pollution reduction. The road consists of two 15 m wide lanes separated by a 4.5 m wide median, with two cross-section configurations: first, 1.5 m road shoulder and 2 m sidewalk; second, 2 m wide sidewalk without road shoulder. The road dimensions and configuration are based on data from official sources and field observations, as illustrated in Figures 4 and 5.

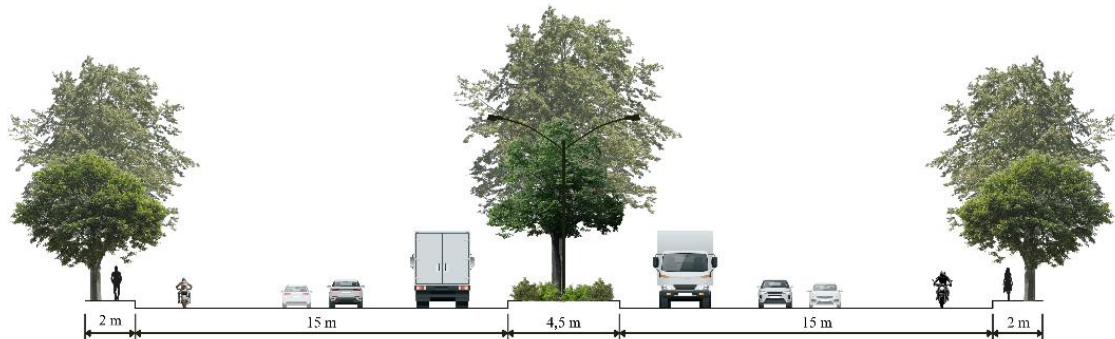


Figure 4. Illustration of the dimensions of Pajajaran Road in Bogor City without road shoulders

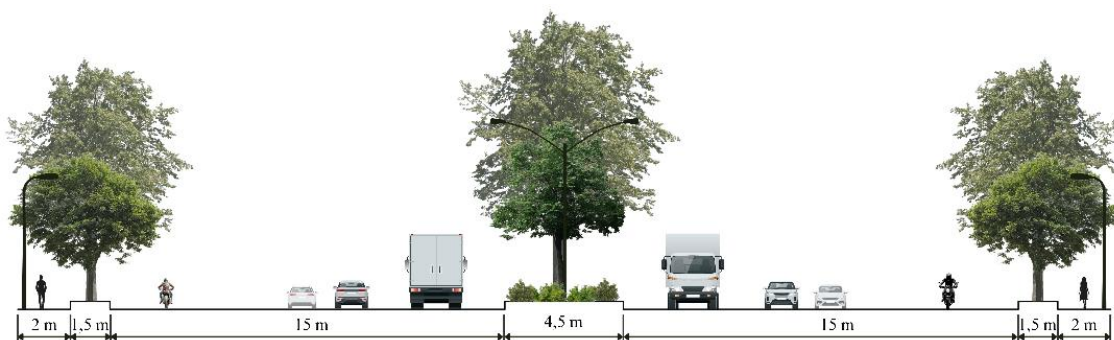


Figure 5. Illustration of the dimensions of Pajajaran Road in Bogor City with road shoulders

The vegetation inventory of Pajajaran Median strip identified 13 tree species with varying health conditions, as shown in Table 1. *Swietenia macrophylla* was the dominant species, with 75 individuals, 98.7% of which were classified in excellent condition. Overall, the trees were in good condition; however, the dominance of a single species indicates low species diversity and an increased risk of pest outbreaks [16, 17]. The presence of trees in fair-to-poor condition suggests environmental stress factors such as limited growing space, water scarcity, and air pollution [18]. Therefore, green infrastructure improvements based on species suitability are necessary to ensure the continued ecological functioning of median strips.

Table 1. Health condition of trees on Pajajaran Road

Scientific Name	Local Name	Total	Tree Condition (%)				
			Excellent	Good	Fair	Poor	Critical
<i>Alstonia scholaris</i>	Pulai	1	100				
<i>Artocarpus heterophyllus</i>	Nangka	1	100				
<i>Cerbera manghas</i>	Bintaro	9	66.7	33.3			
<i>Cochlospermum vitifolium</i>	Kapas Sutra	2			50	50	
<i>Diospyros blancoi</i>	Bisbul	1	100				
<i>Ficus benjamina</i>	Beringin	1		100			
<i>Mimusops elengi</i>	Tanjung	1	100				
<i>Pterocarpus indicus</i>	Angsana	1	100				
<i>Swietenia macrophylla</i>	Mahoni	75	98.7				1.3
<i>Syzigium cumini</i>	Jamblang	1	100				
<i>Syzigium malaccense</i>	Jambu Bol	1				100	
<i>Tabebuia aurea</i>	Tabebuia Kuning	10	90	10			
<i>Tecoma stans</i>	Terompet Kuning	8	37.5		50	12.5	
Total		112	87.5	4.5	4.5	2.7	0.9

b. Kolonel Ahmad Syam Road

Kolonel Ahmad Syam Road is a secondary collector road (RTRW) that connects North Bogor and East Bogor Sub districts as part of the Bogor City Regional Ring Road (R-3) project. The study segment is located on a 660 meters median greenway connecting North Bogor and East Bogor Sub districts through Katulampa area, with the main objective of reducing traffic load on Pajajaran Road. The road has been under intensive construction since 2005, with median vegetation planting starting in 2006. The road structure consists of two lanes each 5 meters wide with a 1-meter shoulder, as well as median strips that vary in width, namely 12 meters (485.7 m), 3 meters (84.5 m), and 1 meter (90.2 m), which affects the growing space capacity and distribution of trees. Illustrations of the road dimensions and configurations are based on actual field measurements, as shown in Figure 6 to 8.

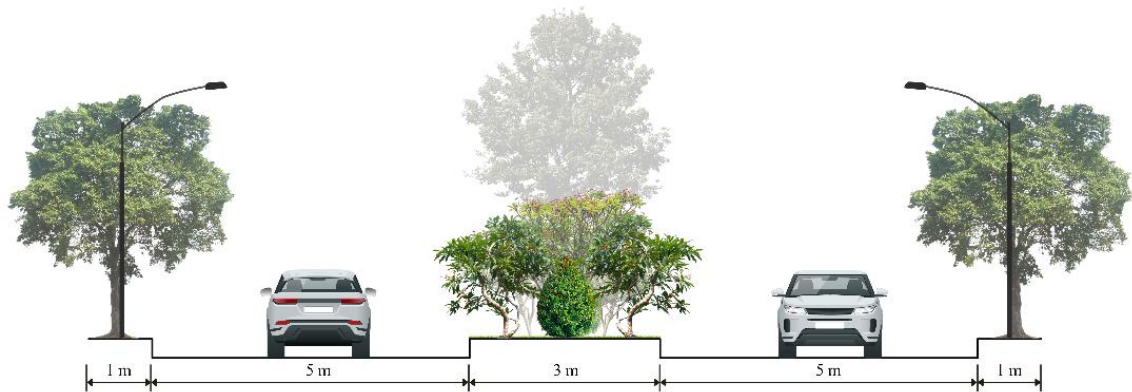


Figure 6. Illustration of the dimensions of Jalan Kolonel Ahmad Syam Bogor City with a median width of 3 m

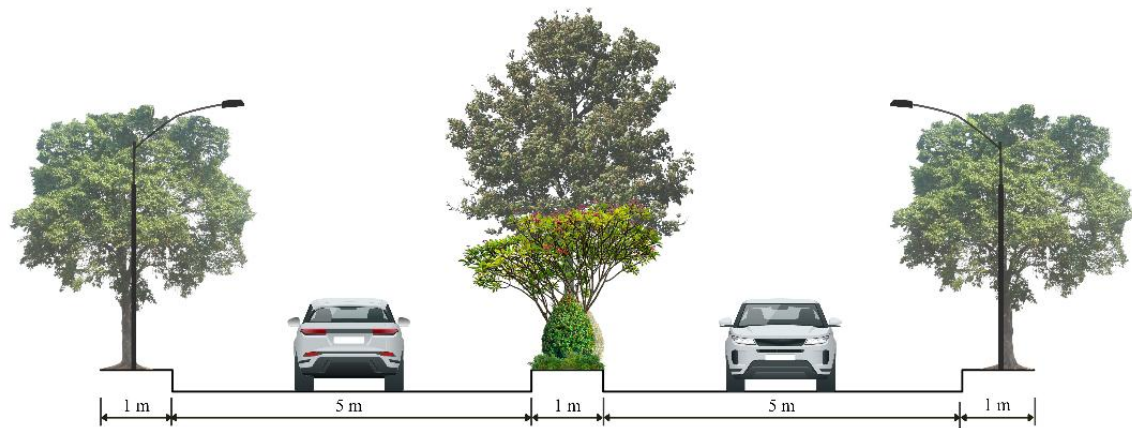


Figure 7. Illustration of the dimensions of Jalan Kolonel Ahmad Syam Bogor City with a median width of 1 m

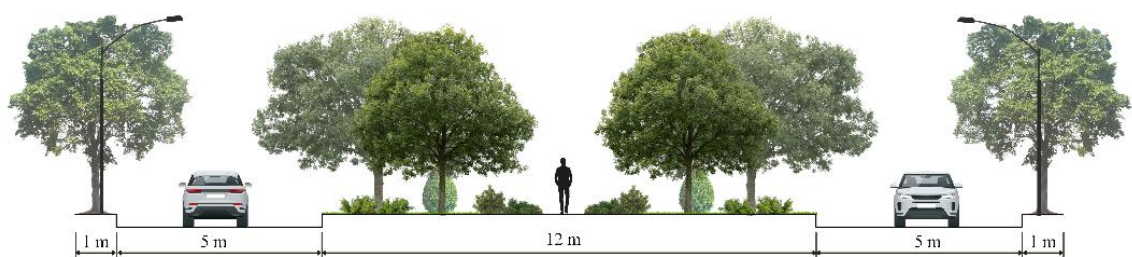


Figure 8. Illustration of the dimensions of Jalan Kolonel Ahmad Syam Bogor City with a median width of 12 m

Vegetation inventory on the median of Kolonel Ahmad Syam Road recorded 143 individuals of 17 tree species, with the dominance of excellent condition (95.8%), followed by good (1.4%), fair (0.7%), and poor (2.1%) which can be seen in Table 2. *Dimocarpus longan* was the most dominant species, with 65 individuals in excellent condition. In general, the vegetation condition on this road is classified as very good and reflects effective site management. However, the

dominance of certain species such as longan and the finding of individuals with suboptimal conditions in several species indicate the importance of increasing species diversity to strengthen ecosystem resilience to potential biotic disturbances.

Table 2. Health condition of trees on Kolonel Ahmad Syam Road

Scientific Name	Local Name	Total	Tree Condition (%)			
			Excellent	Good	Fair	Poor
<i>Artocarpus heterophyllus</i>	Nangka	1	100			
<i>Cerbera manghas</i>	Bintaro	29	100			
<i>Cocos nucifera</i>	Kelapa	2	100			
<i>Dimocarpus longan</i>	Lengkeng	65	100			
<i>Mangifera indica</i>	Mangga	2	100			
<i>Morinda citrifolia</i>	Mengkudu	1	100			
<i>Nephelium lappaceum</i>	Rambutan	1	100			
<i>Persea americana</i>	Alpukat	1		100		
<i>Plumeria alba</i>	Kamboja Putih	12	100			
<i>Plumeria rubra</i>	Kamboja Merah	14	100			
<i>Solanum torvum</i>	Takokak	3			33.3	66.7
<i>Swietenia macrophylla</i>	Mahoni	4	100			
<i>Syzigium malaccense</i>	Jambu Bol	1				100
<i>Syzigium samarangense</i>	Jambu Semarang	1	100			
<i>Syzygium polyanthum</i>	Salam	2	50	50		
<i>Terminalia catappa</i>	Ketapang	3	100			
<i>Wodyetia bifurcata</i>	Palem Ekor Tupai	1	100			
Total		143	95.8	1.4	0.7	2.1

3.2 Analysis of Carbon Sequestration and Storage on Two Median strips in Bogor City

The increase in carbon dioxide (CO₂) emissions, as a primary driver of global climate change, necessitates the implementation of effective mitigation strategies. One such strategy involves carbon sequestration and storage by urban trees. In urban landscapes, trees not only serve aesthetic purposes but also function as carbon sinks through photosynthesis and the accumulation of carbon in biomass and dead organic matter. The efficiency of this process is influenced by species characteristics, tree size, and site conditions. A study conducted in the Muhammad Sabki Urban Forest reported a carbon sequestration capacity of 604.2 tons per hectare and a storage capacity of 164.78 tons per hectare [19]. These results emphasize the critical role of vegetation in climate change mitigation. The selection of appropriate tree species is therefore essential to optimize ecological performance.

a. Pajajaran Road

The results showed that the trees on the median of the 660-meter segment of Pajajaran Road were able to absorb 4.87 tons of carbon per year, providing Rp292,062 in savings (Figure 9), and store 51.3 tons of carbon, providing Rp3,077,804 in savings (Figure 10). These values were calculated using the adjusted local carbon price, which averaged Rp58,800 to Rp69,600 per ton of CO₂e on the Indonesian Carbon Exchange (IDXCarbon) from 2024 to 2025 [20]. The calculations were made using the IDR60,000 per ton CO₂e approach for non-forest vegetation in According to the Table 3, *Swietenia macrophylla* has the highest carbon sequestration contribution at around

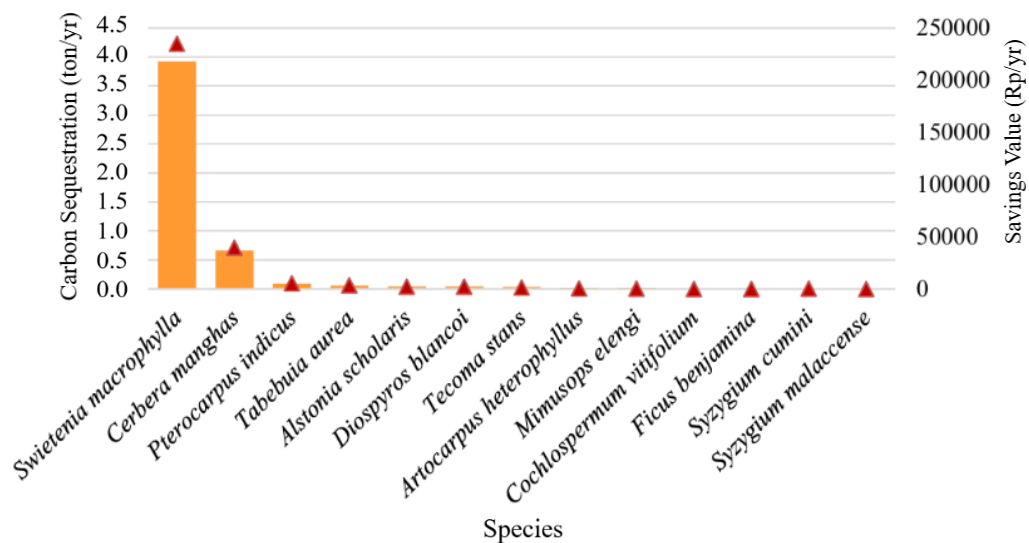


Figure 9. Carbon Sequestration by i-Tree Eco on Pajajaran Road

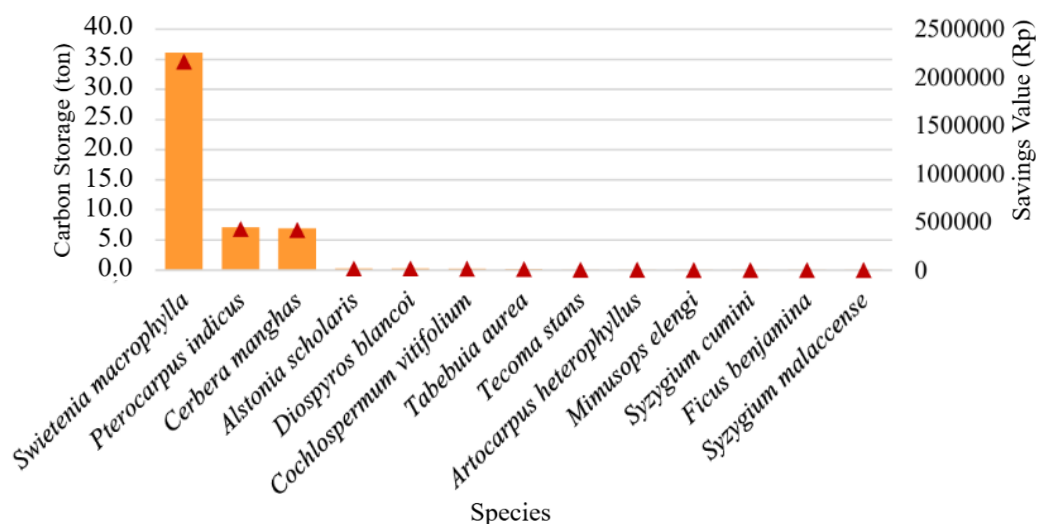


Figure 10. Carbon Storage by i-Tree Eco on Pajajaran Road

80.49% of the total sequestered each year. *Cerbera manghas* occupies the next position with a contribution of 13.55%. Several species, including *Artocarpus heterophyllus*, *Cochlospermum*

vitifolium, *Ficus benjamina*, *Mimusops elengi*, *Syzygium cumini*, and *Syzygium malaccense*, have low carbon sequestration levels, with total sequestration of $\leq 0\%$ per year.

Table 3. Tree carbon sequestration by species on Pajajaran Road

No	Species	Total	Gross Carbon Sequestration (tons/year)	CO ₂ Equivalent (tons/year)
1	<i>Alstonia scholaris</i>	1	0.04	0.15
2	<i>Artocarpus heterophyllus</i>	1	0.01	0.04
3	<i>Cerbera manghas</i>	9	0.66	2.42
4	<i>Cochlospermum vitifolium</i>	2	0.00	0.01
5	<i>Diospyros blancoi</i>	1	0.04	0.14
6	<i>Ficus benjamina</i>	1	0.00	0.01
7	<i>Mimusops elengi</i>	1	0.01	0.02
8	<i>Pterocarpus indicus</i>	1	0.09	0.34
9	<i>Swietenia macrophylla</i>	75	3.92	14.37
10	<i>Syzygium cumini</i>	1	0.00	0.01
11	<i>Syzygium malaccense</i>	1	0.00	0.01
12	<i>Tabebuia aurea</i>	10	0.06	0.22
13	<i>Tecoma stans</i>	8	0.03	0.10
Total		112	4.87	17.85

Meanwhile, in terms of carbon storage (Table 4), *Swietenia macrophylla* contributed the most to the total carbon stored in the Pajajaran Road research segment, at around 70.37%. *Pterocarpus indicus* occupied the second position with a contribution of about 13.9%, followed by *Cerbera manghas* with 13.6%. Several other species, including *Artocarpus heterophyllus*, *Ficus benjamina*, *Mimusops elengi*, *Syzygium cumini*, and *Syzygium malaccense*, have low levels of carbon storage with a total stored carbon of $\leq 0\%$.

Table 4. Tree carbon storage by species on Pajajaran Road

No	Species	Total	Carbon Storage (tons)	Carbon Storage (%)	CO ₂ Equivalent (tons)
1	<i>Alstonia scholaris</i>	1	0.30	0.5	1.00
2	<i>Artocarpus heterophyllus</i>	1	0.00	0.1	0.20
3	<i>Cerbera manghas</i>	9	7.00	13.6	25.50
4	<i>Cochlospermum vitifolium</i>	2	0.20	0.5	0.90
5	<i>Diospyros blancoi</i>	1	0.30	0.5	1.00
6	<i>Ficus benjamina</i>	1	0.00	0.0	0.00

No	Species	Total	Carbon Storage (tons)	Carbon Storage (%)	CO ₂ Equivalent (tons)
7	<i>Mimusops elengi</i>	1	0.00	0.0	0.10
8	<i>Pterocarpus indicus</i>	1	7.10	13.9	26.10
9	<i>Swietenia macrophylla</i>	75	36.10	70.3	132.30
10	<i>Syzygium cumini</i>	1	0.00	0.0	0.10
11	<i>Syzygium malaccense</i>	1	0.00	0.0	0.00
12	<i>Tabebuia aurea</i>	10	0.20	0.4	0.70
13	<i>Tecoma stans</i>	8	0.10	0.2	0.30
Total		112	51.30	100	188.10

b. Kolonel Ahmad Syam Road

Based on the results of research and data processing, the carbon sequestration results for Kolonel Ahmad Syam Road were obtained at 1.81 tons of carbon/year with a savings value of Rp108,764 (Figure 11) and carbon storage at 40.98 tons of carbon with a savings value of Rp2,458,960 (Figure 12). The relatively lower value of carbon sequestration and storage compared to Jalan Pajajaran is thought to be influenced by differences in vegetation structure, the dominance of certain tree species, and morphometric parameters such as tree height, stem diameter (DBH), and crown area that directly affect the capacity of trees to sequester and store carbon.

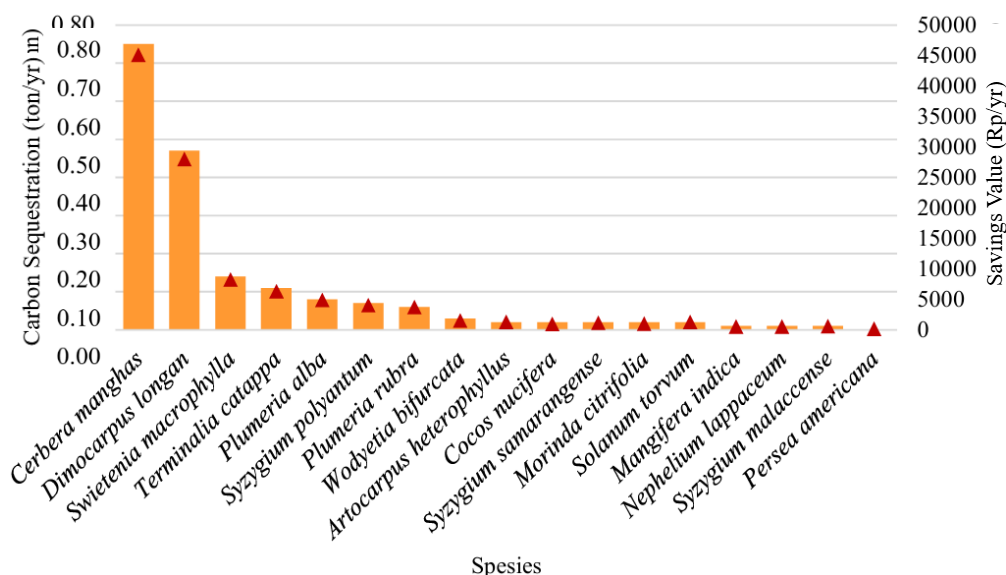


Figure 11. Carbon Sequestration by i-Tree Eco on Kolonel Ahmad Syam Road

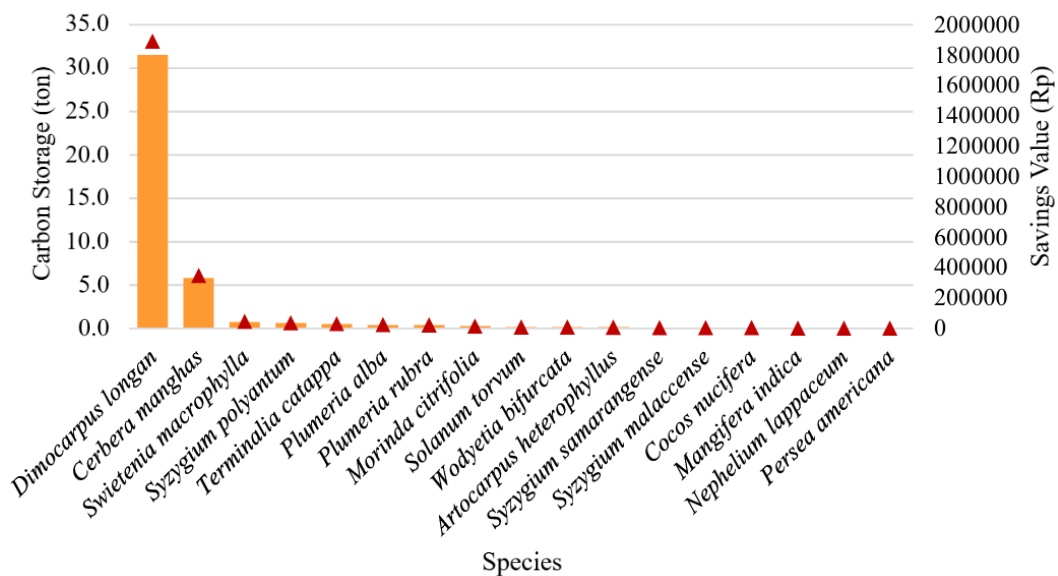


Figure 12. Carbon Storage by i-Tree Eco on Kolonel Ahmad Syam Road

According to Table 5, *Cerbera manghas* contributes the most to carbon sequestration, accounting for about 41.4% of the total sequestered each year. *Dimocarpus longan* absorbs about 25.96%, while *Swietenia macrophylla* absorbs about 7.73%. Other species, such as *Mangifera indica*, *Nephelium lappaceum*, *Syzygium malaccense*, and *Persea americana*, have low sequestration rates, with total sequestration of $\leq 0\%$ per year.

Table 5. Tree carbon sequestration by species on Kolonel Ahmad Syam Road

No	Species	Total	Gross Carbon Sequestration (tons/year)	CO ₂ Equivalent (tons/year)
1	<i>Artocarpus heterophyllus</i>	1	0.02	0.08
2	<i>Cerbera manghas</i>	29	0.75	2.75
3	<i>Cocos nucifera</i>	2	0.02	0.06
4	<i>Dimocarpus longan</i>	65	0.47	1.71
5	<i>Syzygium samarangense</i>	1	0.02	0.07
6	<i>Syzygium polyanthum</i>	2	0.07	0.25
7	<i>Mangifera indica</i>	2	0.01	0.03
8	<i>Morinda citrifolia</i>	1	0.02	0.06
9	<i>Nephelium lappaceum</i>	1	0.01	0.03
10	<i>Persea americana</i>	1	0.00	0.01
11	<i>Plumeria alba</i>	12	0.08	0.30
12	<i>Plumeria rubra</i>	14	0.06	0.22
13	<i>Solanum torvum</i>	3	0.02	0.08

No	Species	Total	Gross Carbon Sequestration (tons/year)	CO ₂ Equivalent (tons/year)
14	<i>Swietenia macrophylla</i>	4	0.14	0.50
15	<i>Syzygium malaccense</i>	1	0.01	0.03
16	<i>Terminalia catappa</i>	3	0.11	0.39
17	<i>Wodyetia bifurcata</i>	1	0.03	0.09
Total		143	1.81	6.65

Meanwhile, for carbon storage (Table 6), *Dimocarpus longan* stores the largest carbon, which is about 76.9% of the total carbon stored. The next position is occupied by *Cerbera manghas* with a contribution of about 14.2%. Meanwhile, some species such as *Mangifera indica*, *Nephelium lappaceum*, and *Persea americana* have low carbon storage levels with total carbon stored $\leq 0\%$.

Table 6. Tree carbon storage by species on Pajajaran Road

No	Species	Total	Carbon Storage (tons)	Carbon Storage (%)	CO ₂ Equivalent (tons)
1	<i>Artocarpus heterophyllus</i>	1	0.10	0.3	0.50
2	<i>Cerbera manghas</i>	29	5.80	14.2	21.30
3	<i>Cocos nucifera</i>	2	0.10	0.2	0.20
4	<i>Dimocarpus longan</i>	65	31.50	76.9	115.60
5	<i>Syzygium samarangense</i>	1	0.10	0.2	0.30
6	<i>Syzygium polyanthum</i>	2	0.60	1.4	2.20
7	<i>Mangifera indica</i>	2	0.00	0.1	0.10
8	<i>Morinda citrifolia</i>	1	0.30	0.6	1.00
9	<i>Nephelium lappaceum</i>	1	0.00	0.1	0.10
10	<i>Persea americana</i>	1	0.00	0.0	0.00
11	<i>Plumeria alba</i>	12	0.40	1.0	1.50
12	<i>Plumeria rubra</i>	14	0.40	0.9	1.40
13	<i>Solanum torvum</i>	3	0.20	0.4	0.60
14	<i>Swietenia macrophylla</i>	4	0.80	1.8	2.80
15	<i>Syzygium malaccense</i>	1	0.10	0.2	0.40
16	<i>Terminalia catappa</i>	3	0.50	1.2	1.90
17	<i>Wodyetia bifurcata</i>	1	0.10	0.3	0.50
Total		143	41.00	100	150.30

c. Effectiveness of carbon sequestration and storage in two street landscapes in Bogor City

Carbon sequestration refers to the uptake of CO₂ from the atmosphere through photosynthesis, while carbon storage involves the accumulation of carbon in above and below ground tree biomass [10]. The effectiveness of these processes varies between streetscapes and is influenced by factors such as species, age, tree health, growing environment, and morphometric characteristics including diameter at breast height (DBH), height, crown area, and leaf area. These variables are directly related to the capacity of trees to sequester and store carbon. Table 7 presents the average values of morphometric parameters and the corresponding carbon sequestration and storage capacities of trees in two streetscapes in Bogor City.

Table 7. Tree carbon storage by species on Pajajaran Road

Species	Total	Mean DBH (cm)	Mean Height (m)	Mean Crown Area (m ²)	Mean Leaf Area (m ²)	Mean Carbon Sequestration (kg/year)	Mean Carbon Storage (kg)
Pajajaran Road							
<i>Swietenia macrophylla</i>	75	37.44	14.65	88.02	207.67	52.26	481.01
<i>Tabebuia aurea</i>	10	14.67	4.85	9.69	10.93	5.94	17.97
<i>Cerbera manghas</i>	9	38.82	13.8	55.98	285.57	73.46	772.73
<i>Tecoma stans</i>	8	11.51	6.05	17.73	21.53	3.43	9.64
<i>Cochlospermum vitifolium</i>	2	44.55	10.5	38.35	117.95	1.8	116.8
<i>Alstonia scholaris</i>	1	42.7	16	50.9	290	40.7	282.1
<i>Artocarpus heterophyllus</i>	1	19.4	9.2	30.7	118.9	11.4	46.7
<i>Diospyros blancoi</i>	1	34.3	10.50	47.2	301.70	39.1	276.70
<i>Ficus benjamina</i>	1	10.7	6.00	16.6	15.40	1.8	8.00
<i>Mimusops elengi</i>	1	12	8.00	19.2	25.80	5.3	24.90
<i>Pterocarpus indicus</i>	1	129.6	26.00	244.7	1866.40	92.7	7113.00
<i>Syzygium cumini</i>	1	10.30	10.30	23.80	33.60	4	33.60
<i>Syzygium malaccense</i>	1	11.50	11.50	8.80	7.80	2	7.80
Kolonel Ahmad Syam Road							
<i>Dimocarpus longan</i>	65	47.37	11.15	85.88	324.54	7.17	485.03
<i>Cerbera manghas</i>	29	25.27	9.33	25.56	54.97	25.9	200.24
<i>Plumeria rubra</i>	14	17.91	5.64	22.4	32.66	4.37	27.77
<i>Plumeria alba</i>	12	15.81	6.21	26.59	28.2	6.78	33.73
<i>Swietenia macrophylla</i>	4	34.05	11.83	68.35	231.15	34.18	188.03
<i>Solanum torvum</i>	3	22.7	6.63	34.87	27.07	6.87	53.2
<i>Terminalia catappa</i>	3	29.37	14.57	116.5	314.97	35.07	169.47
<i>Cocos nucifera</i>	2	21.9	5.3	25.15	16.65	7.95	33.45
<i>Mangifera indica</i>	2	13.35	6.3	25.95	49.95	4.2	15.65
<i>Syzygium polyanthum</i>	2	32.15	11.1	53.1	253.45	33.5	296.5
<i>Artocarpus heterophyllus</i>	1	28.2	11.5	70.90	231.5	20.6	123.4
<i>Morinda citrifolia</i>	1	39.1	10.60	42.40	121.70	16	259.8
<i>Nephelium lappaceum</i>	1	15.9	5.80	23.30	30.80	8.3	26.5
<i>Persea americana</i>	1	11.2	5.00	20.40	14.90	2	8.8
<i>Syzygium malaccense</i>	1	28.5	8.30	26.4	47.9	9.3	96.1
<i>Syzygium samarangense</i>	1	25	9	36.9	115.1	18.3	95.2
<i>Wodyetia bifurcata</i>	1	26.5	7.5	13.5	17.1	25.2	134

The analysis indicated that *Pterocarpus indicus* in the Pajajaran Road segment, although represented by only one individual, recorded the highest carbon sequestration and storage values, amounting to 92.7 kg/year and 7.113 kg, respectively. This species also exhibited the largest trunk diameter (129.6 cm), suggesting mature age and substantial biomass accumulation. These findings are consistent with previous studies reporting that *Pterocarpus indicus* possesses a higher carbon sequestration capacity compared to other shade tree species, such as *Swietenia macrophylla*, with leaf absorption values up to 0.44 times greater [21]. This enhanced capacity is

influenced by internal factors, including stomatal density, leaf thickness, and surface area, as well as external factors such as site specific environmental conditions [22, 23]. Another species with high sequestration performance was *Cerbera manghas*, which recorded 73.46 kg/year in carbon sequestration and 772.73 kg in storage. However, in the Kolonel Ahmad Syam Road segment, this species showed lower values, indicating that growing conditions significantly affect sequestration potential. The carbon content in the leaves of this species varies depending on nutrient availability, water supply, and atmospheric CO₂ concentration in the surrounding environment [20]. *Dimocarpus longan* had the highest carbon storage among the other species, reaching 485.03 kg, followed by *Syzygium polyanthum* (296.50 kg) and *Morinda citrifolia* (259.80 kg). Variations in carbon sequestration and storage among species and locations underscore the importance of species selection and site suitability in roadside vegetation management. These findings suggest that the effectiveness of trees in mitigating climate change is influenced not only by morphometric dimensions but also by physiological adaptability to local environmental conditions.

d. Relationship of carbon sequestration and storage with tree morphometric variables

The Spearman rank correlation test was performed to analyze the relationship between tree morphometric variables (including DBH, height, crown area, and leaf area) and carbon sequestration and storage values. The analysis focused on five species with at least five individual trees each to ensure the validity of the statistical testing. Despite having the highest average carbon sequestration and storage values and the largest DBH, *Pterocarpus indicus* was excluded because it consisted of only one individual and therefore did not meet the quantitative requirements for analysis using SPSS 30. Analyzing the limited number of individuals was considered to risk producing invalid correlation results. The test results are shown in the form of correlation coefficients in Table 8 and Table 9.

Table 8. Rank Spearman correlation test results of morphometric variables on carbon sequestration

	<i>Swietenia macrophylla</i>	<i>Cerbera manghas</i>	<i>Dimocarpus longan</i>	<i>Plumeria alba</i>	<i>Tabebuia aurea</i>
DBH	0.965**	0.870**	-0.731**	0.898**	0.854**
Height	0.939**	0.811**	0.006	0.730**	0.726*
Crown Area	0.837**	0.619**	-0.355**	0.890*	0.778**
Leaf Area	0.864**	0.884**	-0.201	0.919**	0.851**

(* $P < 0.05$; ** $P < 0.01$)

The results of the Spearman's rank correlation test revealed variations in the relationship between tree morphometric variables, diameter at breast height (DBH), height, crown area, and leaf area, and carbon sequestration capacity across different species (Table 8). *Swietenia macrophylla* exhibited a very strong and positive correlation across all variables ($r > 0.83$; $p < 0.01$), as did *Cerbera manghas*, which showed strong correlations with DBH ($r = 0.884$), height ($r = 0.811^{**}$), crown area ($r = 0.619^{**}$), and leaf area ($r = 0.884^{*}$). These results indicate that an increase in tree size is positively associated with higher carbon sequestration capacity. Previous studies have demonstrated that stem and crown dimensions significantly affect above-ground carbon stocks [9]. *Plumeria alba* and *Tabebuia aurea* also exhibited very strong and statistically significant correlations ($r > 0.7^{*}$) for all morphometric variables, confirming a consistent positive

relationship between tree growth and carbon sequestration potential. In contrast, *Dimocarpus longan* showed a significant negative correlation between DBH and carbon sequestration ($r = -0.731^{**}$), along with weak to moderate negative correlations with crown area ($r = -0.355^{**}$) and leaf area ($r = -0.201$). No correlation was found with tree height ($r = 0.006$), suggesting that in this species, increased tree size may be linked to reduced sequestration capacity. The average DBH of *Dimocarpus longan* was 47.37 cm—the highest among the dominant species—indicating a mature growth stage that may reduce physiological efficiency in carbon uptake. Although large trees continue to accumulate biomass, their carbon sequestration rate tends to decline due to increased energy demands for tissue maintenance [8]. This finding aligns with previous research reporting that the biomass of *Dimocarpus longan* was only 0.504 tons, substantially lower than that of *Pterocarpus indicus* (3,293.759 tons) and *Swietenia macrophylla* (1,948.260 tons) [24]. These results emphasize the importance of selecting morphologically and physiologically suitable species to optimize the ecological contribution of trees in roadside afforestation strategies.

Table 9. Rank Spearman correlation test results of morphometric variables on carbon storage

	<i>Dimocarpus longan</i>	<i>Swietenia macrophylla</i>	<i>Cerbera manghas</i>	<i>Plumeria alba</i>	<i>Plumeria rubra</i>
DBH	0.930**	0.988**	0.970**	0.944**	0.912**
Height	0.591**	0.937**	0.805**	0.647*	0.613*
Crown Area	0.715**	0.861**	0.615**	0.825**	0.849**
Leaf Area	0.770**	0.879**	0.892**	0.867**	0.855**

(* $P < 0.05$; ** $P < 0.01$)

Meanwhile, the results of the Spearman rank correlation analysis for carbon storage (Table 9) revealed positive and significant relationships between morphometric variables (DBH, height, crown area, and leaf area) and all analyzed tree species. *Dimocarpus longan*, despite exhibiting a negative correlation with carbon sequestration, showed strong positive correlations between all morphometric parameters and carbon storage. The strongest correlation was observed with DBH ($r = 0.930$), followed by leaf area ($r = 0.770^{**}$), crown area ($r = 0.715^{**}$), and tree height ($r = 0.591^{**}$). These results indicate that total carbon accumulation increases as tree size increases, although the annual rate of carbon sequestration may decline. This finding is consistent with studies conducted in Thailand [25]. *Swietenia macrophylla* also demonstrated strong positive correlations across all variables, with DBH showing the highest value ($r = 0.988^{**}$). Similarly, *Cerbera manghas* exhibited the strongest correlation with DBH ($r = 0.970^{**}$), suggesting a dominant contribution of woody biomass to carbon storage. *Plumeria alba* and *Plumeria rubra*, although classified as medium-sized species, showed significant positive correlations for all morphometric variables, with DBH and leaf area being the most consistent indicators ($r > 0.85^{**}$). Overall, these results suggest that increasing morphometric dimensions—particularly DBH—is a critical factor in enhancing carbon storage capacity, even though the strength of the correlations may vary across species.

3.3 Comparative analysis of two streetscapes in Bogor City

Differences in carbon sequestration and storage values between tree species on Jalan Pajajaran and Jalan Kolonel Ahmad Syam were tested using a Mann-Whitney U analysis with IBM SPSS Statistics software, version 30. The sample included 112 trees from Jalan Pajajaran and 143 trees from Jalan Kolonel Ahmad Syam, for a total of 255 trees. Decision-making was based on the Asymp. Sig. (2-tailed). The criteria were $p < 0.05$ for a significant difference and $p > 0.05$ for no significant difference. The test results are presented in Table 10 and Table 11.

Table 10. Mann-Whitney U test results on carbon sequestration in two streetscapes in Bogor City.

Carbon Sequestration		
	Pajajaran Road	Kolonel Ahmad Syam Road
N	112	143
Mean Rank	157.89	104.59
Z		-5.728
Asymp. Sig. (2-tailed)		<0.001

The Mann-Whitney U test results (Table 10) revealed a significant difference in carbon sequestration capacity between Pajajaran Road and Kolonel Ahmad Syam Road landscapes ($p < 0.001$). The higher mean rank value on Jalan Pajajaran (157.89) than on Kolonel Ahmad Syam Road (104.59) indicates that trees on Pajajaran Road contribute more to carbon sequestration statistically. This finding is consistent with the Spearman Rank correlation results, which showed a strong positive correlation between morphometric parameters and carbon sequestration for the dominant species on Pajajaran Road, such as *Swietenia macrophylla*, *Cerbera manghas*, and *Tabebuia aurea*. In contrast, *Dimocarpus longan*'s presence on Kolonel Ahmad Syam Road decreased the road's average carbon sequestration contribution due to its negative correlation with morphometric variables. These results suggest that the effectiveness of carbon sequestration depends not only on the number or size of trees but also on the composition of dominant species and the relationship between tree morphometrics and carbon sequestration capacity. Therefore, selecting species with consistent positive correlations to morphometric parameters is key to optimizing the ecological function of road greenways.

Table 11. Mann-Whitney U test results on carbon storage in two streetscapes in Bogor City.

Carbon Storage		
	Pajajaran Road	Kolonel Ahmad Syam Road
N	112	143
Mean Rank	123.21	131.75
Z		-0.918
Asymp. Sig. (2-tailed)		0.359

Table 11 shows the results of the Mann-Whitney U test for the carbon storage variable between Jalan Pajajaran and Jalan Kolonel Ahmad Syam. The p -value was 0.359. This value indicates that there is no significant difference in carbon storage capacity between the two streetscapes. This finding aligns with the Spearman Rank correlation analysis, which revealed that all morphometric variables stem diameter (DBH), tree height, crown area, and leaf area—contribute positively and significantly to carbon storage. On Jalan Kolonel Ahmad Syam, the high carbon storage value is influenced by the distribution of medium to large sized trees of dominant species, such as *Dimocarpus longan* and *Cerbera manghas*. Meanwhile, carbon accumulation on Jalan Pajajaran mostly comes from one large *Pterocarpus indicus* tree, as well as from *Swietenia macrophylla* with varying size ranges. The pattern of tree size distribution causes the carbon storage accumulation on both roads to be relatively comparable, despite the structurally different species composition.

4. Recommendations

Based on the results of the ecological function evaluation using i-Tree Eco on both road segments in Bogor City, there are several strategies or approaches that can be used as a reference in planning or improving tree planting in urban streetscapes that can be used and applied as an effort to mitigate carbon emissions in urban areas.

4.1 Recommendations for tree species effective in carbon sequestration

These recommendations are presented in a table of tree species considered effective in providing the ecological function of carbon sequestration. This table is based on the highest sequestration values obtained by processing i-Tree Eco data from all sample trees on both road sections. This information is systematically presented in a table listing the species shown in Table 12.

Table 12. Mann-Whitney U test results on carbon storage in two streetscapes in Bogor City

No.	Species	Local Name	Mean Carbon Sequestration (kg/year)	Photo
1	<i>Pterocarpus indicus</i>	Angsana	92.7	
2	<i>Cerbera manghas</i>	Bintaro	73.46	
3	<i>Swietenia macrophylla</i>	Mahoni	52.26	

4	<i>Alstonia scholaris</i>	Pulai	40.7	
5	<i>Diospyros blancoi</i>	Bisbul	39.1	
6	<i>Terminalia catappa</i>	Ketapang	35.07	
7	<i>Syzygium polyanthum</i>	Salam	33.5	
8	<i>Artocarpus heterophyllus</i>	Nangka	20.6	
9	<i>Syzygium samarangense</i>	Jambu Semarang	18.3	
10	<i>Morinda citrifolia</i>	Mengkudu	16	

4.2 Replacement of poor-condition plants with recommended species

4.2.1 Recommendations for replacing plants in "Poor" condition

The inventory results revealed the presence of several trees in poor condition within both streetscapes, warranting replacement from an ecological perspective. On Pajajaran Road, *Cochlospermum vitifolium* was identified as a candidate for replacement. It is recommended that this species be substituted with *Pterocarpus indicus*, which demonstrated a high annual carbon sequestration capacity of 92.7 kg/tree/year. This recommendation is supported by findings indicating a carbon absorption capacity of 4,642.293 g CO₂/tree/hour for *Pterocarpus indicus* [26]. However, the use of this species requires appropriate management due to potential structural risks associated with root and trunk development [27]. Another alternative species is *Terminalia catappa*, proposed as a replacement for *Tecoma stans*, due to its notable sequestration potential (35.07 kg/year) and favorable morphological traits, such as broad leaves and a wide canopy, which contribute to shading and microclimate regulation. *Syzygium malaccense*, which was found in poor condition across both roads, is recommended for replacement with *Syzygium polyanthum* to maintain taxonomic alignment while improving carbon storage capacity. Additionally, *Solanum torvum* on Kolonel Ahmad Syam Road is considered for replacement due to its low ecological contribution. *Pterocarpus indicus* remains a top recommendation, not only for its high carbon sequestration performance but also for its nitrogen-fixing ability, which enhances soil quality and overall ecosystem function [28]. Nevertheless, the deployment of this species requires selective pruning, periodic health monitoring, and optimal space management to mitigate ecological risks and prevent infrastructure damage.

4.2.2 Recommendations for replacing plants in "Critical" condition

A *Swietenia macrophylla* tree located on the median of Pajajaran Road was identified to be in critical condition. To maintain the ecological function of the road landscape, replacement was deemed necessary. The recommended replacement species is *Alstonia scholaris*, which has an average annual carbon sequestration capacity of 40.7 kg per tree. This species has demonstrated a carbon absorption potential of up to 190.36 tons of carbon per tree, with carbon comprising approximately 43% of its total biomass [29]. In addition to its sequestration capacity, *Alstonia scholaris* exhibits high adaptability to urban environmental pressures, making it suitable for confined planting spaces such as median strips.

4.2.3 Planting Plan Recommendations for Two Urban Road Landscapes in Bogor City

The recommended planting plan for the median strips of Pajajaran Road and Kolonel Ahmad Syam Road (Figures 13 to 16) was developed based on the tree distribution maps generated using Avenza Maps and the results of the i-Tree Eco analysis. These inputs were integrated into the formulation of recommendations for replacing tree species classified as being in "Poor" or "Critical" condition. The planting plan was formulated with consideration of several key factors, including:

- (a) Road activity and spatial use patterns
- (b) The health condition of existing trees
- (c) The role and effectiveness of trees in carbon sequestration
- (d) Species diversit

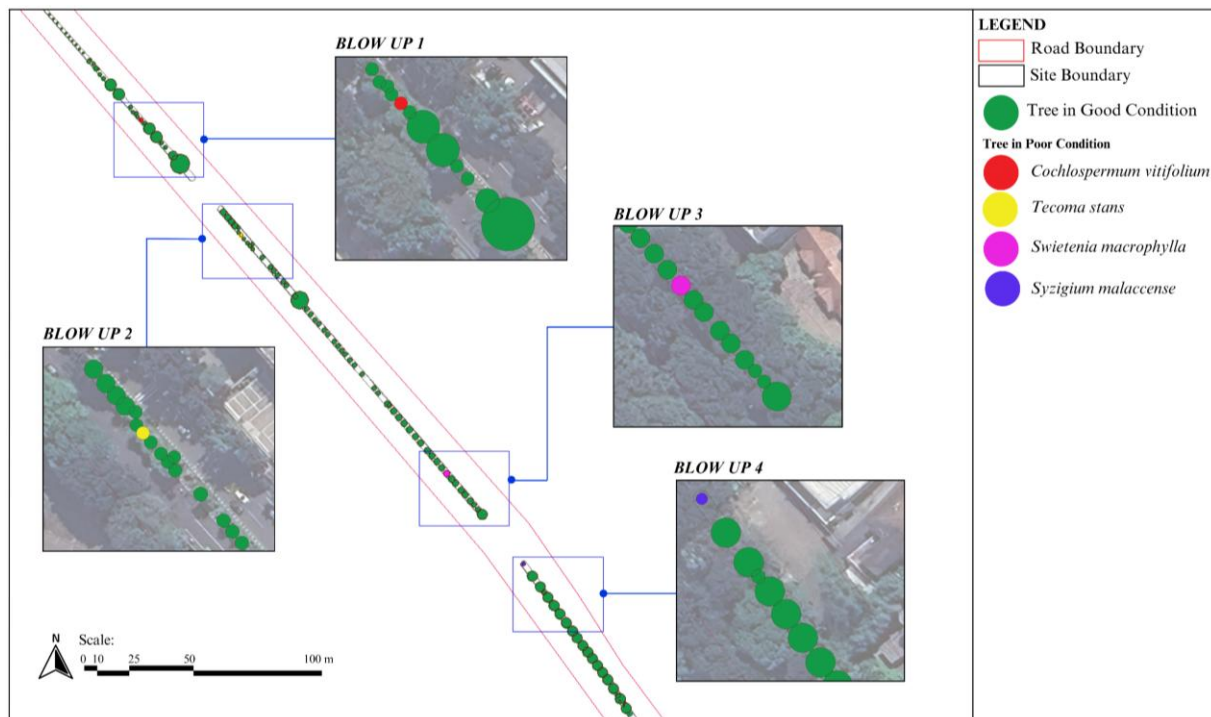


Figure 13. Detailed Location of Trees in Poor Condition on Pajajaran Road

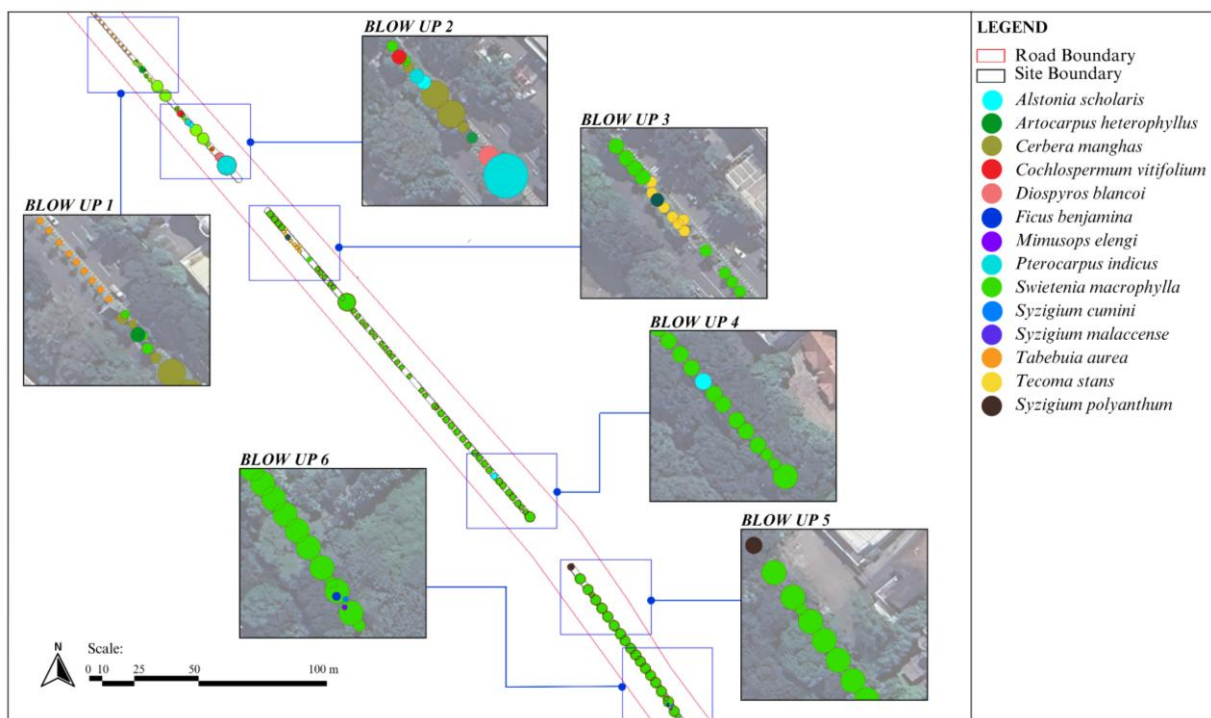


Figure 14. Planting Plan Recommendation for Pajajaran Road

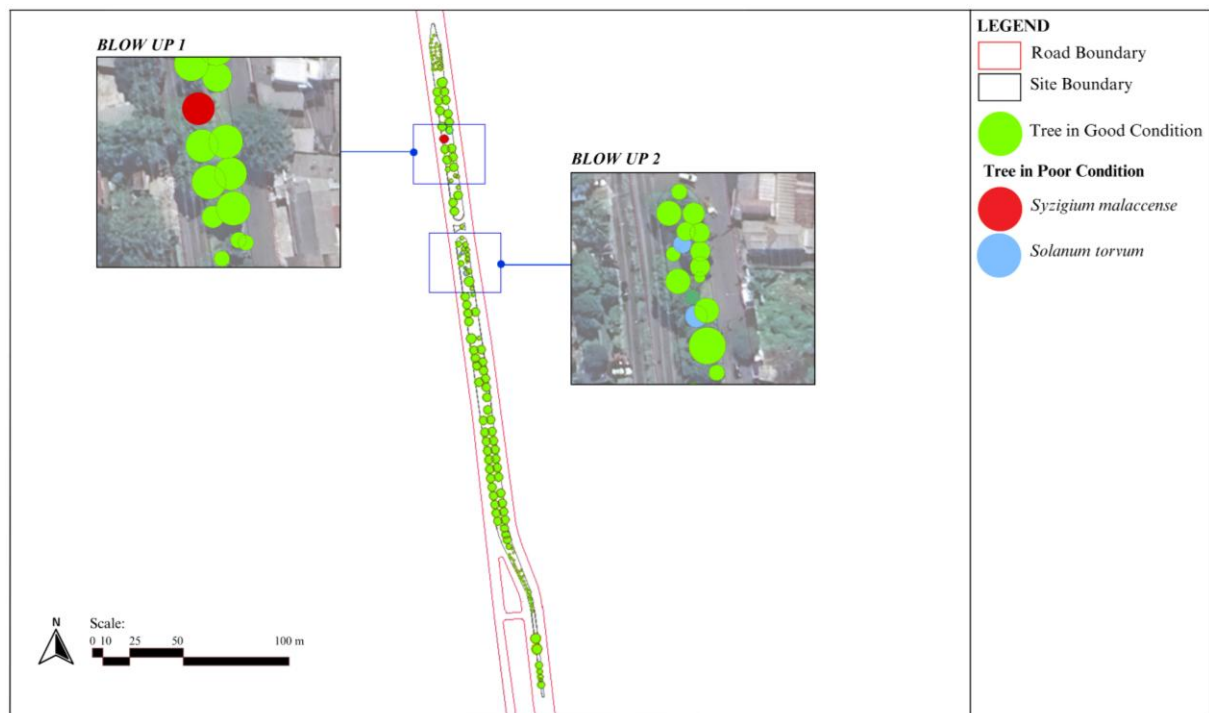


Figure 15. Detailed Location of Trees in Poor Condition on Kolonel Ahmad Syam Road

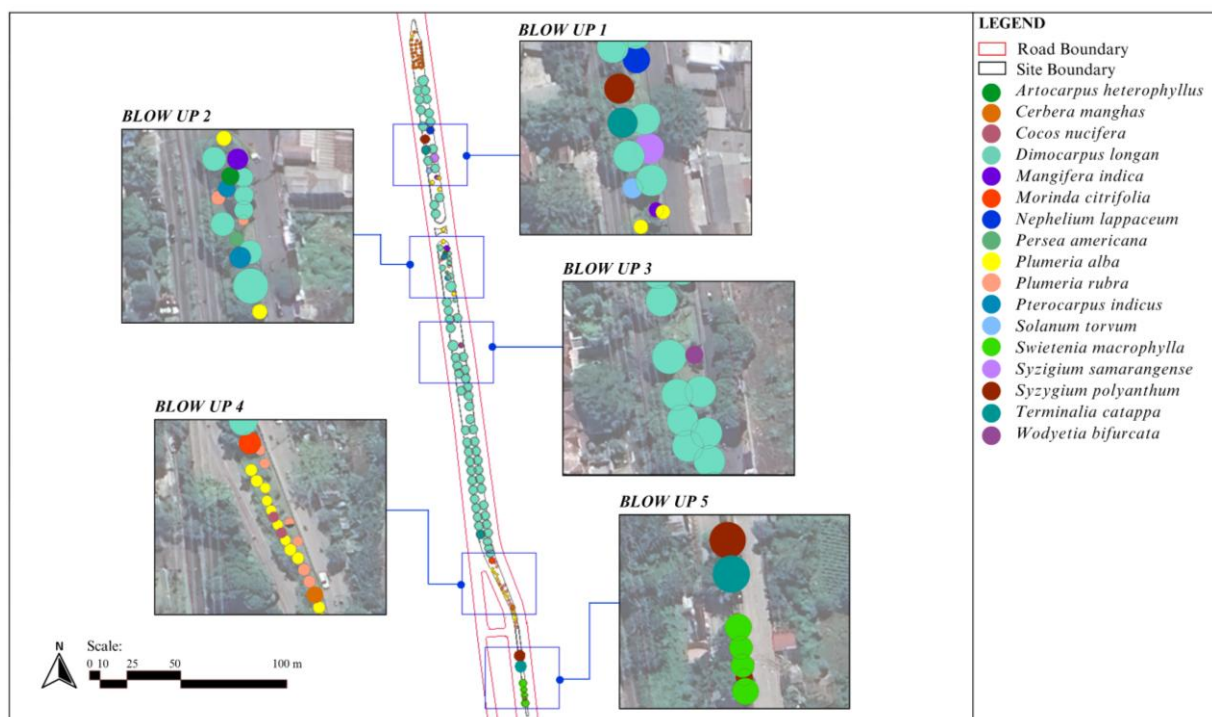


Figure 16. Planting Plan Recommendation for Kolonel Ahmad Syam Road

5. Conclusion

This study demonstrates that the carbon sequestration potential of trees located in the median of Pajajaran Road is significantly higher than that of Kolonel Ahmad Syam Road. The total annual carbon sequestered along Pajajaran Road reached 4.87 tons, predominantly contributed by *Swietenia macrophylla* (80.49%) and *Cerbera manghas* (13.55%). In contrast, carbon storage capacity between the two locations did not differ significantly in statistical terms. The median of Pajajaran Road recorded a total carbon storage of 51.3 tons, with the largest contributions from *Swietenia macrophylla* and *Pterocarpus indicus*, while Kolonel Ahmad Syam Road stored 41 tons of carbon, primarily contributed by *Dimocarpus longan* and *Cerbera manghas*.

The relationship between tree morphometric variables (diameter at breast height [DBH], height, canopy area, and leaf area) and carbon sequestration and storage varied across species. Several species such as *Swietenia macrophylla*, *Cerbera manghas*, *Plumeria alba*, and *Tabebuia aurea* showed a strong positive correlation with both carbon sequestration and storage. Conversely, *Dimocarpus longan* demonstrated a significant negative correlation with carbon sequestration yet maintained a strong positive correlation with carbon storage. This may be attributed to the declining sequestration capacity of mature trees, as indicated by an average DBH of 47.37 cm. This suggests that most individuals were in the late growth phase, which is characterized by reduced photosynthetic activity. Therefore, planting this species in urban roadside landscapes with the specific aim of carbon mitigation is not recommended.

The comparison between the two road landscapes indicates that carbon sequestration effectiveness was statistically higher on Pajajaran Road, influenced by the dominance of species with high absorption capacity and the presence of large sized trees. The higher carbon sequestration performance on Pajajaran Road is primarily influenced by the dominance of large diameter and high biomass species such as *Swietenia macrophylla* and *Pterocarpus indicus*, which exhibit strong positive correlations between morphometric parameters and carbon sequestration rates. In contrast, Kolonel Ahmad Syam Road is dominated by *Dimocarpus longan*, a species that shows a negative relationship between tree size and annual sequestration, resulting in lower overall sequestration performance. In contrast, carbon storage did not differ significantly, likely due to a more even distribution of tree sizes along Kolonel Ahmad Syam Road. These findings suggest that carbon contributions are determined not only by the number of trees but also by species composition and morphometric structure, which influence the accumulation of biomass carbon.

The results suggest that the effectiveness of carbon sequestration and storage in urban green street corridors is determined by species composition, size distribution, and tree morphometric characteristics. Tree species identified as effective carbon sinks include *Pterocarpus indicus*, *Cerbera manghas*, *Swietenia macrophylla*, *Alstonia scholaris*, *Diospyros blancoi*, *Terminalia catappa*, *Syzygium polyanthum*, *Artocarpus heterophyllus*, *Syzygium samarangense*, and *Morinda citrifolia*. In particular, the planting of *Pterocarpus indicus* requires intensive maintenance strategies to minimize the risk of falling without compromising its ecological benefits. These strategies include selective pruning, regular inspection of trunk and root health, and adequate management of planting space.

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