



Spatial Temporal Analysis of Thermal Comfort to Make Liveable City in Palembang, Indonesia

TECHNICAL ARTICLE

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ABSTRACT

Increased anthropogenic activities and reduced urban green space contribute to heating problems, impacting the thermal comfort of urban spaces. This research analyzes spatial-temporal of thermal comfort to inform the creation of liveable cities. Palembang City, experiencing rapid urbanization and land-use changes, was chosen as the study area. Landsat 8 data from 2013 to 2023 was obtained and processed using Google Earth Engine. The land surface temperature algorithm applied to the Landsat 8 thermal infrared channel (band 10) provided data for thermal comfort assessment. Vegetation cover was assessed using the Enhanced Vegetation Index (EVI), and the Normalized Difference Built-up Index (NDBI) combined with the Normalized Burn Ratio 2 (NBR2) was used to refine the identification of built-up areas. These algorithms were applied to channels that had been corrected for surface reflectance radiometry to minimize bias caused by seasonal variations and atmospheric disturbances. The results revealed spatial variations in thermal comfort, with uncomfortable patterns in the central business zone, some comfortable areas in the transition zone, and generally comfortable conditions in the suburban zone. The comparison between EVI and NDBI-NBR2 showed a linear relationship, suggesting that areas previously covered by vegetation have been converted into built-up area. This confirms that land cover conditions, particularly the conversion of vegetation to built-up areas, influence the observed phenomenon. Spatial-temporal analysis of thermal comfort can be a valuable parameter for urban planning. Policymakers can utilize this information as a control mechanism to contribute to the creation of more livable cities.

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INTRODUCTION

Changes in urban land use play an important role in influencing regional climate (García et al., 2023; Imran et al., 2021). Urban researchers are increasingly focused on local and regional climate change phenomena driven by anthropogenic activities, particularly land-use changes (Delfs & Ma, 2022; Kaplan et al., 2018; Yang et al., 2021). These activities often lead to increased space requirements, triggering land-use change and a reduction in green open space. This, in turn, results in higher CO₂ emissions (Sumarmi et al., 2021; S. Wang et al., 2019). Notably, conversion of vegetated land and water bodies to non-vegetated areas, such as settlements, intensifies urban heat islands and contributes to regional climate change (Z. Wang et al., 2015; Mwangi et al., 2018; Richards & Belcher, 2020). The increase in built-up area and reduction in vegetation cover can cause local climate changes (Purwanto et al., 2016; Utaya, 1996; Voogt & Oke, 2003).

Palembang, a vibrant metropolis nestled in South Sumatra, Indonesia, teems with life under a tropical sky. The city offers a clear distinction between the wet and the dry seasons. The Musi River, which divides the city into Palembang Ulu and Palembang Ilir, is a defining feature of Palembang's hydrology (D Nguyen et al., 2016). Palembang's population has grown from 1.5 million in 2013 to an estimated 1.7 million in 2024, resulting in a dense urban environment. In relation to thermal comfort, this can lead to feelings of crowding, competition for resources, and a general sense of overwhelm (D Nguyen et al., 2016; Helmi & Wahab, 2023; Marpen et al., 2022; Sinatra et al., 2021). Further, Palembang city's growth has its challenges. The surge in housing demand has driven development into wetland areas. This conversion of natural landscapes alters the composition of thermal mass materials (buildings, vegetation, water bodies) that regulate air temperature (Rusdayanti et al., 2021; Triyuly et al., 2021). This can contribute to the urban heat island phenomenon, ultimately raising air temperatures and affecting overall thermal comfort (García et al., 2023; Rupp et al., 2015; Zhu et al., 2022). Despite Palembang's efforts to provide green spaces for thermal comfort, the city's rapid transformation outpaces these efforts, leaving a growing gap in needs.

Palembang's experience with rising temperatures is not unique. Many cities face similar challenges due to rapid urbanization, coastal location, and tropical climates. Bangkok, Kuala Lumpur, and Singapore exemplify the challenges of thermal discomfort in Southeast Asia. Densely populated with limited green spaces, and frequent traffic congestion contribute to the urban heat island effect. Combined with hot and humid weather, the cities experiences thermal discomfort throughout much of the year. In recognition of the need for improved thermal comfort, these Southeast Asian cities have incorporated strategies like promoting denser, mixed-use development with integrated green spaces, prioritizing green

infrastructure, promoting sustainable transportation, and identify areas experiencing discomfort. Additionally, they utilize remote sensing data and potentially mobile monitoring units to capture data on temperature, humidity, and wind speed across the city, allowing them to target interventions most effectively (Banerjee et al., 2022; Chea et al., 2021; Ishak et al., 2023). By studying the challenges and solutions employed by these cities, Palembang can gain valuable insights. Adapting these strategies to the specific context of Palembang can lead to improved thermal comfort for its residents.

Thermal comfort is an important indicator for creating urban livability (Hartabela et al., 2021; Richards & Belcher, 2020). Changes in surface temperature will affect the sensation of human comfort (Johansson, 2006; Kruger et al., 2011; Chàfer et al., 2022). Comfort conditions can also be defined as thermal neutrality, which means that a person feels neither too cold nor too hot. Thermal comfort is a complex relationship between surface temperature, air humidity, and air flow speed, coupled with the type of clothing and activities as well as the occupant's metabolic level which provides an expression of feelings of satisfaction with the air conditions in an environment (Gagge et al., 1967; Jo et al., 2023; Rupp et al., 2015). Rapid urbanization has a negative impact on the livability of cities (De Jong et al., 2015; Lehmann, 2016; Fogelman & Christensen, 2022). However, well-planned future urban transformation leads to a safer, healthier and more livable environment. The concept of a livable city emerged as a solution (Boyko et al., 2017; Leach et al., 2020; Dietrich, 2021). In general, a livable city is associated with three dimensions, namely economy, environment and quality of life (Randhawa & Kumar, 2017). Liveable city based on these three dimensions has an effect on local and regional thermal comfort, when the pressure of city development is massive and beyond what was planned, it will be characterized by variations in the condition of the city's thermal comfort (Imran et al., 2021; Mesimäki et al., 2017).

Maintaining thermal comfort presents a significant consideration for urban planning in its pursuit of creating livable cities (De Jong et al., 2015; Fogelman & Christensen, 2022). A surge in studies and research efforts has emerged, focusing on managing through the implementation of the green city concept. However, it is also important to be aware of the changing conditions and local needs. This include monitoring thermal comfort and its intricate connection to the application of spatial-temporal technology (Abdelkader et al., 2024; Hwang et al., 2017). Spatial-temporal analysis helps prioritize resources for interventions with the highest impact, identify the priority of areas, evaluate effectiveness and inform planning decisions, leading to more efficient resource allocation and improved cost-effectiveness of thermal comfort solutions (Hwang et al., 2017; Mwangi et al., 2018). While past studies on thermal comfort have made valuable contributions,

a gap remains in the utilization of spatial-temporal approaches to comprehensively assess thermal comfort and its implications for livable cities.

This research aims to conduct a spatial and temporal analysis of thermal comfort to inform the creation of livable cities. Land Surface Temperature (LST) data from the past 10 years (2013–2023) will be used and analyzed in relation to vegetation cover and built-up cover. LST refers to the temperature of the earth's surface, derived from solar radiation, and impacts organisms and ecosystems at local and global scales. In this study, LST data will be obtained from the thermal infrared channel of Landsat 8 satellite imagery. The research will also examine the dynamic changes in vegetation cover and built-up cover to determine their influence on thermal comfort in urban areas.

METHODS

This research employs a spatial and temporal approach, utilizing Landsat 8 (OLI/TIRS) data acquired from 2013 to 2023. The data is level 2, collection 2, tier 1, path 124 and row 62. This collection provides land surface characteristics, including surface reflectance (corrected for atmospheric effects) and surface temperature. The data encompasses bands: five visible and near-infrared (VNIR), two short-wave infrared (SWIR) with geometric distortions corrected, and one thermal infrared (TIR) processed to surface temperature. Additionally, the data includes intermediate bands used for calculating surface temperature and quality assurance (QA) bands. Landsat 8 (OLI/TIRS) image courtesy of the U.S Geological Survey. Landsat 8 boasts a spatial resolution of 30 meters for multispectral (VNIR & SWIR) sensors and 100 meters for thermal sensors. The satellite has a 16 days recording repetition period, supporting temperature and land cover analysis in urban areas (Mwangi et al., 2018).

Landsat 8 was obtained and processed using the Google Earth Engine (GEE) platform to facilitate and speed up data processing because it is based on cloud computing (Bachri et al., 2022; Ermida et al., 2020; Sari, Ike Astuti, 2019). For robust analysis in GEE, we prioritize data from reputable sources like NASA and USGS. We further ensure data credibility by consulting the documentation for details on processing, sensor types, resolution, and any known limitations (Ermida et al., 2020). In relation to this study, acquiring optimal remote sensing data for Indonesia can be challenging due to frequent cloud cover, which hinders clear observation of the land surface. To address the challenge of persistent cloud cover, Google Earth Engine (GEE) offers a function called reducer. Earth Engine's reducers allow to summarize data across time, space, image bands, or even lists. By applying a reducer

to a collection of images, we can create a single image that represents the minimum, maximum, average, or variability across the entire collection (Chen et al., 2021). By carefully evaluating data credibility and limitations, and employing appropriate data handling and analysis techniques, it is possible to conduct research in GEE that yields credible and accountable findings.

Utilizing a spatial-temporal analysis approach, this study investigates the evolving relationship between thermal comfort, vegetation cover, and built-up coverage across Palembang City. Spatial-temporal analysis is a powerful technique that examines how phenomena unfold across geographic locations and through time. The procedure for conducting spatial-temporal analysis is illustrated in Figure 1. The processing involves applying the Land Surface Temperature algorithm to the thermal infrared channel (band 10) of Landsat 8 data to obtain thermal comfort in Palembang City. Vegetation cover extraction uses the Enhanced Vegetation Index (EVI) algorithm, and the Normalized Difference Built-up Index (NDBI) algorithm combined with Normalized Burn Ratio 2 (NBR2) are used to obtain built-up cover (Mwangi et al., 2018; Salam & Rahman, 2014). These three algorithms are applied to channels that have been corrected for surface reflectance radiometry to minimize bias due to seasonal differences and atmospheric disturbances. A spatial analysis focusing on 18 sub-districts in Palembang City examined thermal comfort, vegetation cover, and built-up cover across yearly timescales from 2013 to 2023.

THERMAL COMFORT

The Land Surface Temperature (LST) algorithm analyzed Landsat band 10 data to create thermal comfort maps from 2013 to 2023, aiding in thermal comfort assessment in Palembang City (Lillesand et al., 2015):

a. Digital Numbers into Spectral Radiance (Ali, 2021)

$$Ly = \left(\frac{L_{max} - L_{min}}{Q_{calmax}} \right) Q_{cal} + L_{min} \quad (1)$$

Information:

- Ly : Spectral radiance W/(m².sr.μm)
- Qcal : Digital value (DN)
- Qcalmin : Minimum digital value
- Qcalmax : Maximum digital value
- LMINλ : Spectral radiance scale W/(m².sr.μm)
- LMAXλ : Maximum spectral radiance scale n W/(m².sr. μm)

b. Spectral Radiance becomes TOA Reflectance (Lillesand et al., 2015)

$$\rho_p = \frac{\pi * L_k * d^2}{ESUN_\lambda * \cos\theta_s} r^2 \quad (2)$$

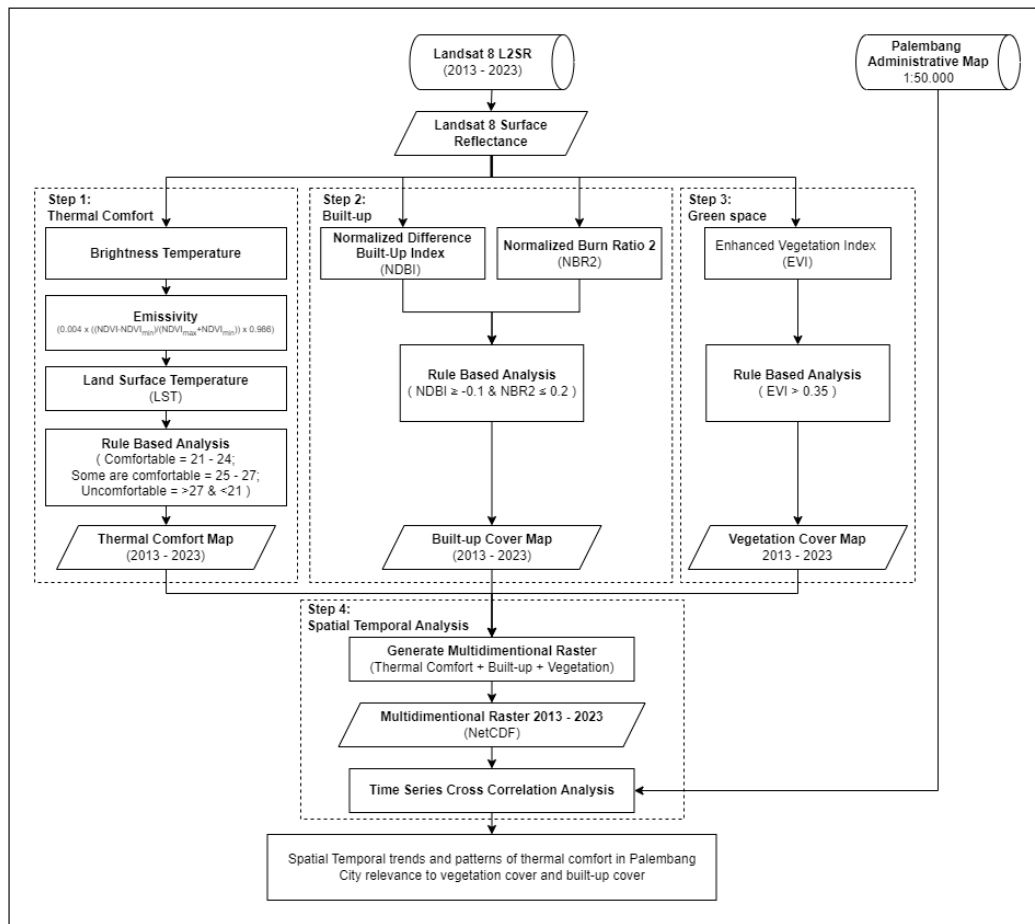


Figure 1 Research flow diagram.

Information

ρ_p : TOA reflectance

L_λ : Spectral radiance on the sensor surface

d : Distance of the earth from the sun (astronomical units)

$ESUN_\lambda$: Average exoatmospheric irradiance on sun

θ_s : Solar zenith

- c.** TOA Reflectance becomes Brightness Temperature (García et al., 2023)

$$BT = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)} - 273 \quad (3)$$

Information

Q : Thermal brightness

$K1$: Calibration constant 1 $W/(m^2 \cdot sr \cdot \mu m)$

$K2$: Calibration constant 2 $W/(m^2 \cdot sr \cdot \mu m)$

L_λ : Spectral radiance at the sensor's aperture

- d.** Normalized Difference Vegetation Index (Choudhury et al., 2019)

$$NDVI = \left(\frac{\text{Infrared Thermal} - \text{Red}}{\text{Infrared Thermal} + \text{Red}} \right) \quad (4)$$

- e.** Proportion of Vegetation Cover (García et al., 2023)

$$P_V = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}} \right) \quad (5)$$

- f.** Emissivity (ϵ) (García et al., 2023)

$$\epsilon = 0.004 * P_V * 0.986 \quad (6)$$

- g.** Land Surface Temperature (García et al., 2023)

$$LST = \left(\frac{BT}{1 + \left(\frac{0.00115 * BT}{1.4388} \right) * \ln(\epsilon)} \right) \quad (7)$$

- h.** Classify Thermal Comfort Levels

Classifying the level of thermal comfort from the results of LST processing into the following categories:

TEMPERATURE (°C)	CATEGORY
21–24	Comfortable
25–27	Some are comfortable
>27 and <21	Uncomfortable

Table 1 Classification of thermal comfort levels.

Source: (Simath & Emmanuel, 2022; Zare et al., 2018) with modifications.

VEGETATION COVER

The Enhanced Vegetation Index (EVI) algorithm allows for the extraction of green space or vegetation cover (Zhen et al., 2023). It surpasses the Normalized Difference Vegetation Index (NDVI) in accuracy for assessing vegetation health. EVI tackles atmospheric interference and background noise, making it the superior tool for monitoring dense vegetation.

$$EVI = 2.5 \times \left(\frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + 6 \times \text{Red} - 7.5 \times \text{Blue} + 1} \right) \quad (8)$$

BUILT-UP COVER

The Normalized Difference Built-up Index (NDBI) algorithm is used to obtain building cover (Mwangi et al., 2018; Salam & Rahman, 2014). Normalized Burn Ratio 2 (NBR2) modifies the Normalized Burn Ratio (NBR) to highlight water sensitivity in vegetation. By analyzing both NDBI and NBR2, we can distinguish built-up areas from natural landscapes.

$$NDBI = \left(\frac{\text{Short Wave Infrared} - \text{Near Infrared}}{\text{Short Wave Infrared} + \text{Near Infrared}} \right) \quad (9)$$

$$NBR2 = \left(\frac{\text{Short Wave Infrared 1} - \text{Short Wave Infrared 2}}{\text{Short Wave Infrared 1} + \text{Short Wave Infrared 2}} \right) \quad (10)$$

SPATIAL TEMPORAL ANALYSIS

The Time Series Cross Correlation tool is a powerful technique for analyzing relationships between spatial and temporal data (Rolwes & Böhm, 2023; Sumarmi et al., 2020, 2021). It calculates how well two data types (primary and secondary) align at different time shifts, revealing both descriptive correlations (data alignment) and potential causal relationships (delayed influence of one variable on another). This research leverages this tool to examine factors influencing thermal comfort across 18 sub-districts in Palembang City. We explore the interaction patterns between vegetation cover, built-up cover, and their combined effects on thermal comfort.

RESULTS AND DISCUSSIONS

Urban Climatology discusses the influence of climate aspects on urban planning. Palembang, a city with a split city typology and a tropical climate. The average monthly temperature of Palembang City based on data recorded by Indonesian Agency for Meteorological, Climatological and Geophysics or simply BMKG in 1991–2020 is around 27.5°C–28.6°C (Figure 2a). In contrast, the average monthly land surface temperature (LST) processed from 2013–2023 shows a range of 24.2°C–26.5°C (Figure 2b). The average yearly temperature for Palembang City based on LST processing from 2013–2023 is 24.8°C (Figure 3). This difference in temperature values between

BMKG data and LST results is likely due to the absence of field measurements and regression analysis in the LST processing. Furthermore, the temperature measured by Meteorological, Climatological, and Geophysical Agency is air temperature, while the temperature obtained from LST processing results is land surface temperature and/or environmental temperature in pixel units of 100 × 100 meters. From analyzing these two data sets, we can identify dry months occurring from May to October and wet months from November to April. October experiences the highest temperature, while January sees the lowest. The relatively constant average monthly and annual temperatures, forming a sinusoidal pattern in Palembang City, can be attributed to its geographical position close to the equator (Sunday et al., 2011).

The results of LST processing for 2013–2023 show that 18 sub-districts in Palembang City have varying yearly cumulative temperature conditions (Figure 4a). The sub-districts with the highest cumulative temperatures, Ilir Timur I, Bukit Kecil, Kemuning and Ilir Barat II, are all part of Palembang City's central business district (CBD). The lowest cumulative temperature was found in the sub-urban sub-districts of Palembang City, including Gandus. Referring to Palembang City Regional Regulation No. 15 of 2012, Gandus and Pulo Kerto are directed to become central areas for integrated agriculture with an agropolitan concept, likely contributing to the consistently lower temperatures in the area each year.

The phenomenon of temperature increase in each sub-district during the period 2013–2023 is shown in Figure 4b. The sub-districts with the highest annual temperature increase, exceeding 1.5°C, are Alang-alang Lebar and Sukarami. The high temperature increase in Alang-alang Lebar is likely due to planned development as a settlement area, facilitated by programs called Ready to Build Area and Ready to Build Environment, which aim to expedite development. Meanwhile, the high temperature increase in Sukarami is because this area is planned to become a technology and light industry area. The sub-districts with the least temperature increase are Ilir Barat II and Seberang Ulu I. Ilir Barat II is home to the Bukit Siguntang green open space and the Sriwijaya Royal Archaeological Park. Additionally, the relatively expensive price of land means that land conversion is relatively low, contributing to lower temperature increases. The low temperature increase in Seberang Ulu I is likely due to the unsuitable condition of the peatlands for development as residential and cultivation areas, resulting in slower land conversion.

Analysis of EVI data during the 2013–2023 period in Palembang City allowed for mapping the extent of vegetation cover. An EVI value greater than 0.35 was used as the threshold for classifying vegetation cover, which can include shrubs, grass, woody and broad-leaf vegetation (Fariña et al., 2023). Built-up cover in Palembang City from 2013–2023 was identified by processing NDBI and NBR2 data. Areas with NDBI values

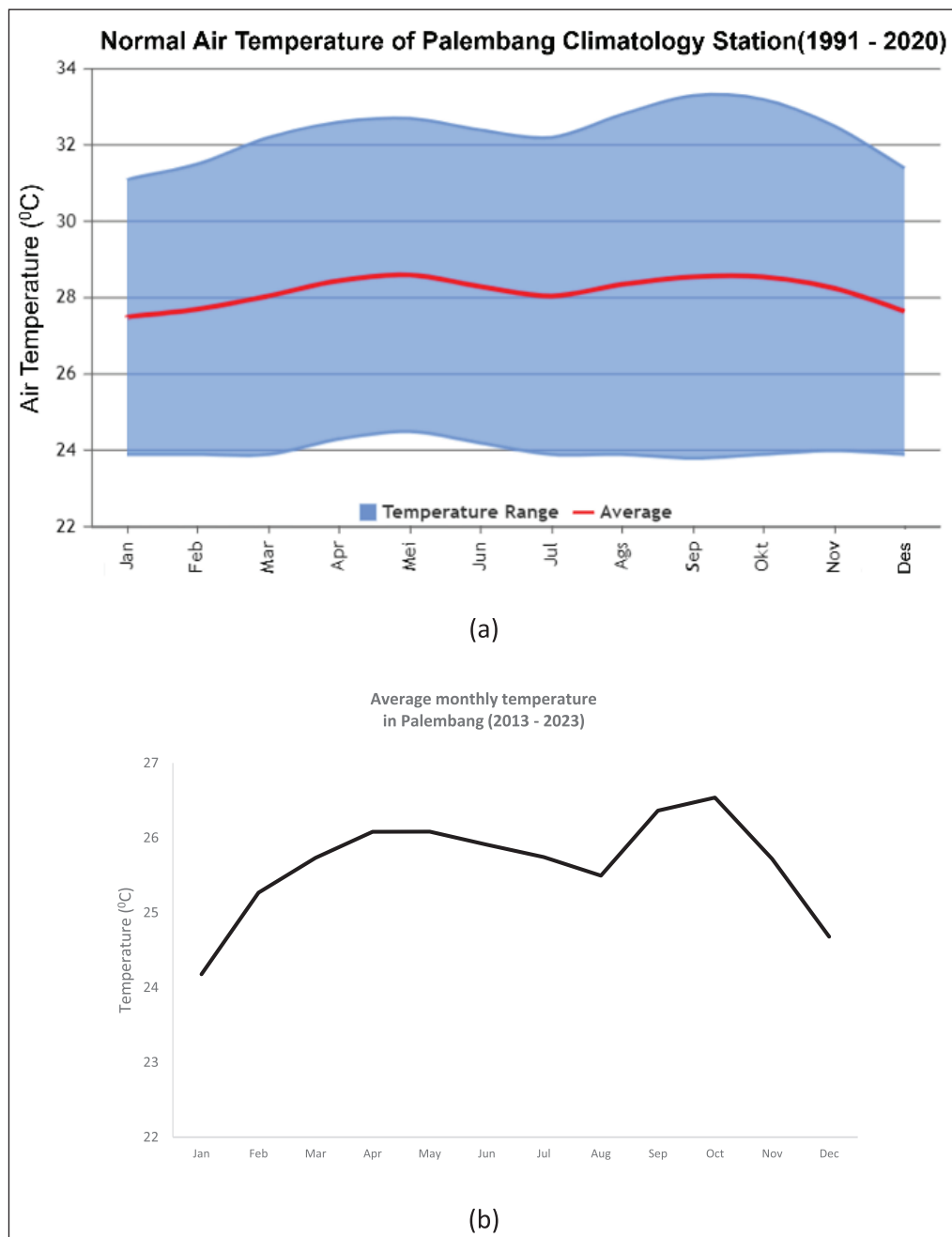


Figure 2 (a) Average monthly air temperature in Palembang City as recorded by the BMKG climatology station for 1991–2020; **(b)** Average monthly surface temperature resulting from LST processing for Palembang City 2013–2023.

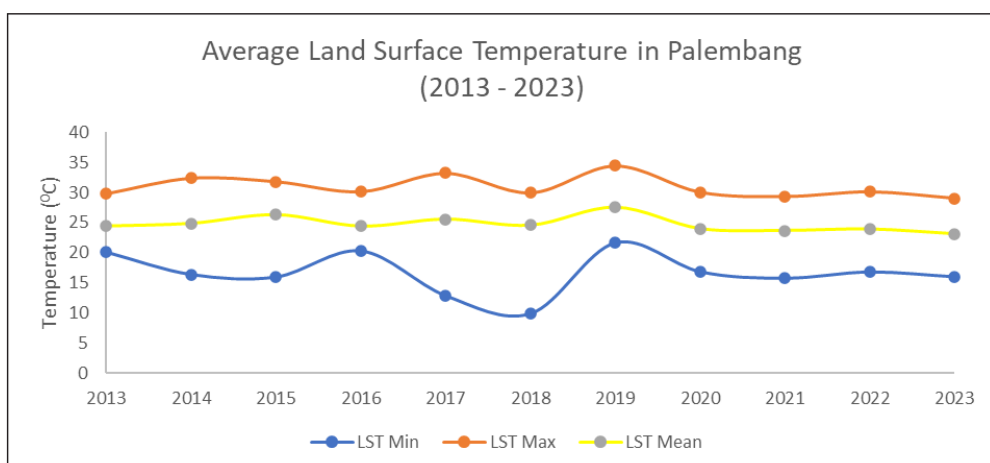


Figure 3 Average yearly temperature resulting from LST processing in Palembang City for 2013–2023.

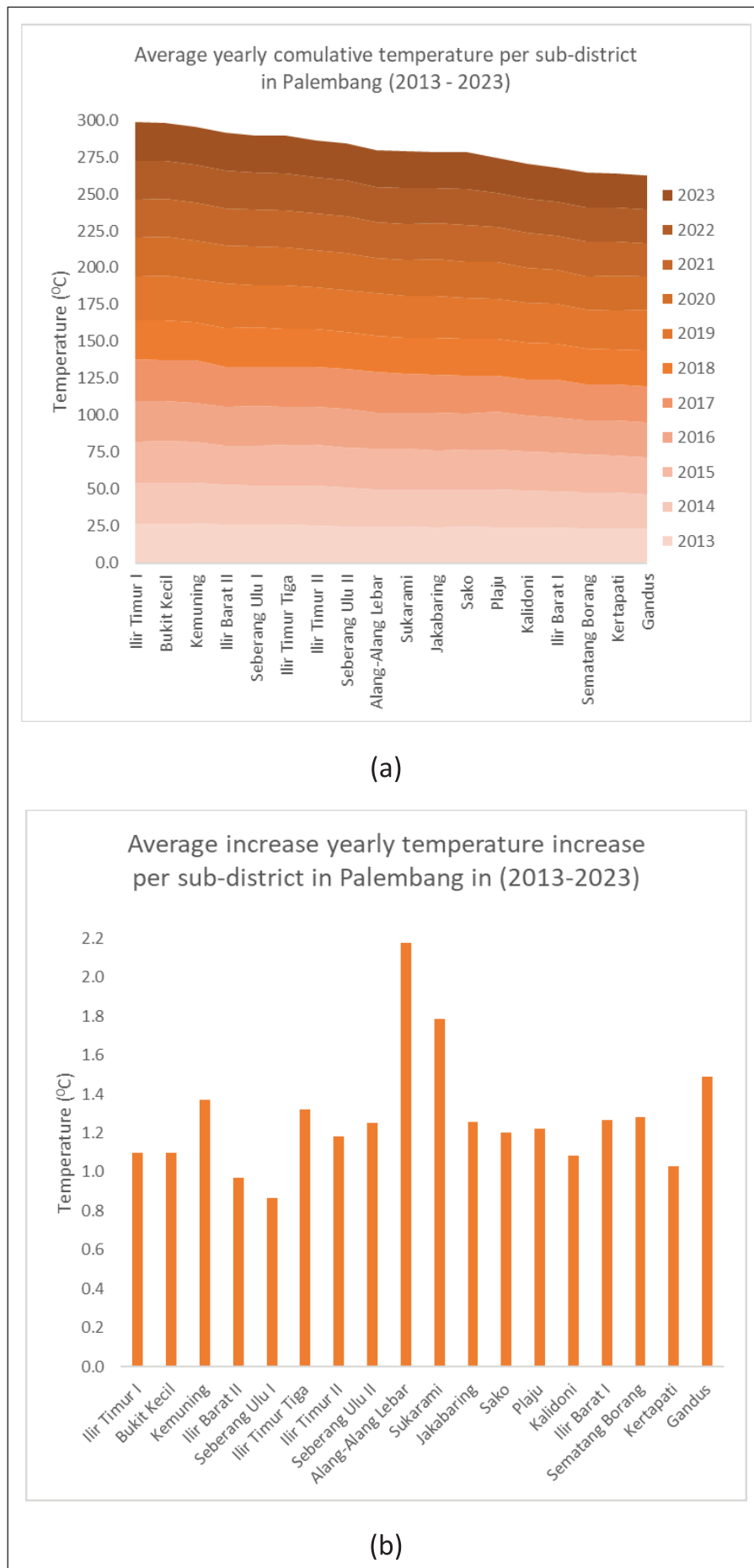


Figure 4 (a) Average yearly cumulative temperature per sub-district in Palembang City in 2013–2023; **(b)** Average increase yearly temperature per sub-district in Palembang City in 2013–2023.

exceeding -0.1 and NBR2 values below 0.2 were classified as built-up cover. Higher NDBI values generally indicate a greater proportion of built-up cover compared to other land cover types (Muhaimin et al., 2022).

Figure 5a presents changes in vegetation cover area per sub-district in Palembang City from 2013 to 2023. Three sub-districts hold the highest vegetation cover, exceeding 57%: Sematang Borang, Gandus, and Ilir Barat I. Conversely, the three sub-districts with the lowest vegetation cover, less than 10% are Ilir Timur I, Bukit Kecil, and Kemuning. The sub-districts that lost the most vegetation cover were Sukarami, Ilir Timur Tiga and Alang-alang Lebar. As indicated by Palembang City Regional Regulation No. 15 of

2012, the decline in vegetation cover in Sukarami is likely due to its planned development as an Industrial and Light Industry Area. Meanwhile, the development of the ready-to-build area and ready-to-build environment program in Alang-alang Lebar, explained in the previous paragraph, is another contributing factor. Analysis of NDBI and NBR2 data for each sub-district in Palembang City (Figure 5b) reveals a general increase in built-up cover area. The sub-districts with the highest percentage of built-up cover are Ilir Timur I, Kemuning, and Bukit Kecil, with values exceeding 80%. Sukarami, Sematang Borang, and Gandus experienced the most significant conversion of non-built-up cover to built-up cover.



Figure 5 (a) Area of vegetation cover per sub district in Palembang City in 2013–2023; **(b)** built-up cover area per sub-district in Palembang City in 2013–2023.

Figure 6 presents the average synthesis of vegetation cover area and the built-up cover area for 18 sub-districts in Palembang City (2013–2023). Ilir Timur Tiga exhibits a high percentage of both vegetation cover and built-up cover. Plaju, Seberang Ulu Dua, and Jakabaring have relatively balanced vegetation and built-up cover. Sematang Borang, Sukarami, Ilir Barat Satu, and Gandus sub-districts have a high percentage of vegetation cover but a low percentage of built-up cover. Kemuning, Ilir Timur Satu, Bukit Kecil, Ilir Barat II, and Seberang Ulu Satu have a high percentage of built-up cover but a low percentage of vegetation cover.

Analysis of vegetation cover and built-up cover across Palembang's 18 sub-districts reveals a trend of land cover conversion from vegetation to built-up areas. Correlation analysis between built-up cover area and vegetation cover area in each sub-district further strengthens this observation, revealing a negative relationship indicated by the R^2 value of -0.73 (Figure 8). This negative value indicates an inverse relationship, meaning that a decrease in vegetation cover area is associated with an increase in built-up cover area. As supported by previous research (Hernawati et al., 2020; Fikriyah & Sunariya, 2022), this suggests that areas with more extensive vegetation cover tend to have lower temperatures, while areas dominated by built-up cover experience higher temperatures.

Analysis of the processing results reveals thermal comfort variations across Palembang City from 2013 to 2023, categorized as comfortable, some are comfortable, and uncomfortable (Figure 7). A positive linear relationship exists between thermal uncomfortable and built-up cover area. Conversely, thermal uncomfortable shows a negative linear relationship with vegetation cover area, indicating that less vegetation cover is associated with increased uncomfortable. Furthermore, the results of NDBI and NBR2 processing show that the red area representing built-up cover expands each year. This suggests ongoing conversion of vegetated areas into built-up cover. Therefore, the observed temperature increase in Palembang City is likely influenced by land cover changes, particularly the decrease in vegetation cover. However, an anomaly appears in the data for 2021. While EVI and NDBI-NBR2 results suggest land cover conversion continued, there was a decrease in temperature. This anomaly can likely be attributed to the lockdown policy implemented due to the COVID-19. Restrictions on people's outdoor activities, reduced traffic congestion, and a halt in industrial operations all likely contributed to the observed decrease in temperature in 2021. This finding highlights that both land cover and human activities can influence temperature dynamics in the city.

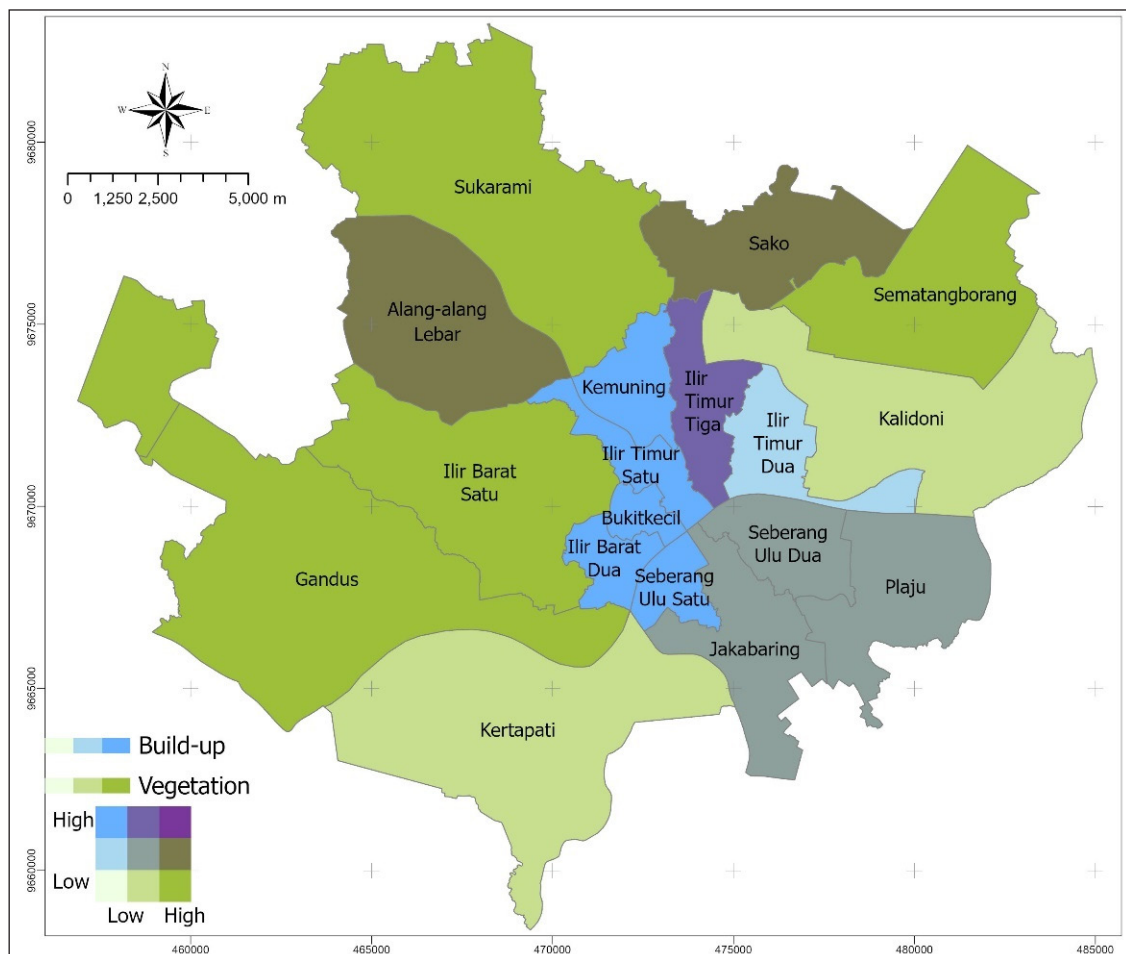


Figure 6 Bivariate maps of vegetation cover and built-up cover.

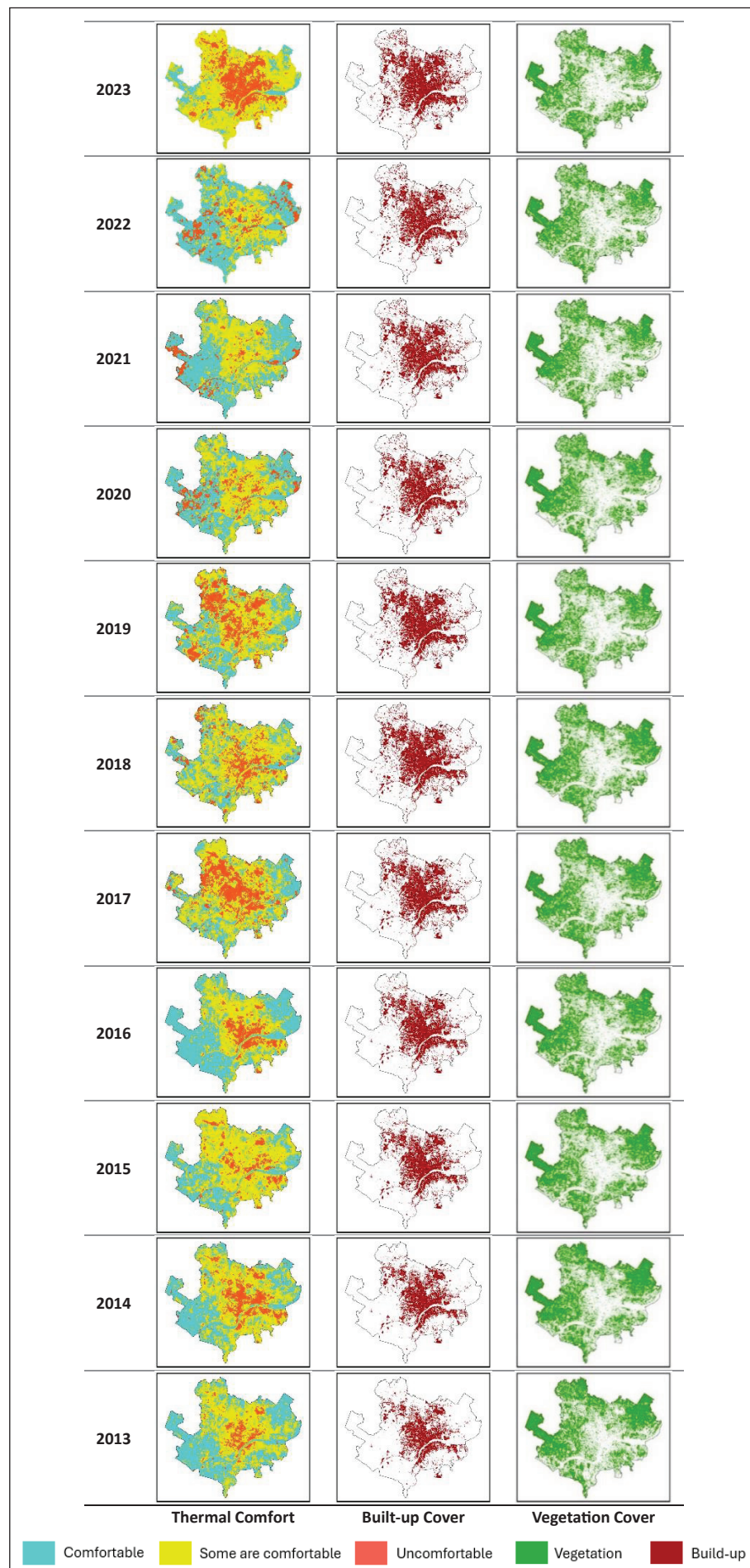


Figure 7 Thermal Comfort, Vegetation Cover, and Built-up Cover of Palembang City in 2013–2023.

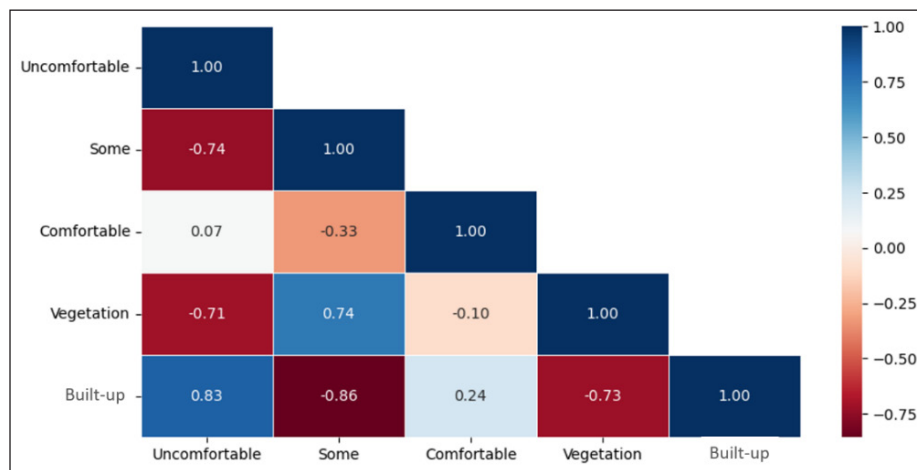


Figure 8 Correlation matrix of thermal comfort, vegetation cover, and built-up cover.

Figure 8 shows a positive correlation ($R^2 = 0.83$) between thermally uncomfortable areas and built-up cover, and a negative correlation ($R^2 = -0.71$) with vegetation cover. In simpler terms, as the percentage of built-up cover increases, the area experiencing thermal uncomfortable also increases. Conversely, a higher percentage of vegetation cover is associated with a decrease in thermal uncomfortable. This suggests that increasing built-up cover is a key factor contributing to thermal uncomfortable, while vegetation cover has the potential to mitigate it. A similar pattern is observed for “some are comfortable” areas. Here, a positive correlation ($R^2 = 0.74$) exists with vegetation cover and a negative correlation ($R^2 = -0.86$) with built-up cover. This means that areas with more vegetation tend to be some are comfortable, while increasing built-up cover reduces such comfort levels. Interestingly, the analysis of “comfortable” areas reveals no significant relationship with either vegetation cover or built-up cover. This could be because these areas experience less dynamic changes in vegetation cover compared to peripheral areas. Based on this correlation analysis, it is clear that monitoring and regulating vegetation cover, particularly in rapidly developing areas, should be a key element in urban planning strategies to address thermal uncomfortable.

The analysis of land surface temperature, vegetation cover, and built-up land area across Palembang’s 18 sub-districts reveals a link between uneven spatial development and thermal uncomfortable. For instance, sub-districts with denser vegetation, like Gandus, tend to have lower temperatures, suggesting a more comfortable living environment. Conversely, sub-districts with extensive built-up areas and less vegetation, like Ilir Timur I and Bukit Kecil, experience higher temperatures, which can contribute to increased heat stress and lower quality of life for residents. This highlights the need for spatial planning strategies that consider the existing distribution of green spaces and infrastructure to create a more balanced and thermally comfortable city for all residents.

GEE data can be a valuable tool for determining a city’s livability based on temperature characteristics (Châfer et al., 2022; Simath & Emmanuel, 2022). Figure 9 shows that 11 from 18 sub-district in Palembang City fall into the comfortable category. These sub-districts include Alang-alang lebar, Ilir Barat Dua, Ilir Timur Tiga, Jakabaring, Kalidoni, Kemuning, Plaju, Sako, Seberang Ulu Dua, Seberang Ulu Satu, and Sukarami. Four sub-districts (Gandus, Ilir Barat Satu, Kertapati and Sematang Borang) are categorized as “some are comfortable,” with these areas exceeding 45% coverage in this category. Conversely, three sub-districts (Bukit Kecil, Ilir Timur Dua, and Ilir Timur Satu) fall into the “uncomfortable” category, where this classification covers more than 37% of their area. The analysis reveals spatial variations in thermal comfort across the city, with an uncomfortable pattern concentrated in the central business zone, a dominance of “some are comfortable” areas in the transition zone, and a prevalence of “comfortable” areas in the suburban zone.

This study offers valuable insights into the relationship between vegetation cover, built-up cover, and thermal comfort in Palembang City. However, further research is necessary to fully understand the nuances of the city’s thermal environment. Delving deeper to differentiate between Land Surface Temperature (LST) and air temperature, along with their determining factors such as humidity and wind patterns, and how these elements interact, will be crucial for developing more comprehensive thermal comfort models and targeted urban planning strategies. This will ultimately lead to the creation of a more livable and thermally comfortable Palembang City for all residents.

Rapid development and continuous human activity in Palembang City can reshape its urban environment. This directly or indirectly affects Palembang’s climate elements, with the most noticeable change being an increase in surface-layer temperature. The rate of temperature increase is likely proportional to the pace of city development (Fukui, 2003). The greater the area

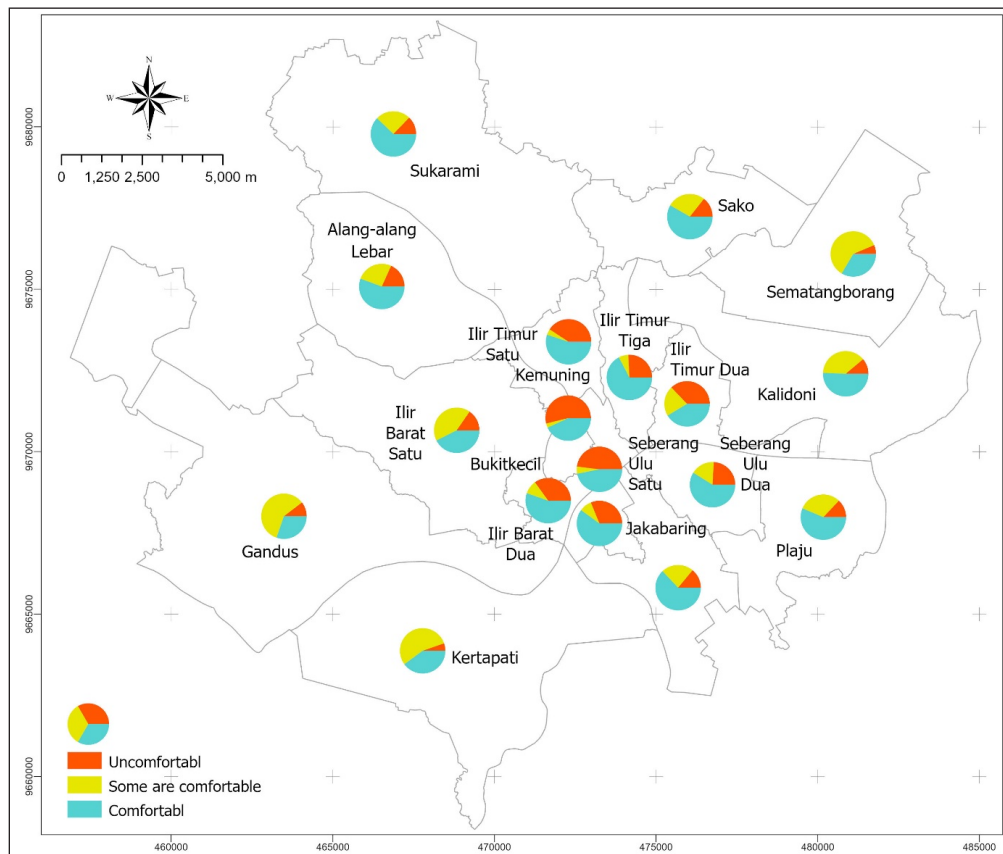


Figure 9 Palembang City thermal comfort map.

classified as thermally comfortable, the more comfortable the city becomes to live in, and vice versa. Thermal comfort serves as a key indicator in assessing sustainable city management, ensuring the well-being of residents. The concept of a livable city prioritizes improving residents' quality of life. This requires creating a physical and social environment that fosters well-being. Information on thermal comfort levels plays a crucial role in urban planning. Policymakers need to consider thermal comfort as a control mechanism in urban development strategies to contribute to the creation of more livable cities.

This study's spatial-temporal analysis of thermal comfort in Palembang City provides valuable insights that can be translated into practical actions for creating more livable urban environments. First, Prioritizing Green Infrastructure Development. The analysis can identify areas with high thermal stress and low vegetation cover. This information can be used to prioritize green infrastructure projects like parks, urban forests, and green roofs in these areas. Strategic planting of trees and vegetation can create shade, reduce surface temperatures, and improve air circulation, leading to a more comfortable urban environment. Second, Developing Early Warning Systems and Heat Action Plans. The analysis can be used to identify areas likely to experience extreme heat events. This information can be used to develop early warning systems and heat action plans to protect vulnerable populations during heat waves. Heat action plans might include measures like

opening cooling centers, extending public transportation hours, and implementing outreach programs for high-risk groups. Third, Continuous Monitoring and Evaluation. Regular monitoring of LST, vegetation cover, and built-up cover using remote sensing techniques is crucial. This allows for tracking the effectiveness of implemented strategies and adapting them as needed over time. This research paves the way for data-driven approaches to urban planning and climate adaptation. By integrating spatial-temporal analysis of thermal comfort into urban planning strategies, cities can proactively address the challenges of urban heat islands and create more livable environments for future generations.

CONCLUSIONS

This study employed a novel spatial-temporal approach to analyze thermal comfort in Palembang, Indonesia. This method effectively revealed the critical role of land cover changes in influencing surface temperature and thermal comfort, with the research identifying a clear correlation between decreasing vegetation cover and increasing thermal uncomfortable. Interestingly, the analysis also captured an unexpected temperature decrease in 2021, possibly due to reduced human activity during COVID-19 lockdowns. The research on thermal comfort in Palembang City shows that 11 from 18 sub-district fall into the "comfortable" category. These sub-districts

include Alang-alang lebar, Ilir Barat Dua, Ilir Timur Tiga, Jakabaring, Kalidoni, Kemuning, Plaju, Sako, Seberang Ulu Dua, Seberang Ulu Satu, and Sukarami. Four sub-districts (Gandus, Ilir Barat Satu, Kertapati and Sematang Borang) are categorized as “some are comfortable,” with these areas exceeding 45% coverage in this category. Conversely, three sub-districts (Bukit Kecil, Ilir Timur Dua, and Ilir Timur Satu) fall into the “uncomfortable” category, where this classification covers more than 37% of their area. The analysis reveals spatial variations in thermal comfort across the city, with an uncomfortable pattern concentrated in the central business zone, a dominance of “some are comfortable” areas in the transition zone, and a prevalence of “comfortable” areas in the suburban zone. This finding highlights the influence of human behavior on urban thermal comfort, prompting further investigation. Furthermore, the spatial identification of uncomfortable provides valuable insights for urban planning interventions. Prioritizing green infrastructure development and establishing early warning systems for heatwaves are crucial steps towards creating more thermally comfortable and livable urban environments in tropical cities like Palembang. This research paves the way for data-driven approaches to urban planning and climate adaptation, ensuring the well-being of future generations.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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