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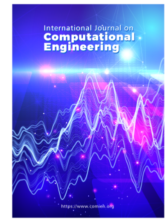

Settlement Analysis Using Normalized Difference Built-Up Index (NDBI) and Land Surface Temperature (LST)

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***Abstract*—The rapid increase in population and income per capita in Makassar City has led to a significant rise in land demand, resulting in land use changes and increased surface temperatures. This study aims to analyze densely populated settlement areas using the Normalized Difference Built-Up Index (NDBI) and Land Surface Temperature (LST) from 2019 to 2022. The research employed Landsat 8 OLI/TIRS satellite imageries and Arcmap software for data processing and analysis. The findings indicate that areas with high building density exhibit higher surface temperatures, while areas with dense vegetation show lower temperatures. The overlay analysis of LST and NDBI for 2013 and 2021 reveals that non-built-up areas experienced a temperature increase from 24°C to 29°C, and high vegetation density areas maintained lower temperatures around 24°C. The study concludes that urban heat islands are significantly influenced by land use changes, particularly the reduction of green spaces and the increase in built-up areas. The research underscores the importance of sustainable urban planning to mitigate the adverse effects of urbanization on local climate. Future studies should incorporate higher spatial resolution data and field verification to enhance the accuracy of the findings.**

***Keywords*—Land surface temperature; NDBI; satellite imagery; settlement analysis.**

Manuscript received 28 Oct. 2025; revised 17 Jan. 2026; accepted 25 Feb. 2026. Date of publication 31 Mar. 2026.

I. Introduction

Makassar City, the capital of South Sulawesi Province, is one of the fastest-growing cities in Indonesia. The significant population growth in Makassar City has impacted the availability of space within the city. Population growth has driven development that changes land use and land functions, contributing to rising land surface temperatures in Makassar City [1]. On October 20, three BMKG observation stations in Sulawesi recorded the highest maximum temperatures: the Hasanuddin Meteorological Station (Makassar) at 38.8°C, followed by the Maros Climatology Station at 38.3°C, and the Sangia Ni Bandera Meteorological Station at 37.8°C [2]. These figures represent the highest temperatures recorded over the past year, surpassing the maximum temperature of 37°C observed during October 2018.

The head of the Service and Information Unit of the Meteorology, Climatology, and Geophysics Agency (BMKG) Region IV Makassar in 2019 stated that the intense heat in Makassar City was due to the environment's lack of representativeness. Green open spaces have been significantly reduced and replaced with tall buildings, leading to land-use changes that expose the community to direct solar radiation, making Makassar City feel very hot. This phenomenon has been studied, showing that built-up land increased by 13.1%, and the average LST in Makassar City rose by 0.39°C [1].

Rapid development has caused land cover changes in major cities, affecting the local weather and climate. This development leads to changes in climate elements, particularly in city centers, creating urban heat islands (UHI) [3], [4], [5], [6]. Surface temperatures in an area are influenced by local conditions, including vegetation density and population density. Surface temperatures are closely related to built-up areas, as they are higher in built-up areas than in non-built-up areas [1].

To analyze surface temperatures, also known as Land Surface Temperature (LST), satellite image processing methods using ArcMap software are employed. The algorithm used for LST measurement is the Monowindow Brightness Temperature Data, utilizing bands 10 and 11 to determine the distribution in the study area [7]. The Vegetation Index, known as the Normalized Difference Vegetation Index (NDVI), is a remote sensing data parameter commonly used to measure vegetated areas. Theoretically, the vegetation index ranges from -1.0 to +1.0, with values between 0.1 and 0.6 representing actual vegetation greenness. High index values indicate dense vegetation [8].

In addition to the vegetation index, there is also the urban index, a parameter for detecting building density. The urban index, known as the Normalized Difference Built-Up Index (NDBI), is designed to facilitate urban area mapping using Landsat 8 satellite imagery. The urban index negatively correlates with the vegetation index, making them inversely related. Previous studies have evaluated the density conditions of Makassar City using satellite image analysis and data processing techniques, combining optical data and active imagery such as SAR.

II. Materials and Method

A. Study Area

The study was conducted in Makassar City, the capital of South Sulawesi Province, Indonesia. Makassar is located between 5°8' South Latitude and 119°24' East Longitude, strategically positioned on the southwest coast of Sulawesi Island, facing the Makassar Strait. This location has made it a significant hub for trade, maritime transport, and a gateway to Eastern Indonesia. Makassar's topography comprises mainly coastal lowlands, with an elevation ranging from 0 to 25 meters above sea level. The terrain is relatively flat in central and western areas, while more hilly regions appear in the eastern part due to the proximity to South Sulawesi's mountainous areas.

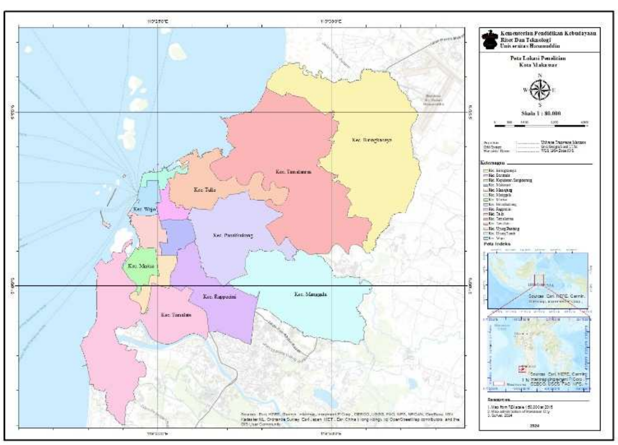

Fig. 1 The research location is in Makassar City, the capital of South Sulawesi Province, Indonesia

B. Data and Equipment

1) Equipment:

- Hardware: A computer with adequate processing power for geospatial data processing and ArcGIS software.
- Software: (1) Geospatial Data Processing Software (ArcGIS), which is used for spatial data processing, analysis, and the layout of final maps. (2) Microsoft Office 365, which is used for statistical calculations, data analysis, and document preparation.

2) Data Sources:

- Landsat 8 OLI/TIRS Satellite Images: These images, sourced from USGS for January 2014, 2019, and 2023, are essential for analyzing urban density, vegetation cover, and land surface temperature.
- Administrative Boundary Shapefile of Makassar City: Sourced from the Makassar City Spatial Plan Database (2023) at a 1:25,000 scale.
- Temperature Distribution Data from BMKG: This data is used to validate surface temperature findings for Makassar City from 2014, 2019, and 2023.

C. Research Methodology

The research follows a multi-stage methodology that includes preparation, implementation, and finalization as adopted from the Stages of Implementation Completion [9]. The stages are as follows:

1) Preparation Stage:

- Problem Identification: The primary focus of this study is to examine the relationship between densely populated residential areas and surface temperature variations in Makassar City over the years 2014, 2019, and 2023.
- Literature Review: Relevant literature is reviewed to gather references on previous data processing techniques, research related to urban heat and land use, the Normalized Difference Built-Up Index (NDBI), and Land Surface Temperature (LST) algorithms, as well as data from Landsat-8.

2) Implementation Stage

- Data Collection: Data collection involves obtaining Landsat-8 OLI/TIRS Level I satellite imagery for January 2014, 2019, and 2023, BMKG temperature data for Makassar City, and the city's administrative boundaries.
- Data Processing:
  Building Density Index (NDBI): The NDBI is calculated using bands 5 (Near Infrared) and 6 (Short-Wave Infrared) of Landsat 8 data. The following processing steps are applied:
  1. Import the satellite image data into ArcGIS.
  2. Perform radiometric calibration to correct for sensor and atmospheric distortions.
  3. Apply the NDBI algorithm, which calculates building density by contrasting the SWIR and NIR bands.
  4. Classify NDBI values into specific categories for urban density.
  5. Crop the image using administrative boundaries to focus the analysis on Makassar City.
  6. Export the processed data in .tif format for visualization and analysis.

  Land Surface Temperature (LST): LST is calculated using thermal infrared bands 10 and 11 to derive surface temperature. Steps include:
  1. Import the thermal band data into ArcGIS.

2. Perform radiometric calibration to convert digital values to reflectance.
3. Calculate Brightness Temperature in Kelvin and convert it to Celsius.
4. Classify the resulting surface temperatures for analysis.
5. Crop the thermal image based on administrative boundaries to ensure data specificity to the city.
6. Export the processed LST data in .tif format.

- Field Survey: A field survey is conducted to validate satellite data, focusing on densely populated, sparsely populated, and non-residential areas. Field observations are compared with satellite-derived data to ensure accuracy in the final analysis.

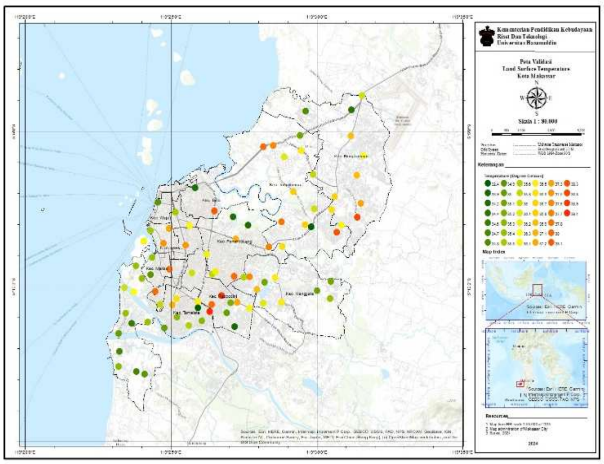

Fig. 2 Location points for surface temperature validation

3) Final Stage

- Data Analysis: This stage involves analyzing relationships between high-density urban areas and land surface temperature by comparing NDBI and LST data across the years 2014, 2019, and 2023.

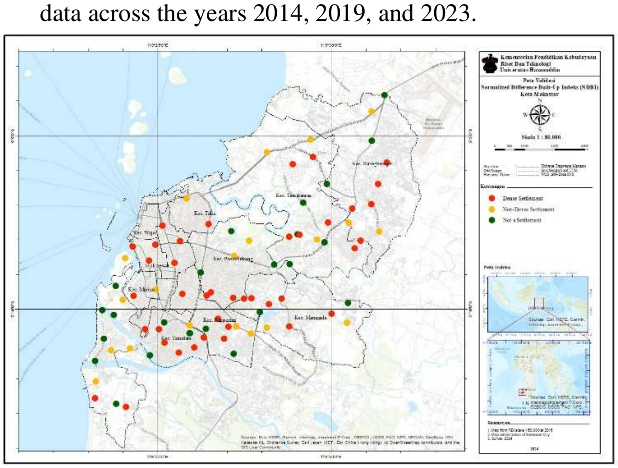

Fig. 3 Location points for NDBI validation

- Report Preparation: A comprehensive report documents all findings, detailing data collection, processing techniques, and analytical results.

III. Results and Discussion

This section presents the analysis of urban density and land surface temperature (LST) in Makassar City in 2014, 2019, and 2023. Results from the Normalized Density Building Index (NDBI) and LST analyses are discussed, highlighting how urban expansion influences surface temperature patterns and contributes to the urban heat island (UHI) effect.

A. NDBI Analysis and Urban Growth Patterns

The analysis of NDBI values across the three study years reveals significant urban expansion in Makassar City. Table 1 summarizes the land area distribution by urban density category, showing that the high-density urban area has grown considerably from 2014 to 2023, while non-built areas have decreased.

TABLE I
Urban density categories in Makassar City (2014-2023).

Year	Non-Built Area (ha)	Low-Density Urban Area (ha)	Medium-Density Urban Area (ha)	High-Density Urban Area (ha)
2014	11,770.45	3,819.13	1,583.66	150.40
2019	11,435.92	3,819.13	2,238.65	180.66
2023	11,000.30	3,650.00	2,500.00	230.00

The data in Table 1 indicate a decline in non-built areas alongside a rise in high-density urban zones, suggesting substantial urban expansion. Figures 5-6 show spatial maps of NDBI values for each year, visually illustrating this trend. By 2023, high-density zones had significantly increased, especially in the central and western parts of Makassar, where urban development has intensified.

Figures 4–6 show the NDBI for each year, indicating that the central and western parts of Makassar have experienced the most extensive urbanization. This pattern suggests that urban growth has been concentrated in central locations, reducing non-built areas and increasing urban density in these regions.

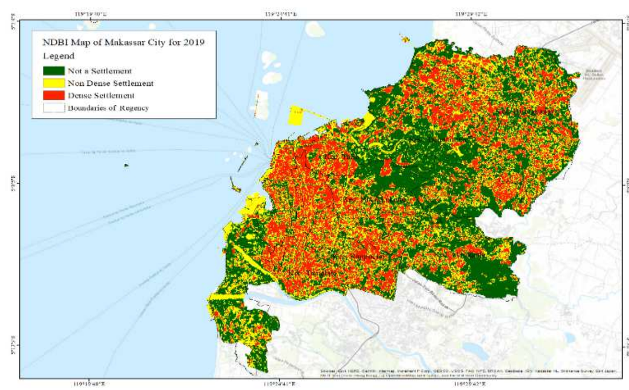

Fig. 4 NDBI Map of Makassar City for 2019.

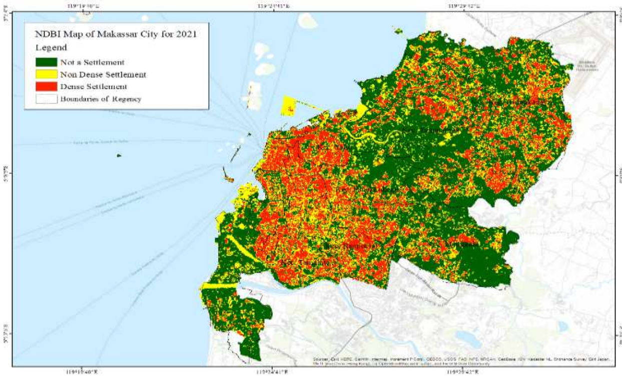

Fig. 5 NDBI Map of Makassar City for 2021

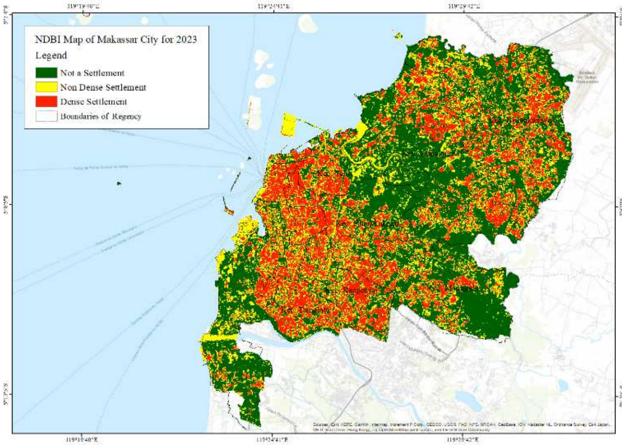

Fig. 6 NDBI Map of Makassar City for 2023.

These findings align with Makassar's growth as a major urban hub, with infrastructural development, population increase, and commercial expansion contributing to more densely built-up areas. The reduction in non-built areas reflects the transformation of green or open spaces into residential and commercial areas, which are characteristic of urbanization [10].

B. *Land Surface Temperature (LST) Patterns*

Analysis of the LST data indicates that surface temperatures are closely linked to urban density. Higher temperatures were recorded in areas with increased building density, consistent with urban heat island (UHI) phenomena. Table 2 shows the average LST values in relation to different urban density categories across the study years.

TABLE II
AVERAGE LAND SURFACE TEMPERATURE BY URBAN DENSITY CATEGORY (2014-2023).)

Year	Low-Density LST (°C)	Medium-Density LST (°C)	High-Density LST (°C)
2014	25	27	30
2019	26	28	31
2023	27	29	33

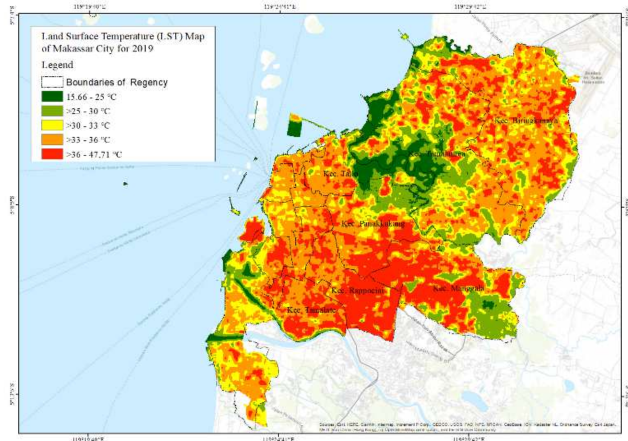

Fig. 7 Land Surface Temperature (LST) Map of Makassar City for 2019.

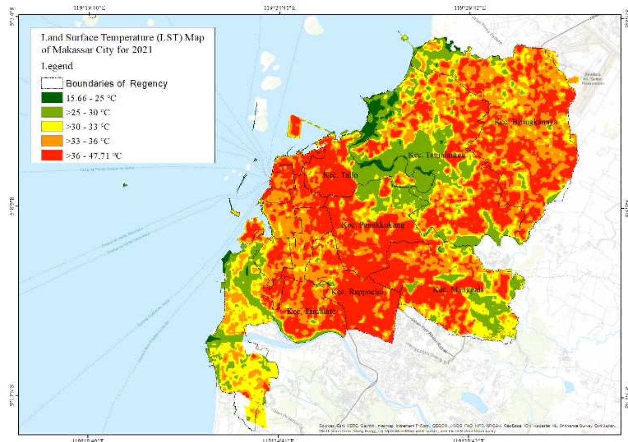

Fig. 8 Land Surface Temperature (LST) Map of Makassar City for 2021.

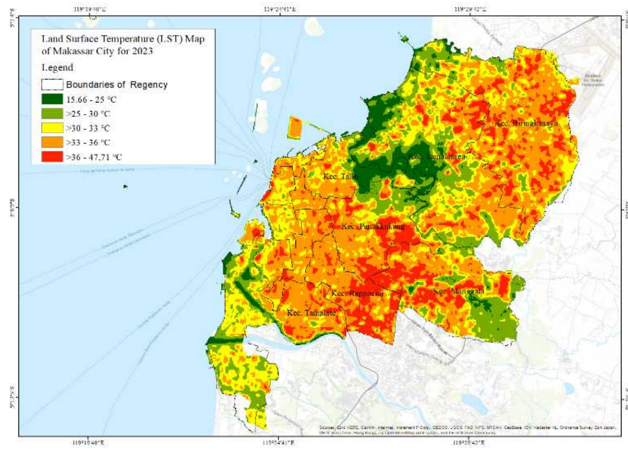

Fig. 9 Land Surface Temperature (LST) Map of Makassar City for 2023.

The LST data presented in Table 2 and Figures 7–9 reveal a clear trend of rising temperatures within higher-density areas. From 2014 to 2023, high-density urban zones experienced an average increase of 3°C, from 30°C to 33°C. This trend correlates with urban development, as buildings and paved surfaces replace natural vegetation. The reduction of vegetation exacerbates warming because plants and trees have cooling effects through evapotranspiration, which is lost as green spaces are converted to impervious surfaces [11].

C. NDBI and LST Overlay Analysis

Overlay analysis of NDBI and LST data provides insight into how urban density impacts surface temperature. showing a strong spatial correlation between high-density urban areas and elevated LST values. These overlays confirm that the UHI effect is pronounced in Makassar, where densely populated areas experience consistently higher surface temperatures than less urbanized regions. The spatial correlation indicates that urban density contributes to temperature increases, with the highest LST values typically found in areas that transitioned from low- to high-density urban classifications over the study period. This correlation highlights the impact of increased infrastructure and reduced green cover, which trap more heat and intensify warming in urban settings [12], [13], [14], [15].

D. Implications and Urban Heat Island (UHI) Effect

The findings underscore the need for strategic urban planning to mitigate the UHI effect in Makassar City. The rise in temperatures within densely populated areas poses risks to public health, energy consumption, and overall urban sustainability. Increased cooling demand during peak temperatures raises energy consumption, compounding greenhouse gas emissions and further intensifying the UHI effect [16], [17], [18], [19], [20], [21]. Some recommendations to address these challenges include:

- Expanding Green Spaces: Establishing parks and planting more trees in high-density urban zones can help reduce temperatures by providing shade and facilitating evapotranspiration.
- Implementing Sustainable Building Practices: Use of reflective materials, green roofs, and other sustainable building techniques can help minimize heat absorption by infrastructure.
- Encouraging Vertical Expansion: Rather than horizontal urban sprawl, vertical development can conserve land and limit the reduction of non-built areas, preserving natural spaces that help cool the environment.

E. Limitations and Future Research

This study provides a valuable perspective on the impact of urbanization on surface temperature; however, certain limitations should be noted. Landsat 8 imagery provides moderate spatial resolution, which may limit analysis of fine-scale temperature variation. Field validation was primarily limited to accessible areas, potentially introducing sampling bias. Future research should consider utilizing higher-resolution satellite data and expanding field validation efforts to capture a more nuanced view of urbanization's impact on LST. Investigating seasonal variations in LST and urban density is also recommended to provide a comprehensive understanding of thermal changes in urban environments.

IV. Conclusion

This study analyzed the relationship between densely populated settlement areas and land surface temperature (LST) in Makassar City using the Normalized Difference Built-Up Index (NDBI) and satellite imagery from Landsat 8 OLI/TIRS for the years 2014, 2019, and 2023. The findings indicate a significant increase in both building density and surface temperatures over the study period, highlighting the impact of urbanization on local climate.

The analysis revealed that areas with high NDBI values, indicating high building density, correspond with higher LST values. Conversely, areas with low NDBI values, indicating dense vegetation, correspond with lower LST values. This inverse relationship underscores the importance of green spaces in mitigating the effects of urban heat islands (UHI). The reduction of green spaces and the increase in impervious surfaces, such as buildings and roads, have contributed to the rise in surface temperatures in Makassar City.

The spatial distribution of LST and NDBI shows that the central and western parts of the city, which are more urbanized, have higher temperatures and building densities compared to the eastern parts, which have more green spaces and less urban development. The increase in surface temperatures from 29°C in 2014 to 33°C in 2023 clearly indicates the impact of urbanization on local climate.

The findings of this study are consistent with previous research on the impact of urbanization on local climate. The results emphasize the need for sustainable urban planning practices that incorporate green spaces to reduce the adverse effects of urbanization on local climate. Future research should focus on higher-spatial-resolution data and field verification to enhance the accuracy of the findings. Additionally, exploring other remote sensing indices, such as the Normalized Difference Vegetation Index (NDVI), can provide further insights into the relationship between vegetation and surface temperature. In conclusion, the study highlights the critical role of green spaces in urban areas in mitigating the effects of urban heat islands. Sustainable urban planning that prioritizes the preservation and expansion of green spaces is essential for maintaining a balanced urban climate and improving the quality of life for residents in rapidly urbanizing cities like Makassar.

Acknowledgment

We would like to express our gratitude to all the organizations and institutions that supported this research. We thank the Indonesian Collaborative Research Program for funding, the Meteorology, Climatology, and Geophysics Agency (BMKG) for providing temperature data, and the USGS for satellite imagery. Special thanks to our university's administrative staff for their assistance.

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