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Ecological Evaluation of Urban Heat Island at Tegal Regency, Central Java Province, Indonesia

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Abstract

Global warming poses a significant threat to environmental and humanitarian stability, prompting urgent action worldwide. This study identifies the spatial distribution and intensity of Urban Heat Island (UHI) phenomenon at Tegal Regency and determine the relationship between the UHI phenomena and ecological condition. Employing direct measurement methods, including surface temperature extraction via remote sensing, and spatial analysis techniques, the study examines the spatial distribution and intensity of UHI across the region. The findings reveal a pronounced UHI effect in the western part of Tegal Regency, highlighting areas of particular ecological concern. This area covers around 31.7% of total area in Tegal Regency which has character of very strong UHI and worst ecological condition. Based on these results, priority zones for both primary and secondary mitigation efforts are identified, emphasizing the importance of targeted interventions in key urban and peri-urban areas. These insights contribute to a better understanding of UHI dynamics and provide valuable guidance for local authorities in implementing effective climate adaptation strategies in Tegal Regency and similar tropical regions facing the challenges of urban heat.

Keywords: Urban Heat Island; Remote sensing; Geographic Information System, Land surface temperature

1. Introduction

Global warming is the most significant environmental and humanitarian crisis currently occurring. The Earth's atmosphere is excessively heated due to the trapping of carbon dioxide gases, posing a threat to climate change and causing disasters on the Earth's surface. National Resource Defence Council (NRDC) urges everyone on earth to take action against global warming, as its adverse effects can be mitigated by human actions. The National Wildlife Federation describes global warming as an event where the earth is getting hotter day by day, leading to more heavy rainfall, floods, intensified storms, and deepened droughts. These events are tangible impacts resulting from global warming on earth. Global warming also alters the landscape of life on Earth and endangers many species (Roessig and Woodley, 2004; Eissa and Zaki, 2011).

Urban Heat Island (UHI) arises due to isothermal patterns forming an island-like structure (Velasco, 2018). The extent of the pattern depends on the urbanized area. This pattern creates a temperature gradient starting from the outskirts to the peak in the city centre. The temperature difference between urban and rural areas can reach up to 12 °C in metropolitan cities. Within built-up areas, this pattern is locally influenced by the presence of green spaces such as city parks, water bodies, and the amount of built-up space (Alexander, 2020). The spatial isothermal pattern usually follows urbanized areas. Topographic patterns (coastal or valley locations) can also add complexity to the spatial characteristics of UHI. The magnitude or intensity of the heat island is measured by the difference between rural air temperature and the highest temperature (Levermore *et al.,* 2018)

Urban areas will tend to retain higher temperatures within the city compared to suburban areas. Furthermore, after sunrise, the air temperature in rural areas will match the air temperature in urban areas. This is because urban areas have a shadow cover by tall buildings (urban canopy) and weakened sunlight due to the lifted pollution layer, causing the air temperature to rise more slowly in the morning. At low latitudes, this effect produces an urban cool island, causing rural areas to be hotter than urban areas. Some UHI studies have identified that urban and suburban air temperature has slightly difference. The urban air temperature is higher by 0.02 - 1 °C compared to the surrounding areas in tropical regions (Cecconet *et al.,* 2020; Stewart *et al.,* 2021).

Tegal Regency is one of the regencies in is a lowland situated north of the Java Sea, surrounded by a range of limestone mountains, and has a tropical climate. In term of population density and urban growth, Tegal Regency is influenced by the growth of Tegal City and Pekalongan City. Located between those well-connected city, Slawi the Capital City of Tegal regency has high population Central Java Province, with its capital located in Slawi, approximately 14 km away from the city of Tegal. The region in Tegal Regency density (Murdiansjah, *et al.,* 2012). The population tends to decrease in the southern part of Tegal Regency which is close to the north slope of Slamet volcano.

The population growth in Tegal Regency also affect the decreasing of agricultural land area as well as an increase in residential land area and infrastructure especially in urbanised area such as north and middle part area of Tegal Regency (Rakuasa and Achmadi, 2024). This condition can lead the UHI phenomena in Tegal regency. Furthermore, the UHI phenomena will be exacerbated by the presence of industrial areas in the middle and north part of Tegal Regency. Thus it is important to characterise the UHI in Tegal Regency. The objective of this study is to investigate the spatial distribution of the UHI phenomena and to determine the relationship between the UHI phenomena and ecological condition

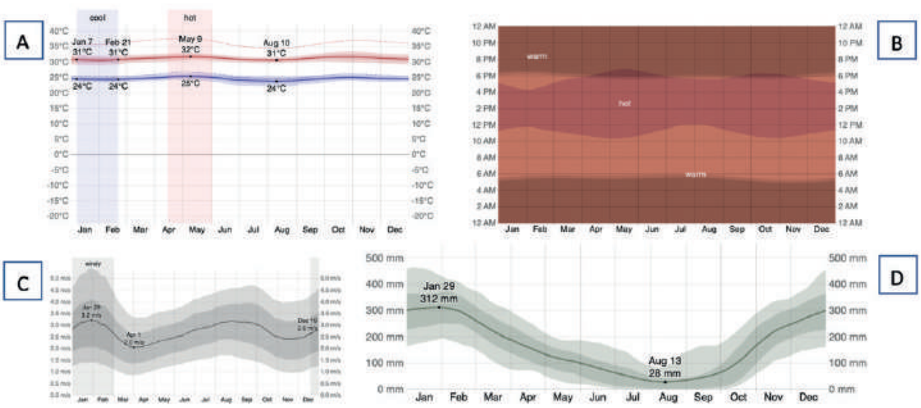
2. Methodology

2.1 Overview of study area

The research area is Tegal Regency, Central Java Province, situated between 108°57’6 to 109°21’30 East Longitude and 6°50’41” to 7°15’30” South Latitude, which has various type of land use and land cover, conservation area to industrial area. Positioned as one of the regions covering the northern coastal area of West Central Java, Tegal Regency holds a strategic position at the intersection of the transportation routes Semarang-Cirebon-Jakarta and Jakarta-Tegal-Cilacap, with a port facility in the city of Tegal. The boundaries of Tegal Regency are to the North of Tegal City and the Java Sea, to the East of Pemalang Regency, to the West of Brebes Regency, and to the South of Brebes and Banyumas Regencies. The regency covers an area of 87,879 hectares, administratively divided into 18 districts, 281 villages, and 6 urban sub-districts (Figure 1).

In term climate condition, Tegal Regency has typical tropical climate with temperature vary from 24 - 32 ºC. The hot season in Tegal spans 1.6 months, from April 14 to June 2, with daily high temperatures averaging above 32 °C. May is the hottest month, with average highs of 32 °C and lows of 25 °C. The cool season lasts 1.5 months, from January 7 to February 21, with daily high temperatures averaging below 31 °C. August is the coldest month, with average highs of 31 °C and lows of 24 °C (Figure 2). To illustrate variations within the months rather than just the monthly totals, we present the rainfall accumulated over a sliding 31 - day period centered around each day of the year. Tegal experiences significant seasonal changes in monthly rainfall. Rainfall occurred year round in Tegal. January is the wettest month, averaging 308 millimeters of rain. August is the driest month, with an average rainfall of 28 millimeters.

Figure 1. Tegal Regency coverage area



Source: Weather Spark, 2024

Figure 2. Methodology and data A) The daily average high (red line) and low (blue line) temperature; B) The average hourly temperature, color coded into bands; C) The average of mean hourly wind speeds (dark gray line); D) The average rainfall (solid line) accumulated over the course of a sliding 31-day period,

2.2 Research Method

The Urban Heat Island (UHI) phenomenon refers to the change in urban temperatures compared to the surrounding areas (Schwarz *et al.,* 2011). Two primary methods for assessing UHI are direct measurement of air temperature and surface temperature measurement (Streutker, 2003). This research use surface temperature as a proxy to extract the UHI condition. There are three steps to conduct this research, first step is to know Normalized Difference Vegetation Index (NDVI). The second step is two extract the surface temperature and the third step are to calculate the UHI.

2.3 NDVI

The Normalized Difference Vegetation Index (NDVI) is one of the first remote sensing analytical tools created to simplify multi-spectral imagery and is now the most commonly used index for assessing vegetation density. The NDVI is attractive due to its capability to swiftly identify vegetation and vegetative stress, making it highly valuable for commercial agriculture and landuse research (Huang *et al,* 2021). The NDVI used to classified the vegetated – water body area and non-vegetated area, which are the vegetated and water body area tend to have low temperature (Grover and Singh, 2015). NDVI provides a visual representation of green vegetation in raster pixels and helps determine land composition to obtain emissivity values. NDVI was derived from Landsat 8 OLI satellite imagery. It is calculated by using Equation 1. The NDVI values range from -1 to 1, where values close to -1 indicate low-density vegetation, water, or soil, and values near 1 indicate high-density vegetation.

$$NDVI = \frac{NIR\ band - Red\ band}{NIR\ band + Red\ band} = \frac{band\ 5 - band\ 4}{badn\ 5 + band\ 4} \quad (1)$$

2.4 LST

The LST was extracted by using several equations through remote sensing software. Several step to extract the LST value are provided in flowchart in Figure 2, meanwhile, the list of equation is provided Table 1 below. LST estimated from the corrected the land emissivity value by using equation in Figure 2 (Avdan and Jovanovska, 2016).

In accordance to Table 1 and Figure 2, the UHI was obtained by calculating the average land surface temperature (LST) and its deviation. Furthermore, to get better understanding of spatial relationship the spatial autocorrelation test for LISA and MORAN index was conducted in study area. The secondary spatial data also used to support the research such administrative data of research area, the number of populations, air temperature and humidity from surrounding weather station are also needed in this research. The summary of data needed in this research shown in Table 2.

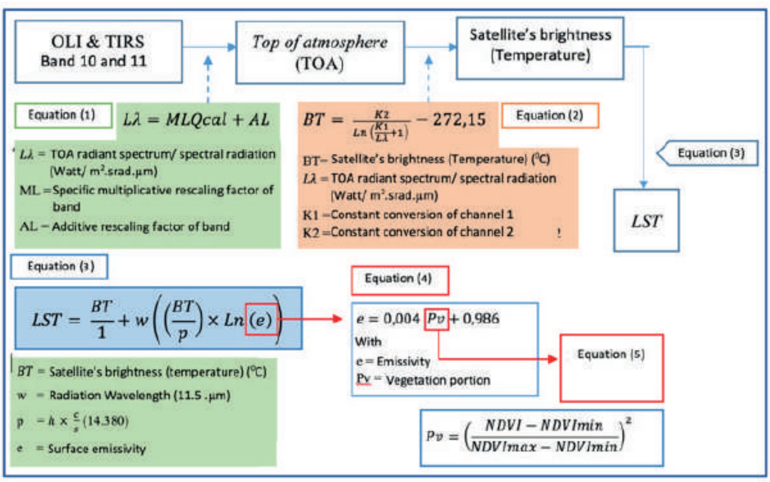


Figure 2. Flowchart of the research

Table 1. list of equation used to calculate the UHI

No	Equation	Function
1	$L\lambda = MLQCal + AL$	Convert DN to radiance
2	$BT = \frac{K2}{Ln\left(\frac{K1}{L\lambda}+1\right)} - 272.15$	Convert Radiance to Brightness index
3	$LST = \frac{BT}{1} + w\left(\frac{BT}{\rho}\right) x\ Ln\ (e)$	Calculate LST
4	$e = 0.004\ Pv + 0.986$	Calculate emissivity
5	$Pv = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right)^2$	Portion of vegetation
6	$UHI = \mu + \frac{\sigma}{2}$	Calculate UHI

Table 2. Data used in the study

Data	**Source**	**Function**
Landsat 8 OLI images (year recorded 2013, 2017, and 2022)	Earth explore (USGS)	Generate NDVI and LST NDBI
Spatial data of Tegal Regency	Indonesia Geospatial Agency	Data visualisation and analysis

2.5 NDBI

Normalised difference built-up index (NDBI) is associated with the NDVI transformation. NDVI indicates the vegetation density index, meanwhile NDBI indicates the built up area index. NDBI transformation utilised the the middle infrared (SWIR 1) and near-infrared (NIR) (eq. 2).

$$NDBI = \frac{SWIR\ 1 - NIR}{SWIR\ 1 + NIR} \quad (2)$$

By using the NDB Index, thus the presence of developed areas can be identified. NDBI is an powerful and effective tools to highlight the density of urban building which is often opposite with the NDVI. (Muhaimin *et al.,* 2022)

3. Results and discussion

3.1 Land surface temperature (LST) Tegal Regency in 2013, 2017, and 2022

Land surface temperature refers to the magnitude of temperature generated by the reflection of objects on the land surface. LST is the magnitude of temperature produced by a land cover that influences the surrounding air temperature in the environment. In theory, LST produced on built-up land will have a greater value compared to vegetated land or open land consisting of natural soil. Mapping LST can be carried out by using geographic information system (GIS) technology and remote sensing (RS). The utilization of GIS and RS in LST analysis is highly advantageous in terms of time and cost, where monitoring can be conducted temporally according to time with relatively low costs compared to direct field observations. The modelling of LST in this study was conducted using Landsat 8 OLI images with a spatial resolution of 30 meters. The Landsat 8 OLI images used were from the years 2013, 2017, and 2022. The selected images for LST analysis in 2013, 2017, and 2022 can be seen in Table 3. The selection of images was based on initial land cover conditions and seasonal similarity, thus the LST analysis generated can be compared for these three years.

Based on the results of LST, the data shows that in 2013, the average LST value in Tegal Regency was 22.795 °C. There are five classifications of LST values in 2013, with the dominant LST value range being 23 – 27 °C, covering an area of 640,138 km^2. The smallest area is within the range of 32 – 41°C, totalling 35.73 Ha. The more detailed area measurements can be seen in Table 3

The highest LST value with a range of 32 – 41 °C is distributed on the west side of Kabupaten Tegal, specifically in areas near City Centre of Tegal. Additionally, areas with high CPL values in 2013 include Kecamatan Dukuhturi, Talang, Adiwerna, and Slawi. Other areas with relatively high CPL values ranging from 28 – 32 are scattered in the northern part of Kabupaten Tegal near the North Coast of Java Island in Kecamatan Kramat, Suradadi, and Warureja in the northern part. The distribution of CPL conditions in Kabupaten Tegal in 2013 can be seen in Figure 3. Based on the analysis of Land Surface Temperature (LST), data obtained for the year 2017 showed that the average LST in Tegal Regency was 23.79 °C. There are five classifications of LST values for the year 2017, with the dominant LST range being 23 – 27 °C, covering an area of 50,350.6 hectares. The smallest area is found in the LST range of 32 – 41 °C, covering only 114.84 hectares. The increase in area at higher temperatures occurred in 2017 compared to 2013, although the largest area is still dominated by the 23 – 27 °C temperature range. A more detailed breakdown of areas can be seen in Table 4. The highest LST values, ranging from 32 – 41 °C, are scattered on the western side of Tegal Regency, particularly in areas near Tegal City Centre.

Table 3. Landsat 8 OLI Images Used in the Study

No	Observation Year	Path	Row	Acquisition Date
1	2013	121	065	17-07-2013
2	2017	121	065	12-07-2017
3	2022	121	065	26-07-2022

Table 2. Data used in the study

No	LST Value Range (°C)	Area in 2013 (Ha)	Area in 2017 (Ha)	Area in 2022 (Ha)
1	14.0 – 23.1	26,358.9	27,869.8	35,332.0
2	23.2 – 27.4	64,013.8	50,350.6	48,766.0
3	27.5 – 29.8	5,305.3	9,441.1	10,828.3
4	29.9 – 32.5	956.7	2,409.3	2,502.9
5	32.6 – 41.9	35.73	114.84	91.98

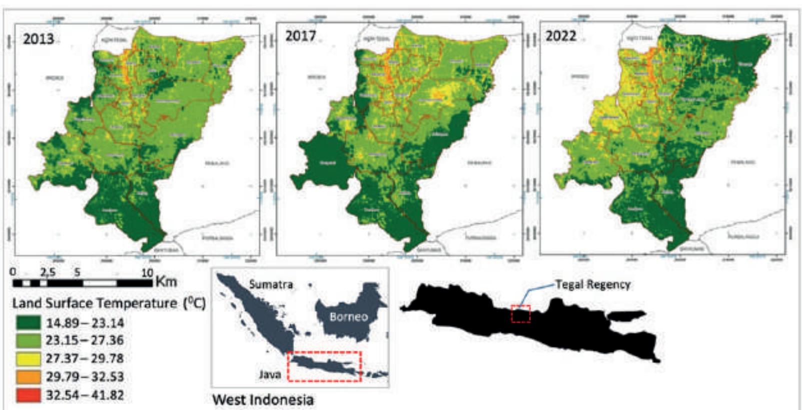


Figure 3. Tegal Regency LST in 2013, 2017, 2022

Regions with high LST values in 2017 include the districts of Dukuhturi, Talang, Adiwerna, and Slawi. Other areas with relatively high LST values, ranging from 28 – 32, are scattered in the northern part of Tegal Regency, near the North Coast of Java Island, in the districts of Kramat, Suradadi, and Warureja. A noticeable difference from 2013 is the increase in relatively high LST values in the districts of Kedungbanteng, Tarub, and Pagerbarang. The distribution of LST conditions in Tegal Regency in 2017 can be seen in Figure 3. Based on the analysis of LST, the data shows that the average LST value in Tegal Regency in 2022 is 23.83 °C. There are five classifications of LST values in 2022, with the dominant LST range being 23 – 27 °C, covering an area of 48,766.0 hectares. The smallest area is found in the range of 32 – 41 °C, with an area of 91.98 hectares. However, in 2022, there is a significant increase in the areas with LST ranging from 27 – 32 °C, indicating that regions with higher temperatures are expanding this year. A more detailed breakdown of the areas can be seen in Table 4.

The highest LST values in the range of 32 – 41 °C are still distributed on the western side of Tegal Regency, particularly in areas near Kota Tegal, similar to previous years. Additionally, areas with high LST values in 2022 include the districts of Dukuhturi, Talang, Adiwerna, and Slawi. A noticeable difference is observed where areas with LST values ranging from 27 – 32 °C are spreading towards the southern side in the western part of Tegal Regency. The coverage area within this LST range includes the districts of Dukuhwaru, Pagerbarang, Lebaksiu, Margasari, and Pangkah. The distribution of LST conditions in Tegal Regency in 2022 can be seen in Figure 3.

3.2 Changes of Land Surface Temperature Conditions in Tegal Regency from 2013, 2017, and 2022

The LST values in Tegal Regency during the period from 2013, 2017, and 2022 experienced an upward trend in almost all areas, specifically in 12 districts of Tegal Regency. There are only 6 districts in which the LST values is relatively constant, namely Bojong, Kedungbanteng, Kramat, Pangkah, Suradadi, and Warureja Districts. In these six districts, the LST conditions tend to have relatively similar values and some even experience decreases, as seen in Warureja, Suradadi, Kedungbanteng, and Kramat Districts. The decrease in LST values in these four districts may be due to the dominance of agricultural land use, resulting in relatively low LST values. Margasari sub-district experienced an unique pattern of average LST in 2017. This sub-district has the lowest average LST comparing to others and from previous year 2013 or in 2023. Several factors can affect this phenomena such as vegetation coverage, rainfall and water index, and distance from the city (Feng *et al.,* 2019). For this case, the most possible reason why the Margasari has lowest LST because this sub-district located in Slamet Volcanic Foot which has relatively dense vegetation cover, and the average air temperature in this year decrease comparing in 2013 and 2023.

The trend of fluctuating LST values in Tegal Regency in each district can be observed in Figure 4.

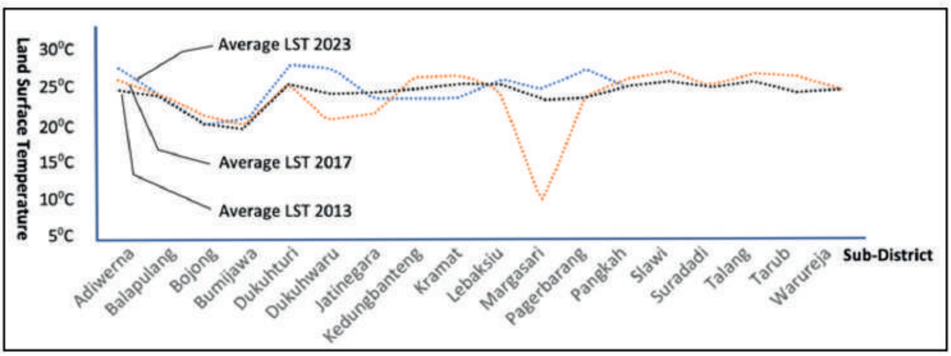


Figure 4. LST distribution in Tegal Regency

The changes of LST in Tegal Regency also need to be further examined as a mitigation effort to reduce the rate of LST increase in this area. Changes in LST values from 2013, 2017, and 2022 were attempted to be modelled by comparing the LST values in 2013 with those in 2022 spatially. Based on the modelling results, it can be observed that LST increase in the most area of Tegal Regency. There are four classes of LST increase trends in Tegal Regency. Most of the areas in Tegal Regency experienced by LST increasing around 0 to 5 °C, spread almost evenly throughout the regency. However, there are some areas in Tegal Regency that experienced significant increases ranging from 6 to 10 degrees Celsius, namely Pagerbarang, Dukuhwaru and Adiwerna Sub-District which are located in the western part of Tegal Regency close to Tegal City Centre. The high increase of LST also experienced in the southpart of Tegal Regency which covers Bumijawa and Bojong Sub-District. Thus, it is important to note that these five areas need to be prioritized in efforts to reduce the phenomenon of increasing LST. A clearer distribution of changes in LST values in Tegal Regency in 2013, 2017, and 2022 can be seen in Figure 5.

Furthermore, based on the changes in LST values, the concentration of areas with high LST increases caused by the influence of other areas can be determined. This modelling can be done using spatial autocorrelation statistical tests. Spatial autocorrelation statistical tests can be used to identify which areas in the Tegal Regency serve as centres or concentrations of the highest LST value increases at the village level. Based on the modelling results, it can be seen that there are 48 villages categorized as High-High. This category means that 48 villages in Tegal Regency have LST change values from 2013 to 2022 surrounded by neighbouring villages with high change values, indicating that the LST value changes in Tegal Regency are concentrated in these 48 villages. These 48 villages are located on the western side of Tegal Regency, specifically in Pagerbarang, Dukuhwaru, Adiwerna, and Dukuhturi Subdistricts. The results of the spatial autocorrelation statistical test can be seen in Figure 5.

3.3 Ecological Conditions and Urban Heat Island (UHI) Phenomenon in Tegal Regency

The results of LST value modelling can be further analysed to obtain data related to UHI phenomena and ecological conditions (Hadibasyir *et al.,* 2020; Saputra *et al.,* 2022). The method used to determine the UHI phenomenon and ecological conditions

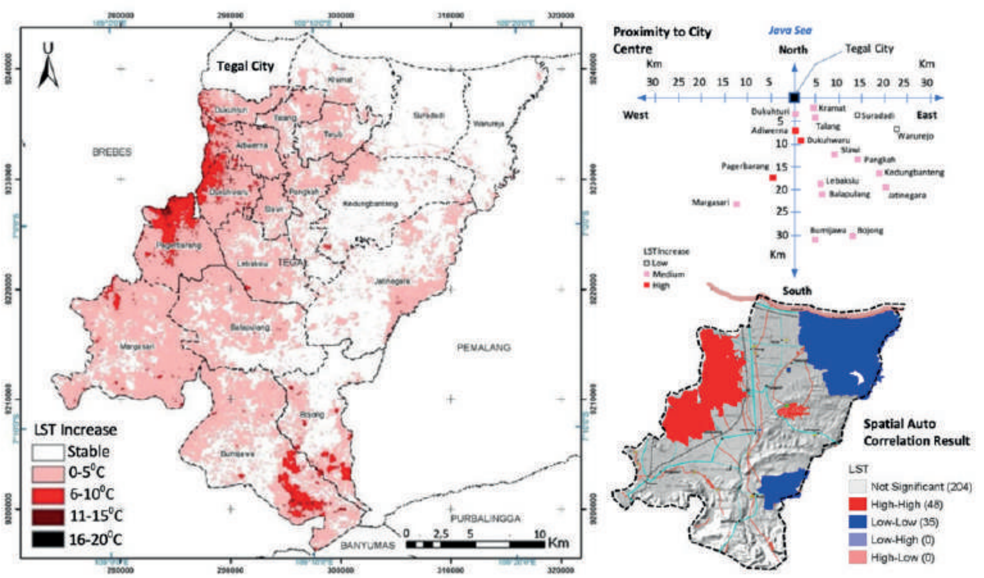


Figure 5. Map of LST Changes (Left), Proximity diagram (up right), and Spatial Auto Correlation results (below right)

of an area using LST value data is UTFVI (urban thermal field variance index) (Naim and Al-Kafy, 2021; Singh *et al.,* 2017; Syah and Nugroho, 2013). The criteria for UTFVI can be seen in Table 4.

Ecological conditions and UHI phenomena will only be modelled in 2022 because the analysed results for recommendation guidance are determined based on the current ecological conditions in the Tegal Regency. Based on the modelling results, it is found that there are 6 classifications of ecological conditions and UHI phenomenon intensities in the Tegal Regency. Very good ecological conditions with no UHI phenomena become the most dominant, covering an area of 61,594.6 hectares. However, the worst ecological conditions with the highest UHI intensity also occupy the second position, covering an area of 31,533.9 Ha. The area of each ecological condition criterion in the Tegal Regency can be seen in Table 5.

Spatially, the areas in Tegal Regency with very good ecological conditions and no UHI phenomena are spread across the eastern and some southern parts. The districts covered include Kramat, Suradadi, Warureja, Kedungbanteng, Jatinegara, Bojong, Bumijawa, parts of Balipulang, and parts of Magersari. Meanwhile, the areas with the worst ecological conditions and the strongest UHI intensity are spread on the western side of Tegal Regency, which administratively belongs to Pagerbarang, Dukuhwaru, Adiwerna, Dukuhturi, Talang, Pangkah, Slawi, and Lebaksiu Subdistricts. For a more detailed spatial distribution of ecological conditions and UHI phenomena in the the Tegal Regency, please refer to Figure 6. The interpretation results of UTFVI indicate extreme differences in ecological conditions, where areas near the regency capital, Slawi, towards the city of Tegal tend to have poor ecological conditions, while rural areas far from the development centre still have very good ecological conditions. Therefore, efforts to improve ecological conditions need to be implemented in the areas on the western side of Tegal Regency classified as having the worst ecological condition. To strengthen the interpretation of ecological condition values in the Tegal Regency, modelling of the Human Comfort Index (HCI) values is also conducted based on thermal comfort conditions. The standard comfort criteria used are (1) comfortably cool, with temperatures ranging from 20.8 - 22.8 °C; (2) optimal comfort, with temperatures ranging from

Table 4. Guide to Interpretation of UTFVI Values

No	UTFVI	Ecological Condition	UHI Intensity
1	< 0	Very good	None
2	0.000 - 0.005	Good	Weak
3	0.005 - 0.010	Normal	Moderate
4	0.010 - 0.015	Poor	Strong
5	0.015 - 0.020	Very poor	Very strong
6	> 0.020	Worst	Strongest

Table 5. UTFVI interpretation results.

No	UTFVI	Ecological Condition	UHI Intensity	Area (hectares)
1	< 0	Very good	None	61,594.6
2	0.000 - 0.005	Good	Weak	1,653.5
3	0.005 - 0.010	Normal	Moderate	1,610.8
4	0.010 - 0.015	Poor	Strong	1,567.2
5	0.015 - 0.020	Very poor	Very strong	1,515.2
6	> 0.020	Worst	Strongest	31,533.9

22.8 - 25.8 °C; and (3) comfortably warm, with temperatures ranging from 25.8 - 27.1 °C (SNI 1993; Elbes and Munawaroh, 2019).

The results of the thermal comfort value modelling show patterns that are consistent with ecological conditions, where areas in Tegal Regency that have thermal discomfort levels are located in the western part, specifically in Pagerbarang, Dukuhwaru, Adiwerna, Dukuhturi, Slawi, Talang, and Lebaksiu Subdistricts. Thermal discomfort occurs in these areas because they have average LST values exceeding 27.1 °C. Meanwhile, areas in the Tegal Regency that are also uncomfortable thermally due to being too cold are located in the southern part, in Bumijawa and Bojong Subdistricts. This occurs because these areas are located on the slopes of Mount Slamet, which tend to have LST values below 20.8 °C. On the other hand, the uncomfortable zone in the northern part of Warureja Subdistrict occurs due to cloud disturbance effects on the image. For a clearer distribution of thermal comfort level values in the Tegal Regency shown in Figure 6.

3.4 The Relationship between LST Changes and Built-up Areas and Vegetated Areas

Further identification of the causes of the UHI phenomenon and LST changes in the Tegal Regency is necessary to determine the initial steps in reducing the risks associated with the UHI phenomenon. In this study, variables used to identify the causes of LST changes are built-up areas and vegetated areas. The relationship between changes in built-up areas and vegetated areas with changes in Land Surface Temperature (LST) is identified using linear regression statistical tests.

The condition of built-up areas in the Tegal Regency is modelled using the Normalized Difference Built-up Index (NDBI). NDBI is an index developed to assess the distribution of built-up areas using shortwave infrared (SWIR) and near-infrared (NIR) image channels (Hanif *et al,* 2019; Orsolya *et al.,* 2016). In this study, the image channels used are channels 6 and 5 of Landsat 8 OLI imagery. NDBI values will be modelled for three years: 2013, 2017, and 2022, to observe trends in changes in built-up area conditions in Tegal Regency. The results of NDBI modelling for three years show significant changes, mainly in areas near the regency capital, especially in Slawi District, extending close to the city of Tegal. The development of built-up areas is concentrated in this area and spreads southward to Dukuhwaru and Pagerbang Districts, southward, and northward to Talang and Kramat Districts. The distribution of changes in built-up area conditions in Tegal Regency from 2013 to 2022 can be seen in Figure 7.

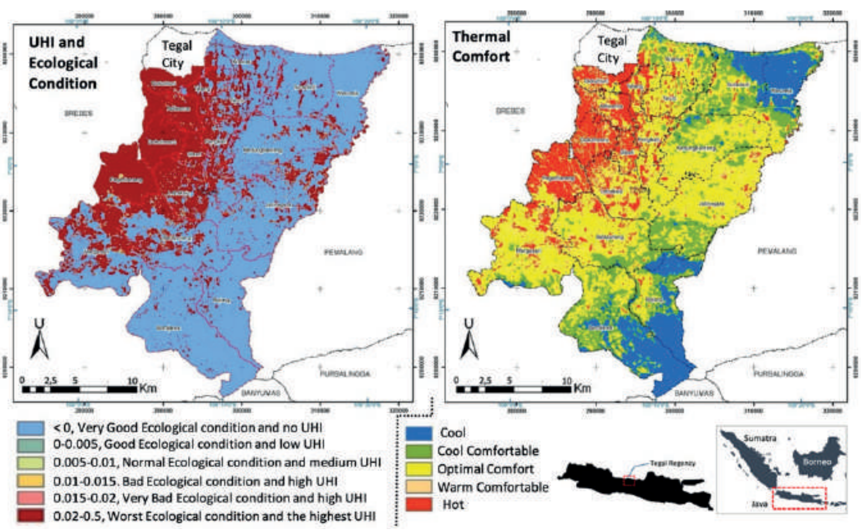


Figure 6. (Left) UHI and Ecological Condition in Tegal Regency; and (Right) map of Thermal Comfort in Tegal Regency in 2022

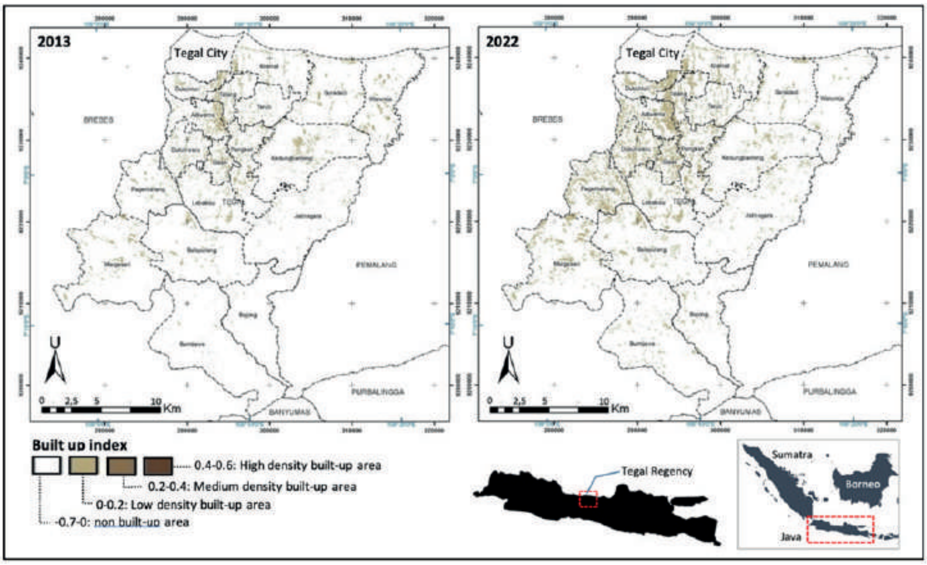


Figure 7. Built-index in Tegal Regency 2013 and 2022

When compared with the pattern of LST changes over the same period, the pattern of changes in built-up areas tends to be similar. This is evident where the concentration of built-up area development is located in the same areas where significant LST changes occur and where the UHI phenomenon occurs. Spatially, the relationship between built-up areas and LST value changes has a strong correlation, indicating that the increase in LST values in Tegal Regency from 2013 to 2022 is triggered, in part, by the development of built-up areas, meanwhile, vegetated land can be modelled using NDVI values. NDVI values are the result of modelling utilizing near-infrared and green channels in the image. The modelling results of NDVI can be used to show the distribution pattern of vegetated land in the research area. Based on the modelling results of NDVI values in Tegal Regency in 2013 and 2022, shows a pattern consistent with NDBI values, where areas with high NDBI values also experience a reduction in NDVI values. The largest reduction in NDVI values is found in the western part of Tegal Regency. This indicates that vegetated land in 2013 has been converted into built-up land in 2022. For a more detailed spatial distribution of changes in NDVI values, please refer to Figure 8.

The relationship between LST changes and variables such as built-up land and vegetated land conditions can be observed by conducting statistical regression tests and scatterplot tests. Statistical regression tests are used to determine the degree of relationship between LST changes and the two variables used, while scatterplot tests are used to understand the tendency of the relationship between LST changes and the tested variables. The results of the statistical regression test can be seen in Table 5.

Based on Table 5, it can be seen that the variable for changes in built-up land has a higher coefficient value compared to the variable for changes in vegetated land. This indicates that changes in built-up land more dominantly influence LST changes in the Tegal Regency. Further analysis of the trend relationship between the two variables is conducted using scatterplot analysis. Based on the scatterplot analysis between LST changes and changes in built-up land (Figure 9), shows a relationship where an increase in built-up land values leads to an increase in LST values in Tegal Regency in Figure 9. Scatterplot Graph of LST Change Values against NDBI Change Values

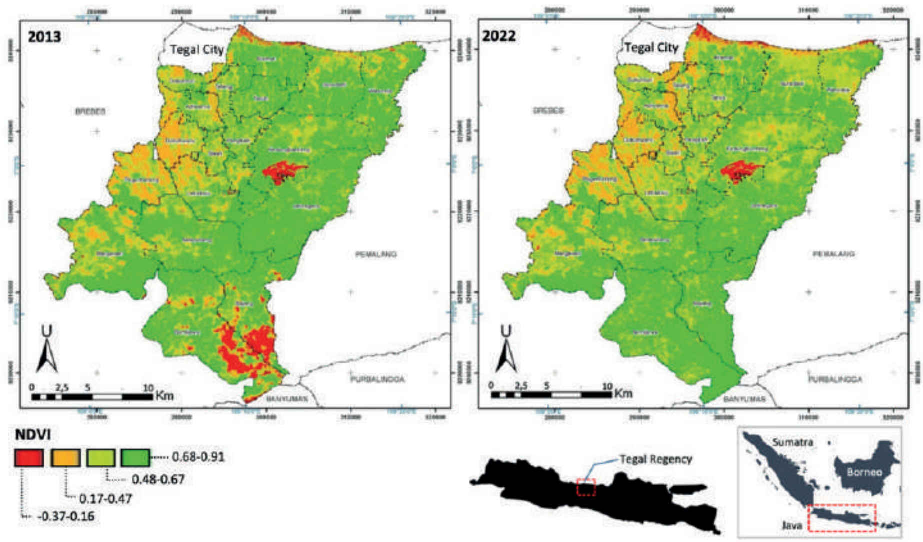


Figure 8. NDV Index in Tegal Regency 2013-2022

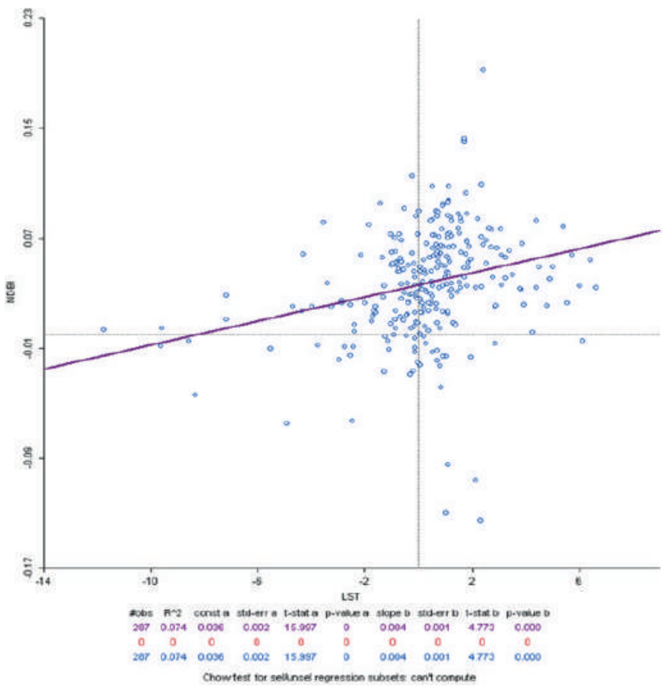


Figure 9. Scatterplot of LST change values against NDBI

3.5 Field Observation

Field survey activities are conducted to compare the modeled results with the actual conditions in the field. Field surveys are carried out to observe the existing land cover conditions in areas with high LST values variation in the Tegal Regency. The observation locations can be seen in Figure 11. The observations indicate that locations with high LST. values are situated in densely populated residential or built-up areas. This is evident at observation point 3, where the location has LST values ranging from 29 to 32 °C, which falls within densely populated residential land use (Figure 10). Meanwhile, in the other observation points with LST value ranges of 27 to 29 °C, specifically at location point 6, it is partially surrounded by agricultural land. At observation point 2, with LST values ranging from 14 to 23 °C, it falls within agricultural land use, particularly paddy fields, hence the high level of greenery leading to low LST values (Figure 10). Based on the field observation results, it can be concluded that the high LST conditions in the Tegal Regency are caused by the presence of increasingly dense built-up areas. This is consistent with the regression statistical test results obtained in this study.

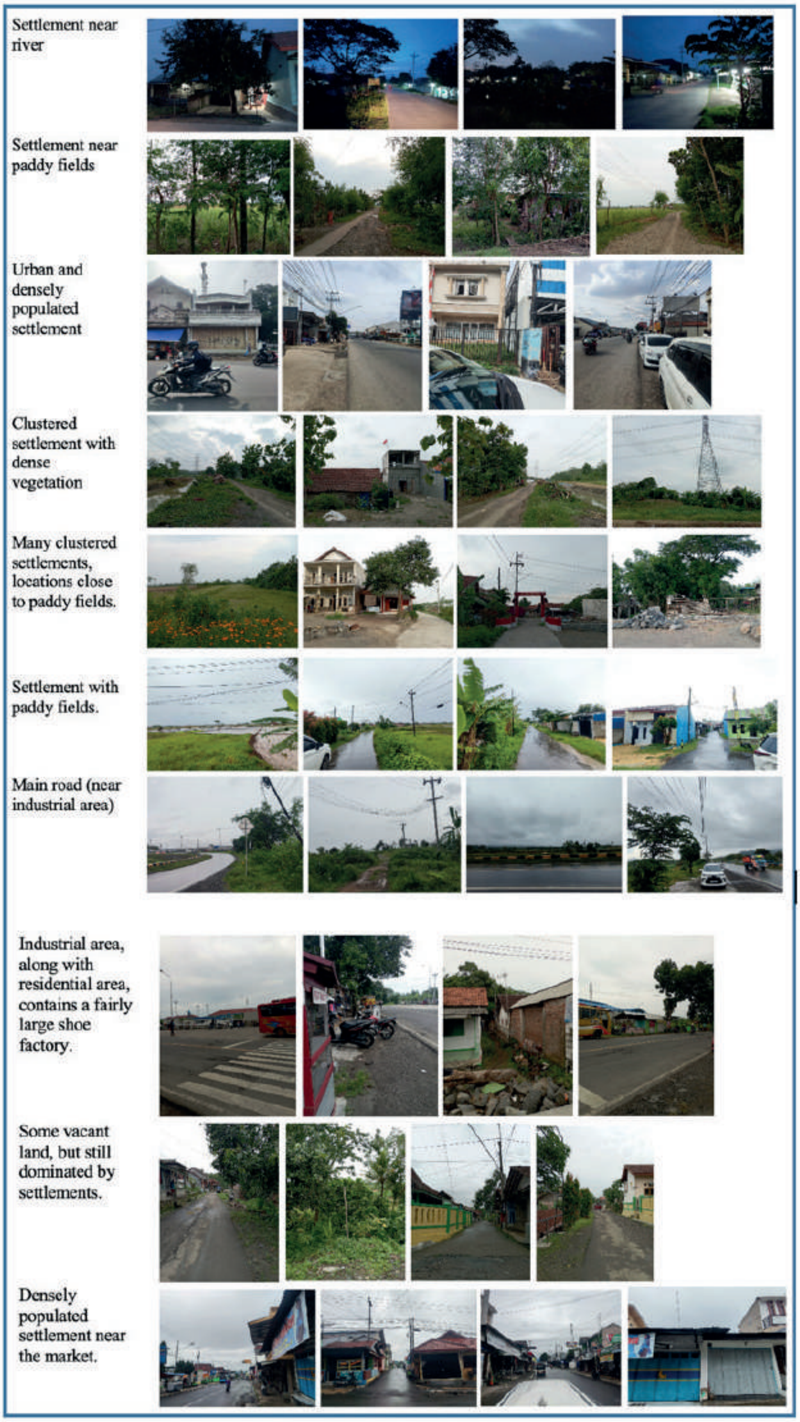


Figure 10. Example of land use and environmental condition in location of sample

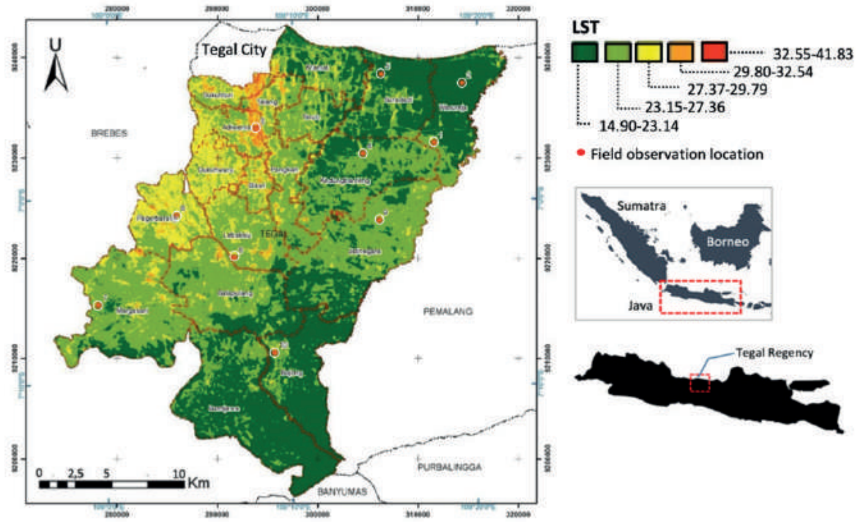


Figure 11. Field observation location

3.4 Guidelines for Mitigating UHI Risk Reduction

Based on the LST and UHI modelling results, it can be concluded that locations with high urgency to minimize their LST increase rates are those areas connecting the capital of Tegal Regency with Tegal City, specifically in Slawi, Adiwerna, and Dukuhturi Subdistricts. Additionally, expanding urban areas such as Talang, Dukuhwaru, Pagerbarang, and Lebaksiu Subdistricts need continuous monitoring as they have highly potential to become new centers of LST increase concentration. These areas are identified as rapidly developing in terms of built-up land expansion.

Several effective mitigation steps for UHI, primarily applied in urban areas in developed countries, are available. Effective UHI reduction methods include (1) planting trees in public green spaces and along roadsides, as tree vegetation is more effective in reducing LST over a larger radius compared to ground-level vegetation such as grass and shrubs; (2) utilizing high-albedo roof coverings in built-up areas; (3) constructing shade structures in urban centers; (4) creating rooftop gardens; (5) incorporating water bodies into open spaces in urban areas, such as artificial lakes; (6) designing environmentally friendly buildings with ample ventilation to minimize air conditioning usage (O'Malley *et al.,* 2015).

The concept of constructing UHI-friendly buildings can be achieved in various ways. There are multiple methods to enhance the albedo value generated by buildings, including tree vegetation, climbing plants on building sides, and utilizing plants on building balconies. The use of tree vegetation is considered the most effective in reducing UHI effects, based on the research by Hayes *et al.,* 2022. Meanwhile, to reduce the UHI phenomenon on asphalt roads, two methods can be employed: (1) planting tree vegetation on both sides of the road can reduce the UHI effect, and/or (2) constructing shade structures along the roads. Shade structures can vary, such as pergolas, plant canopies, or other shading structures. In addition to reducing the UHI phenomenon, this approach can also enhance the aesthetics of the area and potentially create new tourist spots. Another alternative that can be utilized to reduce the UHI phenomenon is by utilizing water bodies. Water bodies can be utilized by creating artificial lakes. If not feasible, water-spraying mist can be installed at certain points along some roads with high LST values. In household scope, reducing the UHI phenomenon can be achieved by reducing the consumption of electricity, especially the use of air conditioning, and by greening the areas around the house. This way, the heat generated by the buildings can be minimized with the presence of vegetation in the household environment.

4. Conclusion

The UHI phenomenon has occurred in Tegal Regency, especially in the western part of the regency, Pagerbarang, Dukuhturi, Dukuhwaru, and Adiwena Sub-District. This area was characterised as very poor ecological environmental values, low NDVI, and High NDBI, while the eastern part of Tegal Regency had very good ecological values and tend to have no UHI phenomena. Priority areas for primary mitigation efforts are Slawi, Adiwerna, and Dukuhturi Subdistricts (especially along the connecting route from the regency capital to Tegal City). Priority areas for secondary mitigation efforts are Talang, Dukuhwaru, Pagerbarang, and Lebaksiu Subdistricts due to being areas of extensive built-up land development in Tegal Regency. This study also signify that when the built-up area increase thus the surface temperatures increase, and potentially cause UHI phenomena.

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