

Analysis of the Effect of Shade Trees on Changes in Canopy-Level Urban Heat Island (Cuhi) Changes Along Road Corridors in Malalayang and Wanea Districts, Manado City

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ABSTRACT

The expansion of built-up areas in Manado City has driven changes in the urban microclimate, marked by an increasing intensity of the Urban Heat Island (UHI) phenomenon. Unlike prior studies that generally apply the Surface Urban Heat Island (SUHI) approach, this study focuses on the Canopy-Level Urban Heat Island (CUHI), which represents air temperature within the layer of human activity (approximately 1.5–2 meters above ground). The study aims to analyze the influence of shade trees on CUHI changes along road corridor segments located in the priority heat zones of Malalayang and Wanea Districts.

Priority zones were determined through Land Surface Temperature (LST) analysis based on Landsat 8–9 imagery, and subsequently verified through direct field measurements of air temperature and humidity along four road corridors, each divided into 100-meter segments, using seven dominant shade tree species as comparison points against unshaded locations. The results show that the presence of shade trees reduced average air temperature by 2.7°C in Malalayang District and 3.8°C in Wanea District, accompanied by an increase in relative humidity.

Mahogany produced the largest temperature reduction (4.2°C). Canopy closure proved to be a more decisive factor for CUHI intensity than canopy diameter alone. Physical corridor elements—dominance of asphalt surfaces, road width, and building density—further intensified CUHI in segments with minimal vegetation. This study recommends Mahogany, Angsana (*Pterocarpus indicus*), and Rain Tree as priority vegetation species for CUHI mitigation strategies along road corridors in Manado City.

Keywords: Canopy-Level Urban Heat Island; Shade Trees; Canopy Closure; Road Corridor

INTRODUCTION

Increasing urban activity in Manado City, particularly in Malalayang and Wanea Districts, has intensified land use and accelerated the expansion of built-up areas. These changes in the city's physical structure have the potential to affect urban microclimate conditions, including an increase in the intensity of the Urban Heat Island (UHI) phenomenon—a condition in which urban areas record higher temperatures than surrounding, less-urbanized areas.

Stewart and Mills (2021) classify UHI into four main types: Surface Urban Heat Island (SUHI), which represents surface temperature derived from remote sensing; Canopy-level Urban Heat Island (CUHI), determined through air temperature measurements near the ground surface; Boundary-layer Urban Heat Island (BLUHI); and Ground Urban Heat Island (GUHI). Among these four types, CUHI is considered the most relevant for outdoor urban studies because it directly reflects the thermal conditions experienced by people at

activity height (approximately 1.5–2 meters), whereas SUHI represents only the temperature of surface materials, which does not necessarily correspond to the air temperature experienced by pedestrians.

Previous UHI studies in Manado City have generally used the SUHI approach based on satellite imagery, such as the surface temperature study in Bitung City (Lempoy, et.al. 2021), which effectively identified the distribution of surface heat but did not represent the air temperature directly experienced by people outdoors.

A study by Zahra et al. (2021) in Manado City demonstrated that shade trees significantly influence microscale air temperature; however, studies specifically analyzing the influence of shade trees on CUHI at the road-corridor-segment scale, as a representation of priority heat zones, remain limited. This study is intended to fill that gap through direct field measurement of air temperature.

The objectives of this study are:

- to identify the density and type of vegetation in road corridor segments within the priority zones of Malalayang and Wanea Districts;
- to identify road corridor elements that influence Canopy-level Urban Heat Island (CUHI) in road corridor segments within the priority zones of Malalayang and Wanea Districts;
- to analyze the influence of shade trees on changes in Canopy-level Urban Heat Island (CUHI) conditions in road corridor segments within the priority zones of Malalayang and Wanea Districts.

LITERATURE REVIEW

Canopy-Level Urban Heat Island (CUHI)

CUHI is the variation of air temperature within the urban canopy layer, the layer of air from ground level to the height of building roofs or tree canopies, where human activity takes place (Branea et al., 2016). CUHI intensity is influenced by the physical characteristics of the urban area, such as building density, the thermal properties of surface materials, and the presence of shade vegetation.

Shade Trees

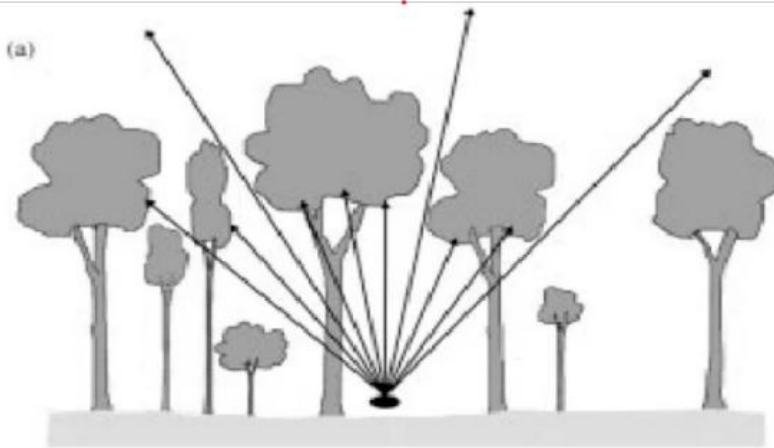
According to Karyati et al. (2023), shade trees are woody vegetation with wide and dense canopies capable of providing shade and reducing the intensity of solar radiation reaching the surface beneath them. The World Bank affirms that vegetation, particularly shade trees, plays a role in reducing urban heat through several main mechanisms: (1) evapotranspiration, in which vegetation releases water vapor that helps cool the surrounding air; (2) shading, which reduces solar radiation exposure on hard surfaces; and (3) altered heat-absorption characteristics, since vegetated areas tend to absorb less heat compared with built surfaces such as concrete and asphalt.

Canopy Closure

Canopy closure is a measure describing the percentage of sky obscured by tree canopy as seen from a single point on the ground. Unlike canopy cover, which is viewed from above, canopy closure uses a ground-based viewpoint, making it more relevant for describing the shading conditions experienced directly beneath vegetation. According to Jennings et al. (1999), canopy closure represents the proportion of the visible sky hemisphere obscured by tree canopy from an observer's viewpoint at ground level.

A meta-analysis by Li et al. (2024) found that pedestrian-level air temperature reduction is strongly influenced by tree attributes such as canopy density, canopy area, and their interaction with street morphology and local climate conditions. This finding confirms that shade trees are an important element in controlling air temperature within the urban canopy layer, particularly in linear spaces such as road corridors.

Figure 1. Canopy Closure (Jennings et al., 1999)



Road Corridors as Urban Outdoor Space

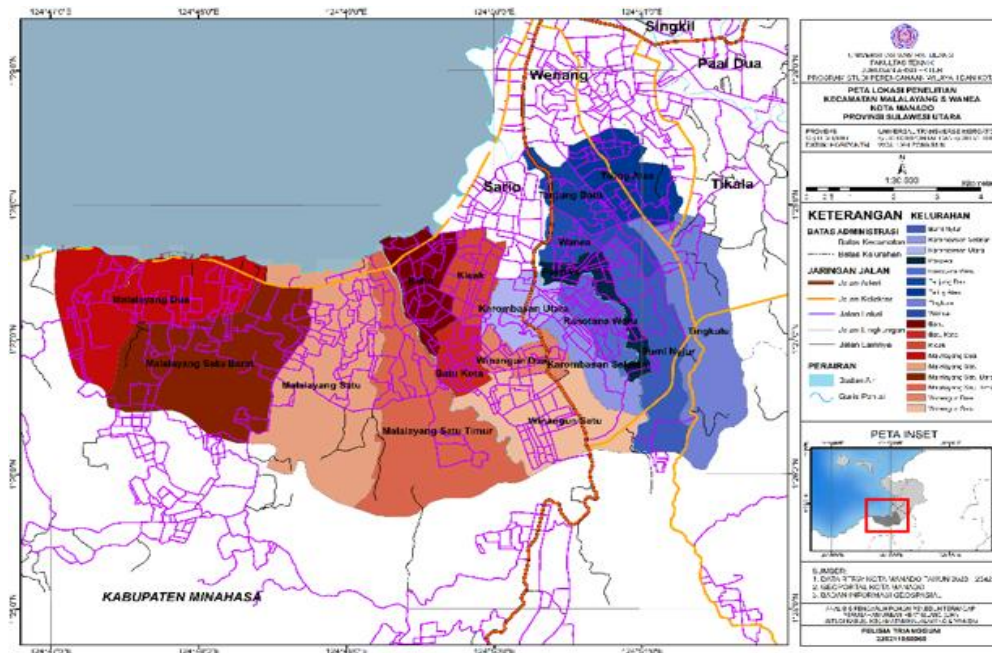
A study by Zhong et al. (2025) demonstrated that the geometric configuration of road corridors—such as the building-height-to-road-width ratio (H/W), road orientation, and spatial openness—strongly influences the distribution of air temperature, humidity, and wind flow patterns at a height of approximately 1.5 meters. A study by Castelo et al. (2024) in George Town, Malaysia, showed that road corridor segments dominated by hard surfaces with minimal vegetation experienced a significant daytime increase in air temperature.

METHODOLOGY

This study applies a quantitative approach using a descriptive-comparative method, supported by a spatial approach based on Geographic Information Systems (GIS). The descriptive method is used to describe the actual conditions of air temperature and vegetation characteristics, while the comparative method is used to compare air temperature in shaded road segments with unshaded segments under relatively similar time and environmental conditions.

Research Location

Figure 2. Administrative Map of Malalayang and Wanea Districts



The study was conducted in Manado City, North Sulawesi Province, with the location focused on Malalayang and Wanea Districts. Malalayang District has a semi-peri-urban character with a relatively higher proportion

of vegetation, whereas Wanea District has a dense urban character dominated by built-up land. Initial analysis of Landsat 8–9 OLI/TIRS Collection 2 Level 2 imagery (November 2025) showed that Malalayang District is dominated by built-up area at around 79.76%, yet still retains 72.93% medium-to-high vegetation cover, while Wanea District has a built-up area of around 71.7% with a more limited medium-to-high vegetation cover (20–30%). Four road corridor segments were purposively selected within the priority heat zone, each divided into 100-meter segments.

Figure 3. Distribution Map of Corridors in Malalayang District

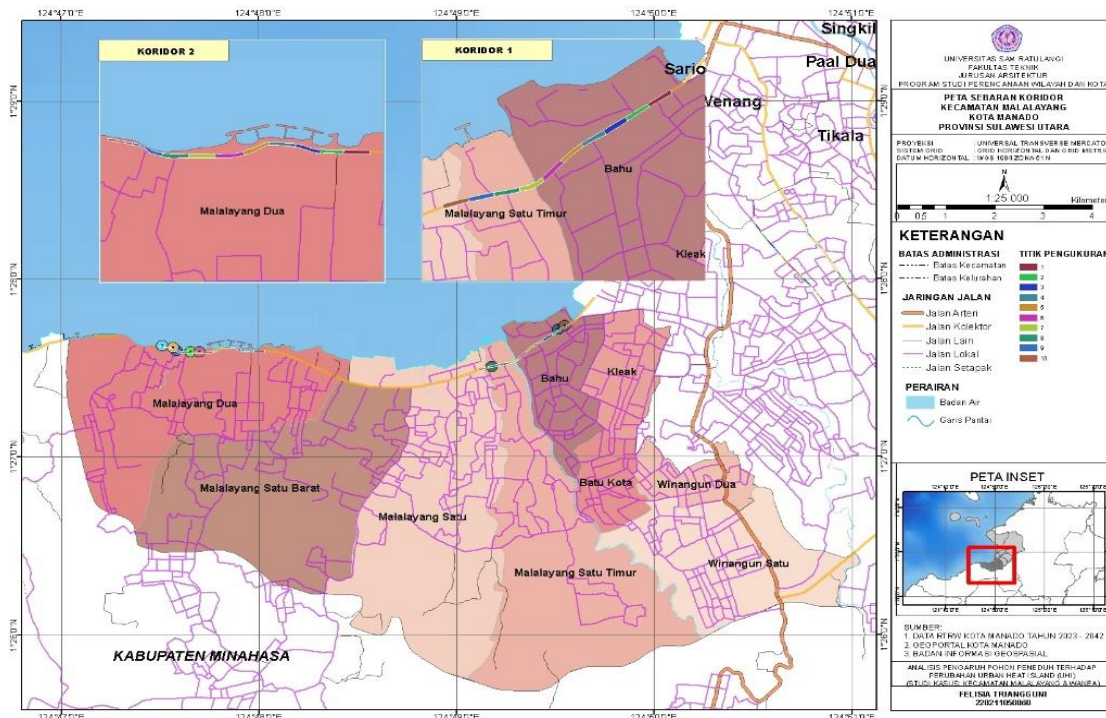
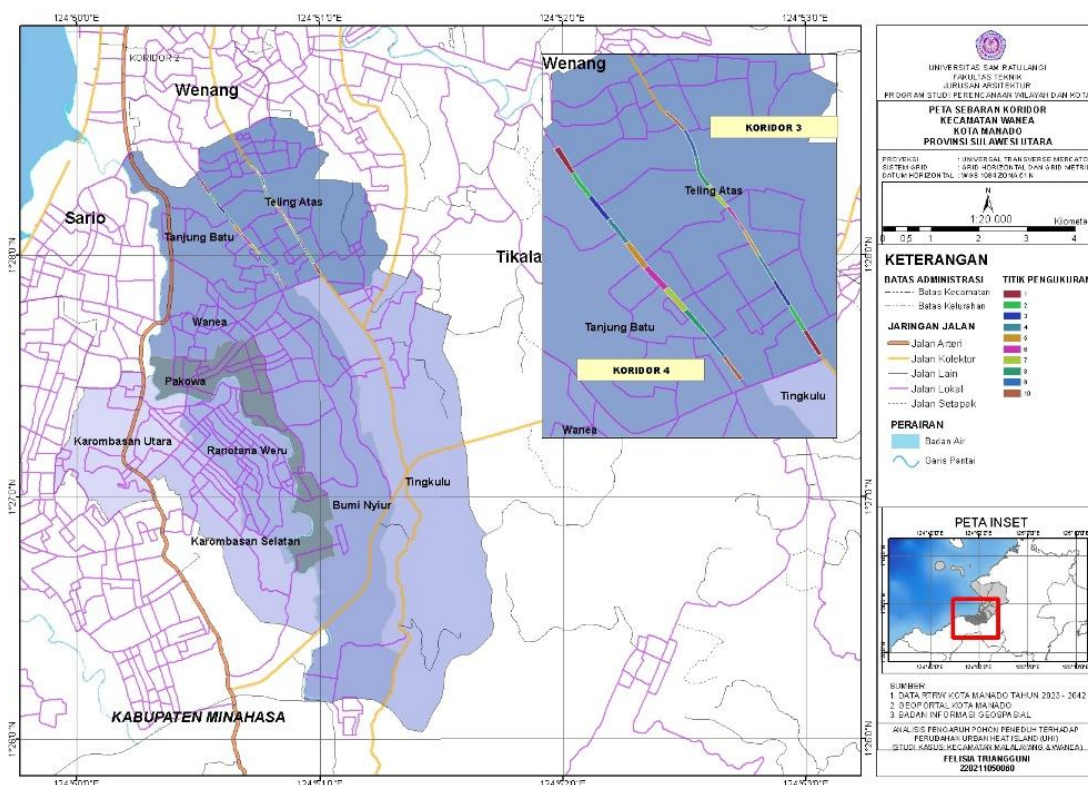


Figure 4. Distribution Map of Corridors in Wanea District



Research Variables

Table 1. Research Variables

Variable	Parameter	Objective
Vegetation Characteristics	Tree species, density, canopy closure, canopy characteristics	To identify the density and type of vegetation along the road corridor
Road Corridor Elements	Surface material, road width, presence of buildings	To identify the elements influencing CUHI
Air Temperature and Humidity (CUHI)	Air temperature (°C) and humidity (%RH) at shaded and unshaded points	To analyze the influence of shade trees on CUHI change
Wind Speed (supporting)	Field-measured wind speed and ECMWF (Open-Meteo) data	Contextual data on the corridor's aerodynamic conditions

Source: Authors' Analysis, 2026

Data Collection Techniques

Data for this study were obtained through the following techniques:

Satellite Image Analysis — Landsat 8–9 OLI/TIRS Collection 2 Level 2 data were used to process Land Surface Temperature (LST) as the basis for determining priority heat zones (hotspots), using the criterion

$$\text{Hotspot} = \boxed{\text{LST} > (\mu + 2\sigma)}$$

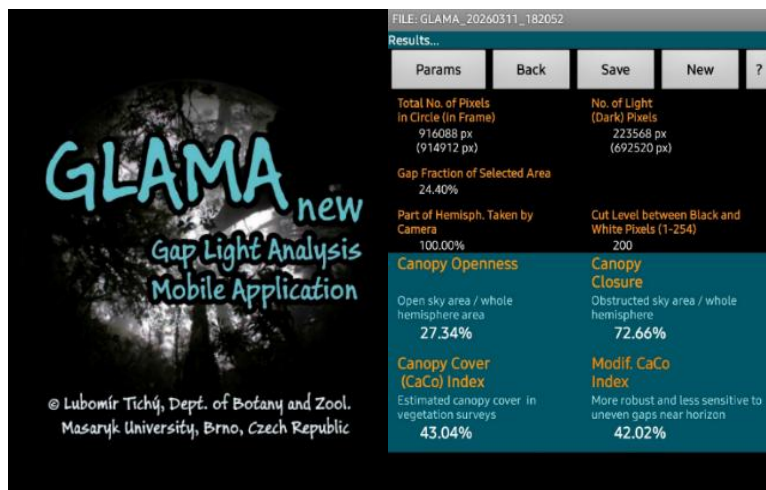
where μ is the mean LST and σ is the LST standard deviation.

Field Observation and Measurement — Air temperature and humidity were measured directly at a height of ± 1.5 meters at points shaded by seven dominant shade tree species (Rain Tree, Mast Tree, Mahogany, Palm, Banyan, Angsana, and Indian Almond) as well as at unshaded comparison points. Canopy closure and canopy characteristics were measured using the hemispherical photography method with a fish-eye lens attachment on a smartphone. Hemispherical photographs were taken directly beneath the tree canopy at each observation point and subsequently analyzed using the GLAMA (Gap Light Analysis Mobile Application) software to obtain the percentage value of canopy closure as an indicator of canopy cover over the visible sky.

Figure 5. Hemispherical image acquisition process and results using a fish-eye lens attached to a smartphone to analyze canopy cover conditions and sky gap distribution (Dharmawan, 2020)



Figure 6. GLAMA (Gap Light Analysis Mobile Application) Interface Display

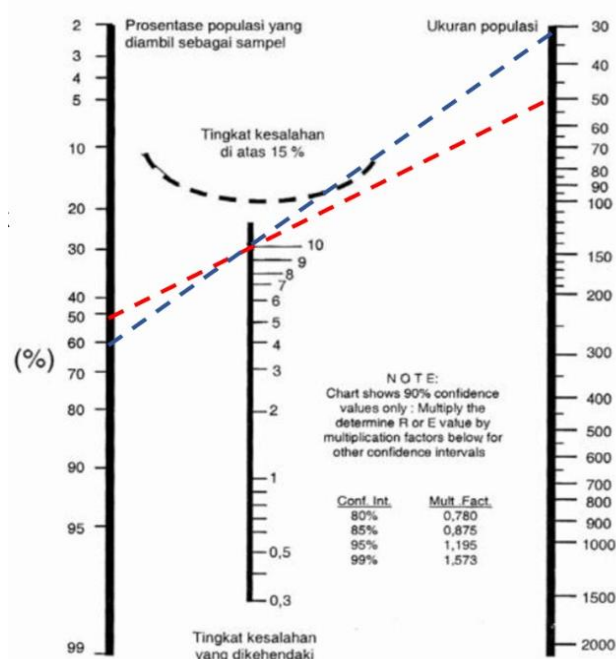


Physical Corridor Element Observation — Recording of road surface condition, road width, and the presence of boundary buildings for each segment.

Secondary Data — Wind speed data from Open-Meteo (ECMWF model), the Administrative and Road Network Map of Manado City, and the Manado City Spatial Plan (RTRW) 2023–2042 document were used as supporting data

Community Perception Survey — A community perception survey was conducted as supplementary data to complement the field measurements and obtain information regarding people's perceptions of the benefits of shade trees along the studied road corridors. The survey was conducted during the daytime observation period from 09:00 to 15:00, when pedestrian activity and exposure to solar radiation were considered relevant to outdoor thermal conditions. The number of respondents was determined using the Harry King Nomogram with a 10% allowable error (Sugiyono, 2007). Based on the observed number of people passing through the corridor, 25 respondents were selected in Malalayang District and 18 respondents in Wanea District, resulting in a total of 43 respondents. The questionnaire consisted of six statements concerning perceived cooling effects, changes in thermal comfort, pedestrian movement, canopy density, the need for shaded resting areas, and the perceived difference between tree shade and metal canopy shade. Responses were recorded using a five-point Likert scale ranging from strongly agree to strongly disagree.

Figure 7. Sample size determination using the Harry King Nomogram (Sugiyono (2007))



Data Analysis Technique

Data were analyzed through: (1) LST analysis and determination of priority heat zones using GIS; (2) descriptive analysis of vegetation characteristics for each corridor segment; (3) comparative analysis of air temperature and humidity between shaded and unshaded points, expressed as the difference

$$\Delta\text{CUHI} = \text{unshaded temperature} - \text{temperature beneath shade}$$

$$\Delta\text{RH} = \text{humidity beneath shade} - \text{unshaded humidity}$$

(4) analysis of the relationship between canopy closure and CUHI intensity; and (5) contextual analysis of physical road corridor elements in relation to CUHI distribution. The effectiveness of each tree species was evaluated based on ΔCUHI , ΔRH , canopy characteristics, and the representativeness of the observation location; (6) descriptive analysis of community perception survey responses using frequency and percentage distributions for each Likert-scale statement. The perception results were interpreted as supplementary evidence to the measured thermal conditions rather than as a primary determinant of CUHI.

RESULTS AND DISCUSSION

Vegetation Characteristics of Road Corridors

The inventory results show a sharp variation in vegetation density and species across corridors. Corridors 1 and 2 (Malalayang District) are dominated by Rain Tree, Angsana, and Indian Almond, distributed evenly along the segments, while Corridor 4 (Wanea District) is dominated by Mast Tree, Banyan, and Palm. Corridor 3 in Wanea District shows extremely limited vegetation conditions, with canopy closure of only 1.38%, compared with 46–51% in densely vegetated corridors.

Table 2. Average Canopy Closure and Corridor Openness

Corridor	Canopy Closure (%)	Corridor Openness (%)	Dominant Vegetation
Corridor 1 (Malalayang)	28.74	71.26	Rain Tree, Angsana, Indian Almond
Corridor 2 (Malalayang)	46.20	53.80	Angsana, Indian Almond, Mast Tree
Corridor 3 (Wanea)	1.38	98.62	Extremely limited vegetation
Corridor 4 (Wanea)	50.68	49.32	Mast Tree, Banyan, Palm

Source: Authors' Analysis, 2026

Characteristics of Road Corridor Elements

All studied corridors are dominated by asphalt and concrete surfaces, with variations in road width and the presence of boundary buildings that influence the amount of solar radiation received by the road surface and air circulation patterns. Corridors with dense buildings on both sides form a street-canyon effect, which may either strengthen or weaken air circulation depending on building orientation and height, consistent with the conceptual UHI framework that places urban geometry, the thermal properties of materials, and vegetation as the three main controllers of canopy heat intensity (Oke et al., 2017).

Table 3. Road Corridor Elements Influencing CUHI

Corridor Element	Effect on CUHI
Shade vegetation (high canopy closure)	Decreases air temperature

Corridor Element	Effect on CUHI
Asphalt and concrete surfaces	Increases air temperature
Corridor openness	Increases solar radiation exposure
Vehicle activity	Adds anthropogenic heat
Building density	Restricts air circulation (street canyon)

Source: Authors' Analysis, 2026

CUHI Distribution across Study Corridors

The distribution of CUHI intensity shows a spatial pattern consistent with the distribution of canopy closure: heat intensity is concentrated in segments with low canopy cover and decreases in densely vegetated segments. In Corridor 3 (Wanea), which is nearly devoid of vegetation, the unshaded air temperature was recorded as the highest in this study, while corridors with canopy closure above 45% show lower and relatively more even temperature distribution along the segments. This finding reinforces the argument that CUHI distribution at the corridor scale is highly sensitive to canopy continuity at the micro-street scale—a nuance not captured by pixel-based SUHI approaches.

Influence of Shade Trees on Air Temperature Change

Comparison of shaded and unshaded air temperatures shows a consistent cooling effect across all observed tree species. The presence of shade trees reduced average air temperature by 2.7°C in Malalayang District (from 33.9°C to 31.2°C) and by 3.8°C in Wanea District (from 34.6°C to 30.8°C).

Table 4. Comparison of Average Shaded and Unshaded Air Temperature

District	Average Temperature Beneath Shade (°C)	Average Unshaded Temperature (°C)	ΔCUHI (°C)
Malalayang	31.2	33.9	2.7
Wanea	30.8	34.6	3.8

Source: Authors' Analysis, 2026

The larger temperature reduction observed in Wanea indicates that in densely built corridors, the thermal contrast between shaded and open areas is actually sharper, because the unshaded baseline temperature is considerably higher, thereby giving vegetation greater room for cooling.

Relationship between Canopy Closure and CUHI

Corridors with high canopy closure (Corridors 2 and 4, above 46%) consistently produced lower air temperature and higher humidity compared with corridors with low canopy closure (Corridor 1, and particularly Corridor 3). This finding supports the theory of Stewart and Oke regarding Canopy-level Urban Heat Island, which explains that vegetation cover characteristics within the canopy layer influence urban energy balance and air temperature. Increasing canopy closure can therefore serve as an effective CUHI mitigation strategy for urban road corridors.

Effectiveness of Shade Trees in Reducing Canopy-level Urban Heat Island (CUHI)

The results show that shade trees are an effective element in reducing the intensity of Canopy-level Urban Heat Island along road corridors. The presence of shade trees was able to reduce air temperature by 2.7°C in

Malalayang District and 3.8°C in Wanea District. This temperature reduction occurs because trees reduce direct solar radiation through canopy shading and generate natural cooling through evapotranspiration. The larger the canopy size and the higher the canopy closure, the greater the tree's capacity to reduce air temperature.

Table 5. Effectiveness of Shade Tree Species in Reducing Air Temperature

Tree Species	ΔT (°C)	ΔRH (%RH)	Canopy Characteristics	Effectiveness Rating
Mahogany	4.2	18.7	Dense canopy, compact crown	Highly Effective
Palm	3.9	22.9	Vertical canopy	Effective (local)
Angsana	3.7	19.5	Wide, spreading canopy	Effective
Banyan	3.2	21.0	Dense, leafy canopy	Fairly Effective
Indian Almond	3.05	9.9	Wide, tiered canopy	Fairly Effective
Rain Tree	2.9	18.6	Very wide canopy	Effective
Mast Tree	2.8	18.7	Medium, dense canopy	Fairly Effective

Source: Authors' Analysis, 2026

The Palm occupies a distinctive position: although its canopy is narrow and vertical, resulting in limited direct shading, this species recorded the highest ΔRH (22.9% RH), indicating a significant evapotranspiration contribution despite the small shaded area. The high relative humidity at locations shaded by the Royal Palm may indicate a more humid microclimate condition, which theoretically may relate to water-vapor release through vegetation transpiration. However, because this study did not directly measure transpiration rate, the increase in humidity cannot be attributed exclusively to Royal Palm transpiration. Other factors such as wind speed, groundwater availability, surface conditions, and canopy characteristics may also influence relative humidity around the observation points. Overall, Mahogany, Angsana, and Rain Tree showed the most consistent performance, being effective in both districts and possessing canopy characteristics ranging from dense to very wide, and are therefore recommended as priority species for CUHI mitigation.

Table 6. Community Perception of Shade Trees

NO	Statement	Malalayang Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Wanea Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	Trees make the surrounding air feel cooler.	36.0%	64.0%	0.0%	0.0%	0.0%	83.3%	16.7%	0.0%	0.0%	0.0%
2	Trees improve thermal comfort along the road corridor.	36.0%	56.0%	8.0%	0.0%	0.0%	16.7%	77.8%	5.6%	0.0%	0.0%
3	Trees do not obstruct pedestrian movement.	24.0%	44.0%	28.0%	0.0%	4.0%	22.2%	61.1%	11.1%	0.0%	5.6%

4	Roadside trees should have dense foliage.	20.0%	56.0%	24.0%	0.0%	0.0%	22.2%	55.6%	11.1%	11.1%	0.0%
5	Trees are needed as shaded areas for resting.	44.0%	56.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%
6	Metal canopy shade feels hotter than tree shade.	24.0%	48.0%	28.0%	0.0%	0.0%	16.7%	55.6%	27.8%	0.0%	0.0%

Source: Community Perception Survey, 2026

Figure 8. Existing conditions of the studied road corridors



Malalayang District



Wanea District

Source: Field Documentation, 2026

The community perception survey provides supplementary evidence regarding the perceived benefits of shade trees along the studied road corridors. Overall, respondents tended to associate the presence of shade trees with cooler and more comfortable outdoor conditions. Dense tree canopies were also perceived as important for providing shade and suitable resting areas for pedestrians. These perceptions complement the field measurements, which showed lower air temperatures at locations under tree shade compared with unshaded locations. The consistency between measured thermal conditions and community perceptions supports the practical importance of shade trees as a component of urban heat mitigation along road corridors.

Influence of Road Corridor Elements on CUHI

Field wind-speed data support the pattern that minimally vegetated corridors recorded the highest average wind speed (1.03 m/s in Malalayang; 1.08 m/s in Wanea), while densely vegetated corridors recorded lower speeds (0.66 m/s in Malalayang; 0.24 m/s in Wanea) due to the aerodynamic resistance of the canopy. Although theoretically higher wind speed supports heat release through convection, air temperature in densely vegetated corridors remained lower despite the slower wind speed, confirming that the shading and evapotranspiration effects of vegetation are more dominant than the weakening of air circulation caused by canopy density.

During field observations, conventional fuel-powered vehicles, including public minibuses (mikrolets), were observed along the studied road corridors. Heat released from vehicle engines may contribute to localized

thermal conditions, particularly in corridors with intensive traffic activity. However, vehicle activity was not treated as the main research object or independently analyzed. It was considered only as a contextual socio-economic factor that may influence local CUHI conditions, while the primary focus of this study remains the role of shade trees.

Implications for Road Corridor Planning

Because canopy closure has proven to be more decisive than tree quantity alone, road-corridor greening policy should emphasize canopy continuity and density—for example, through a planting spacing of 6–10 meters to allow the formation of a continuous canopy. Planting priority should be directed toward corridors with low canopy closure and hard-surface dominance, such as Corridor 3 in Wanea District. Species selection should be adapted to the characteristics of the street space: Mahogany, Angsana, and Rain Tree for arterial and collector roads with adequate planting space, while Palm is suitable for medians or narrow sidewalks. These findings reinforce the position of CUHI as a relevant operational indicator for evaluating the effectiveness of street-level green open space within Manado City's Detailed Spatial Plan (RDTR) document.

CONCLUSION

Based on the results of this study on the influence of shade trees on Canopy-level Urban Heat Island (CUHI) changes along road corridor segments in Malalayang and Wanea Districts, it is concluded that vegetation characteristics and the physical condition of road corridors influence microclimate conditions and CUHI intensity, with densely vegetated corridors showing higher canopy closure and lower air temperature compared with minimally vegetated corridors.

Shade trees have a real effect on changes in air temperature and humidity along road corridors, with Mahogany showing the greatest temperature reduction capacity (ΔT 4.2°C) and Palm producing the highest humidity increase (22.9% RH), although this effect is local in nature. The level of canopy closure has a close relationship with CUHI intensity change: the higher the canopy closure, the lower the air temperature and the higher the humidity. Mahogany, Angsana, and Rain Tree are the most recommended tree species as shade vegetation for CUHI mitigation along road corridors, given their consistent effectiveness in both study districts.

This study contributes to the discipline of Urban and Regional Planning by providing empirical, field-measurement-based evidence on the relationship between road vegetation characteristics and outdoor thermal comfort, and by proposing canopy closure as a more relevant operational indicator than mere tree count in formulating technical standards for road-vegetation planting.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are proposed:

The Manado City Government is advised to improve the quality of green space along road corridors by adding shade trees with wide, dense canopies, particularly in corridors with minimal vegetation such as Corridor 3 in Wanea District, prioritizing Mahogany, Angsana, and Rain Tree.

Road corridor planning should consider not only aesthetic aspects but also the ecological function of vegetation, taking into account tree species, canopy density, planting spacing, and canopy-cover continuity.

Future research is encouraged to expand the analysis by adding other microclimate parameters, such as thermal comfort indices (PET or UTCI), broadening the study area to other road corridors in Manado City, and accounting for seasonal variation in the measurement period.

Microclimate condition measurement should be combined with technologies such as Hemispherical Photography or GLAMA, along with spatial modeling, to produce more accurate information on the distribution of Canopy-level Urban Heat Island.

Table 7. Recommended Tree Selection Criteria

Basic Criteria	Research Finding
Wide canopy	Corridors with denser canopy have lower temperature
Planting spacing 6–10 m	Forms a continuous canopy
Non-aggressive roots	Reduces sidewalk damage
High evapotranspiration	Lowers air temperature
Pollution tolerant	Supports urban vegetation sustainability

Table 8. Recommended Planting Spacing

Canopy Category	Mature Canopy Diameter (± m)	Planting Spacing (m)	Example Species	Function in Temperature Reduction
Small canopy	< 6	4–6	Tabebuia, Golden Trumpet Tree, Cherry (Kersen)	Provides shade for limited areas; suitable for narrow streets and sidewalks.
Medium canopy	6–12	6–8	Mahogany, Angsana, Mast Tree	Forms a sufficiently dense shaded corridor, effective in reducing solar radiation and lowering air temperature.
Large canopy	> 12	8–12	Rain Tree, Banyan, Indian Almond	Forms a broad, continuous canopy, providing the greatest cooling effect through shading and evapotranspiration.

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