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Vegetation Type and Effect on Microclimate Conditions and Comfort Level in Green Open Space of Jenderal Sudirman Street, Yogyakarta

Kajian Jenis dan Pengaruh Vegetasi terhadap Kondisi Iklim Mikro serta Tingkat Kenyamanan di Ruang Terbuka Hijau Jalan Jenderal Sudirman Yogyakarta

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ABSTRACT

The Minister of Environment and Forestry (now the Ministry of Forestry) Decree No. 168 of 2022 recommends developing urban forests as part of green open space (GOS) to improve environmental quality. Therefore, this research aimed to evaluate the suitability of vegetation types and their influence on microclimate conditions and social comfort levels along Jenderal Sudirman Street. The research integrated the analysis of vegetation physical characteristics, microclimate measurements, and social comfort surveys to provide a comprehensive understanding of the role of GOS. The results showed that the vegetation in the GOS on Jenderal Sudirman Street met road planting criteria, with a high suitability level ranging from 87.08% to 92.94%. Vegetation types that provide optimal shade and increase comfort include *Tamarindus indica, Pterocarpus indicus, Monoon longifolium*, and *Mimusops elengi*. This vegetation has been proven to reduce average temperatures by up to 6.36°C and increase humidity by 14.17% compared to areas with minimal vegetation. Although the Temperature Humidity Index (THI) indicated uncomfortable conditions, the THI at the research location (26.20°C–27.16°C) was close to the fairly comfortable range. Most respondents also attested to the comfort of these GOS.

INTISARI

Sebagai langkah dalam meningkatkan kualitas lingkungan, Keputusan Menteri LHK No. 168 Tahun 2022 merekomendasikan pengembangan hutan kota sebagai bagian dari ruang terbuka hijau (RTH). Penelitian ini bertujuan mengevaluasi kesesuaian jenis vegetasi serta pengaruhnya terhadap kondisi iklim mikro dan tingkat kenyamanan sosial di sepanjang Jalan Jenderal Sudirman. Kajian ini mengintegrasikan analisis karakteristik fisik vegetasi, pengukuran iklim mikro, dan survei kenyamanan sosial, yang menjadi kontribusi unik dalam memahami peran RTH secara komprehensif. Hasil penelitian menunjukkan bahwa vegetasi yang terdapat di RTH Jalan Jenderal Sudirman memenuhi kriteria penanaman jalan dengan tingkat kesesuaian tinggi, yakni antara 87,08% hingga 92,94%. Jenis vegetasi yang memberikan keteduhan optimal dan meningkatkan kenyamanan meliputi Tamarindus indica, Pterocarpus indicus, Monoon longifolium, *dan* Mimusops elengi. *Keberadaan vegetasi ini terbukti menurunkan suhu rata-rata hingga 6,36°C dan meningkatkan kelembapan sebesar 14,17% dibandingkan area minim vegetasi. Meskipun Indeks Suhu dan Kelembaban (THI) menunjukkan kondisi tidak nyaman, nilai THI di lokasi penelitian (26,20°C–27,16°C) mendekati kategori cukup nyaman. Mayoritas responden juga menyatakan puas dan sangat setuju bahwa RTH ini adalah tempat yang nyaman. Keberadaan vegetasi pada ruang terbuka hijau berkontribusi signifikan terhadap perbaikan iklim mikro, kualitas udara, dan kenyamanan bagi masyarakat sekitar.*

Introduction

Anthropogenic activities, particularly the intensive use of fossil fuels and land-use changes, have led to a significant increase in atmospheric concentrations of greenhouse gases (GHGs). This accumulation traps outgoing infrared radiation, triggering global warming that fundamentally alters the Earth's climate system, manifested in rising temperatures, erratic rainfall patterns, and sea-level rise (Irma & Gusmira 2024). Indonesia has formally committed to tackling climate change by ratifying the Paris Agreement through Law Number 16 of 2016, which is implemented through the Nationally Determined Contribution (NDC). This commitment involves several priority sectors, including Energy, Waste, Industrial Processes and Product Use (IPPU), Agriculture, and Forestry and Other Land Use (FOLU). Among these, the FOLU sector is expected to provide the largest contribution to emission reductions. To operationalize this, the Indonesian government launched the FOLU Net Sink 2030 program, aiming to achieve a condition in which greenhouse gas sequestration in the forestry sector equals or exceeds its emissions by 2030. The NDC serves as a formal document outlining Indonesia's climate transition and resilience strategies. Within this framework, Indonesia has identified five key sectors for emission reduction targets: Energy, Waste, Industrial Processes and Product Use (IPPU), Agriculture, and Forestry and Other Land Use (FOLU). While all sectors are integral to the national mitigation strategy, the FOLU sector is specifically targeted to become a net sink by 2030, meaning it is expected to absorb more carbon than it emits.

While the FOLU sector holds a significant role in carbon sequestration, urban areas remain a major contributor to national greenhouse gas emissions. The rapid urbanization and high density of activities in cities intensify GHG emissions, primarily through the energy and transport sectors. Urban areas have experienced rapid development, while the number of motorized vehicles, both two- and four-wheeled, continues to increase each year. The increased use of fuels such as gasoline and diesel can significantly raise air pollution levels. According to Sengkey et al. (2011), one pollutant produced by motor vehicles is carbon monoxide (CO), which has potential negative impacts on human health. High levels of air pollutants above the tolerance threshold are detrimental to the environment, affecting plants, rainwater quality (acid rain), and ecosystems.

One alternative to improve the quality of the environment and ecosystems in urban areas is the development of urban forest management in the form of green open space (GOS) in the middle of the areas. The GOS, as defined by Regulation No. 05/PRT/M/2012, is an area for plant growth, both natural and planted. The policy regulating urban forests is Law No. 41 of 1999 on Forestry, specifically Article 9. According to Andryani and Murtini (2020), GOS is important in urban areas. This is due to the various functions of green open space, such as water absorption, aesthetic value, and oxygen production. The potential and use of green open space are highly dependent on the suitability of existing trees and the area's microclimate. For instance, trees with broad, dense canopies, such as *Pterocarpus indicus* and *Tamarindus indica*, are more effective at intercepting solar radiation and increasing transpirational cooling than trees with sparse foliage. Consequently, these suitable species significantly lower ambient temperatures and enhance thermal comfort, thereby encouraging more social activities and public utilization of the green space.

The presence of urban forests will help balance the ecosystem of urban areas, as they provide ecological support for these areas by regulating the microclimate (Sapariyanto et al. 2016). Erdianto et al. (2019) further state that the presence of various tree species in urban forests absorbs solar radiation and lowers air temperature; thus, the characteristics of the tree species planted will determine their ecological function in relation to the surrounding environmental conditions. Assessing and evaluating the suitability of tree characteristics will provide information on the types of trees that are effective in supporting the function of green open spaces in maintaining the microclimate, thereby creating a comfortable environment (Azahra et al. 2023). Prakoso and Herdiansyah (2019) states that the presence of green open spaces in urban areas plays a role in helping to maintain people's physical, emotional, and psycholo-gical health. The role of trees in urban areas is closely tied to their physiological functions, including photosynthesis. Trees and other vegetation are essential in urban areas for absorbing CO_2 and releasing O_2 into the air through photosynthesis, which occurs when sunlight is present, thereby helping to lower air temperatures (Riyanti et al. 2021).

Yogyakarta has experienced a notable increase in air pollution levels over recent years, largely driven by the surge in motorized vehicle volume and urban commercial growth. This environmental pressure is particularly evident along major arterial roads that serve as the city's economic and transportation hubs. One of the most representative locations is Jenderal Sudirman Street, an area characterized by high mobility and dense infrastructure. Previous research has examined the role of vegetation in urban ecosystems from both ecological perspectives, such as microclimate (Saroh & Krisdianto 2020; Wu et al. 2025) and social perspectives (Fakhrurradhi et al. 2018). However, investigations that integrate the three crucial aspects of tree physical suitability, the effect on microclimate, and community perception of social comfort in a single case remain limited. Therefore, this research aims to evaluate the potential of its shade trees in improving the microclimate and social comfort. To provide a robust analysis, the study includes Dr. Wahidin Sudirohusodo Street, a nearby corridor with minimal shade-providing vegetation, as a control location. This comparative approach is essential for investigating empirical differences in environmental quality between vegetated and non-vegetated urban settings.

Methods

Study Site

The research was conducted in the green open space area along Jenderal Sudirman Street, Section 1, as the primary study site. Additionally, Dr. Wahidin Sudirohusodo Street in Yogyakarta City was selected as a comparison (control) location. This comparison is essential for investigating significant interactions and differences between areas with dense vegetation and those with few shade-providing trees. Each road section observed measured approximately 400–500 m long. Data collection occurred between November 2023 and January 2024. This location map (Figure 1) played a central role throughout the entire research procedure. It visualized vegetation distribution and guided the division of research segments and the selection of microclimate observation points.

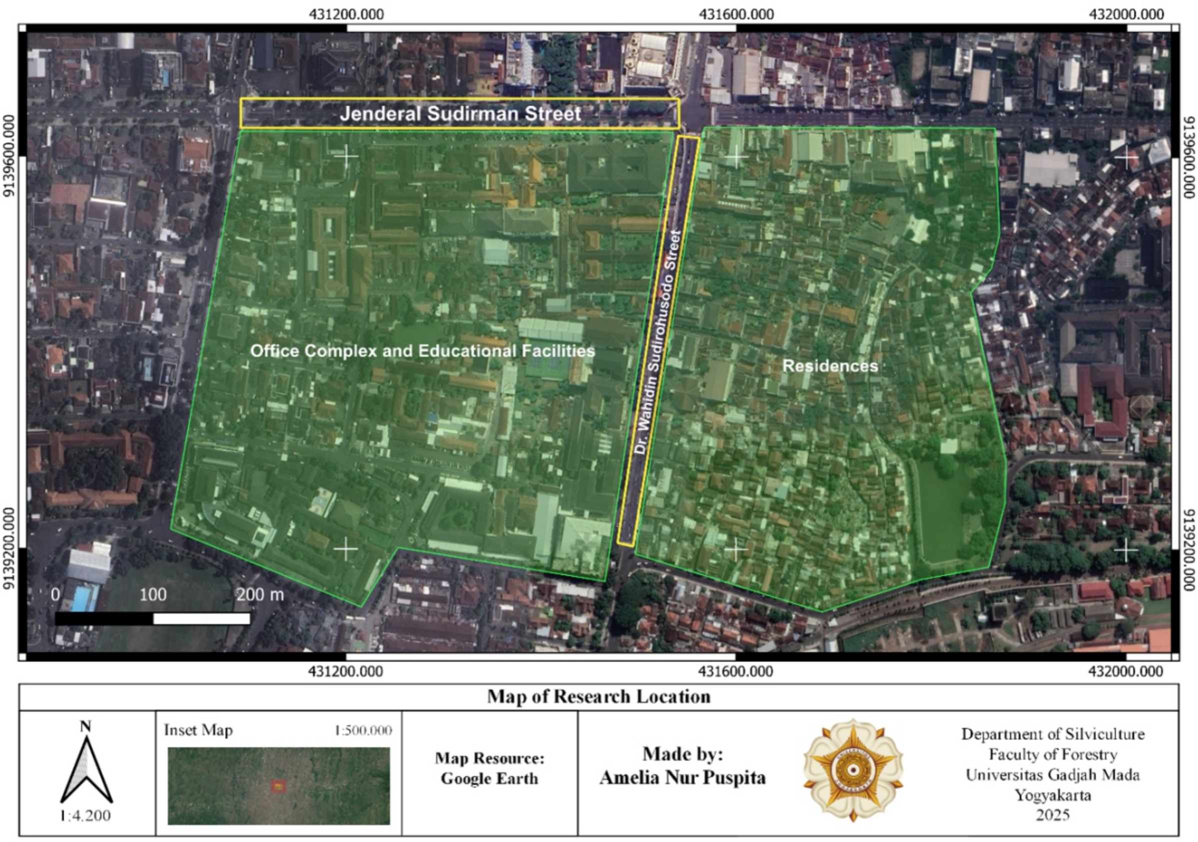

Figure 1. Research location map Jenderal Sudirman Street, section 1

Additionally, the map confirmed the location of the social comfort survey along the green space on Jenderal Sudirman Street, ensuring the collected data were relevant to the area.

Researchers selected Jenderal Sudirman Street for its unique and representative characteristics in the city of Yogyakarta. This road runs through an urban area with dense commercial, educational, and office activity, making it an ideal location to investigate the interactions among vegetation, microclimate, and social comfort. To strengthen the analysis, the investigation also included Dr. Wahidin Sudirohusodo Street as a comparison location. This street has minimal shade-providing vegetation and lies close to residential areas, allowing for a significant comparison of microclimate data.

Materials and Instruments

The tools used included a diameter tape, a Haga altimeter, and digital applications, namely Humidity and Temperature Meter, Luxmeter, as well as software including Microsoft Excel, SPSS, and SExI-FS. The primary objects of this research were the shade tree vegetation located along Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street. Research material included secondary data, such as regional vegetation maps and historical microclimate records, obtained from the Yogyakarta City Environmental Agency (*Dinas Lingkungan Hidup (DLH) Kota Yogyakarta*) and relevant literature to support the field observations. The research involved an inventory and assessment of the trees' physical characteristics. This included identification and inventory of tree species; measurement of tree circumference or Diameter at Breast Height (DBH), tree height, and branch-free trunk height; assessment of the distance between trees from the starting point, outer crown height, and crown length. Observation of two-dimensional (2D) and three-dimensional (3D) tree crowns was performed using the SExI-FS application. Segmentation analysis was conducted for every 80 m based on planting distance and average crown width. The study also assessed the physical characteristics of trees and measured temperature, humidity, and light intensity. Interviews on the use of green open space were carried out using a closed questionnaire.

Tree Inventory and Assessment of Physical Characteristics

The inventory aims to identify tree species and related information, as well as to determine the distribution pattern of vegetation in a location. In addition, this inventory is also used to calculate the number of trees in a location (Hidayat et al. 2021). Trees with DBH larger than 20 cm were observed and measured during the inventory. The tree inventory produced data on species, circumference, and height. Tree crown observation began with data collection of coordinates/distance between trees from the starting point, as well as measurements of outer crown height and the widest crown length. This research adopted five categories of crown stratification of Indriyanto (2006).

After obtaining this data, the SExI-FS application analyzed tree crown observations. Data analysis continued with the division of segments into ±80 m planting distance groups and average crown width groups, based on an overview of 2D and 3D cross-sectional tree crowns. Analysis of the division of crown segments then determined the diversity of micro-climate conditions and the most optimal types of trees providing shade functions.

The physical characteristics assessment used a scoring system based on the Regulation of the Minister of Public Works and Public Housing Number 05/PRT/M/2012. The Regulation of the Minister of Public Works and Public Housing No. 05/PRT/M/2012 was selected as the primary evaluative framework because it provides standardized technical criteria for tree planting within urban road networks. This regulation ensures that the assessed vegetation not only fulfills ecological functions, such as microclimate regulation, but also meets safety and structural integrity standards for urban infrastructure. This assessment relied on primary field data, including identification and visual observation of the physical characteristics of trees, such as root, trunk, branch, leaf, flower, and fruit conditions, and resistance to stress and pollution. Criteria for assessing the physical characteristics of trees are shown in Table 1.

Each criterion received a score between one and four, with four representing the ideal or maximum value. The calculation of evaluation used equation 1. According to Lerebulan et al. (2020), the percentage

Table 1. Assessment criteria for tree physical characteristics

No	Physical Plant Category	Physical Characteristics of Trees
1	Roots	a. Not damage the road structure b. Strong c. Not shallow roots
2	Trunk	a. Strong/Not easily broken b. No branching below
3	Branches/Twigs	a. Not easy to break b. Not dangle down so much that it obstructs the view
4	Leaves	a. Not easy to fall out b. Not too lush c. Not too big so that if it falls, it does not endanger road users
5	Flowers	a. Not easy to fall out b. Non-toxic
6	Fruit	a. Not easy to fall out b. No big fruit c. Non-toxic
7	Other properties	a. Quickly recovering from stress is characterized by releasing new shoots b. Resistant to motor vehicle and industrial pollution

Source: Minister of Public Works and Housing Regulation No. 05/PRT/M/2012

evaluation value of the assessment of the physical characteristics of trees consists of:

1. Score 1: poor, ≤ 40% of criteria met;
2. Score 2: moderate, 41% - 60% of criteria met;
3. Score 3: good, 61% - 80% of criteria met;
4. Score 4: very good, ≥ 80% fulfilled.

$$\text{Evaluation Score} = \left(\frac{\text{Total Score of Assesment Criteria}}{\text{Total of Maximum Score}}\right) x\, 100 \quad ..Equation\ 1$$

Microclimate Differences

The measurement of microclimate conditions included air temperature, humidity, and light intensity at 12 evenly distributed points, including six on Jenderal Sudirman Street and six on Dr. Wahidin Sudirohusodo Street. Data collection spanned three days, with three time points each day: 09:00-09:30 WIB, 12:00-12:30 WIB, and 15:00-15:30 WIB. At each hour and at each point, data were collected three times to obtain more accurate, representative results. The independent-samples t-test was conducted in SPSS to determine whether the two groups differ in mean (Nuryadi et al. 2017). A test of the difference in mean microclimate conditions between Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street was conducted using an independent-samples t-test via SPSS version 20. The significance level used in this study was $\alpha = 0.05$ (5%). A p-value < 0.05 indicates a significant difference between the two locations, while $p \geq 0.05$ indicates no significant difference. Comfort analysis based on air temperature and humidity data obtained by calculating the Temperature Humidity Index (THI). The THI was first introduced by Nieuwolt in 1975 (Nanayakkara & Nianthi 2018), which divided comfort levels into three categories: comfortable (21–24°C), moderately comfortable (24–26°C), and uncomfortable (>26°C). According to Dahlan (2004), the comfort index at a location can be determined using Equation 2.

$$THI = 0.8T + \frac{RHxT}{500} \quad .... Equation\ 2$$

Remarks: THI = Temperature Humidity Index; RH = Relative humidity (%); T = Air temperature (°C)

Social Comfort Analysis of Green Open Space Visitors

The respondents for the social comfort survey consisted of road users in the vicinity of the green open space. Sampling was conducted using an accidental, non-probability sampling technique, in which questionnaires were distributed directly to respondents encountered at the research site. This method was chosen due to the high mobility and transient nature of road users on Jenderal Sudirman Street. The social comfort questionnaire was distributed only to users of the green open space on Jenderal Sudirman Street, while users of Dr. Wahidin Sudirohusodo Street were not included. This was because Dr. Wahidin Street serves as a control site with very minimal vegetation, so there were no regular visitors who utilize the shade or comfort provided by trees. Thus, respondents on Jenderal Sudirman Street were more representative for assessing perceptions of social comfort that are tangibly influenced by the presence of trees within the green open space. The 50 respondents were selected to represent two distinct groups: temporary visitors (pedestrians and cyclists) and regular visitors (traders and local workers), ensuring a balanced perspective between occasional and daily users of the green open space. The questionnaire consisted of 31 closed-ended, multiple-choice questions, and three open-ended questions requiring short answers regarding the potential use of the Jenderal Sudirman Street green open space.

The variables in this research consist of three aspects: attitudes, subjective norms, and behavioral control. According to Jogiyanto (2007), subjective norm aspect refers to the individual's perception or action in response to others' beliefs that influence whether an interest is considered. This behavioral control aspect is influenced by an individual's experience and estimation of the difficulty level in performing a behavior. When a person's attitude and subjective norms toward a behavior are favorable, and the perceived behavioral control is strong, the intention to perform the behavior increases.

The researcher collected data by asking respondents a series of structured written questions about the variables under investigation (Muchlis et al. 2019). Each of these indicators was measured using a Likert scale. A Likert scale uses several items or questions to measure an individual's or group's behavior, attitude, opinion, or perspective, with respondents choosing from five options for each item. This research used a Likert scale with five options (1 = Strongly Disagree to 5= Strongly Agree).

Prior to the main data collection, a pilot test was conducted to ensure the instrument's validity and reliability. The validity test assessed the extent to which the questionnaire items were valid for research use. Each question item is considered valid when the t-count exceeds the t-value from the t-table. A reliability test determines an instrument's ability to be used for a certain period of time and to provide consistent results. The validity and reliability tests involved 30 respondents (separate from the main research sample) to meet the minimum statistical requirements for instrument testing. The validity test assessed the questionnaire's accuracy in measuring the objects (Darma 2021). The t-count for the questionnaire was obtained using Equation 3. The reliability test measured the questionnaire's consistency in describing information. For the reliability test, the r-table and r-count values are needed. The r-count value is the Spearman-Brown correlation between the number of even and odd scores. The r-count for the questionnaire was obtained using Equation 4. Internal consistency was assessed using Cronbach's Alpha coefficients.

$$t\ count = \frac{r_{xy}\sqrt{(n-2)}}{\sqrt{\left(1-r_{xy}^{2}\right)}} \quad \text{..................................} \textit{Equation 3}$$

Remarks: n = number of respondents; r_{xy} = correlation value

$$r = \frac{n\sum X_1X_2 - (\sum X_1)(\sum X_2)}{\sqrt{(n\sum (X_1)^2 - (\sum X_1)^2 (n\sum (X_2)^2 - (\sum X_2)^2)}} \quad \text{.....}\textit{Equation 4}$$

Remarks: n = number of respondents; X = score of each statement from each respondent

As shown in Table 2, all questionnaire items measuring attitude, subjective norms, and behavioral control yielded t-count greater than the corresponding t-table values, indicating that all items were valid. Table 3 shows that the attitude aspect questionnaire's r-count was 0.623. This value falls into the criteria for a high degree of reliability and a strong correlation. The r-count for the subjective norm

Table 2. Validity test results of attitude, subjective norms, and behavioral control aspects

Aspects	t-count Questionnaire	t-table	p-value	Testing Results
Attitude	5.897	2.011	0.000	Valid
Subjective Norm	3.928	2.011	0.001	Valid
Behavior Control	4.536	2.011	0.000	Valid

Table 3. Reliability test results of attitude, subjective norms, and behavioral control aspects

Aspects	r-count	r-table	p-value	Cronbach's Alpha
Attitude	0.623	0.361	0.001	0.742
Subjective Norm	0.484	0.361	0.005	0.685
Behavior Control	0.532	0.361	0.002	0.712

aspect of the questionnaire was 0.484. This value falls into the criteria for a moderate degree of reliability and a significant correlation. The reliability coefficient for the behavior control aspect questionnaire was 0.532, which falls within the criteria for a moderate degree of reliability and a significant correlation. The final results in the form of Validity Test Analysis and Reliability Test of Attitude Aspects, Subjective Norms, and Behavioral Control were then recapitulated and compared between the t-count of the questionnaire and the r-count of Reliability (RR). Initially, the questionnaire consisted of 34 items; however, after the validity test (comparing t-count and t-table) and reliability test, 3 items were dropped due to low correlation, leaving 31 closed-ended items that met the criteria for further analysis.

Table 4. Number of green space trees on Jenderal Sudirman Street

No	Tree Type	Number of Trees	Percentage
1	*Pterocarpus indicus*	40	40%
2	*Monoon longifolium*	38	38%
3	*Tamarindus indica*	14	14%
4	*Mimusops elengi*	5	5%
5	*Ficus benjamina*	2	2%
6	*Terminalia catappa*	1	1%
	Total	100	100

Table 5. Average height, diameter, and crown width of green space trees on Jenderal Sudirman Street

No	Tree Type	Average		
		High (m)	Diameter (cm)	Crown Width (m)
1	*Pterocarpus indicus*	8.48 ± 1.53	67.82 ± 17.8	3.42 ± 0.43
2	*Monoon longifolium*	8.50 ± 1.40	45.08 ± 11.75	2.98 ± 0.12
3	*Tamarindus indica*	11.83 ± 1.59	79.90 ± 16.46	4.14 ± 0.26
4	*Mimusops elengi*	6.98 ± 1.80	46.15 ± 19.87	2.72 ± 0.25
5	*Ficus benjamina*	9.07 ± 0.05	54.75 ± 38.27	3.13 ± 0.24
6	*Terminalia catappa*	5.66 ± 0.00	26.74 ± 0.00	2.18 ± 0.00

Result and Discussion

Tree Physical Characteristics

Based on field data, the crowns of trees in green open spaces along Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street are included in Stratum C. This stratum includes trees with heights of 4-20 m and continuous crowns. The researcher further assessed the physical characteristics of trees based on their functions in the GOS of Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street, evaluating each tree in the area.

Number and Composition of Tree Species in Green Open Space on Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street

Pterocarpus indicus has a dense canopy (high density/lush) with a rounded or dome-shaped canopy. There were 40 *Pterocarpus indicus* in the Jenderal Sudirman Street, making it the most commonly planted tree in the Sudirman Road Green Space. Field observations indicated that the roots of the *Pterocarpus indicus* were strong and did not damage the road, as the trees were planted in sufficient growing space. The branches are resilient and do not hang excessively, ensuring the tree does not obstruct the views of people passing through the GOS. According to Indriyanto (2015), *Pterocarpus indicus* is one of the trees with rapid adaptability, due to its ability to grow in clay-sand, deep and loose soil, and stony soil.

Monoon longifolium belongs to the Annonaceae family. There were 38 *Monoon longifolium* found along the GOS of Jenderal Sudirman Street, making it one of the most commonly planted trees. The branches are resilient and do not hang down excessively, ensuring the tree does not obstruct the view of pedestrians or vehicle users. Furthermore, *Monoon longifolium* has lanceolate leaves, a columnar crown (also called a cylindrical crown), a monopodial trunk, glossy, smooth leaf surfaces, and wavy leaf edges (Rahmadhani et al. 2019). The canopy generally has the same width from the bottom to the top. Hence, the branching system produces a column-like canopy (Indriyanto 2015). The tree is suitable for planting along roadsides due to its high resistance to motor vehicle pollution. This resistance refers to the species' physiological tolerance, where its metabolic processes remain stable despite exposure to toxic gases. Furthermore, the tree exhibits a self-recovery mechanism, as evidenced by its ability to rapidly produce new shoots (resprouting) after experiencing environmental stress or pollutant-induced foliage damage (Rahmadhani et al. 2019).

Tamarindus indica is a member of the Fabaceae family. There were 14 *Tamarindus indica* in the GOS of Jenderal Sudirman Street. The observation indicated that their roots did not damage the road structure. This is in accordance with Utami and Krisnandika

(2016), who state that *Tamarindus indica* has slow root growth, preventing interference with road construction. The tree can produce new shoots when disturbed or damaged by the environment, and offers several benefits for planting in highly polluted areas, especially those polluted by motor vehicles.

Mimusops elengi belongs to the Sapotaceae family, and there were five trees in the green space on Jenderal Sudirman Street. According to Indriyanto (2015), *Mimusops elengi* is highly adaptable to various environmental conditions, making it popular among the community for urban or rural greening and for use as shade trees in office or residential yards and on roadsides. The trees are resistant to motor vehicle pollution, but some are unable to recover from stress caused by damage or environmental disturbances. In this context, resistance refers to the species' high tolerance to chemical pollutants, as *Mimusops elengi* maintains its physiological functions without immediate signs of tissue death or leaf yellowing (chlorosis) when exposed to vehicle emissions. However, this resistance is passive; while the tree can survive in polluted environments, it possesses a limited regenerative capacity (Wibowo et al. 2024). This means that once the tree suffers physical damage or extreme environmental stress beyond its threshold, it struggles to produce new shoots or recover its original vigor compared to more resilient species like *Monoon longifolium*.

Ficus benjamina belongs to the Moraceae family, and two were found in the GOS of Jenderal Sudirman Street. The tree is widely used as a place of shelter and a source of oxygen or an oxygen producer (Indriyanto 2015). *Ficus benjamina* tends to recover quickly from damage or disturbance, as indicated by the growth of shoots, making it a suitable tree for planting in urban areas.

Terminalia catappa is a member of the Combretaceae family, with an Aubreville tree architecture. Only one tree was found in the GOS of Jenderal Sudirman Street. The wood is of fairly good quality, although it is susceptible to termite attacks (Indriyanto 2015). Furthermore, *Terminalia catappa* can absorb pollutants in its surrounding environment, and the tree tends to recover quickly from stress, including motor vehicle pollution.

Field observations showed that the GOS of Jenderal Sudirman Street had six tree species, totaling 100, with *Pterocarpus indicus* (40) and *Monoon longifolium* (38) as the dominant species (Table 4). According to Agathis et al. (2021), the selection of vegetation for greenways considers the function as shade, air pollution reduction, and the philosophical meaning of the plant species. From an ecological perspective, species such as the *Pterocarpus indicus*, *Tamarindus indica*, and *Monoon longifolium* are optimal shade trees, capable of lowering temperatures and increasing air humidity. From an architectural perspective, these trees added significant aesthetic value, enhancing the street's visual appeal and contributing to the community's psychological comfort. Meanwhile, the GOS of Dr. Wahidin Sudirohusodo Street had few trees. Hence, it did not fulfill the functions as a shade provider, air purifier, or aesthetic element optimally. These results demonstrated that the type and quantity of vegetation can impact the quality of the urban environment. Based on the average height, diameter, and crown width (Table 5), the *Tamarindus indica* showed the most optimal characteristics as a shade tree in the GOS of Jenderal Sudirman Street, because it had the widest crown width.

The tree species found on Dr. Wahidin Sudirohusodo Street consist of 11 tanjung trees (*Mimusops elengi*). The small number of trees on Dr. Wahidin Sudirohusodo Street is due to the presence of several drainage points along Dr. Wahidin Sudirohusodo Street, and the fact that Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street are areas surrounded by or adjacent to residential areas, office buildings, educational facilities, hospitals, and shopping centers. In addition to being flanked by several public buildings, Dr. Wahidin Sudirohusodo Street is also a hub for street vendors and shop-house businesses along its length, which is in stark contrast to the Jenderal Sudirman Street area, which is specifically managed to serve as an urban green open space. In light of this, the drainage system on Dr. Wahidin Sudirohusodo Street is highly beneficial for preventing waterlogging, thereby avoiding disruptions to community activities and socioeconomic losses, particularly in terms of environmental health within residential areas. The drainage channels on Dr. Wahidin Sudirohusodo Street are underground, so the number of trees planted along that street is limited. If a large number of trees were planted around the drainage channels, their roots would damage the drainage system and compromise the stability of the channels.

Tree Canopy in Green Open Space on Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street

Based on observations and the division of road segments (Table 6), vegetation along Jenderal Sudirman Street altered microclimate conditions in each segment. In contrast, Dr. Wahidin Sudirohusodo Street, which had minimal shade-providing vegetation, exhibited consistently higher air temperatures, lower humidity, and higher light intensity across all segments, confirming the significant influence of tree cover on microclimate regulation. The total length of tree planting on the north side was 416.9 m, while on the south side it was 405.3 m. The division of five segments and the average crown diameter showed that *Tamarindus indica* and *Pterocarpus indicus* trees were dominant in influen-cing the decrease in air temperature and the increase in air humidity in the area. Therefore, to create comfort along Jenderal Sudirman Street, planting *Tamarindus indica, Pterocarpus indicus*, and *Monoon longifolium* trees can be considered. In contrast, Dr. Wahidin Sudirohusodo Street, which currently has minimal vegetation, would benefit from similar shade-providing tree species to improve microclimate conditions and enhance thermal comfort for pedestrians and road users. Most of the trees in this area have overlapping crowns. Hence, regular pruning is required to support shade and comfort. Pruning should be carried out with the average crown diameter in mind to achieve cool, shady conditions.

Tree inventory data show that vegetation in the GOS of Jenderal Sudirman Street was species intended for shading. These species were planted to provide optimal benefits and functions for the community in carrying out daily social activities. According to Septiawan et al. (2017), overly dense planting can slow tree growth due to competition for resources. Based on tree inventory data, the planting distances of trees in the GOS of Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street varied. Previous research by Ayuningtyas et al. (2020) found that planting distance affects the diameter and crown area of a stand, as crown size correlates with tree growth.

Crown shape, crown density, tree size, and tree growth are factors that affect the quality and quantity of green open space. In general, the crown shape adapts to the branching pattern, while crown density and shape affect microclimate conditions both within and around the green space (Saroh & Krisdianto 2020). Field observations in the green open space of Jenderal Sudirman Street confirmed this relationship as areas with lush trees and wide crowns created a significantly shady environment (Figure 2). In contrast, along Dr. Wahidin Sudirohusodo Street, the limited crown cover did not provide shade, consistent with the cross-sectional conditions illustrated in Figure 3. To enhance greening, planting trees in large pots presents a practical solution. This approach aims to improve

Table 6. Division of Tree Segments on Jenderal Sudirman Street

Segment No.	Number of Trees	Dominant Tree Type	Tree Canopy Conditions	Average Tree Height	Average Canopy Diameter
			North Section		
1	7	*Tamarindus indica*	Overlap and intersection	11.65	3.73
2	5	*Tamarindus indica*	Tangent	11.49	3.72
3	11	*Monoon longifolium*	Overlap and intersection	8.10	2.92
4	9	*Monoon longifolium, Pterocarpus indicus*	Non-overlapping and overlapping	7.99	3.56
5	10	*Mimusops elengi*	Overlap and intersection	8.13	3.37
			Southern Section		
Segment No.	Number of Trees	Dominant Tree Type	Tree Canopy Conditions	Average Tree Height	Average Canopy Diameter
1	8	*Pterocarpus indicus*	Tangent	9.29	3.08
2	11	*Pterocarpus indicus*	Overlap	7.79	2.99
3	13	*Pterocarpus indicus*	Overlap and intersection	8.79	3.08
4	14	*Pterocarpus indicus*	Overlap	8.94	3.64
5	12	*Monoon longifolium*	Overlap	8.83	3.22

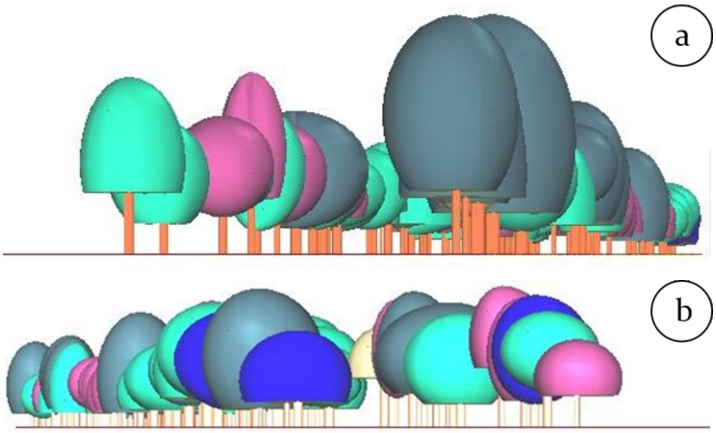

Figure 2. (a). Distribution of trees and tree crowns along Jenderal Sudirman Street, left side cross-section, and (b) right side cross-section (Data processed using SexI-FS application)

Figure 3. Distribution of trees and tree crowns of Dr. Wahidin Sudirohusodo Street, left side cross-section (Data processed using SExI-FS application)

comfort conditions and reduce air pollution. Examples of plants that can be planted using large pots include red shoots, palms, and sansevieria. Therefore, coordination between the Yogyakarta City Environmental Agency and building owners around Dr. Wahidin Sudirohusodo Street is needed to conduct reforestation.

Assessment of Physical Characteristics of Trees in Green Open Space on Jenderal Sudirman Street

Evaluations show that all tree types in the GOS of Jenderal Sudirman Street had scores over 80% in the very good category and meet ecological functions as shade trees (Table 7). Tree plantings comply with the Minister of Public Works Regulation No. 05/PRT/M/2012 guidelines.

Trees planted in the GOS following the established planting criteria offer benefits in everyday life. For instance, Fakhrurradhi et al. (2018) found that vegetation or trees in a green belt function as atmospheric cleaners by absorbing gas pollutants and other particles through the leaves. Furthermore, Bararatin and Hayati (2016) stated that the presence of a plant or tree in an environment provides psychological satisfaction to its inhabitants. In addition, roadside or greenway vegetation serves multiple roles, including ecological (absorbing toxic gases and releasing oxygen), technical (regulating microclimate, reducing wind, filtering light, and guiding traffic), and architectural functions (enhancing road landscapes through diverse plant forms, colors, and textures).

Microclimate Conditions

Comfort Index

The GOS in Jenderal Sudirman Street at 09.00-09.30 WIB had a lower temperature (30.12°C) than Dr. Wahidin Sudirohusodo Street, where the highest temperature was recorded at 38.07°C. Tree canopy cover could reduce solar radiation by up to 80% and lower temperatures, as described by Wu et al. (2025). The average air temperature in the GOS of Jenderal Sudirman Street at 09.00-09.30 WIB was 29.15°C, which falls within the comfortable range, while the average in Dr. Wahidin Sudirohusodo Street was 35.5°C, classified as uncomfortable, with a temperature difference of 6.36°C. This was in accordance with the comfortable temperature standard according to the Minister of Health Decree number 829/Menkes/SK/VII/1999, which is between 18°C and 30°C. The average air temperature in Jenderal Sudirman Street at 12.00 12.30 WIB was 28.55°C, and the average at Dr. Wahidin Sudirohusodo Street was 32.50°C, lower than the average at 09.00-09.30 WIB. This could be explained by the fact that on the first day of the observation, it rained from 12:00-12:30 WIB, during which very heavy

Table 7. Evaluation Results of Plant Characters of green space on Jenderal Sudirman Street

No.	Tree Type	Total Assessment Score	Total Maximum Score	Percentage (%)	Description
1	*Mimusops elengi*	63.20	68.00	92.94	Very good
2	*Monoon longifolium*	62.63	68.00	92.11	Very good
3	*Terminalia catappa*	62.00	68.00	91.18	Very good
4	*Pterocarpus indicus*	61.63	68.00	90.63	Very good
5	*Ficus benjamina*	61.00	68.00	89.71	Very good
6	*Tamarindus indica*	59.21	68.00	87.08	Very good

Table 8. THI value in green space on Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street

Location	Data Capture Hours	Air Temperature	Air Humidity	THI	Description
Jenderal Sudirman Street	09.00-09.30	29.14	65.98	27.16	Uncomfortable
	12.00-12.30	28.54	66.93	26.65	Uncomfortable
	15.00-15.30	27.73	72.48	26.20	Uncomfortable
Dr. Wahidin Sudirohusodo Street	09.00-09.30	35.50	51.81	32.08	Uncomfortable
	12.00-12.30	32.50	53.01	29.45	Uncomfortable
	15.00-15.30	31.75	58.48	29.11	Uncomfortable

rain occurred. The average air temperature of the GOS of Jenderal Sudirman and Dr. Wahidin Sudirohusodo Street at 15.00-15.30 WIB was 27.7°C and 31.75°C, respectively. The air temperature at 15.00-15.30 WIB was lower than at 09.00-09.30 and 12.00-12.30 WIB.

The average humidity of the GOS in Jenderal Sudirman and Dr. Wahidin Sudirohusodo Street at 09.00–09.30 WIB was 65.98% and 51.81%, respectively. These results were consistent with the temperature conditions, showing that when air temperature is lower, humidity is higher, and vice versa. The average difference in humidity in the GOS of both locations was 14.17%. According to Saroh & Krisdianto (2020), tree canopies offer benefits in maintaining the stability of environmental temperature and humidity, especially in environments around the GOS. Shade trees reduce drought risk, maintain lower temperatures and higher humidity, and protect soil nutrients during rainfall. Low air temperature and high humidity can be produced when vegetation density creates lush cover.

Air temperature and humidity are important factors in the microclimate that affect user activities on the GOS. This comfort index can affect the community's potential and utilization of GOS. Comfort refers to the influence of physical, atmospheric, or climatic environmental conditions on humans (Karyati et al. 2021). This comfort level was calculated using the Temperature Humidity Index (THI). Based on the THI, comfort levels are divided into three categories: comfortable (21-24°C), moderately comfortable (24-26°C), and uncomfortable (>26°C) (Effendy & Aprihatmoko 2014). The THI values for the GOS of Jenderal Sudirman Street and Dr. Wahidin Sudiro-husodo Street were presented in Table 8.

Table 8 shows that Jenderal Sudirman Street and Dr. Wahidin Sudirohusodo Street were having an uncomfortable level, as the THI values at all points exceeded 26°C. The GOS of Jenderal Sudirman Street, 12.00-12.30 and 15.00-15.30 WIB, had quite comfortable conditions, with THI values of 26.65°C and 26.20°C, respectively. This was because the field condition was a more-lush area. Consequently, the temperature in the GOS of Jenderal Sudirman Street was lower, and the humidity was higher. The THI value is influenced by several factors, namely building density, distance to an industrial center, distance to a trade center, distance to a main road, and vegetation or trees within a 100 m radius. Urban areas generally show a negative correlation with the THI because buildings there increase solar energy absorption, reduce evaporation, and slow wind movement, thereby elevating air temperature. The THI value is also influenced by air pollution from heavy traffic. Hence, vegetation or trees are very useful for providing environmental comfort (Karyati et al. 2021).

Perception of GOS

The analysis shows the benefits and potential of the GOS of Jenderal Sudirman Street, including refreshing the eyes, reducing people stress level or improving physical and mental health, tidying up the layout of the city or increasing the comfort of the city, helping to improve clean city air or absorbing dust, mitigating the level of air pollution and pollution from motorized vehicles, and decreasing high temperatures. The results suggest that the majority of respondents were satisfied with the facilities and services provided by the manager of the GOS on Jenderal Sudirman Street, and agreed that the area serves as a suitable location for various activities such as walking, socializing, and resting. In contrast, respondents at Dr. Wahidin Sudirohusodo Street reported lower satisfaction levels due to the limited availability of shade-providing trees and minimal facilities, which reduced the overall comfort and usability of the area for similar activities. In addition, respondents generally agreed or strongly agreed that engaging in activities within the green space enhances environmental knowledge and awareness. These respondents considered the GOS as a medium for environmental education and recognized the importance of community participation in maintaining shade trees in the area. The majority agreed that the number of visitors to the GOS needs to be limited. However, some respondents suggested no limitation on the number of visitors to the GOS, provided visitors protect the environment and the facilities provided by the manager.

The Impact of Vegetation on Microclimate and Comfort Level

The data analyses revealed a strong relationship between vegetation suitability, microclimate conditions, and social comfort levels. The results confirm that the trees located in the GOS of Jenderal Sudirman Street met technical planting criteria and had a significant impact on the environment. The high level of tree suitability, with values ranging from 87.08% to 92.94%, directly contributed to a cooler microclimate. Specifically, the presence of shade trees such as *Pterocarpus indicus*, *Tamarindus indica*, and *Monoon longifolium* had reduced the average air temperature by up to 6.36°C and increased humidity by up to 14.17% compared to the control area. This improvement in microclimate conditions, in turn, positively affects public perception. Although the THI values at the research sites were technically in the uncomfortable range, the majority of respondents expressed satisfaction with the GOS as a comfortable and suitable place to visit. Therefore, selecting the appropriate vegetation that functions optimally ecologically can significantly enhance comfort for users of the GOS.

The tree characteristics in the GOS of Jenderal Sudirman Street are generally appropriate. However, maintaining the conditions requires regular post-planting care, maintenance, and periodic evaluation. Field data collection shows that trees with extremely lush leaves tend to fall easily, sometimes disturbing pedestrians and reducing cleanliness and aesthetics in the GOS of Jenderal Sudirman Street. Care and maintenance for trees, based on Waruwu et al. (2022) includes watering, pruning, weeding, felling, treatment of wounds and holes caused by damage, shoring, pest and disease control, control of damage from nuisance plants, fertilization, and tree replacement. Most of these maintenance activities have been carried out by the Yogyakarta City Environmental Agency to maintain the GOS of Jenderal Sudirman Street and all other GOS in the city of Yogyakarta.

Conclusion

Shade trees in the GOS of Jenderal Sudirman Street play a crucial role in enhancing visitor comfort and improving the quality of the urban environment. All tree species in the GOS, such as *Mimusops elengi, Monoon longifolium, Terminalia catappa, Pterocarpus indicus, Ficus benjamina*, and *Tamarindus indica*, have a suitability value above 80%, classified as "very good" based on physical evaluation. This high suitability aligns with the criteria set out in the Regulation of the Minister of Public Works and Public Housing No. 05/PRT/M/2012 concerning Guidelines for Planting Trees on Road Networks, which state that the trees are ideal for shade functions. The tree species significantly influence the microclimate, reducing average temperatures by up to 6.36°C and increasing humidity by up to 14.17% compared to areas with minimal vegetation. In contrast, the lack of vegetation on Dr. Wahidin Street resulted in extreme thermal conditions, with temperatures reaching 38.07°C. An interesting contradiction emerged: despite the technically 'uncomfortable' THI values (26.20°C-27.16°C), the majority of the community perceived Jenderal Sudirman Street as a comfortable space for activities. For governments and urban planners, the results of this research provide specific guidance on the types of shade trees that have been proven effective in mitigating the Urban Heat Island effect and improving air quality. Meanwhile, for GOS managers, the results emphasize the importance of routine maintenance, such as pruning, to ensure that trees can function optimally.

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