ANALYSIS OF THE URBAN HEAT ISLAND PHENOMENON IN WEST KALIMANTAN PROVINCE USING GOOGLE EARTH ENGINE

Fahrulaji[1*], Muhammad Pramulya[2], Hendra Perdana[1]

[1]Statistics Study Program, Faculty of Mathematics and Natural Science, Tanjungpura University, Indonesia.

[2]Plantation Crop Cultivation Study Program, Faculty of Agriculture, Tanjungpura University, Indonesia.

Email: h1091201016@student.untan.ac.id

ABSTRACT

Urban Heat Islands (UHI) refer to areas where urban temperatures are significantly higher than those in surrounding rural regions. This study utilizes remote sensing data from Google Earth Engine to examine spatiotemporal UHI variations in West Kalimantan Province from 2019 to 2023 by analyzing land surface temperature (LST) and vegetation density. The findings reveal that urban areas, especially Pontianak, experienced higher UHI intensity, with temperature differences ranging from 0.5°C to 2°C compared to more vegetated rural zones. Interior regions with dense vegetation showed lower UHI effects, whereas coastal cities such as Pontianak, Kubu Raya, and Mempawah exhibited UTFVI values above 0.02, indicating moderate to strong clustering of UHI. During the COVID-19 pandemic (2020–2021), average temperatures decreased by approximately 2°C due to reduced anthropogenic activity, but rebounded in 2022–2023. The province was categorized into four UHI intensity levels: strong (4 regions), moderate (3), weak (2), and non-UHI (5). These results highlight the crucial role of vegetation in mitigating UHI and emphasize the need for sustainable spatial planning that incorporates green infrastructure to enhance urban thermal comfort and resilience.

Keywords: Remote sensing, Urban heat island, Land surface temperature

INTRODUCTION

Many major cities worldwide are increasingly experiencing the Urban Heat Island (UHI) phenomenon, where temperatures in densely populated downtown areas are significantly higher than in suburban regions (Jiang et al., 2018; Patil & Surawar, 2023). This issue has become more severe over time. UHI refers to the localized increase in temperature, particularly in urban areas with high building density (Bhaskara & Pratomo, 2023; Fajary et al., 2024; Patil & Surawar, 2023). Consequently, urban areas tend to be warmer than their surrounding, more open, and less developed regions (Bhaskara & Pratomo, 2023; Fajary et al., 2024). Rapid urbanization and land-use conversion have intensified the UHI effect in West Kalimantan, particularly in major cities such as Pontianak. The heat island effect has become a critical environmental concern in urban development (Ting et al., 2022). Studies indicate that the UHI phenomenon in Indonesia is often linked to vegetation loss, the expansion of built-up areas, and the use of heat-absorbing materials. This condition is further exacerbated by global climate change, which contributes to rising average temperatures and increased occurrences of extreme heat in tropical regions (Bhaskara & Pratomo, 2023; Ting et al., 2022).

Numerous studies have examined the Urban Heat Island (UHI) effect. For example, research on the Indian Western Coastal where provides a seasonal and temporal analysis to understand the complexity of urban climates better (Patil & Surawar, 2023). Such insights are expected to serve as a foundation for urban planning strategies to mitigate the adverse socio-economic impacts of climate change. A study in New York and New Jersey found that maximum temperatures increased by 3.2°C in July, while minimum temperatures rose by 4.1°C (Yin et al., 2023). The most pronounced heat island effects were observed in New York City, particularly between May and October. The study also highlighted the significant impact of excessive urban development on residents' quality of life, emphasizing the need for sustainable urban planning.

This study examines the impact of urbanization on temperature patterns in Indonesia, with a particular focus on the Urban Heat Island (UHI) effect. It explores key factors such as vegetation density and land surface temperature, as well as the broader implications of UHI on both urban and rural areas. The research employs remote sensing techniques to analyze West Kalimantan (Kalbar), the "Equator's Earth." A crucial tool in this study is Google Earth Engine (GEE), a powerful cloud computing platform developed by Google, which enables large-scale analysis of geospatial data (Gorelick et al., 2017). The findings from this study are expected to provide a scientific basis for urban planning strategies, helping to mitigate the negative socio-economic impacts of climate change.

Urbanization leads to temperature increases through multiple mechanisms: impervious materials like asphalt and concrete absorb and retain more heat than natural surfaces; high building density restricts airflow and traps heat; and anthropogenic activities, such as vehicle emissions and air conditioning units, contribute to elevated temperatures in cities. Furthermore, prolonged exposure to higher urban temperatures can adversely affect residents' health, reduce productivity, and exacerbate thermal discomfort. Populations in low-income urban neighborhoods often face greater exposure due to limited access to cooling and green infrastructure, impacting their overall quality of life.

## METHODOLOGY

Data and materials

This study utilizes secondary data from remote sensing via Google Earth Engine (GEE), a cloud-based platform. GEE allows for the analysis of vast amounts of Earth data (at a petabyte scale, over 1000 terabytes) through its website at https://earthengine.google.com/ (Gorelick et al., 2017). The data used comes from a catalog of images from Landsat-8 satellites provided by the United States and available for access at https://earthexplorer.USGS.gov/ (Selka et al., 2024).

Table 1. Data sourced from Landsat-8.

Bandwidth	Description	Resolution (m)	Years
B4	Reflectance values for the red band below the atmospheric layer	30	2019-2023
B5	Reflectance values for the near-infrared band below the atmospheric layer	30	2019-2023
B11	Thermal Infrared Sensor (TIRS 2)	100	2019-2023

Study Area

This study examines the boundaries of West Kalimantan (Kalbar), a province in Indonesia often referred to as the "Equator's Earth" due to the equator passing through Pontianak. Geographically, West Kalimantan is located between 2°08' N and 3°05' S, and 108°00' E and 114°10' E. The province is predominantly lowland and spans approximately 147,307 km² (Badan Perencanaan Pembangunan Daerah, 2024). The study focuses on the entire province, which consists of twelve districts and two cities. The administrative boundaries used in this research are derived from a 1:250,000 scale shapefile provided by tanahair.go.id. For the pre-processing of Landsat-8 satellite data, key steps include selecting the appropriate period, extracting the study area, and removing cloud cover to ensure accurate spatial and spectral values for each band.
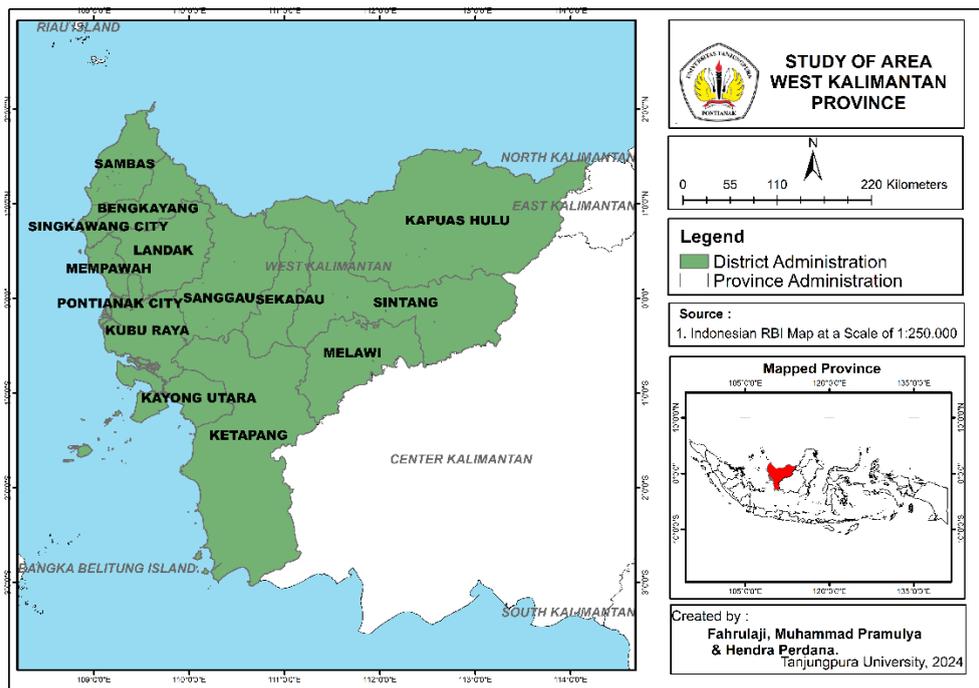
Figure 1: Administrative Study Area of West Kalimantan Province, Indonesia

Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing metric for assessing vegetation health, density, and distribution (Zhao & Qu, 2024). It is based on the difference in reflectance between near-infrared (NIR) and visible red light, as captured by satellite sensors. The mathematical formula for NDVI is (Waleed & Sajjad, 2022) as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{1}$$

where NIR = B5 dan Red = B4

Table 2. Categories of areas based on NDVI values

Classification	NDVI Value Interval
Water bodies	< 0
Built-up areas	$0 – 0,2$
Mixed open land	$0,3 – 0,4$
Green vegetation	$0,5 – 0,8$

Next, one of the standard methods used to determine the proportion of vegetation in remote sensing and satellite imagery is NDVI, as shown in the following equation (Tanoori et al., 2024) As follows:

$$PV = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right)^2 \tag{2}$$

Emissivity

Emissivity correction helps eliminate the atmospheric effects that can impact the pixel values the image sensor detects when determining temperature. The equation below gives the land surface emissivity (e) required for calculating Land Surface Temperature (LST). (Tanoori et al., 2024) as follows:

$$e = mPV + n \tag{3}$$

where, n = 0.986, represents the cavity effect and m = 0.004, represents the mixture of vegetation and soil.

Land Surface Temperature (LST)

Land surface temperature is represented in each pixel area, which includes different surface types. The LST equation is written as follows (Waleed & Sajjad, 2022):

$$LST = \left(\frac{T_B}{1 + \left(\lambda \frac{T_B}{\rho}\right) \ln e}\right) - 273,15 \tag{4}$$

Where TB is the atmospheric correction parameter obtained from Landsat-8 Band 11, λ is the radiation wavelength for the TIRS 2 band (11.50–12.51 µm) (Ahmad et al., 2024), ρ (rho) is the Planck radiation constant (1.438 µmK), and e is the emissivity value.

Urban Heat Island

In addition to "hotspots" within the research region based on land surface temperature (LST) data, urban heat islands (UHI) are the variations in LST between urban and non-urban areas. The intensity of surface temperature on a larger scale is reflected in UHI. Equation (Waleed et al., 2023) It's used to calculate the distribution of UHI as follows:

$$UHI = \frac{LST - T_m}{T_{std}} \tag{5}$$

The study area's average land surface temperature (T_m), standard deviation of LST (T_{std}), and land surface temperature (LST) in degrees Celsius are all represented by these variables.

The Urban Thermal Field Variance Index (UTFVI) is one technique for measuring and comparing UHI. Determining how comfortable or uncomfortable the temperature feels in a specific location explains UHI. One of the most used techniques for assessing thermal comfort is this index. A particular formula is used to determine the UTFVI values (Waleed et al., 2023) as follows:

$$UTFVI = \frac{LST - T_m}{LST} \qquad (6)$$

The results provide spatial insights into regional variations, enhancing the current understanding of urban thermal comfort distribution over time and across different areas. This data can support informed decision-making and contribute to developing targeted strategies for addressing specific challenges. To facilitate the analysis of temperature patterns across various locations, the Urban Thermal Field Variance Index (UTFVI) is classified into six categories, making the data more accessible and easier to interpret (Waleed et al., 2023).

Table 3. UTFVI clusters

Threshold value	UHI classification
< 0	Non-UHI
0 – 0,005	Weak
0,006 – 0,01	Moderate
0,012 – 0,015	Fairly strong
0,016 – 0,02	Strong
> 0,02	Very strong

RESULTS AND DISCUSSION

Spatiotemporal Vegetation Density Distribution (2019–2023)

Color schemes corresponding to different land cover categories are used to represent vegetation density spatially in West Kalimantan Province. Due to their varied and complex land cover, areas with low and mixed vegetation densities are expected to have warmer surface temperatures. Over the past five years, vegetation classes with NDVI values ranging from 0.5 to 0.8 have primarily represented vegetation density in West Kalimantan. This is largely due to the province's extensive tropical forests, which dominate most districts and cities.

Mapping studies indicate that West Kalimantan remains largely covered by vegetation. As shown in Table 2, most regions exhibit NDVI values between 0.5 and 0.8, signifying high vegetation cover with minimal variation over time. Degraded vegetation is highlighted in yellow, representing areas affected by human activities, such as land clearing for settlements or large-scale modifications of open spaces. The distribution of water bodies, including rivers and lakes, remains relatively stable due to the province's natural hydrological network. Meanwhile, urbanized areas, such as Pontianak City and its surroundings, are characterized by built-up regions with low vegetation indices. These areas have experienced consistent urban expansion over the years.
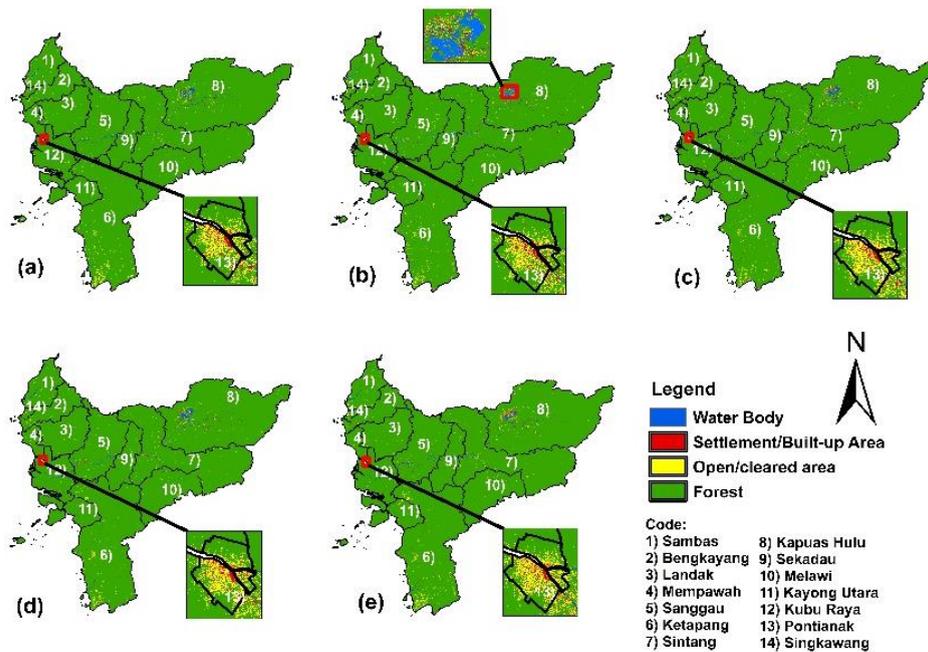
Figure 2: Spatial distribution of NDVI in West Kalimantan during the period of (a) 2019, (b) 2020, (c) 2021, (d) 2022, (e) 2023.

## Spatiotemporal LST Distribution (2019–2023)

Analyzing the thermal radiation data gathered by TIRS 2 band 11 and grouped into spectral channels obtained the LST (Land Surface Temperature). This calculation's output is in Kelvin; thus, by customary procedure, the LST values were converted to Celsius by reducing them by 273.15. The following table shows the distribution of LST for the previous five years in the province of West Kalimantan.

Table 4. Descriptive statistics of LST in West Kalimantan

Years	2019	2020	2021	2022	2023
LST average	25.23	23.35	23.02	23.77	25.30
LST standard deviation	1.66	2.28	2.25	2.01	1.71

Over the past five years, the average temperature has ranged between 23°C and 25°C. A notable decrease of approximately 2°C in surface temperature occurred between 2020 and 2021, which can be attributed to the onset of the COVID-19 pandemic and the associated social restrictions. In 2022, as social activities resumed in the "new normal", temperatures began to rise again. By 2023, surface temperatures had increased by 2°C, reflecting a return to pre-pandemic human activities and environmental conditions. Urban areas such as Pontianak City and Kubu Raya Regency recorded the highest temperatures in 2019, while non-urban regions with abundant vegetation, like the interior of West Kalimantan, experienced the lowest temperatures. Between 2020 and 2021, Pontianak and its surrounding areas saw moderate temperatures, with maximum temperatures becoming less frequent. Coastal zones were represented by orange pixels, while inland regions, typically with lower temperatures, were marked with minimum temperature pixels.

By 2022–2023, coastal areas such as Pontianak, Kubu Raya, Singkawang, Mempawah, and Sambas experienced the highest temperatures, while interior regions generally maintained their cooler temperatures. However, some areas exhibited warming, as indicated by orange and yellow pixels.
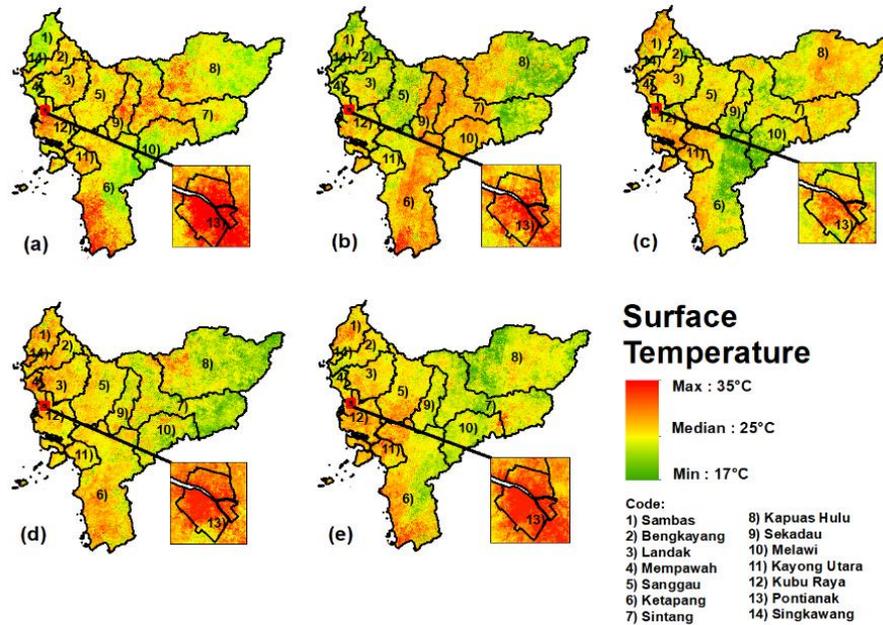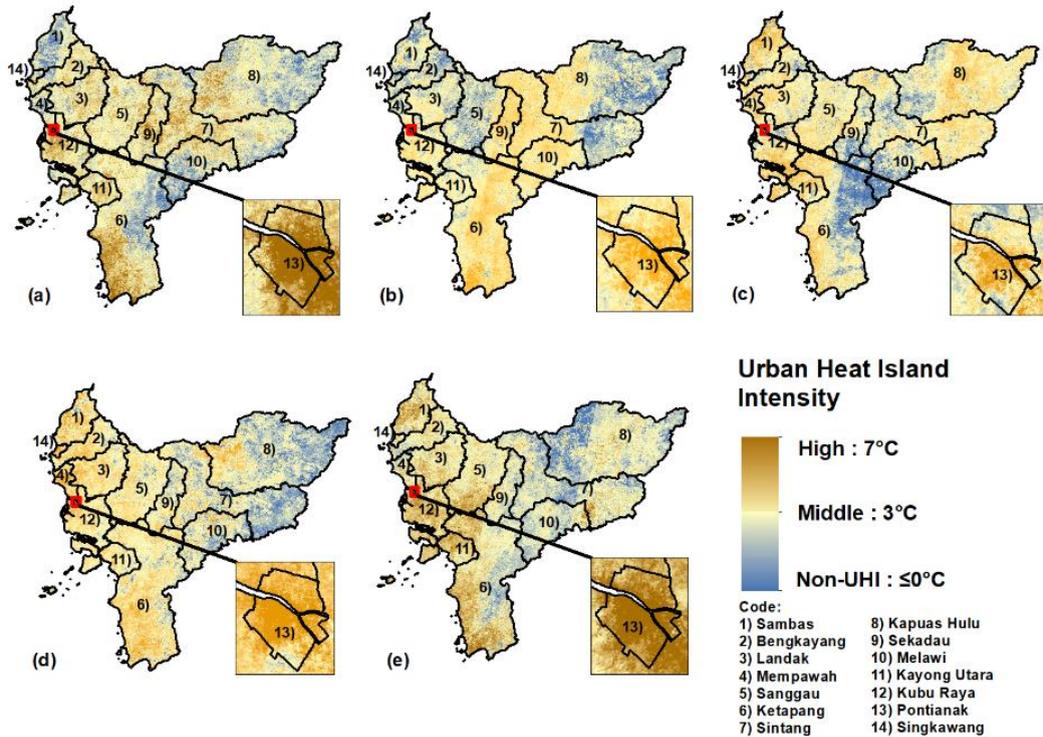

Figure 3: Spatial distribution of LST in West Kalimantan during the period of (a) 2019, (b) 2020, (c) 2021, (d) 2022, (e) 2023.

Distribution of UHI in West Kalimantan (2019 – 2023)

An area's average LST is subtracted from the LST value, and the result is divided by the LST standard deviation to determine UHI.

Table 5. Urban Temperature Change in West Kalimantan

| Location	LST					UHI max temp.				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
Sambas	24.22	22.12	24.10	25.06	26.35	4.85	3.23	4.77	4.56	5.24
Bengkayang	24.98	22.22	23.57	24.89	25.77	5.95	3.36	4.35	4.80	5.24
Landak	25.39	22.58	23.38	24.90	25.81	5.95	4.45	4.46	5.74	5.27
Mempawah	25.52	23.53	24.01	25.68	26.12	5.61	3.96	4.73	5.74	5.27
Sanggau	25.62	22.56	22.97	24.08	25.79	5.95	4.45	3.71	3.97	4.99
Ketapang	25.36	24.38	22.13	24.42	25.78	7.61	3.58	4.58	4.11	5.99
Sintang	25.24	23.35	22.85	22.92	24.47	5.80	4.70	3.54	4.53	5.52
Kapuas Hulu	24.69	22.27	23.25	22.47	24.07	5.80	4.70	3.54	4.38	4.10
Sekadau	25.75	24.17	22.06	23.67	25.00	5.32	4.37	3.65	4.18	4.42
Melawi	24.56	24.29	21.21	22.98	24.24	5.42	3.71	3.11	4.49	5.52
Kayong Utara	25.76	23.62	24.45	24.37	26.75	5.08	3.44	4.19	3.82	5.65
Kubu Raya	25.85	23.83	24.13	24.73	26.84	5.61	4.21	4.73	5.09	5.41
Pontianak	28.53	26.05	24.36	27.19	29.00	5.61	3.96	4.73	5.09	5.27
Singkawang	25.00	21.82	23.47	25.92	25.24	4.02	2.16	3.90	4.80	4.24

Figure 4: Spatial distribution of UHI in West Kalimantan during the period of (a) 2019, (b) 2020, (c) 2021, (d) 2022, (e) 2023.

The results of this study highlight varying levels of Urban Heat Island (UHI) intensity across different districts and cities, particularly in metropolitan areas and their surrounding regions. These variations reflect the impact of surface temperature changes driven by shifts in vegetation cover. The UHI phenomenon occurs when the intensity of the temperature difference exceeds zero, indicating that the urban area is notably warmer than its surrounding environment. In 2019, the UHI distribution in Pontianak City exhibited sharp gradients, showcasing significant temperature variations between urban and surrounding areas. However, between 2020 and 2021, there was a noticeable decrease in UHI intensity, with Pontianak and its neighboring regions experiencing a moderate gradient of UHI distribution. This shift can be attributed to the social and environmental changes brought on by the COVID-19 pandemic, leading to reduced urban activity and lower temperature variations. By 2022–2023, the UHI intensity gradients began to rise again, signaling increased temperature fluctuations between urban and rural areas. Pontianak City was among the regions showing the most significant intensity gradients, reflecting the city's growing urbanization and the corresponding increase in surface temperatures as human activities resumed.
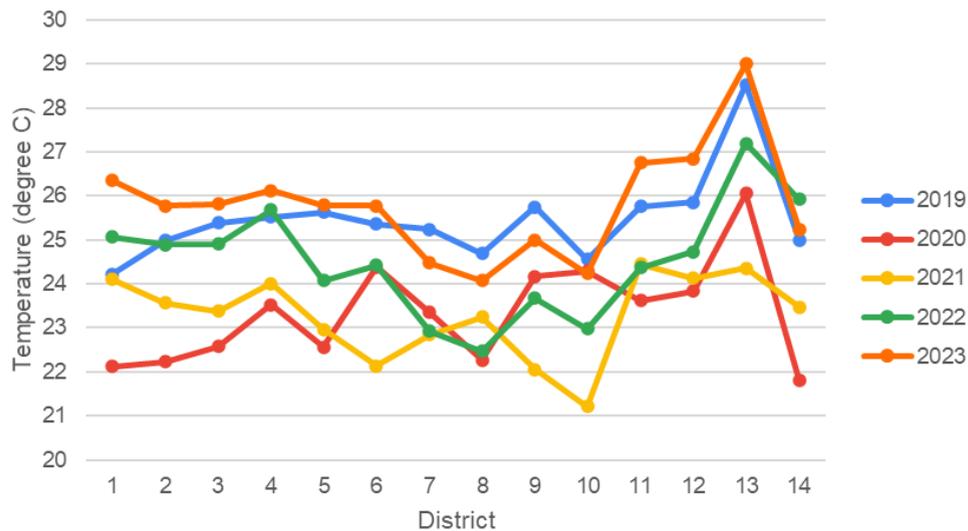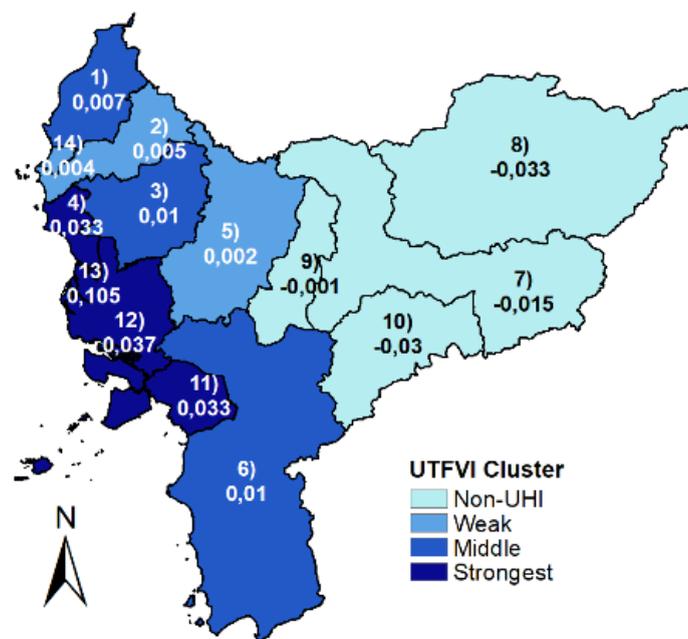
Figure 5: Time series of LST in districts: 1) Sambas, 2) Bengkayang, 3) Landak, 4) Mempawah, 5) Sanggau, 6) Ketapang, 7) Sintang, 8) Kapuas Hulu, 9) Sekadau, 10) Melawi, 11) Kayong Utara, 12) Kubu Raya, 13) Pontianak, 14) Singkawang.

Pontianak City typically experiences the fastest rate of surface temperature increase, followed by Kubu Raya and Kayong Utara Regencies. Due to the COVID-19 pandemic, all regencies and cities saw a significant drop in temperatures between 2019 and 2020–2021, ranging from 22°C to 25°C. In 2022, temperatures rose again, marking a noticeable shift from the previous year. As human activities resumed and social restrictions were lifted, surface temperatures increased significantly, coinciding with the transition to the "new normal". By 2023, land surface temperatures had risen again, approaching the pre-pandemic levels in 2019. Geographical variations among the 14 regencies and cities influence the spatial differences in land surface temperatures. To assess Urban Heat Island (UHI) effects, one of the key metrics for evaluating annual surface temperature variations due to urbanization activities, the five-year average across the regencies and cities in West Kalimantan is used for comparison. Variations in UHI intensity are associated with urbanization activities such as road construction, housing development, and the expansion of commercial and industrial zones. These activities reduce vegetative cover and increase heat-absorbing surfaces, contributing to localized temperature rise.
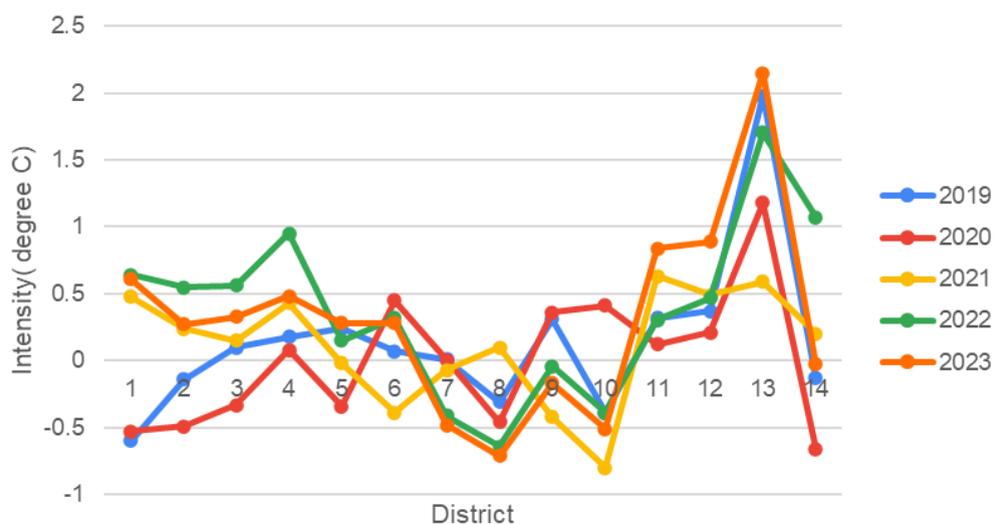
Figure 6: Time series of LST in districts: 1) Sambas, 2) Bengkayang, 3) Landak, 4) Mempawah, 5) Sanggau, 6) Ketapang, 7) Sintang, 8) Kapuas Hulu, 9) Sekadau, 10) Melawi, 11) Kayong Utara, 12) Kubu Raya, 13) Pontianak, 14) Singkawang.

Over the past five years, the UHI effect index across the 14 districts/cities has revealed significant disparities between city centers and districts near and far from the city center. The intensity of the spatiotemporal UHI effect was highest in Pontianak, where temperatures were 0.5°C to 2°C higher between 2019 and 2023. Although the UHI patterns varied yearly, some districts, including Mempawah, Kayong Utara, and Kubu Raya, exhibited UHI intensities similar to those in Pontianak. Conversely, areas with UHI intensities below 0°C are classified as rural regions, where urbanization and human activity are minimal, indicating a lack of significant UHI effects (Darlina et al., 2018).

Figure 7: Clustering of UHI effects based on Eq. (6) from 2019 to 2023 in districts: 1) Sambas, 2) Bengkayang, 3) Landak, 4) Mempawah, 5) Sanggau, 6) Ketapang, 7) Sintang, 8) Kapuas Hulu, 9) Sekadau, 10) Melawi, 11) Kayong Utara, 12) Kubu Raya, 13) Pontianak, 14) Singkawang.

Based on the spatiotemporal distribution of the Urban Thermal Field Variance Index (UTFVI) over the past five years, the western region, particularly the western coastal areas of Kalimantan, exhibits the strongest clusters, with a UTFVI threshold greater than 0.02. The eastern and northern parts of West Kalimantan follow this. Regarding UHI intensity, Non-UHI predominates in five regions of West Kalimantan, while Weak UHI is found in two regions, Moderate UHI in three, and Strong UHI in four. The four regions with the highest UHI intensity are located in the urbanization clusters of West Kalimantan, including the city of Pontianak and the surrounding areas of Kubu Raya, Kayong Utara, and Mempawah.

CONCLUSION

The spatiotemporal interaction between vegetation changes and land surface temperature has significantly influenced the characteristics of the Urban Heat Island (UHI) phenomenon in West Kalimantan over the past five years. The study identified substantial UHI intensity, with temperature gradients exceeding 2°C in areas with low or mixed vegetation, particularly in urban centers such as Pontianak. Coastal urban regions, including Kubu Raya, Kayong Utara,

and Mempawah, consistently recorded the highest UHI intensity, while inland areas with dense vegetation experienced weaker or negligible effects.

The impact of UHI temporarily decreased during the COVID-19 pandemic (2020–2021) due to reduced human activity but rebounded as socio-economic activities resumed in 2022–2023. Based on the Urban Thermal Field Variance Index (UTFVI), West Kalimantan was classified into Non-UHI (5 regions), Weak UHI (2 regions), Moderate UHI (3 regions), and Strong UHI (4 regions).

These findings confirm that UHI effects are significantly more intense in urban areas with reduced vegetation and high anthropogenic activity. Therefore, policymakers and urban planners must integrate green infrastructure and implement sustainable spatial planning strategies. Such approaches are essential to mitigate the adverse impacts of UHI and enhance the livability and resilience of urban environments in the face of ongoing climate change.

REFERENCE

Ahmad, H., Jose, F., Nabi, M. M., Jhara, S. I., & Juma, F. (2024). Assessing Land Use and Land Cover Dynamics of Irrawaddy Delta : Remote Sensing Analysis and Future Projections Assessing Land Use and Land Cover Dynamics of. https://doi.org/10.20944/preprints202407.0442.v1

Badan Perencanaan Pembangunan Daerah. (2024). Bappeda. Bappeda Kalbar. https://bappeda.kalbarprov.go.id/gambaran-umum-kalbar/

Bhaskara, B. E., & Pratomo, R. A. (2023). Perkembangan Fenomena Urban Heat Island di Kota Samarinda. Jurnal Wilayah Dan Lingkungan, 11(1), 22–35. https://doi.org/10.14710/jwl.11.1.22-35

Darlina, S., Sasmito, B., & Yuwono, B. (2018). Analisis fenomena urban heat island serta mitigasinya studi kasus kota semarang. Jurnal Geodesi Undip, 7(3), 77–87.

Fajary, F. R., Lee, H. S., Kubota, T., Bhanage, V., Pradana, R. P., Nimiya, H., & Putra, I. D. G. A. (2024). Comprehensive spatiotemporal evaluation of urban growth, surface urban heat island, and urban thermal conditions on Java Island of Indonesia and implications for urban planning. Heliyon, 10(13), e33708. https://doi.org/10.1016/j.heliyon.2024.e33708

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Jiang, W., Huang, Y., & Sha, A. (2018). A review of eco-friendly functional road materials. Construction and Building Materials, 191, 1082–1092. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.10.082

Patil, R., & Surawar, M. (2023). Impact of Urban Heat Island on Formation of Precipitation in Indian Western Coastal Cities. Journal of Contemporary Urban Affairs, 7(2), 37–55. https://doi.org/10.25034/ijcua.2023.v7n2-3

Selka, I., Malika, K., Mokhtari, A. M., Aoul, K. A. T., Bengusmia, D., & Djebbar, K. E.-B. (2024). Assessing the Impact of Land Use and Land Cover Changes on Surface Temperature Dynamics Using Google Earth Engine : A Case Study of Tlemcen Municipality , Northwestern Algeria (1989 – 2019). International Journal of Geo-Information.

Tanoori, G., Soltani, A., & Modiri, A. (2024). Predicting Urban Land Use and Mitigating Land Surface Temperature: Exploring the Role of Urban Configuration with Convolutional Neural Networks. Journal of Urban Planning and Development, 150(3). https://doi.org/10.1061/jupddm.upeng-5010

Ting, Z., Yexing, G., & Chong, L. (2022). Characteristic Analysis of Urban Heat Island Effect in Hainan Island from 2019 to 2021 Based on FY-3D MERSI-II. Advances in Geosciences,

12(11), 1542–1551. https://doi.org/10.12677/AG.2022.1211149

Waleed, M., & Sajjad, M. (2022). Leveraging cloud-based computing and spatial modeling approaches for land surface temperature disparities in response to land cover change: Evidence from Pakistan. Remote Sensing Applications: Society and Environment, 25(August 2021), 100665. https://doi.org/10.1016/j.rsase.2021.100665

Waleed, M., Sajjad, M., Acheampong, A. O., & Alam, M. T. (2023). Towards Sustainable and Livable Cities: Leveraging Remote Sensing, Machine Learning, and Geo-Information Modelling to Explore and Predict Thermal Field Variance in Response to Urban Growth. Sustainability (Switzerland), 15(2). https://doi.org/10.3390/su15021416

Yin, Z., Liu, Z., Liu, X., Zheng, W., & Yin, L. (2023). Urban heat islands and their effects on thermal comfort in the US: New York and New Jersey. Ecological Indicators, 154(November 2022), 110765. https://doi.org/10.1016/j.ecolind.2023.110765

Zhao, Q., & Qu, Y. (2024). The Retrieval of Ground NDVI (Normalized Difference Vegetation Index) Data Consistent with Remote-Sensing Observations. Remote Sensing, 16(7). https://doi.org/10.3390/rs16071212