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Surface Temperature Variations Due to Land Cover Changes in Jambi City: A Comparative Study of 2013 and 2024

(Variasi Suhu Permukaan Akibat Perubahan Tutupan Lahan di Kota Jambi: Studi Perbandingan Tahun 2013 dan 2024)

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ABSTRACT

This study investigates the spatio-temporal changes in land surface temperature (LST) patterns in Jambi City, Indonesia, between 2013 and 2024 using Landsat 8-9 OLI/TIRS imagery. The research employs thermal band analysis (bands 10 and 11) and geographical information systems to evaluate urban heat island (UHI) effects across 68 sub-districts. Results demonstrate significant thermal landscapetransformations, with surface temperatures expanding from 21.5-26.20°C in 2013 to 19.02-27.33°C in 2024. Highly urbanized areas, particularly in Jambi Selatan, Jelutung, and Paal Merah districts, experienced the most substantial temperature increases (up to 1.13°C), while areas maintaining vegetation cover and proximity to water bodies showed remarkable thermal stability. The study reveals strong correlations between land use changes and temperature variations, with built-up areas exhibiting significantly higher temperatures compared to vegetated regions and water bodies. These findings provide crucial insights for urban planning and climate adaptation strategies, emphasizing the importance of preserving green spaces and water bodies as natural cooling mechanisms in rapidly developing tropical cities.

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ABSTRAK

Penelitian ini mengkaji perubahan spasial dan temporal pola suhu permukaan tanah (LST) di Kota Jambi, Indonesia, antara tahun 2013 dan 2024 menggunakan citra Landsat 8-9 OLI/TIRS. Penelitian ini menggunakan analisis band termal (band 10 dan 11) dan sistem informasi geografis (SIG) untuk mengevaluasi efek pulau panas perkotaan (UHI) di 68 kecamatan. Hasil menunjukkan transformasi lanskap termal yang signifikan, dengan suhu permukaan meningkat dari 21,5-26,20°C pada tahun 2013 menjadi 19,02-27,33°C pada tahun 2024. Wilayah yang sangat terurbanisasi, terutama di distrik Jambi Selatan, Jelutung, dan Paal Merah, mengalami peningkatan suhu yang paling signifikan (hingga 1,13°C), sementara wilayah yang mempertahankan tutupan vegetasi dan dekat dengan badan air menunjukkan stabilitas termal yang luar biasa. Studi ini mengungkapkan korelasi yang kuat antara perubahan penggunaan lahan dan variasi suhu, dengan kawasan yang padat bangunan menunjukkan suhu yang jauh lebih tinggi dibandingkan dengan kawasan bervegetasi dan badan air. Temuan ini memberikan wawasan penting bagi perencanaan kota dan strategi adaptasi iklim, menekankan pentingnya menjaga ruang hijau dan badan air sebagai mekanisme pendinginan alami di kota-kota tropis yang berkembang pesat.

1. Introduction

Urban development and rapid population growth significantly impact the thermal environment of cities, particularly through the Urban Heat Island (UHI) phenomenon. This environmental challenge has become increasingly prominent in developing countries, where urbanization often occurs at an unprecedented pace. The city of Jambi, Indonesia, represents a compelling case study of this phenomenon, as it undergoes substantial urban transformation while attempting to maintain environmental balance. The modification of natural landscapes into built environments fundamentally alters the surface energy balance and local climate patterns. Previous research by Rahman et al. (2020) has demonstrated that rapid urbanization creates complex thermal mosaics in urban areas, leading to increased surface temperatures and modified microclimate conditions. The replacement of natural vegetation with impervious surfaces, combined with anthropogenic heat emissions, contributes to the formation and intensification of urban heat islands.

Recent studies have highlighted the significance of understanding thermal landscape dynamics in tropical cities. Liu and Zhang (2021) identified the complex interactions between physical urban structures and heat generation, while Chen et al. (2022) emphasized the crucial role of urban vegetation in temperature regulation through evapotranspiration processes. However, there remains a gap in understanding how these thermal patterns evolve over extended periods in rapidly developing tropical cities, particularly in the Indonesian context. The relationship between urban development and thermal environment changes has been explored in various contexts. Kim and Park (2023) investigated the cooling effects of urban water bodies, while Wang et al. (2023) examined the impacts of land cover conversion on local atmospheric dynamics. These studies provide valuable insights but often focus on developed cities or short-term changes. There is limited research on the long-term thermal evolution of medium-sized tropical cities undergoing rapid development. Understanding the spatio-temporal dynamics of surface temperature changes is crucial for sustainable urban planning and climate adaptation strategies. While previous research has established the general principles of urban heat island formation, there is a need for detailed analysis of how different urban features and land use changes influence thermal patterns over extended periods. This is particularly relevant for cities like Jambi, where rapid urbanization intersects with the need to preserve natural cooling mechanisms. The present study addresses these research gaps by analyzing the evolution of land surface temperature patterns in Jambi City over an 11-year period (2013-2024). This research employs advanced remote sensing techniques, utilizing Landsat 8-9 OLI/TIRS imagery to examine thermal changes across 68 sub-districts. The study specifically aims to:

1. Analyze the spatio-temporal changes in land surface temperature patterns across different urban zones in Jambi City between 2013 and 2024.
2. Evaluate the relationship between land use changes and surface temperature variations in rapidly developing urban areas.
3. Assess the effectiveness of natural features (vegetation and water bodies) in moderating urban temperatures over the study period.
4. Provide evidence-based recommendations for urban thermal environment management and heat island mitigation strategies.

This research contributes to the growing body of knowledge on urban climatology by providing a comprehensive analysis of thermal landscape evolution in a rapidly developing tropical city. The findings will be valuable for urban planners, policymakers, and researchers working on sustainable urban development and climate adaptation strategies in similar contexts.

2. Materials and Methode

2.1. Time and Place

This research was conducted over a period of 3 (three) months, from August to October 2024, with the research location in Jambi City, Jambi Province. Jambi City has a total area of 16,985.35 hectares, as shown in **Figure 1**.

2.2. Tools and Materials

Tools and materials used in this research include ArcGIS 10.8, Landsat 8-9 OLI/TIRS Collection 2 Level-1 imagery from 2013 (acquired on June 27, 2013), Landsat 8-9

OLI/TIRS Collection 2 Level-1 imagery from 2024 (acquired on June 9, 2024, and June 17, 2024), Jambi City administrative boundary map (shp format), and Jambi City sub-district boundary map (shp format).

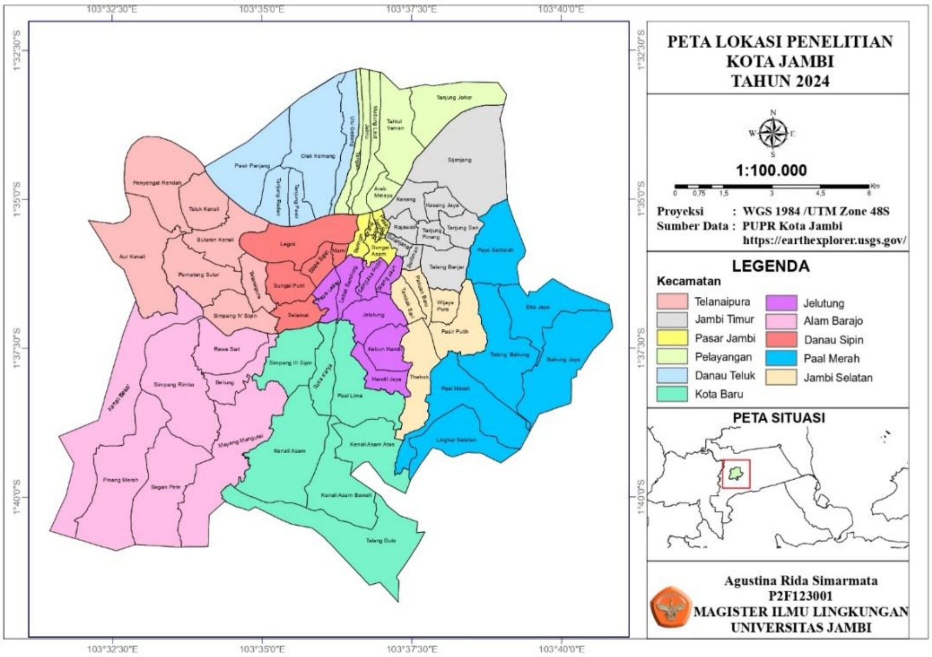

Figure 1. The Map of Jambi City

2.3. Research Procedures

2.3.1 Radiometric Correction

The Landsat 8 data from 2013 and 2024 for each band underwent radiometric correction using Top of Atmosphere (ToA) correction, which includes ToA Reflectance and solar correction. ToA Reflectance correction was performed by converting Digital Number (DN) values to reflectance values. According to (USGS, 2015), the conversion equation for ToA reflectance correction is:

$$\rho\lambda' = M\rho Qcal + A\rho$$

Where:

$\rho\lambda'$ = TOA reflectance, without correction for solar angle

$M\rho$ = REFLECTANCE_MULT_BAND_x, where x represents the band number

$A\rho$ = REFLECTANCE_ADD_BAND_x, where x represents the band number

$Qcal$ = Digital Number (DN) value

Next, the image undergoes solar angle correction to eliminate DN (Digital Number) value differences caused by sun position. The sun's position relative to Earth varies depending on recording time and object location. The equation for solar angle correction is:

$$\rho\lambda = \rho\lambda'/(\cos(\theta SZ)) = \rho\lambda'/(\sin(\theta SE))$$

Where:

$\rho\lambda$ = ToA (Top of Atmosphere) reflectance

θSE = sun elevation

θSZ = solar zenith angle

θSZ = 90° - θSE

2.3.2 Image Cropping

The subsequent step involves image cropping. This process is performed to obtain imagery corresponding to the study area, specifically Jambi City. The corrected imagery will be cropped using the administrative boundary shapefile of Jambi City. Image cropping is conducted to establish the research analysis unit.

2.3.3 Land Surface Temperature (LST) Distribution

Temperature processing to obtain distribution patterns can be performed using bands equipped with Thermal Infrared Sensor (TIRS) on Landsat 8 imagery, specifically bands 10 and 11. The processing steps for surface temperature parameter values involve several stages, including converting Digital Number values to Radiance Number.

$$L\lambda = ML \times QCAL + AL$$

Where:

Lλ = Spectral radiance of band-i (Wm-2 sr-1µm-1)

ML = Band-specific multiplicative rescaling factor (Radiance_MULT_BAND_x)

AL =Band-specific additive rescaling factor (Radiance_ADD_BAND_x)

QCAL =The spectral radiance that is scaled to QCALmax in watts.

Converting Radiance Number values to Brightness Temperature (TB) Brightness Temperature (TB) represents the thermal radiation intensity emitted by an object in temperature units. The thermal constant values are available in Landsat 8 satellite metadata (USGS, 2015).

$$TB = K2 / \ln((K1 / L\lambda) + 1)$$

Where:

TB = Brightness Temperature in Kelvin

K2 = Calibration constant 2 K1 = Calibration constant 1 Lλ = Spectral radiance in watts/(Wm-2 sr-1µm-1). The TB value when converted to Celsius units becomes:

TB(°C) = TB(K) - 273.15

3. Result and Discussion

3.1. Land Surface Temperature Distribution in Jambi City during 2013

The analysis of land surface temperature (LST) distribution in Jambi City reveals significant spatio-temporal variations between 2013 and 2024 (Pict.2) providing valuable insights into urban thermal dynamics and the impacts of land use changes. The study, utilizing Landsat 8 thermal bands 10 and 11, demonstrates complex patterns of thermal variation across different land cover types and urban development intensities. The research findings indicate a remarkable transformation in the urban thermal landscape, with surface temperatures ranging from 21.5°C to 26.20°C in 2013, expanding to 19.02-27.33°C by 2024. This broadening temperature range reflects the increasing thermal complexity of the urban environment, consistent with Rahman et al. (2020) observations of thermal mosaics in rapidly urbanizing cities. The spatial distribution of surface temperatures exhibits strong correlations with land cover characteristics, where vegetated areas and water bodies consistently maintain lower temperatures compared to built-up regions.

Areas with high vegetation cover and proximity to water bodies, such as the Pelayangan district (including Jelmu, Mudung Laut, and Tahtul Yaman sub-districts), demonstrate notably lower temperatures, consistently below 21.5°C. This thermal pattern is primarily attributed to the cooling effects of the Batanghari River and the presence of substantial vegetation cover. Similarly, the Danau Teluk district, particularly in Olak Kemang and Pasir Panjang areas, maintains relatively cool temperatures due to the combined cooling effects of Lake Teluk and peripheral vegetation. The study identifies distinct thermal zones corresponding to different stages of urban development. Transition areas, characterized by moderate construction activity while retaining significant vegetation, such as Kota Baru and Paal Merah districts, exhibit intermediate temperatures ranging from 22.04°C to 22.74°C. This thermal pattern reflects the balanced interaction between built environment and natural cooling mechanisms, as evidenced in areas like Kenali Asam and Bakung Jaya. The intensification of the Urban Heat Island (UHI) effect is particularly evident in highly urbanized areas. Districts such as Jelutung and Jambi Selatan demonstrate elevated surface temperatures (22.75°C to 23.48°C), with some areas experiencing temperatures exceeding 24°C by 2024. This thermal intensification aligns with Liu and Zhang (2021) findings regarding the complex interactions between physical and anthropogenic factors in urban heat generation. The research particularly highlights Tambak Sari sub-district as a prominent UHI hotspot, where intensive commercial activity and minimal green space contribute to elevated temperatures.

The study emphasizes the crucial role of urban green spaces in temperature moderation, supporting Chen et al. (2022) research on evapotranspiration-driven cooling mechanisms. The preservation of vegetation in areas like Penyengat Rendah and Teluk Kenali has resulted in consistently lower temperatures, with cooling effects reaching 2-4°C. This finding underscores the importance of green infrastructure in UHI mitigation strategies. Water bodies emerge as significant thermal regulators in the urban landscape. The research corroborates Kim and Park (2023) explanation of water body cooling mechanisms, where high specific heat capacity and evaporative cooling contribute to temperature stabilization. Areas proximate to the Batanghari River and Lake Teluk demonstrate enhanced thermal stability throughout the study period. The temporal analysis reveals concerning trends in thermal expansion, particularly in rapidly developing districts. Wang et al. (2023) observations regarding the cumulative impacts of land cover conversion are supported by the documented increase in high-temperature areas (>23°C) from 2013 to 2024, especially in Jambi Selatan, Jelutung, and Paal Merah districts. This thermal intensification is attributed to the combined effects of vegetation loss, increased anthropogenic heat emissions, and modified urban geometry. These findings carry significant implications for urban planning and climate adaptation strategies. The research supports Lee and Kim (2024) advocacy for comprehensive UHI mitigation approaches, emphasizing the need for integrated green infrastructure, high-albedo construction materials, and climate-conscious urban design. The study concludes that understanding these spatio-temporal thermal dynamics is crucial for developing effective adaptation and mitigation strategies to create more thermally comfortable and sustainable urban environments in rapidly developing cities like Jambi.

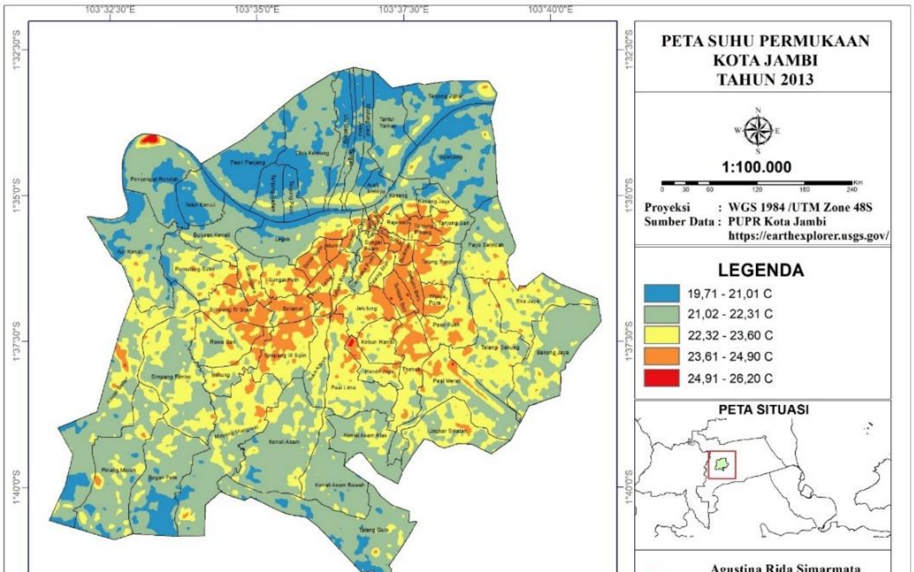

Figure 2. Land Surface Temperature Distribution Map in Jambi City 2013

3.2. Land Surface Temperature Distribution in Jambi City during 2013 and 2024

The comprehensive analysis of surface temperature changes in Jambi City from 2013 to 2024 reveals significant transformations in the urban thermal landscape, demonstrating the complex interplay between urbanization and environmental thermal dynamics. Through satellite imagery analysis utilizing Zonal Statistics, the study documented substantial temperature variations across 68 sub-districts, highlighting the emergence and intensification of the urban heat island (UHI) phenomenon. The temporal analysis demonstrates a notable expansion in the surface temperature range, evolving from 19.71-26.20°C in 2013 to 19.02-27.33°C in 2024, representing a maximum temperature increase of 1.13°C in specific areas. This thermal amplification is particularly pronounced in regions experiencing rapid urbanization and land-use conversion. The districts of Jambi Selatan, Jelutung, and Paal Merah exemplify this trend, with temperatures escalating from 22.75-24.82°C in 2013 to 24.83-27.33°C in 2024, primarily attributed to the transformation of green spaces into residential and commercial zones. The research identifies distinct patterns of thermal variation correlated with urban development intensity and land cover characteristics. Areas maintaining substantial vegetation cover and proximity to water bodies, such as Danau Teluk, Pelayangan, and portions of Telanaipura districts, exhibit remarkable thermal stability. These regions maintained temperatures between 19.71-22.74°C in 2013, with only modest increases to a maximum of 23.77°C by 2024. This thermal resilience can be attributed to the preserved green spaces and the cooling effects of water bodies like Lake Teluk and the Batanghari River, which act as natural temperature regulators through their high heat capacity and evaporative cooling mechanisms.

The study reveals a clear urban heat island effect, particularly evident in the city center and highly urbanized areas. This phenomenon manifests through significantly higher surface temperatures in developed areas compared to peripheral regions with preserved vegetation. The thermal gradient is exacerbated by the widespread use of construction materials with low albedo, such as concrete and asphalt, which enhance solar radiation absorption and heat retention. The reduction in green spaces further diminishes the environment's natural cooling capacity through reduced evapotranspiration. These findings carry significant implications for urban planning and climate adaptation strategies in rapidly developing cities. The research underscores the critical importance of preserving and expanding green infrastructure and water bodies as natural cooling mechanisms. The observed temperature stability in areas with maintained vegetation and proximity to water bodies provides empirical evidence supporting the effectiveness of these natural features in mitigating urban heat island effects.

The spatial analysis, conducted using Geoprocessing Tools and Zonal Statistics, provides a detailed assessment of temperature changes across all 68 sub-districts, offering valuable insights for targeted urban heat mitigation strategies. This comprehensive approach to thermal mapping enables the identification of critical areas requiring intervention and highlights successful examples of thermal regulation through natural landscape features. These results contribute to the growing body of knowledge on urban climatology and thermal landscape evolution in tropical cities undergoing rapid development. The findings emphasize the urgent need for integrated urban planning approaches that prioritize thermal comfort and environmental sustainability alongside development objectives. This research provides valuable guidance for policymakers and urban planners in developing strategies to create more thermally comfortable and sustainable urban environments while managing the challenges of rapid urbanization. The documented thermal changes in Jambi City over this 11-year period serve as a crucial case study for understanding the long-term impacts of urbanization on local climate patterns and the effectiveness of various natural and built environment features in moderating urban temperatures. This understanding is essential for developing effective climate adaptation and mitigation strategies in rapidly growing urban centers.

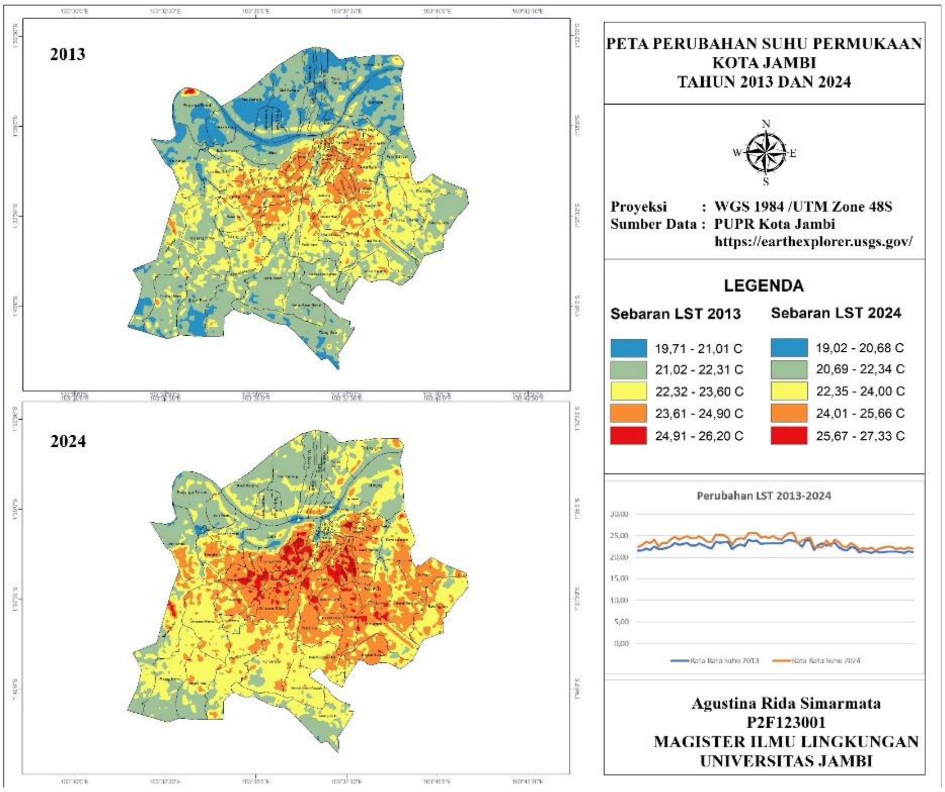

Figure 3. Land Surface Temperature Distribution Map in Jambi City 2013 and 2024

4. Conclusion

The comprehensive analysis of LST changes in Jambi City from 2013 to 2024 reveals several significant findings. First, the study demonstrates clear evidence of UHI intensification in rapidly urbanizing areas, with maximum temperature increases of 1.13°C over the 11-year period. Second, the research confirms the crucial role of vegetation cover and water bodies in maintaining thermal stability, with areas like Danau Teluk and Pelayangan showing minimal temperature increases due to preserved natural features. Third, the spatial analysis identifies distinct thermal patterns strongly correlated with urban development intensity, where areas experiencing rapid land-use conversion show the most significant temperature increases. The findings emphasize the critical importance of integrated urban planning approaches that balance development needs with environmental sustainability. The study provides empirical evidence supporting the effectiveness of green infrastructure and water bodies in mitigating urban heat island effects. The documented thermal changes serve as valuable guidance for urban planners and policymakers in developing climate-conscious urban development strategies. These results contribute significantly to understanding the long-term impacts of urbanization on local climate patterns and provide a foundation for developing effective heat mitigation strategies in rapidly growing tropical cities. The research recommends implementing comprehensive UHI mitigation measures, including: preserving and expanding urban green spaces, maintaining natural water bodies, utilizing high-albedo construction materials, and developing integrated green infrastructure networks. Future urban development plans should prioritize thermal comfort considerations and incorporate natural cooling mechanisms to create more sustainable and livable urban environments. This study's findings are particularly relevant for tropical cities experiencing rapid urbanization and can serve as a reference for developing climate-resilient urban planning strategies.

Conflict of Interest

All the authors assert that they possess no identifiable financial conflicts of interest or personal affiliations that may have seemingly impacted the work presented in this study

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