

The Influence of Public Green Open Space Availability on Land Surface Temperature in Wenang District, Manado City

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ABSTRACT

Urban thermal conditions at the ground level are heavily influenced by the extent of vegetated public space a district manages to preserve, given that such areas function as natural buffers against excess heat accumulation and help sustain livable outdoor environments. This dynamic is clearly visible in Wenang, one of Manado City's officially designated urban service centers, where dense settlement patterns combined with extensive conversion of land into built structures have placed sustained pressure on remaining shared green space. Responding to this condition, the research pursued three objectives: first, to document the current extent of public green space provision; second, to trace how thermal patterns manifest across and around vegetated land; and third, to convert these findings into actionable guidance on siting future green infrastructure and upgrading existing locations, grounded throughout in empirical temperature and comfort measurements. The study integrated numerical analysis with spatial mapping methods. Vegetation condition was tracked using an index-based calculation (NDVI), while ground-level heat was estimated through satellite-derived temperature data (LST), both extracted from three Landsat 8 OLI/TIRS image captures taken in 2016, 2021, and 2025. To confirm these remote measurements matched actual field conditions, the research team cross-checked them against direct site visits, manual sol-air temperature calculations, and thermal comfort assessments recorded on location. The findings revealed a substantial shortfall: only 11.19 hectares of land in Wenang currently serves as public green space, representing just 3.29% of the sub-district's total 339.6-hectare area—far below the 20% (67.92 hectares) threshold legally mandated by Law No. 26 of 2007, leaving an unmet requirement of 56.73 hectares. Notably, although vegetation cover intensified across nearly all monitored sites over the study period, six of the seven locations examined still recorded temperature increases of up to 2.8°C, demonstrating that greening alone has not been sufficient to counteract heat generated by surrounding development. Given its markedly elevated thermal readings, Wenang Selatan is identified as the top-priority site for establishing new green space, while the three existing locations are recommended for targeted improvements—primarily the addition of shade-producing vegetation and the replacement of heat-retaining surface materials with more thermally favorable alternatives.

Keywords : Public Green Open Space; Surface Temperature; NDVI; Land Surface Temperature; Thermal Comfort

INTRODUCTION

Wenang Sub-district has been designated as the Urban Service Center (PPK) of Manado City, functioning as a hub for trade and services, transportation, offices, and various public and social facilities as stipulated in the 2023–2042 Manado City Spatial Plan (RTRW). This strategic position makes Wenang Sub-district an area with a very high intensity of community activity. According to 2024 data from the Manado City Statistics Agency (BPS), this area of approximately 3.34 km² has an average population density of around 13,330 people/km². The growing population drives land demand that is not matched by the availability of fixed land, thereby encouraging land-use change from non-built-up to built-up areas (Sari et al., 2023). This condition makes it difficult to provide public Green Open Space, both in terms of quantity and quality, even though the need for green open space as an element that safeguards environmental quality is becoming greater.

The presence of green open space not only improves environmental quality but also plays a role in regulating air temperature and mitigating urban heat, thereby reducing the risk of health problems caused by high surface temperatures (WHO Regional Office for Europe, 2017). green open space also supports the hydrological cycle, the formation of microclimates, and the reduction of air pollution (Sugiyanto & Sitohang, 2017). Based on the study by Longaris et al. (2019), the availability of green open space in Wenang Sub-district was recorded at 47.63 Ha, consisting of 39.37 Ha of public green open space and 8.26 Ha of private green open space, or approximately 12.9% of the total area. In accordance with the provision that green open space should comprise 30% of the total area, consisting of 20% public green open space and 10% private green open space, this figure was compared with the overall 30% green open space target. However, the present study specifically focuses on public green open space; therefore, the 20% minimum provision for public green open space is used as the main benchmark, while the 10% provision applies to private green open space, in accordance with Law No. 26 of 2007 on Spatial Planning. The difference between the findings of Longaris et al. (2019) and the present study is therefore partly related to the scope of green open space assessed, as the former included both public and private green open spaces, whereas the present study focuses only on public green open spaces. This condition has the potential to trigger the Urban Heat Island (UHI) phenomenon, namely an increase in air temperature in urban areas compared to surrounding areas due to the dominance of built-up materials (Sangkertadi et al., 2022).

As a central urban area, Wenang Sub-district has a relatively high environmental temperature due to intense urban activity and the dominance of built-up land. According to a report by the Manado City Regional Development Planning, Research, and Development Agency (Bappelitbangda), the average temperature rose from 25.53°C in 2013 to 27.05°C in 2023, with a maximum temperature reaching 34.76°C. Rumengan et al. (2019) showed that built-up areas can have surface temperatures of up to 48°C, whereas well-vegetated areas are only around 25°C. Widyanti et al. (2025) stated that the reduction of urban vegetation can increase surface temperature by up to 1.7°C. This condition indicates that limited green open space contributes to rising environmental temperatures and declining community thermal comfort.

Based on the above description, this study aims to (1) identify the availability of public green open space in Wenang Sub-district; (2) analyze the surface temperature characteristics of public green open spaces; and (3) analyze the placement and development needs of public green open spaces based on surface temperature and thermal comfort. The influence of public green open space availability on surface temperature and thermal comfort is examined through a spatial approach utilizing changes in vegetation density (NDVI) and surface temperature (LST), reinforced by field verification (ground check), while temporal analysis is used to identify changes in green open space availability and surface temperature over time.

LITERATURE REVIEW

Green Open Space

Green Open Space is an important component of the urban spatial planning system, taking the form of open areas that may be linear, in the form of corridors, or specific zones dominated by vegetation, whether naturally occurring or planted by humans. Public urban green spaces play an important role in microclimate control, carbon absorption, oxygen supply, and improving thermal comfort in urban areas (Hamidah & Santoso, 2022). In line with this definition, Law Number 26 of 2007 on Spatial Planning affirms that the provision of green open space in urban areas must meet a minimum proportion of 30% of the total city area, with at least 20% of that being public green open spaces.

Normalized Difference Vegetation Index (NDVI)

NDVI is a vegetation index that utilizes the difference in spectral reflectance between the red (Red) and near-infrared (NIR) bands. The calculation of NDVI is based on the characteristic of vegetation absorbing most red light for photosynthesis while reflecting near-infrared energy through leaf structure, resulting in higher NDVI values compared to non-vegetated objects (Rouse et al., 1974). NDVI is widely used to monitor changes in vegetation density over time using remote sensing imagery such as Landsat.

Land Surface Temperature (LST)

Land Surface Temperature (LST) represents the thermal condition of the earth's surface as measured through the thermal infrared radiation emitted by soil, vegetation, and built-up surfaces. LST is highly sensitive to variations in land cover and can change significantly over relatively short spatial and temporal scales, particularly in urban areas (Stewart, 2021). The magnitude of surface temperature is influenced by the physical characteristics of objects—emissivity, specific heat capacity, and thermal conductivity—so that hardened surface materials such as concrete and asphalt tend to have higher surface temperatures than vegetation (Sangkertadi, 2012). Generally, the higher the vegetation density of an area, the lower its surface temperature, although this relationship is not always linear, as it is also influenced by paving materials and the spatial configuration of the city.

Urban Heat Island Phenomenon

When the temperature in urban areas is consistently higher than in surrounding non-urban areas, this phenomenon is known as the Urban Heat Island (UHI), which is triggered by the reduction of vegetation, the expansion of paved surfaces, and anthropogenic heat from urban activities (Ana-Maria et al., 2016; Stewart, 2021). UHI can be distinguished based on its measurement medium into Canopy Layer, Boundary Layer, Surface, and Ground/Subsurface Urban Heat Island (Stewart, 2021). Studies using LST data from satellite remote sensing generally refer to the Surface Urban Heat Island (SUHI) form, because the analysis is conducted on land surface temperature rather than air temperature.

Sol-Air Temperature (Tsa) and Outdoor Thermal Comfort

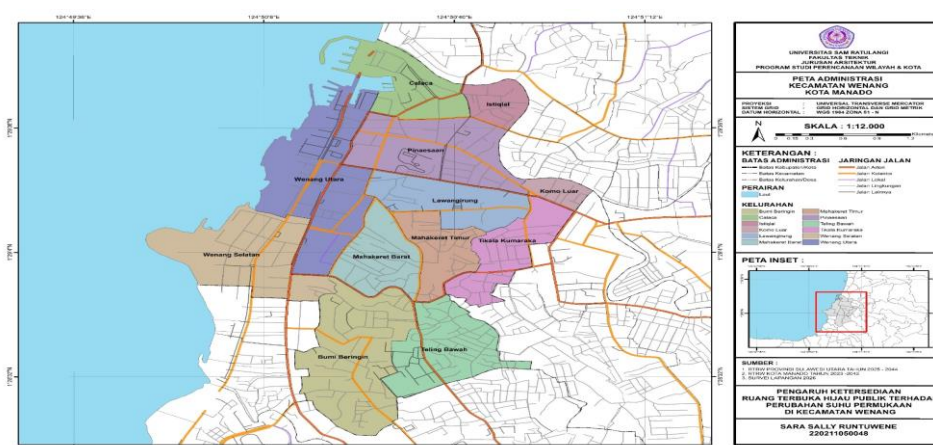
Sol-Air Temperature (Tsa) is an equivalent temperature that describes the combined effect of air temperature, solar radiation, and heat transfer on a surface (Thakur, 1989; Bouchair, 2001), used to compare the thermal response of different surface materials. Tsa values increase on surfaces with high heat-absorption capacity, while vegetation tends to produce lower Tsa values due to the evapotranspiration process. Thermal comfort is measured through microclimate parameters (air temperature, radiant temperature, relative humidity, and wind speed) processed using a thermal comfort regression model for humid tropical climates (Sangkertadi, 2012), producing a thermal comfort index (YD) that reflects the heat perception of space users.

METHODOLOGY

Research Location

The research was conducted in Wenang Sub-district, Manado City, North Sulawesi Province, which consists of 12 urban villages (kelurahan), namely Bumi Beringin, Teling Bawah, Tikala Kumaraka, Mahakeret Barat, Mahakeret Timur, Wenang Utara, Wenang Selatan, Lawangirung, Komo Luar, Pinaesaan, Istiqlal, and Calaca, covering a total area of 339.6 Ha. The object of the research comprises all public Green Open Spaces located within Wenang Sub-district.

Figure 1. Administrative Map of Wenang Sub-district



Research Design and Variables

This study employed a quantitative method with a spatial analysis approach. The research variables included the availability of public green open spaces (distribution, type, and area), vegetation density (NDVI), land surface temperature (LST), field surface-temperature validation, Sol-Air Temperature (Tsa), thermal comfort (YD), as well as the placement needs and development directions for public green open spaces. The data used consisted of Landsat 8 OLI/TIRS Collection 2 Level-2 imagery for 2016, 2021, and 2025, Manado City administrative data, and field measurement results.

Data Analysis Technique

NDVI analysis was carried out using the Near Infrared (Band 5) and Red (Band 4) channels, with the formula:

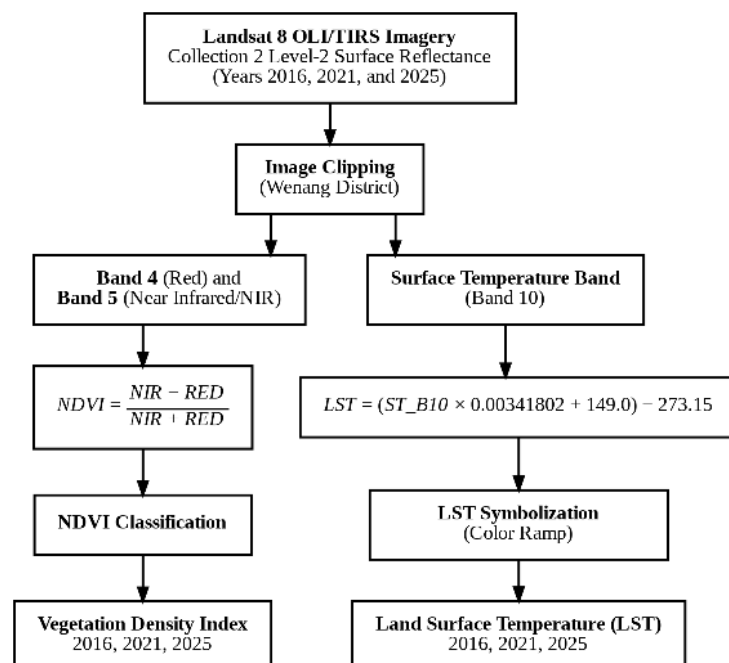
$$NDVI = (NIR - RED) / (NIR + RED)$$

Land Surface Temperature (LST) analysis used the Surface Temperature Band 10 (ST_B10) from Landsat 8 OLI/TIRS Collection 2 Level-2 data. The ST_B10 values were converted to degrees Celsius using the scale factor and offset provided in the image metadata, according to the following equation:

$$LST = (ST_B10 \times 0.00341802 + 149.0) - 273.15$$

where LST is Land Surface Temperature (°C), ST_B10 is the Surface Temperature value from Landsat 8 Band 10, 0.00341802 is the temperature scale factor, 149.0 is the offset specified in the Landsat metadata, and 273.15 is the conversion factor from Kelvin to Celsius. The Level-2 Surface Temperature product was used as the source of the surface temperature values, and emissivity-related processing followed the parameters incorporated in the Level-2 product.

Figure 2. NDVI & LST Processing Scheme



To statistically examine the relationship between vegetation density and land surface temperature, a correlation and simple linear regression analysis was conducted between NDVI and LST values for each observation year (2016, 2021, and 2025). NDVI was used as the independent variable (X), while LST was used as the dependent variable (Y). The NDVI and LST values were extracted from the same spatial locations (pixels) within the study area to ensure spatial correspondence between the two variables.

The Pearson correlation coefficient (r) was used to determine the direction and strength of the linear relationship between NDVI and LST. Simple linear regression was then applied to determine the extent to which variations in NDVI could explain variations in LST. The regression model was expressed as:

$$LST = a(NDVI) + b$$

where LST is land surface temperature ($^{\circ}\text{C}$), NDVI is vegetation density, a is the regression coefficient, and b is the intercept. The coefficient of determination (R^2) was used to indicate the proportion of variation in LST that could be statistically explained by NDVI. The correlation and regression analyses were performed separately for 2016, 2021, and 2025 using Microsoft Excel.

Sol-Air Temperature (T_{sa}) analysis used the equation:

$$t_{sa} = t_a + \frac{I\alpha}{h}$$

where: T_a = Air temperature ($^{\circ}\text{C}$); I = Global solar radiation (W/m^2); α = Material absorptivity; h = Total heat transfer coefficient ($\text{W}/\text{m}^2\text{K}$).

Wind speed was first corrected to wind speed at a height of 1 m (V_h) using the equation:

$$V_h = V_{ref} \alpha \left(\frac{h}{10} \right)^{\beta}$$

where: V_h = Wind speed at the reference height (m/s); V_{ref} = Measured wind speed (m/s); h = Observation height (m), i.e., 1; α and β = Environmental characteristic coefficients.

With the convective heat transfer coefficient $h_c = 8.55 + 2.56 \cdot V_h$, the radiation coefficient $h_r = 5 \text{ W}/\text{m}^2\text{K}$, and the vegetation evapotranspiration coefficient $h_e = 5.2 \text{ W}/\text{m}^2\text{K}$; the heat absorptivity coefficient of material values used were 0.70 for paving blocks (Stella Tsoka et al 2026), and 0.75 for grass (Stella Tsoka et al, 2026), and 0.90 for asphalt (Zheng et al, 2019).

Thermal comfort analysis used a thermal comfort regression model for seated activity in a humid tropical climate (Sangkertadi, 2012):

$$YD = -7,91 - 0,52 v + 0,047 Ta + 0,167 Tg - 0,0007 HR + 1,43 Adu$$

Thermal comfort measurements were conducted on 30 April 2026 at four purposively selected locations in Wenang District: Taman Kecamatan IPAL Reklamasi Teluk Manado, Taman Kelurahan Pohon Kasih, Taman Kota Bumi Beringin, and a high-LST, predominantly paved area in Wenang Selatan. Six observation settings were evaluated: open and shaded areas at IPAL, an open area at Pohon Kasih, open and shaded areas at Bumi Beringin, and an open area at Wenang Selatan. At each observation setting, a Delta OHM HD32.3 Thermal Comfort Meter was used to record air temperature (T_a), globe temperature (T_g), relative humidity (RH), and wind speed (v) at one-minute intervals. The body surface area (Adu) was set at 1.77 m^2 . The measurements were conducted during daytime periods to capture outdoor thermal conditions under direct and shaded exposure.

RESULTS AND DISCUSSION

Availability of Public Green Open Space

The identification results show that public green open spaces in Wenang Sub-district consists of 7 locations comprising city parks, sub-district parks, urban-village parks, and cemeteries, which are concentrated in the western and southern parts of the sub-district, particularly in Bumi Beringin and Wenang Selatan urban villages.

Figure 3. Map of Public Green Open Space

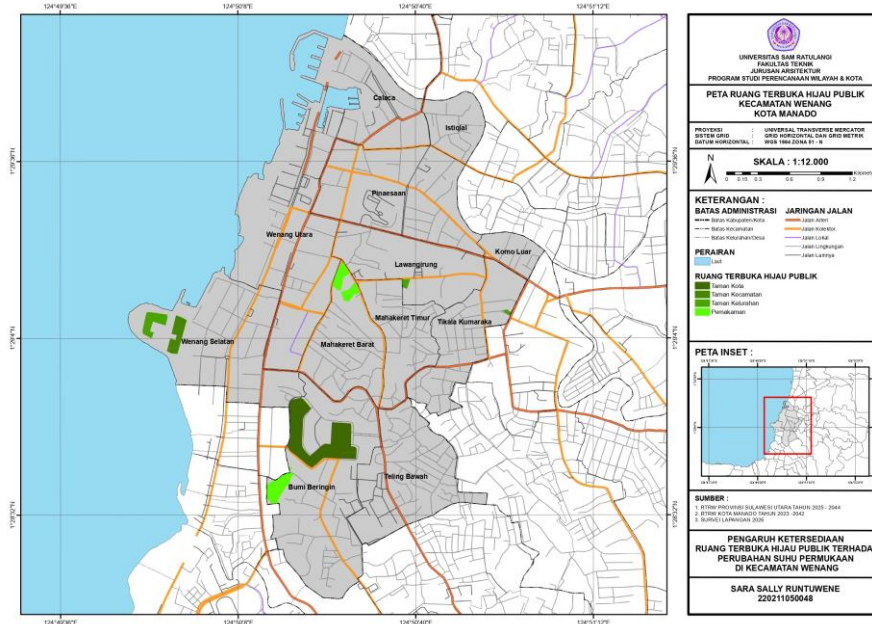


Table 1. Area and Percentage of Public Green Open Spaces in Wenang Sub-district

Type Of Public Green Open Spaces	Area (Ha)	Percentage (%)
City Park	6.08	54.33
Sub-district Park	1.18	10.55
Urban-village Park	1.30	11.62
Cemetery Park	2.63	23.50
Total	11.19	100.00

The total area of public green open spaces reaches only 11.19 Ha or 3.29% of the total area of Wenang Sub-district (339.6 Ha), far below the minimum requirement of 20% (67.92 Ha) under Law No. 26 of 2007 on Spatial Planning, leaving a deficit of 56.73 Ha.

Table 2. Availability, Need, and Deficit of Public Green Open Spaces

Description	Area (Ha)
Area of Wenang Sub-district	339.60
Total Existing Public Green Open Spaces	11.19
Minimum Required Public Green Open Spaces (20%)	67.92
Public Green Open Spaces Deficit	56.73

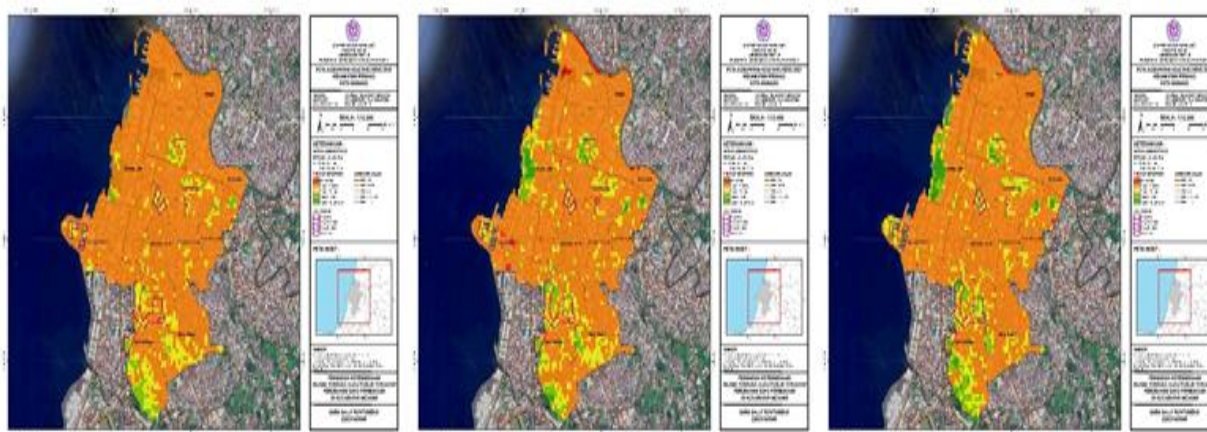
Condition and Change in Vegetation Density (NDVI) In Public Green Open Spaces

The NDVI analysis results for 2016–2025 show that most public green open spaces experienced an increase in vegetation density in the dense and very dense classes. The largest increase in the dense vegetation class occurred at Pohon Kasih Urban-village Park (+0.50 Ha) and Bumi Beringin City Park (+1.68 Ha), while the largest

increase in the very dense vegetation class occurred at the Manado Bay Reclamation WWTP Sub-district Park (+0.36 Ha). Conversely, the sparse vegetation class tended to decrease in nearly all public green open spaces, except at Tugu Dharma Wanita Urban-village Park. Overall, only Lawangirung Urban-village Park showed a decrease in vegetation density (−0.11 Ha), while the other six public green open spaces locations showed an improvement in vegetation quality over the 2016–2025 period.

Table 3. Change in Vegetation Density Class of Public Green Open Space, 2016–2025

Public Green Open Spaces	Non-vegetated	Sparse Vegetation	Moderate Vegetation	Dense Vegetation	Very Dense Vegetation
Pohon Kasih Urban-village Park	-	Decreased 0.40 Ha	Decreased 0.15 Ha	Increased 0.50 Ha	Increased 0.04 Ha
IPAL Teluk Manado Reclamation Sub-district Park	-	Decreased 0.38 Ha	Decreased 0.24 Ha	Increased 0.27 Ha	Increased 0.36 Ha
Mahakeret Barat Public Cemetery	-	Decreased 0.11 Ha	Decreased 0.16 Ha	Increased 0.26 Ha	-
Bumi Beringin City Park	-	Decreased 2.24 Ha	Increased 0.29 Ha	Increased 1.68 Ha	Increased 0.26 Ha
Titiwungen Kuhun Village Cemetery	-	Decreased 0.08 Ha	Decreased 0.07 Ha	Increased 0.09 Ha	Increased 0.06 Ha
Lawangirung Urban-village Park	-	Decreased 0.05 Ha	Decreased 0.06 Ha	-	-
Tugu Dharma Wanita Urban-village Park	-	Increased 0.06 Ha	-	-	-



Figures 4–6. Vegetation Density (NDVI) Maps for 2016, 2021, and 2025

Characteristics of Surface Temperature (LST) In Public Green Open Spaces Areas

Land surface temperature (LST) in Wenang Sub-district shows an increasing trend over the 2016–2025 period. Low-temperature areas are generally located along the coast, rivers, and around public green open spaces, while high-temperature areas are concentrated in built-up and densely populated settlements, particularly in Teling Bawah, Mahakeret Timur, Mahakeret Barat, and Wenang Selatan.

Table 4. Land Surface Temperature (LST) 2016, 2021, and 2025

Year (Recording Date)	Max Temperature (°C)	Min Temperature (°C)
27 August 2016	50.8	31.0
09 August 2021	51.6	34.3
15 October 2025	53.9	34.7

Table 5. Surface Temperature by Public Green Open Space Location, 2016–2025

Public Green Open Spaces	2016 (°C)	2021 (°C)	2025 (°C)	Change (°C)
Pohon Kasih Urban-village Park	42.3	40.1	42.3	0.00
IPAL Reclamation Sub-district Park	45.5	42.8	47.7	2.20
Mahakeret Barat Urban-village Public Cemetery	44.4	44.2	47.2	2.80
Bumi Beringin City Park	47.0	47.2	48.6	1.61
Titiwungen Kuhun Village Cemetery	43.6	45.3	45.5	1.90
Lawangirung Urban-village Park	46.3	44.5	47.9	1.60
Tugu Dharma Wanita Urban-village Park	47.0	44.9	49.3	2.30

The highest temperature increase occurred at the Mahakeret Barat Urban-village Public Cemetery (+2.80°C), followed by Tugu Dharma Wanita Urban-village Park (+2.30°C) and the Manado Bay Reclamation WWTP Sub-district Park (+2.20°C). Pohon Kasih Urban-village Park was the only location with a relatively stable surface temperature.



Figures 7–9. Land Surface Temperature (LST) Maps for 2016, 2021, and 2025

Change in Vegetation Density (NDVI) and Surface Temperature (LST), 2016–2025

The NDVI analysis results show that 6 of the 7 public green open spaces locations experienced an increase in vegetation density during 2016–2025, with the largest increase at Bumi Beringin City Park (2.23 Ha). A decrease in vegetation density occurred only at Lawangirung Urban-village Park (0.11 Ha). Nevertheless, the LST analysis results show that surface temperature continued to rise at almost all locations, with the highest increase at the Mahakeret Barat Urban-village Public Cemetery (2.8°C) and the lowest increase at Bumi Beringin City Park (1.61°C). Only Pohon Kasih Urban-village Park showed no net change in surface temperature over the full period, although, as discussed above, this masks an interim decrease followed by an equivalent increase rather than a genuinely constant temperature.

Table 6. Change in Vegetation Density (NDVI) and Land Surface Temperature (LST) of Public Green Open Space, 2016–2025

Public Green Open Spaces	Vegetation Density (NDVI)	Land Surface Temperature (LST)
Pohon Kasih Urban-village Park	Increased 0.54 Ha	Stable
IPAL Teluk Manado Reclamation Sub-district Park	Increased 0.63 Ha	Increased 2.2°C
Mahakeret Barat Urban-village Public Cemetery	Increased 0.26 Ha	Increased 2.8°C
Bumi Beringin City Park	Increased 2.23 Ha	Increased 1.61°C
Titiwungen Kuhun Village Cemetery	Increased 0.15 Ha	Increased 1.9°C
Lawangirung Urban-village Park	Decreased 0.11 Ha	Increased 1.6°C
Tugu Dharma Wanita Urban-village Park	Increased 0.06 Ha	Increased 2.3°C

It should be noted that the vegetation-density figures reported for Bumi Beringin City Park differ between Table 3 and Table 6 (an increase of 1.68 Ha versus 2.23 Ha, respectively); this is not an inconsistency in the underlying data but a difference in scope. Table 3 reports the change within the Dense Vegetation class alone, whereas Table 6 reports the combined net increase across the Moderate, Dense, and Very Dense classes (0.29 Ha + 1.68 Ha + 0.26 Ha = 2.23 Ha), net of the 2.24 Ha decline in the Sparse Vegetation class. The same class-level versus combined-total logic applies to the other locations in Tables 3 and 6.

These findings indicate that the relationship between vegetation density and surface temperature is complex. Increased vegetation cover helps lower temperature through the shading effect and evapotranspiration, but its influence has not been fully able to offset the temperature increase caused by urbanization, the dominance of impervious materials, and the expansion of paved areas around green open spaces. This condition is consistent with the IPCC Special Report on Global Warming of 1.5°C (SR15), which emphasizes that any increase in temperature, however small, has implications for increased multisectoral risk, so that controlling urban surface temperature requires nature-based solutions that focus not only on adding vegetation but also on managing materials and the spatial arrangement of the area.

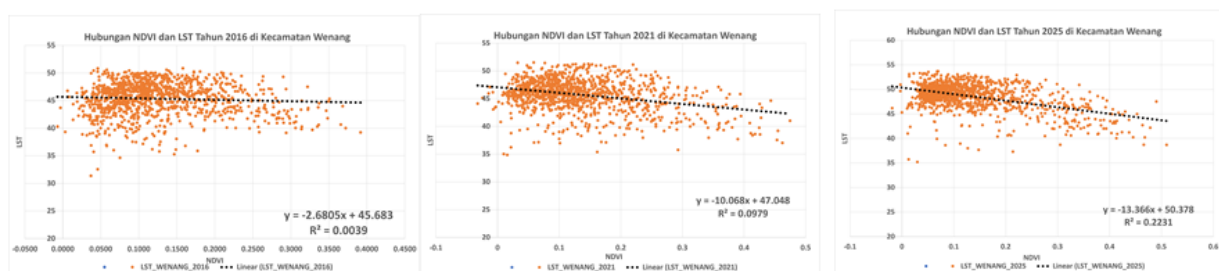
Statistical Relationship between Vegetation Density (NDVI) and Surface Temperature (LST)

To complement the spatial and location-based comparison in Table 6, a Pearson correlation and simple linear regression analysis was performed between NDVI and LST values extracted from approximately 1,144 sample points distributed across Wenang Sub-district, following the procedure described in the Data Analysis Technique section. This analysis was carried out separately for each observation year (2016, 2021, and 2025) to examine how the strength of the vegetation–temperature relationship changed over time.

Table 7. Correlation and Regression Results between NDVI and LST in Wenang Sub-district, 2016, 2021, and 2025

Year	Correlation Coefficient (r)	Coefficient of Determination (R ²)	Regression Equation	n (sample points)
2016	-0.062	0.0039 (0.39%)	LST = -2.6805(NDVI) + 45.683	1,144
2021	-0.313	0.0979 (9.79%)	LST = -10.068(NDVI) + 47.048	1,144
2025	-0.472	0.2231 (22.31%)	LST = -13.366(NDVI) + 50.378	1,144

As shown in Table 7, the correlation between NDVI and LST was negative in all three years, confirming the expected inverse relationship in which higher vegetation density is associated with lower surface temperature (Rouse et al., 1974; Sangkertadi, 2012). However, the strength of this relationship increased markedly over time: in 2016 the correlation was very weak ($r = -0.062$; $R^2 = 0.39\%$), indicating that NDVI explained almost none of the variation in LST that year, whereas by 2025 the relationship had strengthened to a moderate level ($r = -0.472$; $R^2 = 22.31\%$). A similarly weak NDVI–LST correlation in an early-period, less built-up condition has also been reported in a tropical case study by Sagita et al. (2022), supporting the interpretation that in tropical urban settings with relatively limited built-up extent, factors other than vegetation density can dominate surface-temperature variation. This trend suggests that as built-up and paved surfaces have expanded in Wenang Sub-district, the remaining vegetation has become an increasingly influential, though still partial, factor in moderating surface temperature. The comparatively weak relationship observed in 2016 also indicates that surface temperature that year was more strongly governed by other factors, such as building and paving material, surface albedo, and urban morphology, than by vegetation density alone — a pattern that is consistent with the finding in Table 6 that vegetation gains in most public green open spaces have not been sufficient to offset the overall rise in surface temperature



Figures 10–12. Scatter Plots of the Relationship between NDVI and LST in Wenang Sub-district, 2016, 2021, and 2025

Thermal Comfort in Public Green Open Space and Non-Green Open Space Areas

Thermal comfort measurements using the YD index show that the high-surface-temperature area in Wenang Selatan urban village (Non-Green Open Space Areas) has the hottest thermal condition, with YD values ranging from 2–4 and dominated by the very hot category, including 4 points in the very hot & painful category. In contrast, vegetation-shaded areas within Public Green Open Space, such as the Manado Bay Reclamation WWTP Sub-district Park and Bumi Beringin City Park, show relatively more comfortable conditions (ranging from comfortable to slightly hot), confirming the important role of shade vegetation in improving outdoor thermal comfort.

Table 8. Field Observation Sites and Measurement Timing

Observation Location	Shading	Time	Interval
IPAL Reclamation Sub-district Park	Open	10:37–10:52 WITA	1 minute
IPAL Reclamation Sub-district Park	Shaded	10:55–11:10 WITA	1 minute
Pohon Kasih Urban-village Park	Open	11:32–11:49 WITA	1 minute
Bumi Beringin City Park	Open	13:59–14:15 WITA	1 minute
Bumi Beringin City Park	Shaded	14:25–14:40 WITA	1 minute
High LST Area, Wenang Selatan	Open	12:10–12:26 WITA	1 minute

Table 9. Range of Yd Values and Thermal Comfort Conditions at Observation Locations

Observation Location	Shading	YD Value Range	Dominant Condition
IPAL Reclamation Sub-district Park	Open	Scale 1–3	Hot (Scale 2)
IPAL Reclamation Sub-district Park	Shaded	Scale 0–2	Slightly Hot (Scale 1)
Pohon Kasih Urban-village Park	Open	Scale 2–3	Hot (Scale 2)
Bumi Beringin City Park	Open	Scale 0–2	Slightly Hot (Scale 1)
Bumi Beringin City Park	Shaded	Scale 0–1	Slightly Hot (Scale 1)
High LST Area, Wenang Selatan	Open	Scale 2–4	Very Hot (Scale 3)

Placement and Development Directions for Public Green Open Space Based on Surface Temperature and Thermal Comfort

Based on the surface temperature and thermal comfort analysis results, the high-surface-temperature area in Wenang Selatan urban village is directed as a priority location for adding new Public Green Open Space, as it is dominated by built-up land and paved surfaces with limited vegetation cover and the lowest level of thermal comfort. Meanwhile, three existing Public Green Open Space— the Manado Bay Reclamation WWTP Sub-district Park, Pohon Kasih Urban-village Park, and Bumi Beringin City Park — are directed toward development through the optimization of shade vegetation, the addition of wide-canopy trees suited to each location’s characteristics, the application of more thermally friendly paving materials such as grass block or porous paving, and the arrangement of activity spaces that take vegetation shade distribution into account.

Table 10. Problems and Development Directions for Public Green Open Space

No	Public Green Open Space Location	Main Problem	Development Direction
1	IPAL Teluk Manado Reclamation Sub-district Park	Uneven vegetation cover, dominance of paved areas, and still-untended land, resulting in relatively high surface temperature in open areas.	Maintain existing shade trees, reduce the dominance of paved surfaces by using grass block or porous paving, rearrange shrub areas and untended land, and add wide-canopy trees in remaining open areas.
2	Pohon Kasih Urban-village Park	Shade vegetation concentrated on the eastern side, while the coastal area still lacks shade, so all observation points fall into the hot to very hot category.	Maintain existing vegetation, accelerate the growth of young trees, add vegetation suited to coastal characteristics, and reduce paved area to improve the distribution of shade and thermal comfort.
3	Bumi Beringin City Park	Open areas resulting from vegetation removal, and some seating facilities without optimal tree shade.	Protect existing vegetation, revegetate areas that have lost tree cover, and rearrange activity areas and seating so they are located under vegetation shade or equipped with shade structures.

CONCLUSION

1. The area of Public Green Open Space in Wenang Sub-district is 11.19 Ha (3.29% of the total area of 339.6 Ha), still far below the minimum requirement of 20% (67.92 Ha), leaving a deficit of 56.73 Ha. Most Public

Green Open Space experienced an increase in vegetation density during 2016–2025, but this increase only reflects an improvement in vegetation quality within existing Green Open Space, without being followed by an increase in the area or overall availability of Public Green Open Space.

2. The LST analysis results show that most Public Green Open Space areas experienced an increase in surface temperature during 2016–2025, with the highest increase at the Mahakeret Barat Urban-village Public Cemetery (2.8°C). Six of the seven Public Green Open Space experienced an increase in vegetation density, yet their surface temperature still increased, indicating that the increase in vegetation has not been fully able to offset the effects of built-up area development and paving materials. This is corroborated by the NDVI–LST correlation analysis, whose explanatory strength rose from $R^2 = 0.0039$ in 2016 to $R^2 = 0.2231$ in 2025, confirming that the statistical influence of vegetation density on surface temperature became more pronounced as built-up areas expanded, even as it remained insufficient to fully offset the temperature increase.

3. Areas with high surface temperature and low vegetation cover, namely the area in Wenang Selatan urban village, have the lowest thermal comfort (YD value 2–4, dominantly very hot), and are therefore directed as a priority location for adding new Public Green Open Space. Three existing Public Green Open Space are directed toward development through the optimization of shade vegetation, the application of thermally friendly materials, and spatial arrangement that supports thermal comfort.

Limitations

This study has several limitations that should be considered when interpreting the results. First, while satellite-derived LST was cross-checked against field verification (ground check) and Sol-Air Temperature analysis at sample locations, no quantitative validation statistics (e.g., RMSE or MAE) between the Landsat Level-2 LST product and field-measured temperatures were computed; future studies could strengthen confidence in the satellite-derived values by reporting such statistics. Second, the NDVI–LST relationship was assessed through correlation and regression analysis (Table 7) without a buffer-based analysis of surrounding built-up land use, so the extent to which adjacent development specifically offsets the cooling effect of a given green space could not be isolated. Third, each annual NDVI and LST dataset was derived from a single Landsat scene (27 August 2016, 9 August 2021, and 15 October 2025), so year-to-year differences may partly reflect seasonal or short-term meteorological variation rather than long-term land-cover change alone, as illustrated by the non-monotonic temperature pattern at Pohon Kasih Urban-village Park. Finally, this study focuses on surface temperature rather than near-surface air temperature, which future research combining LST with air-temperature measurements (as noted in Recommendation 3) can help address.

RECOMMENDATIONS

1. The Manado City Government is advised to increase the provision of Public Green Open Space in Wenang Sub-district, prioritizing areas with high surface temperature, low vegetation cover, and low thermal comfort. Given that Wenang Sub-district is already almost fully built up, acquiring land for large new parks may not always be feasible; a land-availability assessment (e.g., identifying underused public land, road reserves, or vacant parcels) should therefore accompany this recommendation. Where new land acquisition is not feasible, alternative and complementary greening strategies should be considered, including pocket parks on small or irregular plots, green roofs and green walls on public and commercial buildings, street-tree corridors, and vertical greening along paved corridors, each of which can contribute shade and cooling within a dense urban fabric.

2. The development of existing Public Green Open Space should be directed toward improving the quality of shade vegetation and using more thermally friendly surface materials, accompanied by activity-space arrangements that take shade distribution into account.

3. Future research is recommended to combine LST analysis with air temperature measurements at a height of 1.5–2 meters at the same observation points, in order to provide a more comprehensive picture of the relationship between surface temperature, air temperature, and thermal comfort.

4. Implementation should specify responsible actors and financing mechanisms: the Manado City Parks and Landscaping Agency and the Regional Development Planning, Research, and Development Agency (Bappelitbangda) can lead land identification and park development, the Public Works Agency can incorporate porous paving and street-tree corridors into road and drainage projects, and private-sector or community partnerships (e.g., corporate social responsibility funding, community-managed pocket parks, or green-roof incentives for building owners) can support smaller-scale greening measures where municipal budgets or land are constrained.

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