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Original Article

Spatiotemporal Analysis of The Urban Heat Island Phenomenon in Built-Up Areas of Makassar City Using Google Earth Engine (2019–2024)

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Abstract

This study analyzes the Urban Heat Island phenomenon in built-up areas of Makassar City during the period 2019–2024. The objective of the study is to identify the development of built-up areas, changes in vegetation cover, the distribution of land surface temperature, and the relationship between building density and increasing surface temperature. The research employs a quantitative approach using spatial-temporal analysis based on remote sensing and geographic information systems through the Google Earth Engine platform. The data used consist of Landsat satellite imagery from 2019 and 2024, processed to generate a built-up density index, vegetation index, and land surface temperature. The results indicate that the extent of built-up areas increased from 891.49 hectares to 1,001.74 hectares, representing an increase of 12.37 percent, while newly expanded urban areas reached 297.33 hectares. The growth of built-up areas reduced vegetation cover and intensified the Urban Heat Island phenomenon. The highest surface temperatures were observed in industrial zones, central business districts, and densely populated residential areas, ranging from 36 to 41 degrees Celsius, whereas vegetated areas and water bodies exhibited lower temperatures. The study concludes that the expansion of built-up areas is the primary factor contributing to the increase in surface temperature and the intensity of the Urban Heat Island phenomenon in Makassar City, highlighting the need to strengthen urban green spaces as an environmental mitigation strategy.

Keywords: Built-up Areas, Land Surface Temperature, Makassar City, Urban Heat Island

INTRODUCTION

Global urbanization has become one of the major drivers of changes in the Earth's physical surface during the twenty-first century (“Singapore as A Global City,” 2025). Large-scale migration from rural to urban areas, accompanied by sustained economic growth, has accelerated extensive land-use change across many cities. As the primary economic growth center and national activity hub in Eastern Indonesia, Makassar City has undergone rapid spatial and temporal transformation over the past five years (2019–2024). The continuous expansion of infrastructure, residential neighborhoods, and industrial areas has significantly altered the city's thermal environment. One of the most visible consequences of this transformation is the Urban Heat Island (UHI) phenomenon, in which urban areas experience substantially higher surface and air temperatures than the surrounding rural areas due to human activities (Larasati et al., 2022). The increasing severity of UHI and its implications for urban environmental sustainability and human well-being provide the main motivation for this study. Rising Land Surface Temperature (LST) in Makassar is no longer simply a matter of urban thermal comfort but has become a pressing environmental concern. Higher surface temperatures pose risks to public health, increase household electricity consumption through greater dependence on air conditioning, and contribute to the deterioration of overall environmental quality. At the same time, rapid urban expansion has been accompanied by the uncontrolled conversion of vegetated land and green open spaces,

Vol X No X Month Year
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https://ejournalfish.unima.ac.id/index.php/georhexis/

resulting in a continuous decline in urban vegetation cover (Prihandono, 2010). When natural vegetation is replaced by impervious surfaces such as asphalt, concrete, and metal roofs, the surface energy balance changes considerably. Rather than being used for evapotranspiration, incoming solar radiation is absorbed, stored as sensible heat, and gradually released into the atmosphere, leading to persistent heat accumulation over densely built urban areas (Ramadanti, 2025).

Research on the Urban Heat Island phenomenon has gradually evolved from conventional meteorological observations toward the use of multispectral remote sensing technologies (Ditami, 2023). However, long-term spatiotemporal analysis of satellite imagery remains challenging because of limited local computing capacity, persistent cloud cover in tropical regions such as Makassar, and the large computational resources required to process multitemporal datasets efficiently. These challenges make Google Earth Engine (GEE) a particularly suitable platform for this type of analysis. By providing cloud-based access to petabyte-scale satellite archives, including Landsat 8/9 and Sentinel imagery, GEE enables efficient retrieval of Land Surface Temperature (LST) and extraction of built-up indices such as the Index-based Built-up Index (IBI) and the Normalized Difference Built-up Index (NDBI) (Deng & Wu, 2012). Consequently, large-scale multitemporal analyses can be performed rapidly without being constrained by local hardware limitations. This study is based on the interrelated dynamics among three key variables: rapid urbanization, increasing built-up density, and declining vegetation cover represented by the Normalized Difference Vegetation Index (NDVI). Between 2019 and 2024, Makassar experienced substantial demographic growth and spatial transformation, encompassing the periods before, during, and after the COVID-19 pandemic, all of which directly influenced the pace and pattern of urban development (Muhyiddin, 2020). Understanding how these changes affect the spatial distribution and temporal evolution of the Urban Heat Island phenomenon is therefore essential. Previous studies have generally examined UHI at a single point in time or at relatively coarse spatial resolutions, limiting their ability to capture localized thermal variations within densely developed urban environments.

The novelty of this study lies in the application of Google Earth Engine to examine spatiotemporal changes in urban temperature across Makassar, particularly within densely built-up areas, using atmospherically corrected thermal satellite imagery acquired between 2019 and 2024—a period marked by rapid urban development. Beyond producing Land Surface Temperature maps, this research develops a quantitative model to evaluate the relationship between built-up density and UHI intensity. In addition, it identifies urban hotspots that should be prioritized for heat mitigation efforts. Accordingly, this study focuses on the spatiotemporal characteristics of the Urban Heat Island phenomenon within the administrative boundary of Makassar City. Landsat 8/9 OLI/TIRS imagery processed through the Google Earth Engine platform (Sianturi, 2022) was used for the analysis, covering the period from 2019 to 2024. The evaluated variables include the built-up density index, vegetation density index, and Land Surface Temperature (LST) (Fitriani et al., 2023). Specifically, this study aims to:

1. Analyze the spatiotemporal expansion of built-up areas and the decline in vegetation cover in Makassar City between 2019 and 2024.
2. Identify the spatial distribution and intensity of the Urban Heat Island (UHI) phenomenon in Makassar City using Google Earth Engine.
3. Examine the relationship between built-up density and increasing land surface temperature in urban areas.
4. Delineate urban heat vulnerability zones to support environmentally adaptive and climate-responsive urban spatial planning in Makassar City.

The theoretical framework of this study draws upon urban thermal dynamics and blackbody radiation theory, particularly Planck's Law, which forms the basis for retrieving Land Surface Temperature (LST) from satellite thermal infrared imagery. It also incorporates the concept of Urban Morphology to explain how street geometry, building density, and surface materials influence sensible heat retention. Furthermore, urban spectral indices (NDBI/IBI) and the Normalized Difference Vegetation Index (NDVI) are employed to examine the contrasting relationship between impervious surfaces and green open spaces. Through this Google Earth Engine-based approach (Tika Christy Novianti & Hendry Natanael Gumano, 2023), the study is expected to provide reliable empirical

Vol X No X Month Year
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https://ejournalfish.unima.ac.id/index.php/georhexis/

evidence to support the Government of Makassar City in developing greener urban spatial planning strategies for mitigating the local impacts of global warming.

MATERIALS AND METHODS

This study employed a quantitative approach using a spatiotemporal analytical design based on remote sensing and Geographic Information Systems (GIS). The approach was selected to quantitatively measure, map, and model the causal relationship between the physical expansion of built-up areas and the intensity of the Urban Heat Island (UHI) phenomenon in Makassar City over the period from 2019 to 2024. All satellite image processing was conducted within the cloud-based Google Earth Engine (GEE) platform (Fathoni dkk., 2025). The study relied on secondary data in the form of multispectral satellite imagery obtained directly from the Google Earth Engine data repository. The datasets used consisted of:

1. Landsat 8 OLI/TIRS satellite imagery (Collection 2 Level 2 Tier 1) acquired in 2019 with atmospheric correction applied (Surface Reflectance).
2. Landsat 9 OLI/TIRS satellite imagery (Collection 2 Level 2 Tier 1) acquired in 2024 with atmospheric correction applied (Surface Reflectance).
3. The digital administrative boundary of Makassar City (shapefile format, .shp) obtained from the Geospatial Information Agency (BIG) for clipping the study area.

Satellite imagery was selected based on a cloud cover threshold of less than 10% during the dry season (July–October) to minimize radiometric bias and accurately represent peak land surface thermal conditions. Image processing within the Google Earth Engine platform consisted of the following stages:

1. **True Color (RGB) Image Processing**. True Color composites were generated using the Red, Green, and Blue spectral bands (Bands 4, 3, and 2 of Landsat 8/9) to visualize the actual land surface conditions of Makassar City in 2019 and 2024.
2. **Built-up Area Mapping Using the Normalized Difference Built-up Index (NDBI)**. The Normalized Difference Built-up Index (NDBI) was used to map the spatial distribution of built-up areas based on the spectral response of the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) bands using the following equation:
$$\mathrm{NDBI} = \frac{\mathrm{SWIR}_1 - \mathrm{NIR}}{\mathrm{SWIR}_1 + \mathrm{NIR}}$$
where SWIR_1 corresponds to Band 6 and NIR corresponds to Band 5 of Landsat 8/9.
3. **Built-up Area Classification and Urban Expansion Analysis**. Built-up and non-built-up areas were classified by applying an NDBI threshold followed by visual verification using RGB composite imagery. Built-up areas identified in 2019 were assigned the spatial code orange, whereas those identified in 2024 were assigned the spatial code red. Spatial changes occurring between the two observation years were extracted through Boolean logical operations in Google Earth Engine to produce an Urban Expansion (2019–2024) map, represented in yellow.
4. **Land Surface Temperature (LST) Retrieval.** Land Surface Temperature (LST) was derived from the thermal infrared band (Band 10) using a Land Surface Emissivity (LSE) correction algorithm based on the Normalized Difference Vegetation Index (NDVI). The procedure consisted of the following steps.
   a. Vegetation Fraction (P_v)
   $$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2$$
   b. Land Surface Emissivity (ε)
   $$\varepsilon = 0.004 \times P_v + 0.986$$
   c. Brightness Temperature (B_T)
   Brightness Temperature (B_T) was calculated from the thermal radiance.
   d. Land Surface Temperature (LST)
   LST (°C) was calculated using the following equation:

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$$LST = \frac{B_T}{1 + \left(\lambda \times \frac{B_T}{\rho}\right) \times \ln(\varepsilon)}$$

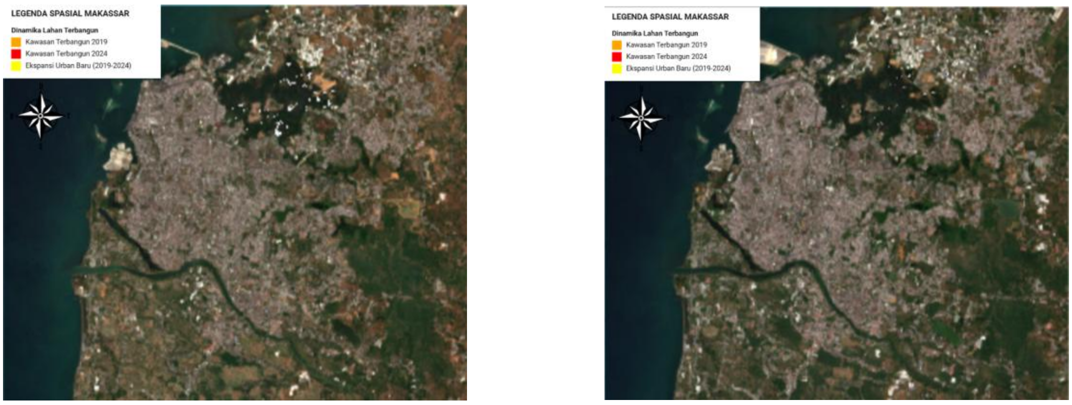
e. Urban Heat Island (UHI) Delineation

The Urban Heat Island (UHI) phenomenon was identified by applying a standardized land surface temperature threshold to delineate thermal hotspot zones throughout the Makassar urban corridor. The resulting output was presented as a full-view Land Surface Temperature Urban Heat Island (LST-UHI) map

RESULTS AND DISCUSSION

A. Visual Interpretation of the True Color (RGB) Composite in 2019 to 2024

This section presents the results of the multi-temporal interpretation of Landsat imagery to examine land cover dynamics in Makassar City between 2019 and 2024. True Color (RGB) composites were employed to visually identify the spatial distribution of major land cover types, including built-up areas, vegetation, agricultural land, and coastal reclamation zones. Comparative interpretation of satellite imagery provides a fundamental basis for understanding the magnitude and direction of urban expansion, as well as the resulting transformation of the city's physical landscape. The visual analysis not only reveals changes in land cover composition but also illustrates the progressive replacement of permeable, vegetated surfaces by impervious urban structures. Such transformations are closely associated with modifications in surface energy balance, reduced evapotranspiration, and increased heat storage capacity, all of which contribute to the intensification of the urban thermal environment. Therefore, the interpretation of the RGB composites serves as an essential preliminary step for explaining subsequent analyses of land surface temperature (LST), vegetation dynamics, and the development of urban heat island (UHI) patterns in Makassar City. The following figures present the spatial characteristics of Makassar City's land cover in 2019 and 2024, providing visual evidence of urban growth and environmental transformation during the study period.



(a) (b)

Figure 1. True Color (RGB) Composite of Makassar City: (a) 2019 and (b) 2024

Figure 1(a) illustrates the baseline environmental conditions of Makassar City in 2019, revealing a distinct contrast between the urban core and its surrounding areas. The coastal zone extending toward the city center is dominated by dense silver-gray features with coarse textures, representing impervious surfaces such as residential rooftops, commercial buildings, and the primary road network. In contrast, the eastern, southeastern, and northern parts of the city are characterized by dark to light green tones with relatively smooth textures, indicating the extensive presence of green open spaces, plantations, and natural forest vegetation. Light brown patches observed in the northeastern area correspond to exposed agricultural land, particularly paddy fields in the fallow stage. Along the western coastline, the initial land reclamation of the Center Point of Indonesia (CPI) is clearly visible as bright white artificial landforms with little or no vegetation cover. Overall, the 2019 land cover pattern provides an important baseline for evaluating the spatial distribution of heat absorption

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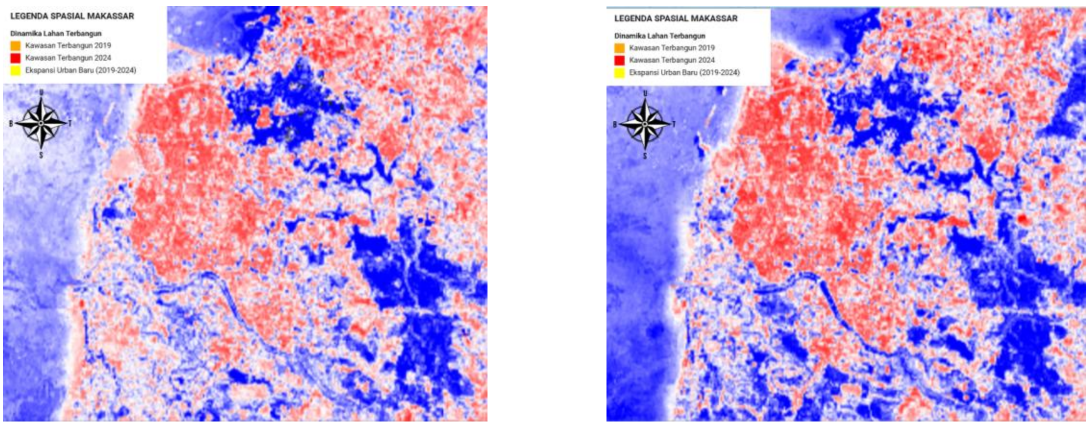
and storage across the city, where thermal accumulation remained localized, particularly within the western urban sector.

The transformation of Makassar's urban landscape over the five-year period is clearly evident in Figure 1(b). Visual interpretation indicates a rapid expansion of built-up areas toward the eastern and northern parts of the city. The extensive silver-gray tones that were previously concentrated in the urban core have progressively expanded into areas formerly dominated by vegetation. Significant fragmentation of vegetated land is observed in the districts of Manggala, Tamalanrea, and Biringkanaya, where large residential developments and newly established industrial zones have replaced natural land cover. In the western coastal area, particularly within the Center Point of Indonesia (CPI) reclamation site, the bright white surfaces identified in 2019 have evolved into gray rectangular patterns, indicating the completion of permanent buildings and modern infrastructure. Similarly, along the northern coastline, the strategic Makassar New Port (MNP) development has expanded further into coastal waters through extensive land reclamation. At the city scale, the transition from predominantly green (organic) surfaces to gray and white (impervious) surfaces reflects a substantial reduction in natural urban cooling capacity as a consequence of accelerating urban development and increasing anthropogenic pressure.

B. Spatial Distribution of Built-up Areas Derived from the Normalized Difference Built-up Index (NDBI) in 2019 to 2024

To quantify the intensity and spatial distribution of urban development, the Normalized Difference Built-up Index (NDBI) was employed to identify built-up areas and monitor changes in impervious surface coverage between 2019 and 2024. Unlike true color imagery, which primarily provides visual interpretation of land cover, NDBI enhances the spectral response of built-up surfaces, enabling a more objective assessment of urban expansion and land surface transformation. Higher positive NDBI values indicate areas dominated by buildings, roads, and other impervious materials, whereas lower or negative values generally correspond to vegetation, agricultural land, wetlands, and water bodies. The comparison of NDBI maps across the two observation years provides valuable insights into the spatial dynamics of Makassar City's urban growth. Changes in the extent and concentration of high NDBI values reflect the conversion of vegetated and open lands into built-up environments, illustrating the increasing intensity of urbanization across the metropolitan area. These patterns are particularly important because the expansion of impervious surfaces alters hydrological processes, reduces infiltration capacity, increases surface runoff, and enhances heat storage, thereby contributing to the development of urban environmental problems such as flooding and the Urban Heat Island (UHI) effect. The following figures present the spatial distribution of built-up areas in Makassar City in 2019 and 2024, providing a basis for evaluating the magnitude and direction of urban expansion during the study period.



(a) (b)

Figure 2. NDBI Map of Makassar City: (a) 2019 and (b) 2024

Vol X No X Month Year
ISSN: XXXX-XXXX
DOI: 10.xxxxxxxxxx
https://ejournalfish.unima.ac.id/index.php/georhexis/

The physical transformation of the land surface was evaluated using the spectral-based Normalized Difference Built-up Index (NDBI). As shown in Figure 2(a), the spatial distribution of built-up areas in Makassar City was represented using a spectral gradient based on NDBI values. Areas with high positive NDBI values (greater than 0.15) are displayed in dark red and are primarily concentrated within the historic urban core, including the districts of Wajo, Ujung Pandang, Mariso, Makassar, Bontoala, and parts of Rappocini. In contrast, the eastern and northern parts of the city are characterized by negative to near-zero NDBI values, represented by blue to light blue tones, indicating that land cover in these areas was still largely dominated by non-built-up surfaces such as vegetation and wetlands in 2019. Overall, the spatial variation in NDBI values clearly distinguishes the highly urbanized western sector of Makassar from the agricultural and suburban landscapes extending toward the neighboring regencies of Gowa and Maros.

The post-pandemic expansion of built-up areas is clearly illustrated by the 2024 NDBI map presented in Figure 2(b). A direct spatial comparison with the 2019 map reveals a pronounced outward expansion of high positive NDBI values (displayed in red), radiating from the city center toward the surrounding urban fringe. Major transportation corridors, including Jalan Perintis Kemerdekaan toward Maros and Jalan Sultan Alauddin toward Gowa, now appear as continuous dark red linear features, reflecting intensive urban development along these routes. Marked increases in built-up areas are evident in the districts of Biringkanaya and Tamalanrea, driven by the expansion of warehouse complexes, private residential developments, and the continued growth of university campuses. Meanwhile, areas characterized by negative NDBI values (shown in blue) have declined substantially and become increasingly confined to the southeastern part of the city. These spatial patterns indicate extensive surface sealing across Makassar, where the rapid expansion of impervious surfaces has reduced soil permeability and diminished the land's capacity to absorb and infiltrate rainwater.

C. Built-Up Area Classification in 2019 to 2024

To provide a more explicit representation of urban expansion, the continuous NDBI values were further converted into a binary built-up classification. This classification distinguishes impervious built-up surfaces from non-built-up land cover, enabling a clearer assessment of the magnitude and spatial configuration of urban growth. Compared with continuous spectral indices, binary classification facilitates the identification of the spatial extent of urbanized land and provides a more intuitive basis for evaluating changes in urban morphology. The comparison between the 2019 and 2024 built-up area maps highlights the intensity of land conversion associated with rapid urbanization and reveals the progressive transformation of Makassar City from a relatively compact urban center into a more spatially extensive metropolitan landscape.

(a) (b)

Figure 3. Built-up Area Classification: (a) 2019 and (b) 2024

To quantify the absolute extent of built-up land, the 2019 NDBI values were classified using a binary thresholding approach, resulting in a single built-up area classification map (Built-up Area 2019), displayed in orange in Figure 3(a). The spatial pattern reveals an elongated urban morphology

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that follows the coastline, characteristic of a linear coastal city, with several narrow urban corridors extending inland. Undeveloped areas continued to function as the city's primary open spaces, including the natural wetlands in Manggala District and rainfed agricultural land along the urban fringe. This binary classification indicates that, in 2019, the physical influence of urban development on the city's microenvironment remained relatively localized and had not yet formed a continuous impervious urban surface.

Figure 3(b) presents the updated built-up area classification for 2024, where built-up surfaces are represented in red. Compared with 2019, the spatial morphology of the urban area has evolved into a more extensive and highly interconnected pattern. The fragmented urban patches observed in 2019 have largely been infilled by new developments, producing a more continuous urban fabric through the process of urban infill. The districts of Tamalate, Rappocini, Panakkukang, Tamalanrea, and Biringkanaya are now almost entirely covered by contiguous built-up areas. This substantial land conversion indicates that impervious surfaces have expanded extensively across the administrative area of Makassar City, reducing the capacity of urban land to transfer latent heat through natural surface processes.

D. Urban Expansion Dynamics (2019-2024)

To further quantify urban expansion, the NDBI results were converted into a binary built-up area classification, distinguishing impervious urban surfaces from non-built-up land. This classification simplifies the spectral information into two categories, enabling a clearer assessment of the spatial extent, morphology, and continuity of built-up areas over time. By identifying the distribution of developed land, the analysis provides a more direct measure of urban growth and facilitates comparisons between different observation periods. The comparison of built-up area classifications for 2019 and 2024 illustrates not only the increase in urban land coverage but also the evolution of Makassar City's spatial structure. Changes in the size, connectivity, and configuration of built-up areas reveal the progression from a relatively fragmented urban landscape toward a more continuous and compact urban form. Such morphological transformations are closely associated with the expansion of impervious surfaces, which alter natural land surface processes by reducing infiltration, limiting evapotranspiration, and increasing the storage of sensible heat. Consequently, built-up area classification provides an important spatial indicator for understanding the relationship between urban expansion, land cover transformation, and the intensification of the urban thermal environment. The following figures present the distribution of built-up areas in Makassar City for 2019 and 2024, highlighting the spatial evolution of urban development throughout the study period.

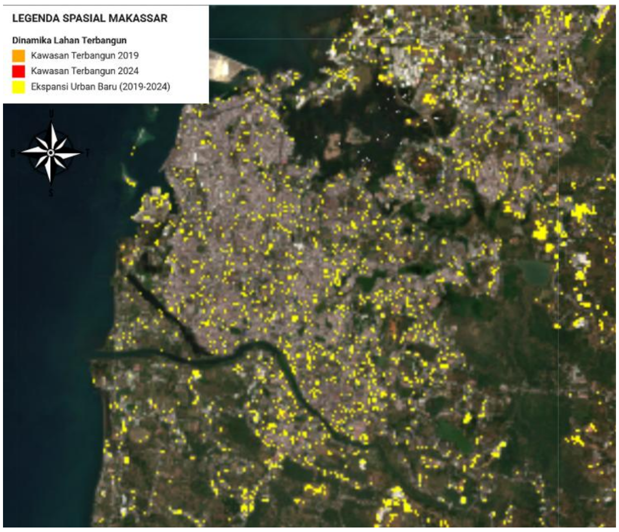

Figure 4. Urban Expansion Map (2019–2024)

To identify land-use changes that occurred during the five-year study period, the classified built-up area maps from 2019 and 2024 were overlaid using a Boolean logical AND operation. The resulting change detection map is presented in Figure 4, where newly developed urban areas between 2019 and

Vol X No X Month Year
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DOI: 10.xxxxxxxxxx
https://ejournalfish.unima.ac.id/index.php/georhexis/

2024 are highlighted in yellow. These yellow pixels precisely indicate locations where vegetation or previously undeveloped land was converted into built-up areas during the study period. The expansion pattern exhibits a leapfrog development pattern across the urban fringe. Large clusters of newly developed land are concentrated in the eastern part of Manggala District, which has been developed as a new self-contained residential area, as well as around the Makassar Industrial Estate (KIMA). This spatial pattern suggests that recent urban development policies have primarily directed expansion toward the eastern and northern sectors of Makassar, resulting in the conversion of water infiltration areas and urban green spaces that previously contributed to the city's ecological functions.

E. Spatial Modeling of the Urban Heat Island Phenomenon (LST-UHI)

Following the analysis of urban expansion and the spatial distribution of built-up areas, it is essential to examine the environmental consequences associated with these land cover changes. One of the most significant impacts of rapid urbanization is the alteration of the surface thermal environment, which can be effectively evaluated using Land Surface Temperature (LST). LST provides a reliable indicator of the spatial variation in surface heat resulting from differences in land cover characteristics, particularly the replacement of vegetated surfaces by impervious materials such as concrete, asphalt, and buildings. The integration of LST with urban land-use information enables a comprehensive assessment of how urban growth influences surface energy balance and contributes to the development of the Urban Heat Island (UHI) phenomenon. By comparing thermal conditions across the study area, the analysis identifies spatial patterns of heat accumulation and highlights areas where urban development has significantly modified the local microclimate.

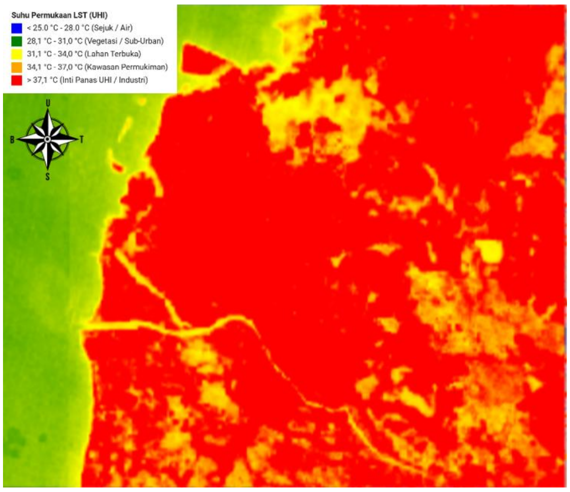

Figure 8. Land Surface Temperature (LST) and Urban Heat Island (UHI)

The environmental impacts of land-use change were assessed through Land Surface Temperature (LST) analysis covering the entire study area. The thermal visualization reveals a strong spatial association between the distribution of built-up areas and elevated land surface temperatures. Spatial integration of the datasets demonstrates a high degree of correspondence between areas dominated by extensive built-up surfaces and zones exhibiting pronounced thermal anomalies. Newly developed built-up areas identified in the 2024 classification map (shown in red) are spatially adjacent to thermal hotspot zones, indicating the development of the Urban Heat Island (UHI) phenomenon. Industrial estates, warehouse complexes, central business districts (CBDs), and densely populated residential areas with limited vegetation recorded land surface temperatures ranging from 36°C to 41°C. In contrast, areas dominated by vegetation and water bodies, represented in blue, maintained considerably cooler microclimatic conditions, with temperatures ranging between 26°C and 29°C.

The Urban Heat Island (UHI) phenomenon in Makassar City intensified markedly during the five-year study period (Bhaskara & Pratomo, 2023). In 2019, thermal hotspots were largely concentrated around the port area and the historic city center. By 2024, however, these hotspots had expanded into a multi-core UHI pattern that closely followed the spatial distribution of newly developed urban areas, as

Vol X No X Month Year
ISSN: XXXX-XXXX
DOI: 10.xxxxxxxxxx
https://ejournalfish.unima.ac.id/index.php/georhexis/

indicated by the yellow zones on the urban expansion map. The high heat absorption and storage capacities of urban materials such as metal roofs, concrete, and asphalt, combined with the reduced cooling effect of vegetation through evapotranspiration, are the primary factors driving this increase in land surface temperature. Consequently, these changes have contributed directly to the deterioration of thermal comfort and overall environmental quality within Makassar City.

F. Built-up Area Change and Urban Expansion

To complement the spatial interpretation presented in the preceding maps, quantitative analysis was conducted to measure the magnitude of built-up area expansion between 2019 and 2024. While visual analysis effectively illustrates the spatial distribution and morphological patterns of urban growth, statistical measurements provide objective evidence of the rate and extent of land conversion occurring during the study period. By comparing the total built-up area across the two observation years, this analysis quantifies the scale of urban expansion and identifies the proportion of newly developed impervious surfaces. These spatial statistics provide an essential basis for understanding the relationship between urban growth, landscape transformation, and subsequent environmental changes, particularly the increasing intensity of land surface heating and the emergence of Urban Heat Island (UHI) conditions.

Table 1. Spatial Statistics of Built-up Area Change During 2019–2024

Spatial Metric	Area (ha)	Percentage Change (%)
Built-up Area in 2019	891.49	–
Built-up Area in 2024	1,001.74	+12.37
Newly Developed Built-up Area (Urban Expansion)	297.33	+33.35

Source: *Authors Analysis, 2026*

Between 2019 and 2024, the total built-up area increased by 12.37%, reflecting the rapid development of infrastructure, residential areas, and urban facilities across Makassar City. The addition of 297.33 ha of newly developed built-up land indicates substantial urban expansion through both outward growth toward the urban fringe and infill development within previously developed areas. This increase in built-up land suggests an extensive conversion of vegetated surfaces into impervious land cover, including buildings, roads, and paved areas (Ramadanti, 2025). Such land-use changes reduce the landscape's capacity to absorb and infiltrate rainfall while simultaneously diminishing its natural cooling function through evapotranspiration. From an ecological perspective, the increasing dominance of artificial materials such as concrete, asphalt, and building roofs enhances daytime heat absorption and storage, which is subsequently released into the surrounding environment. As a result, land surface temperatures (LST) increased considerably, reaching extreme values of up to 41°C in several locations (Iqbal dkk., 2025).

The strong positive correlation (r = 0.784) between the Normalized Difference Built-up Index (NDBI) and Land Surface Temperature (LST) demonstrates the direct influence of urban development on the microclimate of Makassar City. The conversion of 297.33 ha of vegetated land into impervious surfaces (Table 1) has altered the local surface energy balance by changing both surface albedo and heat storage capacity. According to the principles of environmental thermodynamics, the loss of vegetation suppresses latent heat flux normally generated through evapotranspiration (Chairunnisak dkk., 2025). Consequently, a greater proportion of incoming solar radiation is converted into sensible heat, which is absorbed by impervious materials such as concrete and asphalt and gradually released into the atmosphere, producing extreme land surface temperatures ranging from 36°C to 41°C. From the perspective of urban morphology, the increase in built-up area from 891.49 ha in 2019 to 1,001.74 ha in 2024 reflects a structural transition from a relatively compact urban form toward a more dispersed pattern of urban sprawl. This predominantly horizontal expansion has reshaped the Urban Heat Island (UHI) pattern from a single dominant hotspot into a multi-core UHI system. Whereas thermal anomalies in 2019 were largely concentrated within the historic western urban area, they had expanded toward the eastern and northern sectors by 2024, closely following the distribution of newly developed built-up areas identified on the urban expansion map. The Makassar Industrial Estate (KIMA) and its surrounding warehouse complexes represent the most thermally vulnerable zones because of the

Vol X No X Month Year
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DOI: 10.xxxxxxxxxx
https://ejournalfish.unima.ac.id/index.php/georhexis/

extensive use of high-emissivity metal roofing combined with the scarcity of vegetated buffer areas, thereby intensifying the urban canyon effect. The coefficient of determination ($R^2 = 0.615$) indicates that approximately 61.5% of the spatial variability in Urban Heat Island intensity across Makassar City can be explained by local anthropogenic land-cover changes. This finding reinforces the Local Climate Zones (LCZ) framework, which emphasizes that land-use characteristics exert a stronger influence on urban microclimate than broader regional climate variability. From a practical standpoint, these findings highlight the urgent need for the Makassar City Government to incorporate thermal mitigation strategies into future urban spatial planning. Recommended measures include implementing regulations that promote cool roofs and green roofs in industrial and commercial areas, expanding urban green infrastructure with dense tree canopies along rapidly developing urban corridors, and strategically restoring urban green open spaces (RTH) within areas where land surface temperatures exceed 36°C to improve the city's thermal resilience.

CONCLUSION

The findings of this study demonstrate that Makassar City experienced substantial urban expansion between 2019 and 2024. Spatiotemporal analysis based on satellite imagery revealed that the total built-up area increased by 12.37%, from 891.49 ha in 2019 to 1,001.74 ha in 2024 (Oktafiola, 2025). In addition, approximately 297.33 ha of newly developed urban land were identified, reflecting the rapid growth of infrastructure, residential areas, and other urban developments. This land-use transformation has directly affected the urban environment by reducing vegetation cover, which plays a crucial role in regulating surface temperature. Areas characterized by extensive built-up surfaces consistently exhibited higher land surface temperatures than locations dominated by vegetation and water bodies. Thermal hotspot zones with land surface temperatures ranging from 36°C to 41°C were primarily observed in industrial areas, central business districts, and densely populated residential neighborhoods.

These findings indicate that the expansion of built-up areas has become a major driver of the Urban Heat Island (UHI) phenomenon in Makassar City. As vegetated land is progressively converted into impervious surfaces, greater amounts of solar energy are absorbed, stored, and subsequently released as heat, leading to intensified surface warming across the urban landscape. The results also highlight the importance of preserving urban vegetation and integrating green infrastructure into future urban development to mitigate rising land surface temperatures. Expanding urban green spaces, establishing green corridors, promoting urban greening programs, and encouraging the use of climate-responsive building materials may help improve urban thermal conditions while enhancing environmental quality. Furthermore, the findings provide valuable scientific evidence for supporting climate-responsive spatial planning and sustainable urban development in Makassar City. Future research is recommended to employ higher-resolution remote sensing data and incorporate additional environmental variables influencing land surface temperature in order to obtain a more comprehensive understanding of the spatial dynamics of the Urban Heat Island phenomenon.

REFERENCES

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

Chairunnisak, A., Sawab, H., & Zaki, M. (2025). *Estimasi Suhu Permukaan dan Suhu Udara di Kota Sabang, Aceh, Indonesia*. *5*.

Deng, C., & Wu, C. (2012). BCI: A biophysical composition index for remote sensing of urban environments. *Remote Sensing of Environment*, *127*, 247–259. https://doi.org/10.1016/j.rse.2012.09.009

Fathoni, H. A., Junaidi, A., & Aditiawan, F. P. (2025). *Klasifikasi Tutupan Lahan Pada Citra Sentinel-2 di Kawasan IKN Menggunakan Google Earth Engine*. *9*(3).

Fitriani, V., Gandri, L., Indriyani, L., Bana, S., & Ahmaliun, L. D. (2023). Analisis Hubungan Land Surface Temperature (LST) dan Indeks Kerapatan Vegetasi (Ndvi) Das Wanggu, Sulawesi Tenggara. *Jurnal Ilmu-Ilmu Kehutanan*, *7*(1), 49-57. https://doi.org/10.31258/jiik.7.1

Iqbal, F., Auliany, F. K., Permata, C. F., Gabriel, G., & Al Asy Ari, A. M. (2025). Analisis Spasio-Temporal Tutupan Lahan dan LST AST di Universitas Indonesia dan Kawasan Perpustakaan

Universitas Indonesia. *Jurnal Sains Geografi*, *3*(2), 137–154. https://doi.org/10.21009/JSG.v3i2.06

Larasati, A. P., Rahman, B., & Kautsary, J. (2022). Pengaruh Perkembangan Perkotaan Terhadap Fenomena Pulau Panas (Urban Heat Island). *Jurnal Kajian Ruang*, *2*(1), 35. https://doi.org/10.30659/jkr.v2i1.20469

Muhyiddin, M. (2020). Covid-19, New Normal, dan Perencanaan Pembangunan di Indonesia. *Jurnal Perencanaan Pembangunan: The Indonesian Journal of Development Planning*, *4*(2), 240–252. https://doi.org/10.36574/jpp.v4i2.118

Oktafiola, H. (2025). *Analisis Perubahan Lahan Terbangun Menggunakan Metode IBI (Index-Based Built-Up Index) Terhadap Rencana Tata Ruang Wilayah di Kabupaten Lampung Selatan Tahun 2014-2024*.

Prihandono, A. (2010). Penyediaan Ruang Terbuka Hijau (RTH) Menurut UU No. 26/2007 tentang Penataan Ruang dan Fenomena Kebijakan Penyediaan RTH Di Daerah. *Jurnal Permukiman*, *5*(1), 13. https://doi.org/10.31815/jp.2010.5.13-23

Ramadanti, L. N. (2025). *Evaluasi Efektivitas Ruang Terbuka hijau dalam Menurunkan Suhu di Wilayah Perkotaan*.

Sianturi, R. S. (2022). *Komparasi Metode Klasifikasi Tersupervisi untuk Pemetaan Lahan Terbangun dan NonTerbangun Menggunakan Landsat 8 OLI dan Google Earth Engine*. (Studi Kasus: Kota Malang). *Jurnal Penataan Ruang*, 82. https://doi.org/10.12962/j2716179X.v17i2.13434

Singapore as A Global City: Response to Urbanization, Climate Change, and Digital Economy. (2025). *Cities and Urban Development Journal*, *3*(2). https://doi.org/10.7454/cudj.v3i2.1044

Tika Christy Novianti & Hendry Natanael Gumano. (2023). Pemanfaatan Google Earth Engine dan Citra Terra Modis Untuk Analisis Suhu Permukaan Tanah di Provinsi Sumatera Selatan. *Jurnal Tekno Global*, *12*(01), 18–23. https://doi.org/10.36982/jtg.v12i01.3139