



URBAN HEAT ISLAND DYNAMICS IN RESPONSE TO LAND COVER CHANGE IN URBAN AREA: A CASE STUDY OF MEDIUM-SIZED CITY, MAJENE, INDONESIA

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Abstract

The urbanization process often results in reduced green space, increased electricity consumption, and the use of fossil-fuel vehicles. It triggers urban heat islands (UHI)—a phenomenon characterized by increasing surface temperatures in urban spaces. This impacts thermal comfort, quality of life, and the environment. This study aims to identify UHI based on the land cover change in Majene Urban Area, a medium-sized city that acts as a center for educational activities in the province of West Sulawesi in Indonesia. Interpretation of satellite imagery in 2011 and 2022 was carried out to determine land cover changes, including built-up land, open land, agricultural vegetation, non-agricultural vegetation, and waters. Then, UHI is analyzed by measuring brightness temperature, normalized difference vegetation Index (NDVI), the proportion of vegetation, land surface emissivity, and land surface temperature. The UHI calculation is divided into four temperature classes: Non-UHI ($<0^{\circ}\text{C}$), UHI I ($0-2^{\circ}\text{C}$), UHI II ($2-4^{\circ}\text{C}$), and UHI III ($>4^{\circ}\text{C}$) to simplify the spatial analysis of affected areas. The results indicate that while land cover in Majene City has not changed significantly, UHI dynamics are evident in temperature class. This supports previous studies in larger cities, where increased built-up areas raise surface temperatures, though the effect is less pronounced in Majene. However, Majene still experiences temperature rises of over 4°C due to expanding land use for settlements, offices, and services. Therefore, it is crucial to develop strategies that balance built-up areas with green spaces and promote sustainable urban planning to mitigate the impacts of climate change.

Keywords: Urban heat island (UHI), land cover change, land surface temperature, normalized difference vegetation index (NDVI), Majene

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INTRODUCTION

Urban areas globally are experiencing increasing temperatures due to the Urban Heat Island (UHI) effect, where urban regions are warmer than their rural counterparts as a result of human activities and alterations to land cover. The UHI effect is particularly intensified by rapid urbanization, which transforms natural landscapes into built environments, leading to significant modifications in local climate systems, including higher urban temperatures, altered air circulation patterns, increased energy consumption, and health risks (Tsou et al., 2014; Ranagalage et al., 2017). These impacts underscore the importance of understanding the relationship between urban development and UHI to formulate effective mitigation strategies.

In Indonesia, cities are categorized based on population size and functional dynamics, as outlined in the Government Regulation 26 of 2008 on National Spatial Planning. These categories include Megapolitan (multiple interconnected metropolitan areas), Metropolitan (urban areas with populations exceeding 1 million), Large Cities (over 500,000 people), Medium Cities (100,000 to 500,000 people), and Small Cities (50,000 to 100,000 people). Majene, with 177,390 residents, is classified as a medium-sized city.

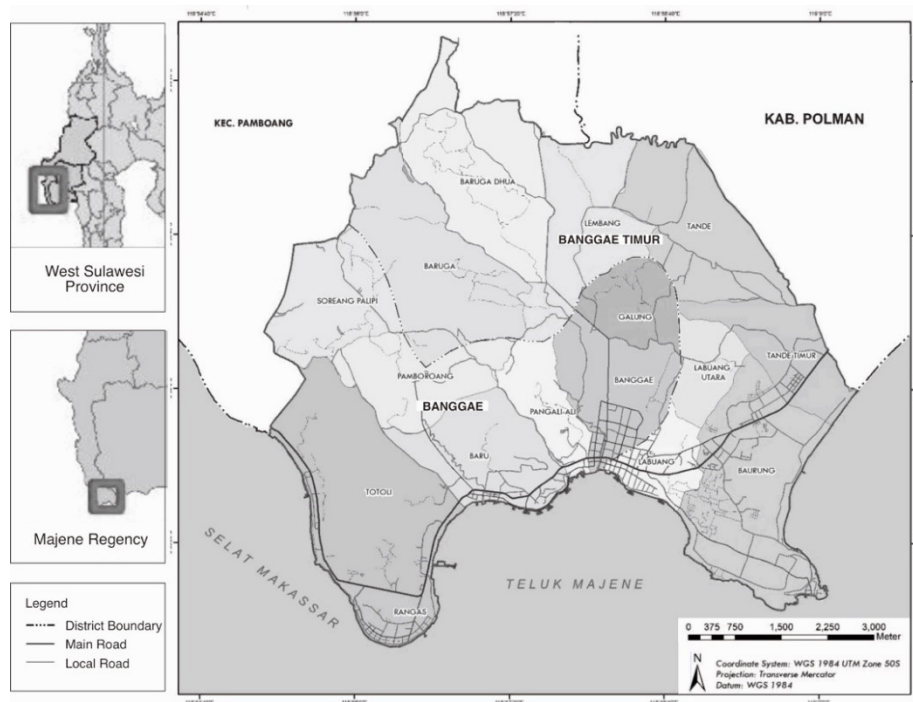


Figure 1: Study Area: Majene Urban Area

Majene, a coastal city in West Sulawesi Province, was selected as the study area due to its relevance in examining UHI effects in medium-sized cities (Figure 1). It serves as a hub for office, commercial, and residential activities, which are expanding and contributing to significant land use changes, particularly the conversion of vegetated areas into impervious surfaces. These changes exacerbate UHI and emphasize the need to preserve green spaces as a mitigation strategy, as highlighted by Rushayati et al. (2018). The relevance of this study is further strengthened by Majene's inclusion in the West Sulawesi development corridor, where sustainability and climate resilience are regional priorities. Large cities constitute a common discussion in UHI study literature; therefore, this research will attempt to contribute to a better understanding of UHI phenomena dynamics in medium-sized cities.

LITERATURE REVIEW

UHI effect, where urban areas are warmer than rural surroundings, is largely driven by land cover changes that are associated with urbanization. Replacing natural surfaces such as vegetation with impervious materials increases heat retention and reduces cooling processes, exacerbating the UHI effect (Zhou et al., 2015). As cities expand, this transformation significantly reduces evapotranspiration while increasing heat storage, contributing to the intensification of UHI (Keeratikasikorn & Bonafoni, 2018).

Several studies have demonstrated that land use and land cover changes are primary drivers of UHI intensity. For instance, research in Kota Bharu, Malaysia, found that urban expansion led to significant temperature increases, particularly in areas where vegetated landscapes were replaced with built-up areas (Ibrahim & Ash'aari, 2023). A study in Kuching, Malaysia, also revealed that a rise in land surface temperature is associated with a reduction in green areas due to growth in urban development (Ali et al., 2021). These findings underscore the importance of urban vegetation in cooling the environment and mitigating UHI effects, as supported by remote sensing studies that show vegetation's role in reducing local temperatures (Luan et al., 2020).

UHI intensity varies spatially and temporally, with higher temperatures typically found in urban centers and diminishing toward rural areas (Zhou et al., 2015). UHI is most pronounced at night when built surfaces release stored heat more slowly than natural landscapes. Additionally, seasonal factors, particularly during summer, can exacerbate the UHI effect due to increased solar radiation (Wang et al., 2019).

As Majene continues to grow, with increasing urban and commercial activities, land cover changes will likely amplify the UHI phenomenon. This aligns with findings that emphasize the critical role of land use planning in

controlling UHI through the preservation of green spaces and sustainable urban design (Rushayati et al., 2018).

MATERIALS AND METHOD

This study was conducted in an urban area in Majene Regency, a medium-sized city located in the Eastern Indonesia region. Using two different data from satellite imagery for 2011 and 2022, dynamics are performed on the urban heat islands in Banggai and the Banggai Timur District. These satellite images are the major data source, identifying land cover types such as water bodies, built-up areas, bare land, non-agriculture vegetation, and agricultural vegetation. Temporal change analysis in land cover classes was realized through a decade's change in land cover.

The assessment of Urban Heat Island (UHI) can be effectively conducted using satellite-derived environmental indicators, including Top of Atmosphere (TOA) radiance, Brightness Temperature (BT), Normalized Difference Vegetation Index (NDVI), Proportion of Vegetation (PV), Land Surface Emissivity (E), and Land Surface Temperature (LST). The measurement of UHI typically begins with the acquisition of satellite imagery, which provides the necessary data for calculating various thermal and vegetation indices. TOA radiance is the first step in this process, as it represents the amount of solar radiation reflected from the Earth's surface back to space. This data is crucial for deriving LST, a key indicator of UHI intensity (Liu & Zhang, 2011). Brightness Temperature (BT) is derived from the thermal infrared bands of satellite data, allowing researchers to estimate the surface temperature of urban areas (Liu & Zhang, 2011). The NDVI is another critical indicator for assessing vegetation cover in urban areas. It is calculated using the reflectance values in the red and near-infrared bands of satellite imagery, providing insights into the health and extent of vegetation (Anurogo et al., 2022). The Proportion of Vegetation (PV) is derived from NDVI and indicates the fraction of an area that is covered by vegetation, which inversely correlates with UHI intensity; areas with higher vegetation cover typically experience lower temperatures (Liang et al., 2022). Land Surface Emissivity (E) is also essential for accurate temperature measurements, as it accounts for the ability of different surfaces to emit thermal radiation. This factor varies significantly between urban materials (e.g., concrete, asphalt) and natural surfaces (e.g., vegetation, water bodies) (Montaseri et al., 2022). Finally, LST is calculated using the previously mentioned indicators, providing a direct measure of surface temperatures that can be compared across urban and rural areas to quantify UHI intensity (Han et al., 2014). The following sections illustrate the analytical stages that are undertaken to establish the relationship between UHI and land cover changes (Figure 2).

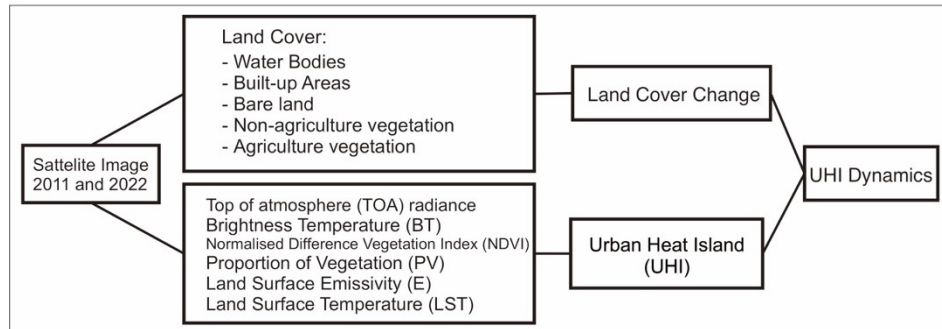


Figure 2: Framework of UHI Dynamics

Remote Sensing in Identifying Land Cover Change

Remote sensing techniques have been widely used to analyze land cover change through a supervised classification approach. For multitemporal analysis, this study selected Landsat 7 ETM images from 2011 and Landsat 8 OLI/TIRS images from 2022. The data were radiometrically corrected based on reflectance values using ENVI 5.3 software, which is essential for ensuring the accuracy of the spectral data used in classification (Chi et al, 2011). The land cover classification was done using composite bands 1 to 7, starting with identifying 30 training samples per class. The supervised classification was performed using the maximum likelihood classification method, which is a common approach for land cover studies due to its effectiveness in handling multi-spectral data. The validation process employed kappa validation, with the overall accuracy and kappa coefficient calculated using the following formulas:

$$\text{Overall Accuracy} = \frac{TCS}{TS} \times 100 \dots\dots\dots(1)$$

$$\text{Kappa Coefficient } (T) = \frac{(TS \times TCS) - \sum (\text{Column Total} \times \text{Row Total})}{TS^2 - \sum (\text{Column Total} \times \text{Row Total})} \times 100\% \dots \quad (2)$$

Where TCS = Total Correct Sample
TS = Total Sample

Land cover change and its validation were further analyzed spatially using the Calculate Geometry tool in the attribute table within ArcGIS 10.5.

Measuring Urban Heat Island

The Urban Heat Island calculation utilized Landsat 7 satellite imagery recorded on July 26, 2011, and Landsat 8 imagery recorded on April 11, 2022. Initially, the digital number values from Landsat 8 band 10 imagery were converted into radiance data through top-of-atmosphere (TOA) radiance calculations. The following formula was employed for this process.

$$L\lambda = ML * Q_{cal} + AL - O_i \dots\dots\dots(3)$$

Where $L\lambda$: Top of Atmosphere (TOA) spectral radiance
 ML : Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number); The radiance multiplicative value of Band 10, as seen from the metadata information on Landsat 8 satellite imagery
 Q_{cal} : Digital number in the band 10 image
 AL : Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_X, where x is the band number); value of radiance add Band 10, as seen from the metadata information on Landsat 8 satellite imagery
 O_i : the correction for Band 10, that is: 0.29

To measure Land Surface Temperature (LST), the radiance values from TOA are then used to derive the brightness temperature. The inversion of the Planck Law equation is used, assuming that the Earth's surface behaves like a black body with an emissivity value of one. The calculation for brightness temperature is as follows:

$$BT = \left(\frac{K_2}{\ln\left(\frac{K_1}{L\lambda}\right)} \right) - 273.15 \dots\dots\dots (4)$$

Where BT : Brightness temperature (°C)
 $L\lambda$: Top of Atmosphere (TOA) spectral radiance
 K_1 : Constant value

Normalized Difference Vegetation Index (NDVI) is one of the parameters used to analyze the vegetation condition of an area. The formula used to calculate NDVI is as follows:

$$NDVI = \frac{NIR-RED}{NIR+RED} \dots\dots\dots (5)$$

Where RED : the reflection in the red range of the spectrum (band 4)
 NIR : the reflection in the near-infrared spectrum (band 5)

In this study, land surface emissivity data was obtained by utilizing NDVI values. To determine the emissivity value in mixed areas, the proportion of vegetation (PV) formula was used, calculated as follows:

$$PV = \left(\frac{NDVI-NDVI_{min}}{NDVI_{max}-NDVI_{min}} \right)^2 \dots\dots\dots (6)$$

Where PV : Proportion of Vegetation
 $NDVI$: Normalised Difference Vegetation Index
 $NDVI_{min}$: NDVI minimum
 $NDVI_{max}$: NDVI maximum

Next, the emissivity value was obtained through the following calculation:

$$E = 0.004*PV + 0.986 \dots\dots\dots (7)$$

Where PV : Proportion of Vegetation
E : Land Surface emissivity

The Land Surface Temperature (LST) is obtained by calculating the brightness temperature (BT) along with the emissivity value. The calculation used is as follows:

$$LST = BT / (1 + (\lambda * BT / c^2) * \ln(E)) \dots\dots\dots (8)$$

Where λ for Landsat 8 satellite imagery, band 10: 10.8
LST : Land surface temperature
BT : Brightness temperature
E : land surface emissivity
 C^2 : $1.4388 * 10^{-2}$ mK = 14388 mK

The Urban Heat Island (UHI) is determined by observing land surface temperatures exceeding a given area's average temperature. The calculation used for UHI is as follows:

$$UHI = Tr - (\mu + 0,5 \alpha) \dots\dots\dots (9)$$

Where Tr : the temperature in the urban area
 μ : mean temperature of the reference area
 α : Standard deviation

RESULTS AND DISCUSSION

Land Cover Change in Majene Urban Area

Land cover change was assessed through satellite image interpretation, utilizing data from 2011 to 2022. The classification method employed was supervised classification with maximum likelihood classification. The land cover classification results can be seen in Table 1 and Figure 3. Based on Table 1, there is a noticeable change in the land cover area, including an increase in built-up areas in the Urban Areas of Majene, where the development of built-up areas extends northward following the main road pattern. Conversely, other land covers experience a decrease in area. This is consistent with the increasing trend of built-up land development.

Table 1: Land Cover Change in Majene Urban Areas in 2011 and 2022

Land Cover	Area in 2011		Area in 2022	
	(Ha)	(%)	(Ha)	(%)
Water Bodies	12.78	0.25	10.53	0.20
Built-up Areas	574.19	11.09	636.27	12.30
Bare land	1367.86	26.43	1357.38	26.25
Non-agriculture vegetation	2390.70	46.19	2371.30	45.85
Agriculture vegetation	829.92	16.04	799.97	15.47
Total Area	5175.45	100	5175.45	100

The Dynamic of Land Surface Temperature in Majene Urban Areas

The LST in the Majene urban area from 2011 to 2022 varied and increased. Based on LST calculations, the temperature in 2011 ranged from 20.26°C to 27.49°C, with an average of 22.41°C. By the end of the study in 2022, these figures had changed drastically: the minimum increased to 11.16°C, the maximum to 33.01°C, and the average to 26°C.

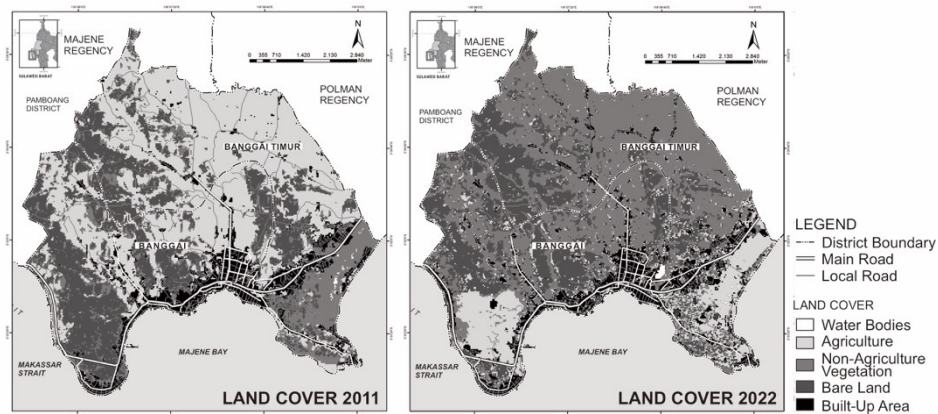


Figure 3: Land Cover in Majene Urban Areas 2011 and 2022

The LST changes from 2011 to 2022 reveal new temperature patterns. In 2011, there were only three classes (<20°C, 21-24°C, 25-28°C) identified, but by 2022, a >28°C category emerged in the southern urban area, as shown in Figure 4. Table 2 shows that in 2011, there were 4,932.63 hectares in the temperature range of 21-24°C, accounting for approximately 95% of the total area of the Urban Areas of Majene. The lowest temperature class <20°C had an area of 7.83 hectares, constituting only about 0.15% of the total area of the Urban Areas of Majene. Moving on to the subsequent period in 2022, the temperature class of 25-28°C is the most dominant, covering an area of 4,048.97 hectares or approximately 78.23% of the total area of the Urban Areas. Furthermore, the highest temperature range (>28°C) covers an area of 315.13 hectares, representing about 6.09% of the total area of the Urban Areas of Majene in 2022. These changes indicate a significant rise in higher-temperature areas and are bound to decrease in lower-temperature areas, indicating a tendency toward warming. The UHI effect seems to have increased during one decade, which is possibly caused by the increase in urbanization and reduced vegetation cover.

Table 2: Land Surface Temperature in Majene Urban Areas 2011-2022

Class	LST	Area in 2011		Area in 2022	
		(Ha)	(%)	(Ha)	(%)
1	<20°C	7.83	0.15	121.50	2.35
2	21-24°C	4,932.63	95.31	689.85	13.33
3	25-28°C	234.99	4.54	4,048.97	78.23
4	>28°C	0	0	315.13	6.09
Total Area		5,175.45	100	5,175.45	100

In 2011, it could be observed that the highest temperature range of 25-28°C was concentrated in the city center in the urban areas of Majene itself, i.e., in the southern area, where the dominant feature of land cover is comprised of built-up areas, commercial zones, and office spaces (Figure 4). The most significant increase was within the 25-28°C LST interval, which increased from approximately 235 hectares or 4.54% of the urban area in 2011 to 4,049 hectares or 78.23% of the urban area. This high-temperature zone expanded to the western and southern parts of the city, mainly in Banggai district, due to the increase in built-up areas along the coastline.

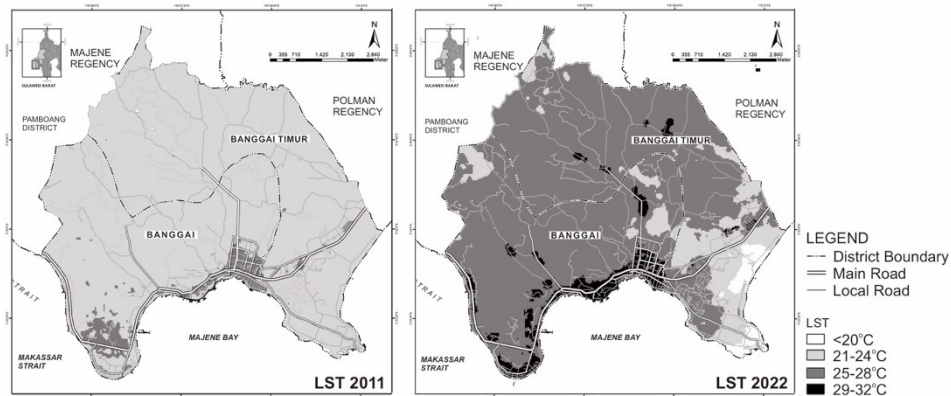


Figure 4: Land Surface Temperature in Majene Urban Areas 2011 and 2022

In 2022, the lowest temperatures (<20°C) were found in coastal areas of southeast Majene, in Banggai Timur, which were dominated by rice fields, fishponds, and mangrove forests. Rising land surface temperatures typically progress from these coastal regions to the built-up areas, which include residential, office, and commercial spaces. Table 3 shows that from 2011 to 2022, all land cover types have experienced an increase in average LST, with built-up areas, agricultural land, non-agricultural land, and water bodies seeing temperature rises exceeding 2°C, although the overall LST development did not show significant changes.

Table 3: Average Land Surface Temperature (LST) by Land Cover, Majene Urban Area

Land Cover	LST 2011 (°C)	LST 2022 (°C)
Built-up Areas	23.65	25.70
Bare land	23.03	25.00
Agriculture vegetation	22.51	24.61
Non-agriculture vegetation	21.77	23.88
Water Bodies	21.34	23.80

Factors that could explain such temperature dynamics for Majene include its coastal urban setting and a mix of built-up areas, agriculture, and non-agriculture. Increases in built-up and high-temperature areas signal urban growth and changes in land use that support positive heat retention and limit any cooling effect that is created by vegetation and previous spaces.

The Dynamics of Urban Heat Island in Majene

The UHI assessment was conducted in 2011 and 2022, categorizing temperature variations to map their spatial distribution in urban areas. This classification links land cover changes to heat levels, identifying the most affected regions and informing interventions, such as increasing green spaces. Previous studies highlight the significance of these classifications in prioritizing mitigation strategies during urban renewal (Liu et al., 2023) and improving our understanding of daily urban heating dynamics.

Regions with temperatures exceeding the threshold by 0-2°C will be classified as UHI class I. Subsequently, areas with temperatures exceeding the threshold by 2-4°C will be categorized as UHI class II. Finally, regions with temperatures surpassing the threshold by more than 4°C will be classified as UHI class III. Most of the areas are categorized as non-UHI, which means they do not exceed the yearly threshold temperature. However, UHI Class I dominates with a temperature difference of around 0-2°C from the threshold. In 2011, it covered 1,062.18 hectares or 20.52 of the total area, increasing to 1,656.36 hectares (32%) in 2022. This indicates an increase in the UHI-affected areas over the decade, as shown in Table 4.

Class UHI I represents areas experiencing a temperature increase of 0-2°C compared to their surroundings. In 2011, Class UHI I was evenly distributed across the study area, in Banggai to the south and Banggai Timur to the north. The predominant land cover in these areas consisted mainly of open land, with some sections covered by vegetation, including both agricultural and non-agricultural types. The dynamic in Class UHI II shows slight differences. In both 2011 and 2022, UHI II is predominantly located in the central urban areas, where the land cover consists of built-up areas, including residential and office areas. The difference occurs in 2022 when the UHI II areas expand following the

existing pattern of built-up land cover. Figure 3 provides the details of the built-up area location.

The UHI III ($>4^{\circ}\text{C}$) classified areas are predominantly the built-up areas that are located in the city center, specifically in the Banggae District. Both in 2011 and 2022, these UHI III areas are situated in this district, characterized by built-up land cover consisting of residential, office, commercial, and service areas.

Considering the spatial development of built-up areas as represented in Figures 3 and Figure 5, it can be said that, similar to large cities, the UHI effect in Majene results in higher temperatures within the urban zone compared to vegetated or non-urban surroundings. This effect is driven by urban expansion following road networks, where natural landscapes such as agricultural fields, grasslands, and wetlands are replaced by buildings, roads, and infrastructure. Again, vegetation removal contributes to increasing surface temperatures by cooingly shading the environment and through evapotranspiration processes.

Table 4: UHI Area in Majene Urban Area 2011 and 2022

No	Class	Area in 2011		Area in 2022	
		(Ha)	(%)	(Ha)	(%)
1	Non UHI	3,981.69	76.93	3,207.96	61.98
2	UHI I ($0-2^{\circ}\text{C}$)	1,062.18	20.52	1,656.36	32.00
3	UHI II ($2-4^{\circ}\text{C}$)	125.37	2.42	225.63	4.36
4	UHI III ($>4^{\circ}\text{C}$)	6.21	0.12	85.5	1.65
Total Area		5,175.45	100	5,175.45	100

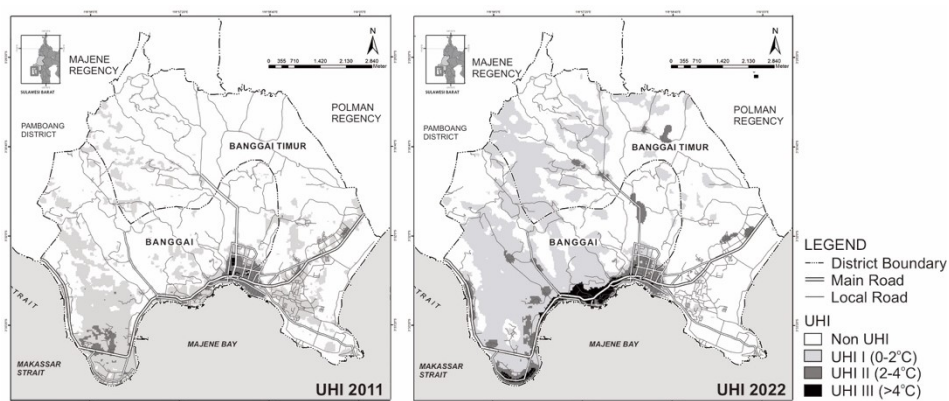


Figure 5: UHI in Majene Urban Area in 2011 and 2022

Generally, an increase in water-resistant surfaces such as asphalt, concrete, and rooftops contributes to high thermal conductivity and low albedo, leading these surfaces to absorb more heat during the day and release it slowly

at night, thereby intensifying the UHI effect. Majene's local government should incorporate UHI mitigation strategies into urban planning as a medium-sized coastal city. These could include expanding green spaces, establishing green buffer zones along the waterfront, protecting natural wetlands and mangrove areas, using permeable materials for walkways and plazas, incorporating ponds, and designing open corridors that allow coastal breezes to cool the city. Planting trees along streets to provide shade for pedestrians, encouraging community-based initiatives such as tree planting and water conservation, and implementing sustainable building practices with large coverage ratios can support effective UHI management, reduce energy demand for cooling, and improve urban comfort and resilience against climate impacts.

CONCLUSION

Based on the results and discussion of the study, it can be concluded that Majene, a medium-sized city, also experiences the Urban Heat Island (UHI) effect. Although the changes in land cover within Majene's urban areas from 2011 to 2022 are not highly significant, there has been an increase of 62.27 hectares in built-up land. This development predominantly extends northward, following the existing infrastructure development pattern.

The study shows that land cover changes and urbanization contribute to elevated temperatures in cities compared to their natural landscapes or rural counterparts. This is evident from the average land surface temperature rise in the Urban Areas of Majene by 3.55°C over the decade. According to UHI calculations, the area affected by UHI has expanded considerably, with UHI I increasing by 594.18 hectares, UHI II by 100.26 hectares, and UHI III by 79.29 hectares between 2011 and 2022.

The relationship between the growth of built-up land and the increasing area of Urban Heat Islands (UHIs) demonstrates that changes in land use patterns and urbanization significantly intensify the UHI effect. The study confirms that larger areas of built-up land are associated with higher UHI values, while greater vegetation cover leads to lower land surface temperatures and reduced UHI effects. This highlights the need to incorporate strategies to mitigate the UHI effect into urban planning, ensuring that future urban development considers sustainable land use and integrating green spaces. The local government of Majene should apply the inclusion of strategies in urban planning for UHI.

ACKNOWLEDGMENT

Gratitude is extended to the Regional Planning, Tourism, and Disaster Mitigation Laboratory at the Department of Urban and Regional Planning, Faculty of

Engineering, Hasanuddin University. The invaluable support and resources from the laboratory have been crucial in advancing this research.

DISCLOSURE STATEMENT

The authors confirm that there are no conflicts of interest related to this paper. Our research was carried out independently, without any financial support or benefits from commercial entities or organizations that could affect the results.

REFERENCES

- Ali, A. S., Zaini, F., & Jamian, M. A. H. (2021). The relationship of land use changes and land surface temperature for urban areas in Kuching, Sarawak. *Planning Malaysia Journal*, 19(4), 149-160. <https://www.planningmalaysia.org/index.php/pmj/article/view/1041/732>
- Anurogo, W., Sidabutar, R. T. C., Lubis, M. Z., Panuntun, H., Nugroho, C., & Sufwandika, M. (2022). Estimation of land surface temperature-assessment with remote sensing data for urban heat island in batam municipality. *GeoEco*, 9(1), 1. <https://doi.org/10.20961/ge.v9i1.54510>
- Government Regulation of Indonesia number 26 of 2008 on National Spatial Planning. (2008). <https://peraturan.bpk.go.id/Details/4839>.
- Chi, M., Liu, J., Bao, J., & Benediktsson, J. A. (2011). Scalable semi-supervised classification of hyperspectral remote sensing data with spectral and spatial information. *2011 IEEE International Geoscience and Remote Sensing Symposium*. <https://doi.org/10.1109/igarss.2011.6049562>
- Ibrahim, B., & Ash'aari, Z. H. (2023). Climate variability in relation to land use and land cover changes in Kota Bharu, Kelantan, Malaysia. *Planning Malaysia Journal*, 21(5), 1-16. <https://www.planningmalaysia.org/index.php/pmj/article/view/1352/1032>
- Keeratikasikorn, C., & Bonafoni, S. (2018). Urban heat island analysis over the land use zoning plan of Bangkok by means of Landsat 8 imagery. *Remote Sensing*, 10(3), 440. <https://doi.org/10.3390/rs10030440>
- Liang, J., Bai, Y., Gao, Z., Yang, X., Li, L., Zhang, C., & Qiao, F. (2022). A study on the dynamic relationship between landscape information and heat island intensity of urban growth patterns—A case of five cities in the Beijing–Tianjin–Hebei city cluster. *Sustainability*, 14(21), 14099. <https://doi.org/10.3390/su142114099>
- Liu, X., Wang, N., Li, Z., Jia, R., & Qiao, Z. (2023). Research on time series and spatial gradient of urban heat island expansion from the perspective of urban renewal. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 16, 8680-8688. <https://doi.org/10.1109/jstars.2023.3314970>
- Liu, L., & Zhang, Y. (2011). Urban heat island analysis using the Landsat TM data and ASTER data: A case study in Hong Kong. *Remote Sensing*, 3(7), 1535-1552. <https://doi.org/10.3390/rs3071535>.
- Luan, X., Yu, Z., Zhang, Y., Wei, S., Miao, X., Huang, Z., & Xu, C. (2020). Remote sensing and social sensing data reveal scale-dependent and system-specific

- strengths of urban heat island determinants. *Remote Sensing*, 12(3), 391. <https://doi.org/10.3390/rs12030391>
- Montaseri, M., Masoodian, S. A., & Guo, X. (2022). Evaluation of surface urban heat island intensity in arid environments (Case study: Isfahan metropolitan area). <https://doi.org/10.21203/rs.3.rs-1591895/v1>
- Ranagalage, M., Estoque, R. C., & Murayama, Y. (2017). An urban heat island study of the Colombo metropolitan area, Sri Lanka, based on Landsat data (1997–2017). *ISPRS International Journal of Geo-Information*, 6(7), 189. <https://doi.org/10.3390/ijgi6070189>
- Rushayati, S. B., Shamila, A. D., & Prasetyo, L. B. (2018). The role of vegetation in controlling air temperature resulting from urban heat island. *Forum Geografi*, 32(1), 1-11. <https://doi.org/10.23917/forgeo.v32i1.5289>
- Tsou, J., Chao, M., Xiang, L., & Chen, K. (2014). Applying RS and GIS to study the impacts of urban regeneration on thermal environment in built-up areas: A case study of Kowloon, Hong Kong. <https://doi.org/10.1061/9780784413616.074>
- Wang, K., Aktas, Y. D., Stocker, J., Carruthers, D., Hunt, J., & Malki-Epshtein, L. (2019). Urban heat island modelling of a tropical city: Case of Kuala Lumpur. *Geoscience Letters*, 6(4). <https://geoscienceletters.springeropen.com/articles/10.1186/s40562-019-0134-2>
- Zhou, D., Zhao, S., Zhang, L., Sun, G., & Liu, Y. (2015). The footprint of urban heat island effect in China. *Scientific Reports*, 5, 11160. <https://doi.org/10.1038/srep11160>

Received: 7th December 2024. Accepted: 5th March 2025