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Carbon Sequestration in the Green Open Spaces along Primary Road of Pontianak City, West Kalimantan, Indonesia

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ABSTRACT

Global climate change caused by greenhouse gas (GHG) emissions is currently a focus for various countries worldwide, including Indonesia. Carbon dioxide (CO_2) is the main source of emissions, with a significant portion originating in urban areas. This is due to the high levels of air pollution from motor vehicles and rapid industrial growth. Urban green spaces are areas within cities that consist of non-built-up spaces filled with naturally grown or cultivated vegetation. These green spaces exist directly alongside the transportation infrastructure, which helps reduce air pollution, especially CO_2, through the vegetation that makes up these areas. One type of urban green space is a green corridor, which forms elongated paths or areas. This study assessed the carbon sequestration of 17 primary road networks in Pontianak City using three allometric models. Plot positions for data collection were determined using purposive sampling, with each side accounting for 5% of the total zigzag plots. This research focused on vegetation at different growth stages, such as saplings, poles, and trees. The results were estimated at 256.86 tons ha^{-1} (Hardiansyah and Ridwan formula), 269.96 tons ha^{-1} (Chave formula), and 193 tons ha^{-1} (Brown formula).

Introduction

According to Ulfa et al. [1], green open space is a combination of natural and human systems in an urban environment that provides benefits to environmental quality, such as helping meet oxygen needs, maintaining wildlife habitat, and maintaining groundwater regulation. Laksemi et al. [2], pointed out that forests are the origin of life and a life support system because forests function ecologically, economically, and socially. Public green open space is formed from a combination of tree vegetation which creates a microclimate and can influence temperature and humidity and reduce wind speed thereby providing comfort for residents in the surrounding area by Sulystiana et al. [3]. Green Open Spaces are areas within cities in the form of open spaces or corridors without buildings filled with naturally occurring or cultivated vegetation. Most carbon dioxide (CO_2) emissions are found in urban areas, primarily due to pollution in significant quantities from motor vehicles and industries. This is reinforced Arifin and Nakagoshi [4], which states that increased air pollution and reduced environmental carrying capacity result from population growth due to urbanization and industrialization. CO_2 traps heat, preventing it from escaping into space and leading to its accumulation in Earth's atmosphere. An effective solution for mitigating the impact of climate change is to enhance carbon sequestration. In the Indonesian operational plan of FOLU Net Sink 2030 [5], Indonesia will increase its ambition to reduce GHG emissions by the peak of national net GHG emissions (all sectors) reached in 2030 at 1,244 million tons of CO_2e or the equivalent of 4.23 tons of CO_2e per capita.

A report distributed by the Worldwide Board of Nearby Natural Activities (ICLEI), South Asia, has expressed that normal per capita carbon emanations are higher within the metropolitan cities of India, being 1.19 tons per capita, as compared to as it were 0.90 tons per capita within the non-metropolitan cities Sharma et al.

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[6]. Research conducted by Singh et al. [7] states that urban green spaces buffer noise pollution, are locales of biodiversity preservation, relieve the Urban Warm Island impact, direct nearby climate, stabilize soil and groundwater recharge, and anticipate soil disintegration and carbon sequestration. Carbon sequestration could be a normal prepare for evacuating carbon from the climate into its stores within the biosphere [8]. The CO_2 within the environment is ingested by carbon sinks and put away as carbon. Trees act as sinks for CO_2 by fixing carbon during photosynthesis and storing abundance carbon as biomass [9]. The higher the photosynthesis process, the greater the absorption of atmospheric CO_2 into biomass. Trees from urban regions currently store carbon, which can be released back into the atmosphere after the death of the tree, and capture carbon as they grow [10].

Public Green Open Spaces in urban areas are driven by rapid urban growth but are at odds with environmental degradation caused by air pollution. Urban areas are rapidly growing economic sectors that must be balanced with environmental sustainability, particularly by developing green open spaces [11]. Green open spaces are dominated by corridors and networks in mixed gardens, river border lines, road green lines, and railroad border lines with several patterns, namely network patterns, linear patterns, and natural patterns [12]. One component of public green open spaces in urban areas is green corridors, which consist of non-built areas. Trees in green corridors play a crucial role in carbon sequestration [13]. Carbon sequestration can be achieved by preserving existing carbon reserves through tree conservation and increasing carbon reserves by planting woody plants.

Thus, converting natural and semi-natural landscapes into built-up regions has influenced urban thermal behavior [14,15]. Therefore, the urban heat island effect has become one of the most critical climate change issues [16]. According to the United Nations [17], the global urban population will increase from 50% in 2010 to 70% in 2050. An increase in the urban population will lead to more urban development and diversity, altering the future climate. Degradation of the terrestrial carbon pool leads to low soil fertility, erosion, and food shortages [18]. Thus, monitoring carbon stock decline is crucial for ecosystem sustainability. The density of transportation in every city in Indonesia, including Pontianak, directly affects the air quality in its vicinity. The role of green open spaces along the main transportation road network is to facilitate carbon sequestration by vegetation within them. Currently, data on carbon sequestration by green open spaces in the main road network of Pontianak are not fully known. Pontianak City has 17 primary road networks for transportation, and research has aimed to assess their carbon using three allometric models [19–21].

Material and Method

Research Location and Time

The study was conducted on 17 primary road network corridors in Pontianak City, namely Pak Kasih, Rahadi Usman, Tanjung Raya, Imam Bonjol, Pahlawan, Veteran, Sultan Hamid II, Gusti Situt Mahmud, Khatulistiwa, Ya'M Sabran, Komodor Yos Sudarso, Hasanuddin, Haji Ais Rachman, Husein Hamzah, Jenderal Ahmad Yani, and Adisucipto Road. The time required for data preparation and analysis was six months (October 2022–March 2023).

Data Collection Method

This study focused on vegetation at different growth stages, such as saplings, poles, and trees. The research involved data processing (for field data collection preparation), field data collection, and analysis. Data processing for field data collection preparation was conducted by planning sample plots measuring 20 x 20 meters based on the IPCC [22] guidelines for tree measurements, positioned in a zigzag pattern along the corridors (transects). Plot positions for data collection were determined using purposive sampling, with each side accounting for 5% of the total zigzag plots, resulting in a total data collection of 10%. The concept of the sample plot design was adapted from a study on carbon in street trees by Rahman et al. [23] and further customized for the research area. The planned locations of the research plots are shown in Figure 1 and 2.

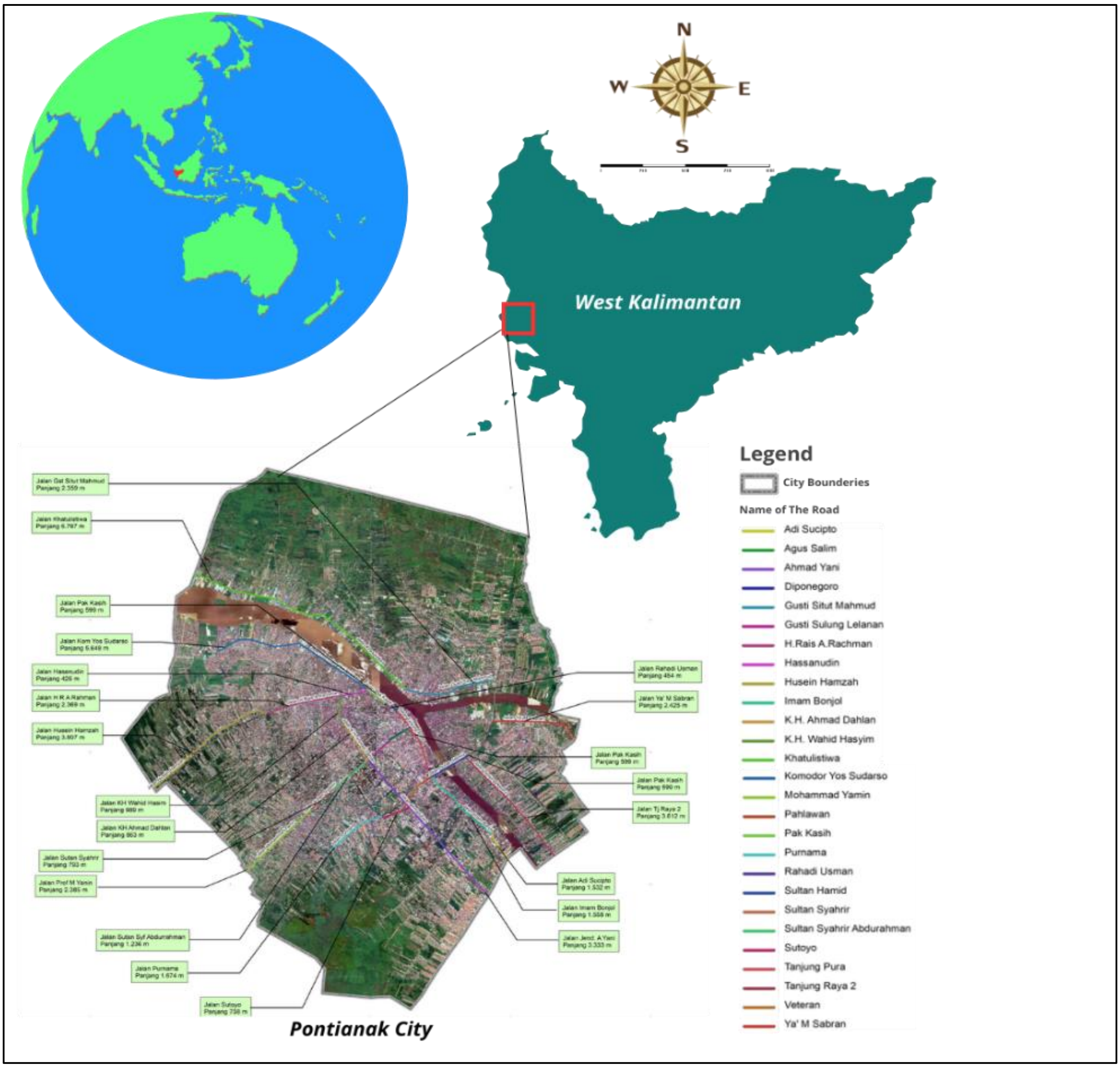
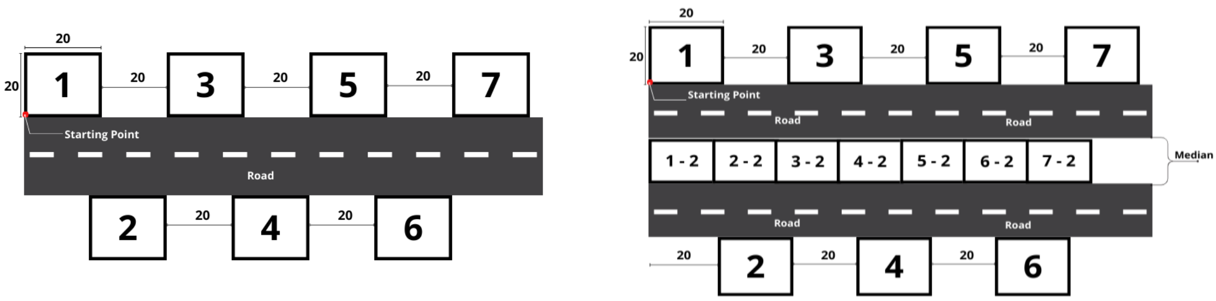


Figure 1. Map of research location.



(a) (b)

Figure 2. Research location (a) along the edge path (b) edge path and median.

Data Analysis Method

The data analysis involved calculating density, frequency/abundance, dominance, importance value index (IVI), Shannon-Wiener diversity index, richness index, and evenness index.

1. Density

The density represents the number of individuals of a particular plant species within a specific area.

$$Density = \frac{Number\ of\ individuals\ of\ a\ particular\ species}{Total\ area\ of\ sample\ plots\ (ha)} \quad (1)$$

2. Frequency

Frequency represents the occurrence of a particular species across all sampled areas studied.

$$Frequency = \frac{Number\ of\ plots\ where\ a\ particular\ species\ is\ found}{Total\ number\ of\ sample\ plots} \quad (2)$$

3. Dominance

Dominance signifies the proportion covered by the plant canopy.

$$Dominance = \frac{Total\ basal\ area\ of\ a\ particular\ species}{Total\ basal\ area\ of\ all\ samples} \quad (3)$$

$$The\ basal\ area = \frac{1}{4}\pi\left(\frac{d}{100}\right)^2 \quad (4)$$

Where π = phi (3.14), d = diameter (m).

4. Importance Value Index (IVI)

The Importance Value Index is a commonly used metric for quantifying the relative importance of plant species within a given ecosystem or habitat considering different life forms and age groups. The IVI is calculated by combining the relative density, relative frequency, and relative dominance in percentage [24].

5. Richness Index

The richness of different species present in a given area can be calculated using the Margalef index formula of Ludwig and Reynolds [25].

$$R = \frac{(S-1)}{ln\ N} \quad (5)$$

where S = number of species and N = Total individuals of a particular species. Criteria: R < 2.5 Low richness, 2.5 < R < 4 Moderate richness, R > 4 High richness.

6. Shannon-Wiener Diversity Index

This index combines the species richness and evenness into a single value.

$$H' = -\sum\left[\left(\frac{ni}{N}\right) \times ln\left(\frac{ni}{N}\right)\right] \quad (6)$$

where ni = number of individuals of a particular species, N = total number of individuals of all species. Criteria: H' < 1 Low, 1 < H' < 3 Moderate, H' > 3 High.

7. Evenness Index

This index is used to measure the distribution of individuals within a community in terms of frequency and abundance.

$$E = \frac{H'}{ln\ S} \quad (7)$$

where H' = Shannon-Wiener diversity index and S = number of species. Criteria: E < 0.31 Low, suppressed community; 0.31 < E ≤ 1 Moderate, labile community; E > 1 High, stable community.

8. Biomass Content

To estimate tree biomass, a non – destructive method was used. Total biomass includes above-ground biomass, known as AGB, and was calculated using the volume of the tree by Gupta *et al*. [26]. Biomass content was calculated using three different formulas. The formula for the biomass content is as follows:

$$AGB = \rho \times 0.18D^{2.50}\ [19] \quad (8)$$

(Not applicable to palm species)

$$AGB = \rho \times exp(-1.499 + 2.148\ ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)\ [20] \quad (9)$$

$$Biomass = 42.69 - 12.800(D) + 1.242(D^2)\ [21] \quad (10)$$

where D = DBH = (Circumference / 3.14) = Diameter at Breast Height, that is, the diameter approximately 1.3 meters above the ground, and ρ = Wood Density [22].

9. Carbon Sink

The carbon sink is the absolute carbon content in plant biomass at a certain time. The percentage of carbon sink is around 47%, so when activities such as deforestation, logging, or forest fires occur, it releases and increases the amount of carbon in the atmosphere. Less carbon in the atmosphere will reduce the greenhouse gas effect and reduce the impacts of climate change. The formula is.

$$C = 0.47 \times \text{biomass} \tag{11}$$

where 0.47 is the conversion factor for carbon estimation based on international standards.

10. Carbon Dioxide Sequestration

Carbon sequestration calculates the amount of carbon dioxide (CO_2) that is removed from the atmosphere and stored in various carbon sinks.

$$CO_2 = 3.67 \times C \tag{12}$$

where 3.67 is the equivalent number or the conversion of elemental C to CO_2.

Result and Discussion

The findings revealed 19 species belonging to 14 families, with 592 individuals observed across 260 experimental plots. The relative density (RD), relative frequency (RF), relative dominance (RC), and importance value index (IVI) calculations based on species names are listed in Table 1.

Table 1. The RD, RF, RC, and IVI were based on the species found in the research locations, arranged by IVI Percentage (from high to low).

Species	RD	RF	RC	IVI (%)
Pterocarpus indicus Willd.	38.01	44.94	71.67	51.54
Samanea saman (Jacq.) Merr.	9.46	10.44	7.10	9.00
Swietenia mahagoni (L.) Jacq.	10.64	9.49	5.78	8.64
Syzygium myrtifolium (Roxb.) Walp.	9.97	6.01	0.90	5.63
Roystonea regia (Kunth) O.F.Cook	7.26	5.06	3.83	5.39
Terminalia catappa Linn.	6.08	6.96	1.95	5.00
Mimusops elengi Linn.	7.09	5.38	1.85	4.77
Elaeis guineensis Jacq.	2.03	2.53	3.51	2.69
Eucalyptus deglupta Blume	3.89	3.16	0.72	2.59
Mangifera indica Linn.	1.18	0.95	0.30	0.81
Cocos nucifera Linn.	0.51	0.95	0.50	0.65
Anthocephalus cadamba (Roxb.) Miq	0.51	0.95	0.43	0.63
Polyalthia fragrans (Dalzell) Hook. f. & Thomson	1.01	0.63	0.09	0.58
Vitex pinnata Linn.	0.84	0.32	0.52	0.56
Artocarpus altilis (Parkinson) Fosberg	0.34	0.63	0.53	0.50
Lagerstroemia speciosa Linnaeus	0.68	0.63	0.13	0.48
Acacia auriculiformis A.Cunn. ex Benth	0.17	0.32	0.10	0.20
Canarium commune Linn.	0.17	0.32	0.05	0.18
Aleurites moluccanus (L.) Willd.	0.17	0.32	0.04	0.17

The results indicated that the highest density, frequency, and dominance were found in *Pterocarpus indicus* Willd. Differences between these three parameters in *Pterocarpus indicus* Willd. and other species were quite significant, ranging from 37% to 65%. Therefore, it is essential to promote the evenness of each species across all research locations to enhance species diversity. The highest IVI is observed in *Pterocarpus indicus* Willd. with a value of 51.54%, while the lowest IVI is in *Aleurites moluccanus* (L.) Willd. with a value of 0.17%. This suggests that some species exhibited high densities, indicating a larger number of individuals. Vegetation types with higher IVI values generally possess better adaptability, competitiveness, and reproductive capabilities than other plant species within an area. A detailed breakdown of RD, RF, RC, and IVI based on family names is presented in Table 2.

Table 2. RD, RF, RC, and IVI were based on families found in roadside plants at the research location, arranged by IVI Percentage (from high to low).

Family	RD	RF	RC	IVI (%)
Fabaceae	47.64	55.41	78.87	60.64
Meliaceae	10.64	9.84	5.78	8.75
Arecaceae	9.80	7.54	7.84	8.39
Myrtaceae	13.85	9.51	1.62	8.33
Combretaceae	6.08	7.21	1.95	5.08
Sapotaceae	7.09	5.57	1.85	4.84
Anacardiaceae	1.18	0.98	0.30	0.82
Rubiaceae	0.51	0.98	0.43	0.64
Annonaceae	1.01	0.66	0.09	0.59
Lamiaceae	0.84	0.33	0.52	0.56
Moraceae	0.34	0.66	0.53	0.51
Lythraceae	0.68	0.66	0.13	0.49
Burseraceae	0.17	0.33	0.05	0.18
Euphorbiaceae	0.17	0.33	0.04	0.18

The highest density, frequency, and dominance were observed in the Fabaceae. This family comprises the species *Pterocarpus indicus* Willd., *Samanea saman* (Jacq.) Merr., and *Acacia auriculiformis* A.Cunn. ex Benth. The IVI was also the highest for the Fabaceae family, with a value of 60.64%. In contrast, the lowest IVI (0.18%) was found in the family Euphorbiaceae. The dominance of the family Fabaceae indicated the significant presence of species from this family within the studied vegetation. The high IVI value for Fabaceae highlights its ecological importance and suggests that species within this family play crucial roles in the ecosystem. These species may have favorable adaptability and competitive abilities, contributing to their prominence in the studied areas. Conversely, the low IVI value for the family Euphorbiaceae implies that species from this family were less abundant in the studied vegetation. Further investigation into the ecological characteristics and potential threats to the Euphorbiaceae family is warranted to address their lower representation.

Diversity, Evenness, and Richness Indices for Trees

Environmental conditions at different locations (roads) influence the diversity, evenness, and richness of species in each research area. These three parameters can be observed in the index values listed in Table 3.

Table 3. Mean Diversity Index (H'), Evenness (J'), and Richness (R) across 17 research locations in Pontianak, West Kalimantan.

Parameter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
n	4	5	7	3	7	1	9	4	6	3	6	4	8	1	2	2	2
f	4	4	7	3	4	1	8	4	6	2	5	4	7	1	2	1	1
N	20	39	66	7	35	18	58	12	87	23	82	11	72	3	11	10	38
H'	1.32	1.37	1.77	0.80	1.72	0	1.26	1.24	1.58	0.67	1.21	1.03	1.55	0	0.66	0.33	0.58
R	1.00	1.09	1.43	1.03	1.69	0	1.97	1.21	1.12	0.64	1.13	1.25	1.64	0	0.42	0.43	0.27
E	0.95	0.85	0.91	0.72	0.89	-	0.57	0.89	0.88	0.61	0.68	0.75	0.75	-	0.95	0.47	0.83

Note: n = number of species; f = number of families; N = number of individuals; H' = diversity index; R = richness index; E = evenness index. Road A = Pak Kasih, B = Rahadi Usman, C = Tanjungpura, D = Pahlawan, E = Sultan hamid II, F = Gusti Situt Mahmud, G = Khatulistiwa, H = Veteran, I = Ahmad Yani, J = Ya'M Sabran, K = Kom. Yos Sudarso, L = H.R.A. Rachman, M = Husein Hamzah, N = Hasanuddin, O = Imam Bonjol, P = Adisucipto, Q = Tanjung Raya II.

The Diversity Index was used to determine the number of species at each research location. The Diversity Index ranged between 0 and 1.77, indicating low to moderate diversity. A value of 0 at locations Jalan Gusti Situt Mahmud and Hasanuddin is due to the presence of only one species in the experimental plots, resulting in ln (ni/N)=0 calculation. The Evenness Index was used to assess the evenness of the species frequency/abundance. The evenness values ranged between 0 and 1. The Richness Index in the study locations ranged from 0 to 0.95, indicating low richness. Maximum evenness occurs when each species has the same number of individuals, whereas low evenness suggests dominant and subdominant species, resulting in minimum evenness. An evenness value of 0 indicates uneven species distribution, while a value close to 1 indicates nearly equal abundance among all species. The Richness Index helps to determine the composition and abundance of species within a community. The Richness Index ranged from 0 to 1.97, indicating a low richness. Gusti Situt Mahmud and Hasanuddin still had a value of 0 because they could not be compared with other species (only one species was found) in the experimental plots on each road. The concept of the Margalef Richness Index formula states that an increase in the number of species is inversely proportional to an increase in the number of individuals.

The diversity, evenness, and richness indices presented in Table 3 offer valuable insight into the ecological dynamics of the studied trees at different locations. These indices reflect the variation and balance of tree species across research areas, providing essential information for effective forest management and conservation efforts. Understanding the factors influencing diversity and evenness at each location can help guide conservation strategies, including identifying areas for habitat restoration and targeting conservation efforts for certain tree species. In addition, such research can aid in developing sustainable forest management practices that promote biodiversity and enhance the overall health of forest ecosystems. The results of the diversity, richness, and evenness indices at the research locations indicated a low category, indicating the need for the addition of different species. Planting different species can increase biodiversity, create layered compositions and structures, and most importantly, optimize carbon sequestration.

Biomass content and carbon sequestration

Regarding biomass content and carbon sequestration, the research employed three allometric formulas [19–21]. Therefore, the biomass content of each species was different (Table 4). The parameters that determined the differences in biomass content for each species were wood density and diameter.

Table 4. Biomass content by species found in the study locations (the highest IVI values are listed in Table 1).

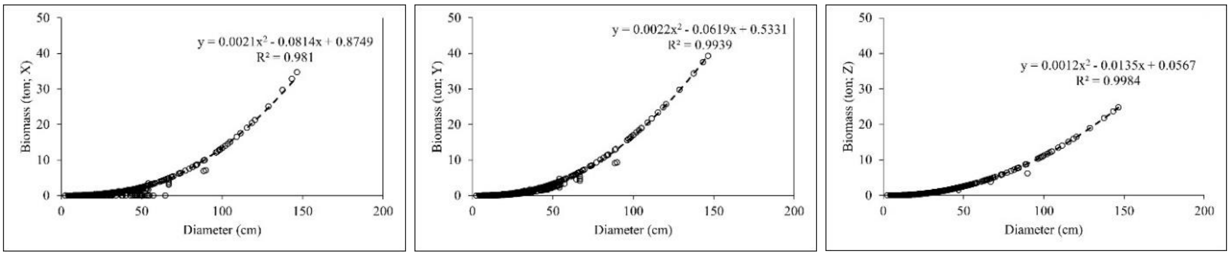
Species	Biomass content (ton ha^{-1})		
	X	Y	Z
Pterocarpus indicus Willd.	129.63	128.71	83.86
Samanea saman (Jacq.) Merr.	6.98	7.28	7.49
Swietenia mahagoni (L.) Jacq.	4.98	5.21	5.67
Syzygium myrtifolium (Roxb.) Walp.	0.68	0.64	0.54
Roystonea regia (Kunth) O.F.Cook	-	3.13	3.75
Terminalia catappa Linn.	1.74	1.81	1.85
Mimusops elengi Linn.	2.40	2.45	1.62
Elaeis guineensis Jacq.	-	4.18	3.98
Eucalyptus deglupta Blume	0.43	0.42	0.54
Mangifera indica Linn.	0.24	0.24	0.25
Cocos nucifera Linn.	-	0.50	0.45
Anthocephalus cadamba (Roxb.) Miq	0.34	0.36	0.46
Polyalthia fragrans (Dalzell) Hook. f. & Thomson	0.05	0.04	0.05
Vitex pinnata Linn.	0.66	0.69	0.51
Artocarpus altilis (Parkinson) Fosberg	0.55	0.57	0.61
Lagerstroemia speciosa Linnaeus	0.10	0.09	0.09
Acacia auriculiformis A.Cunn. ex Benth	0.10	0.10	0.10
Canarium commune Linn.	0.04	0.04	0.04
Aleurites moluccanus (L.) Willd.	0.02	0.02	0.03

Note: X = Hardiansyah and Ridwan [19]; Y = Chave *et al.* [20]; Z = Brown [21].

Table 5. Biomass content by family found in the research locations (the highest IVI values are presented in Table 2).

No	Family	Biomass content (ton ha^{-1})		
		X	Y	Z
1	Fabaceae	136.71	136.09	91.45
2	Meliaceae	4.98	5.21	5.67
3	Arecaceae	-	7.81	8.18
4	Myrtaceae	1.10	1.07	1.08
5	Combretaceae	1.74	1.81	1.85
6	Sapotaceae	2.40	2.45	1.62
7	Anacardiaceae	0.24	0.24	0.25
8	Rubiaceae	0.34	0.36	0.46
9	Annonaceae	0.05	0.04	0.05
10	Lamiaceae	0.66	0.69	0.51
11	Moraceae	0.55	0.57	0.61
12	Lythraceae	0.10	0.09	0.09
13	Burseraceae	0.04	0.04	0.04
14	Euphorbiaceae	0.02	0.02	0.03

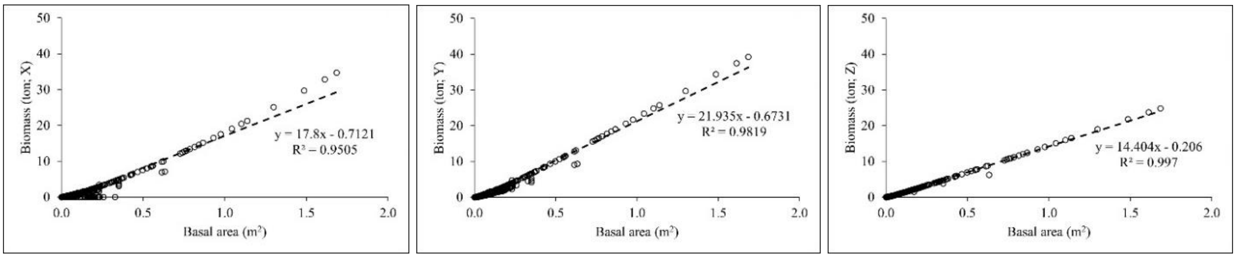
The three allometric models yielded varying results within a single species. The Hardiansyah and Ridwan [19] model originated from a dedicated study of the Dipterocarpaceae family. Both the Hardiansyah and Ridwan [19] and Chave et al. [20] models incorporate the wood density parameter, in contrast with the Brown et al. [21] model. The biomass content by family is shown in Table 5. The Fabaceae family exhibits the highest biomass content, with values of 136.71 ton ha^{-1} (Hardiansyah and Ridwan formula), 136.09 ton ha^{-1} (Chave et al. formula), and 91.45-ton ha^{-1} (Brown formula). This family comprises species, such as *Pterocarpus indicus*, *Samanea saman*, and *Acacia auriculiformis*. The correlation between diameter and biomass is shown in Figure 3.



(a) (b) (c)

Figure 3. The polynomial correlation between biomass and diameter based on the model development of (a) Hardiansyah and Ridwan [19] (b) Chave et al. [20], (c) Brown [21].

The correlation coefficient (R) is a measure of the correlation between the dependent and independent variables, while the coefficient of determination is a measure of model accuracy by Herjanto [27]. Based on the correlation coefficient values (R), all three allometric models, that is, Hardiansyah and Ridwan [19], Chave et al. [20], and Brown [21], showed a strong correlation between biomass content and diameter (R > 0.7). The most appropriate order of models for predicting biomass content based on R^2 values was the Brown model (R^2 = 0.9984), followed by the Chave model (R^2 = 0.9939) and the Hardiansyah and Ridwan models (R^2 = 0.981). The coefficient of determination (R^2) of the Brown model (0.9984) indicated that 99.84% of the total variation in biomass from 592 individuals could be explained by the regression line $Y = 0.0012x^2 – 0.0135x + 0.0567$. However, it is important to note that the Hardiansyah and Ridwan models considered only 534 individuals for analysis, excluding the category of palms. Additionally, biomass was correlated with basal area (Figure 4). Areas with low basal areas require intensification through the addition of more individuals or different species to enhance vegetation density.



(a) (b) (c)

Figure 4. The linear correlation between biomass and basal area based on the model development of (a) Hardiansyah and Ridwan [19], (b) Chave *et al.*[20], (c) Brown [21].

The correlation coefficients between biomass as the dependent variable and basal area as the independent variable for all three models were within a high level of correlation. Based on the coefficient of determination values, all three models are suitable for this research, as they approach a value of one. The most appropriate order of models is as follows: the Brown model (R^2 = 0.997), the Chave model (R^2 = 0.9819), and the Hardiansyah and Ridwan model (R^2 = 0.9505). Notably, the Brown model does not use density parameters, which is why it has the highest R^2 value compared with the other two models. The graphs depicting biomass with the diameter and basal area above indicate that the Brown model has the strongest correlation between variables and is the most suitable among the Chave & Hardiansyah and Ridwan models. The Hardiansyah and Ridwan models were specifically designed for the Dipetrocarpaceae Family. These different biomass content calculations will result in varying carbon sequestration values (Table 6).

Table 6. Carbon sink and carbon sequestration at 17 research locations.

Location	Carbon (ton ha^{-1})			CO_2 (ton ha^{-1})		
	X	Y	Z	X	Y	Z
Pak Kasih	28.60	33.15	27.52	104.97	121.67	100.99
Rahadi Usman	166.12	32.65	23.76	609.66	119.84	87.21
Tanjungpura	9.04	11.77	9.56	33.17	43.20	35.08
Pahlawan	3.45	3.53	4.27	12.65	12.94	15.68
Sultan Hamid II	28.97	24.07	21.91	106.32	88.34	80.41
Gusti Situt Mahmud	86.04	114.47	81.56	315.78	420.11	299.32
Khatulistiwa	76.06	100.03	71.14	279.13	367.10	261.08
Veteran	22.80	30.39	24.33	83.67	111.53	89.30
Ahmad Yani	20.30	26.53	24.12	74.49	97.38	88.53
Ya' M. Sabran	16.07	22.01	22.36	58.96	80.77	82.07
Kom. Yos Sudarso	33.91	40.32	30.24	124.46	147.99	110.98
H.R.A Rachman	142.47	155.70	103.99	522.87	571.43	381.64
Husein Hamzah	23.77	32.47	31.26	87.25	119.17	114.74
Hassanuddin	330.12	390.47	250.18	1.211.54	1.433.02	918.18
Imam bonjol	75.84	67.96	50.02	278.32	249.41	183.56
Adi Sucipto	114.46	148.85	103.18	420.05	546.27	378.66
Tanjung Raya II	11.82	16.12	14.62	43.37	59.15	53.66
Average	69.99	73.56	52.59	256.86	269.96	193.00

Note: X = Hardiansyah and Ridwan [19]; Y = Chave *et al.* [20]; Z = Brown [21].

The biomass content, carbon sink, and carbon sequestration values obtained using the three allometric models yielded different results. The recommended allometric model from this research is the Chave et al. [20] model because it provides the highest results despite its coefficient of determination (R^2) not being as high as the other two models. In addition, the Chave model offers practical advantages. In contrast, the Brown [21] model has the highest scientific value owing to its high R^2 value.

The research results indicate that the total area of green open spaces filled with vegetation in Pontianak is 14.44 hectares, representing 21% of the total research area of green open spaces along the primary routes. Carbon sequestration values are listed in Table 6. These findings suggest that there is still potential for optimizing the development of green open spaces along primary routes, such as planting species with high carbon sequestration capacity and adjusting planting distances. The species with the highest biomass content, carbon sequestration capacity, and CO_2 sequestration were *Pterocarpus indicus*, whereas the lowest was *Aleurites moluccanus*. This aligns with their density, number of individuals, average diameter, and importance value index compared with other species. Notably, the species *Pterocarpus indicus* demonstrates the highest carbon sequestration capacity, particularly for tree and sapling growth forms. The significant difference between *Pterocarpus indicus* and other species highlights the need for intensification through an increase in the number of individuals of this species on existing land to enhance carbon sequestration values at the research location, especially for species with the lowest sequestration rates, such as *Polyalthia fragrans*, *Lagerstroemia speciosa*, *Acacia auriculiformis*, *Canarium commune*, and *Aleurites moluccanus*. Optimal management of green open spaces needs to consider factors to improve sustainability status, such as potential CO_2 removal, public RTH area, tree biomass, and diversity. Vegetation, socialization of public RTH, education level, educational and research facilities, public perception, public communication, value of environmental services, business income, cooperation between stakeholders, and central and local government policies [28]. Open green spaces were analyzed with a holistic approach, and a multi-dimensional framework (ecological, recreational, and disaster oriented) was presented, emphasizing its integration with spatial planning by Senik and Uzun [29]. According to Anbarashan *et al*. [30], mixed-species plantings had higher values of carbon sequestration than mono plantations. Vasagadekar *et al*. [31] studied urban trees not only for beauty and aesthetic purposes but also for their carbon sequestration potential to combat climate change at the local level.

Conclusion

The carbon sequestration in public green open spaces along the primary road network in Pontianak City is estimated to be 256.86 tons ha^{-1} according to the Hardiansyah and Ridwan allowmetric formulas, 269.96 tons ha^{-1} according to the Chave formulas, and 193 tons ha^{-1} according to the Brown formulas. Based on these findings, the authors suggest the following: a) Adding research data on biomass content, carbon sink, and carbon sequestration to the structure of shrubs and bushes; b) Improving research data collection in every open green space, both private and public, in addition to the primary road network in Pontianak City, to enhance the accuracy and comprehensiveness of carbon sequestration estimations and CO_2 sequestration in green spaces, which will be beneficial for effective mitigation planning. These recommendations aim to enhance the accuracy and comprehensiveness of carbon and CO_2 sequestration estimations in green spaces, which will be beneficial for effective mitigation planning.

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