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SPATIAL TEMPORAL ANALYSIS OF URBAN HEAT ISLAND AND URBAN ECOLOGICAL CONDITIONS USING GOOGLE EARTH ENGINE IN TEGAL CITY, INDONESIA

Fresilia Audi[1], Hamim Zaky Hadibasyar[2*], Kuswaji Dwi Priyono[3], Rohman Hakim[4], Alif Noor Anna[5]

[12345]Faculty of Geography, Universitas Muhammadiyah Surakarta, Indonesia

Email: e100200138@student.ums.ac.id[1], hamim.zaky.h@ums.ac.id[2*], kdp130@ums.ac.id[3], rh208@ums.ac.id[4], ana265@ums.ac.id[5]

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ABSTRACT

Tegal city is located on the main transportation route of Central Java's pantura and has strong trade access. Due to its strategic location, the city's significant development led to an increase in built-up land. The growth of built-up land indicates an overall increase in temperature that affects urban heat island conditions and urban ecology. The data used in this study is from Landsat 8 accessed from Google Earth Engine. The research aims to 1) analyze the phenomena of urban heat island (UHI) and 2) urban ecological conditions related to temperature based on the value of urban thermal field variance index (UTFVI). The results of the research show that spatial relationship between the East and South of Tegal City with Tegal Regency caused almost all of its territory classified as affected areas. In addition, the East Tegal area is the center of the city where all concentrations of economic activities, education centers, and government service centers in Tegal City. Linkage of Evaluation the urban ecological conditions in the aspect of land surface temperature based on UTFVI values showed the same pattern.

Keywords: *LST, Tegal, UHI, UTFVI*

INTRODUCTION

Tegal City is a development area in the northern region which is on the main transportation route of Pantura Central Java and has very strong trade access. Its strategic location caused industry and infrastructure to develop rapidly, along with an increase in population and natural migration (Innayatuhibbah et al., 2019).

Population growth can increase the number of places to live, resulting in many land use changes (Nayak, 2006). Land use change can cause problems such as increased surface temperatures causing an phenomena urban heat island. The urban heat island (UHI) is a town area that is much is warmer than the nearby rural region. At concept of urban heat island was described by luke howard (Mills, 2008), and from then an this area of research received increasing attention (Dettwiller, 1970; Katsoulis et al., 1985; Wang et al., 1990; Kim, 1992; Lee, 1993; Pielke et al., 1998; Meng et al., 1996; & Camilloni et al., 1997). Urban heat island causes damage to ecological quality and thermal discomfort is inevitable.

The ecology quality is the basis for a successful sustainable city into the future. A decline in the ecological quality of cities has an impact on the quality of urban life and comfort of cities. Previous studies have revealed that significant land cover changes can lead to temperature increases (Budi et al., 2017). Therefore, it is very practical and necessary to conduct research on urban heat island analyzes and evaluation of urban ecological conditions, which can provide information and suggestions for urban planning and environmental protection in the future. An urban heat island basically appears in the spatial distribution of ground surface temperature (LST). LST acquisition is a major and key step an urban heat island analysis. Obtaining temperature data requires time-consuming and costly field surveys. Therefore, the use of Google Earth Engine can be an alternative to obtain data. Processing is done spatially by utilizing cloud-based satellite imagery, which allows users to visualize and analyze satellite image results and can be used for various information on the earth's surface.

Previous research revealed that the uhi phenomenon in the city of tegal is at a high temperature and is found in high built-up land (Aziz, 2021). This Research is a continuation of the evaluation of urban ecological conditions using the Urban thermal field variance index (UTFVI) is one of the indices derived from SPL extracted from satellite data which can be used as an alternative to measuring urban ecological conditions (Nguyen et al., 2019). The use of UTFVI helps map the degree of temperature variation within the city, providing a better understanding of heat distribution in urban areas. This information is important in planning a sustainable urban environment, helping to identify areas vulnerable to extreme heat conditions. The findings of this research are expected to be used for better urban development planning so that later the following research results can be used as a reference material in planning the development of Tegal city by considering the impact of UHI and environmental degradation. Therefore, This research aims to analyze the impact of distribution of urban heat island phenomenon and urban ecological conditions related to temperature based on urban thermal field variance index (UTFVI) values.

METHOD

The research area is located in Tegal city, which is at the western end of Central Java province. Geographically located at 06°50'21" to 06°54'00" LS and 109°04'28" to 109°09'41" East. The Tegal city is administrative bounded by the Java Sea to the north and by Tegal regency to the eastern side, Tegal regency to the southern side, and Brebes regency to the western side. Tegal city consists of 4 sub-districts, namely South Tegal sub-district, West Tegal sub-district, East Tegal sub-district and Margadana sub-district.

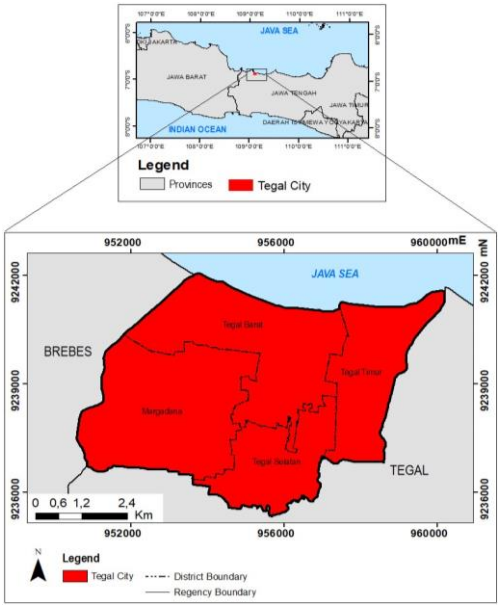

Figure 1. Map Of Tegal City.

DATA PROCESSING AND ANALYSIS

This research uses Accessed and analyzed image data from Landsat 8 on Google Earth Engine (https://earthengine.google.com/). with year selection using the Date filter from January 1 - December 31. The research flow chart can be shown in Figure 2.

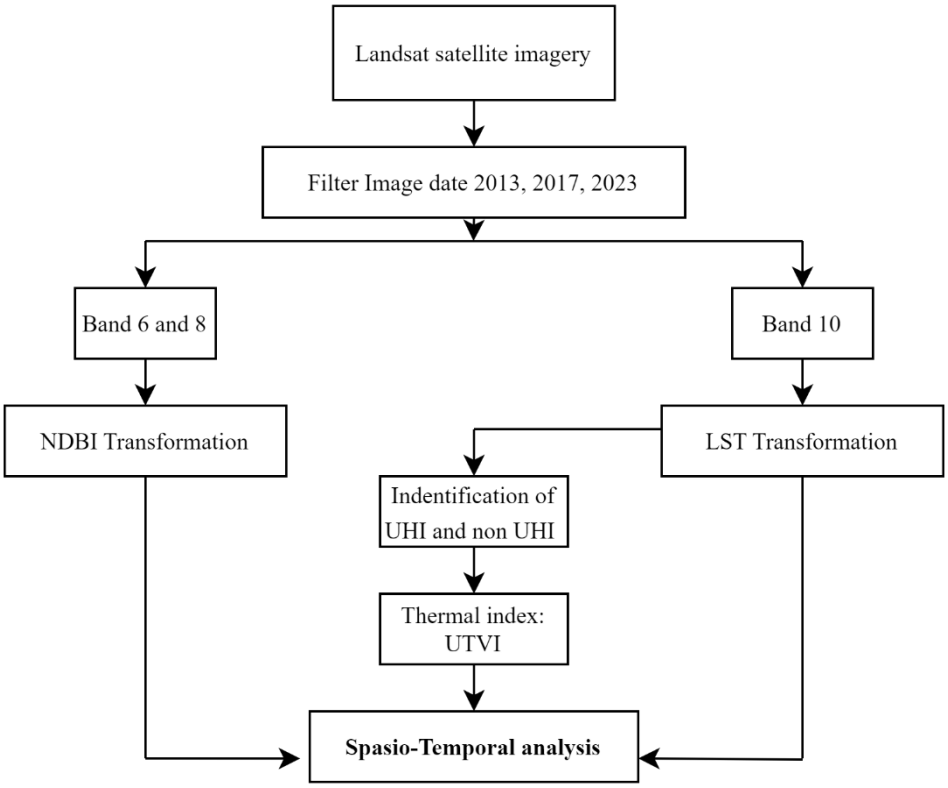

Figure 2. Research Flowchart.

TRANSFORMATION NORMEMALIZED DIFFERENCE BUILT UP INDEX

Normalized Difference Built-Up Index (NDBI) is used to identify building density (Handayani et al., 2017) NDBI is use as the basis for land use classification. The classification of this research uses the classification of (Khoirurrizqi et al., 2023) which is modified with the parameters in table 1. NDBI is calculated from the Landsat 8 multispectral band and calculated from bands 5 and 6 developed (Hongmei et al., 2005) which is used to calculate the built-up area using the equation 1:

$$NDBI = \frac{Band\ 6 - Band\ 5}{band\ 6 + Band\ 5} \quad (1)$$

Table 1. Classification Land cover

NDBI Value	Density
<-0,36	Non building
-0,36 – 0,05	Low building
0,05 – 1,1	High building

TRANSFORMATION LAND SURFACE TEMPERATURE

Surface temperature can be detected by utilizing the use of Remote Sensing technology using satellite imagery that has Thermal sensors such as Landsat 8 imagery. The data on the

satellite image when it is being downloaded is still in the form of digital numbers, so it must go through some conversion steps first to get the actual surface temperature value. The first thing to do is to convert the digital number (DN) value into a ToA radiance value (radiance value) using the bandmath tool using equation 2:

$$L_\lambda = M_L Q_{cal} + A_L \quad (2)$$

L_λ = ToA radiance (radiance value)
M_L = Band-specific multiplicative rescaling factor (found in the metadata)
Q_{cal} = DN of each pixel in the Landsat image band
A_L = Band-specific additive rescaling factor (available in the metadata)

Then the sensor radiance in band 10 is converted into brightness temperature using equation 3:

$$BT = \left(\frac{K_2}{In\left(\frac{K_1}{L_\lambda} + 1\right)} \right) \quad (3)$$

BT = Brightness Temperature (K)
K_1 = Band-specific thermal conversion constant
K_2 = Band-specific thermal conversion constant
L_λ = ToA radiance

This method accounting for the standard deviation (m), the combined mean value of soil emissivity, vegetation cd (n), NDVI calculation, and vegetation presentation (Pv) each computed by Equations (4) - (7)

$$m = \varepsilon v - \varepsilon s\, 1 - \varepsilon s F \varepsilon v 4 \quad (4)$$

$$n = \varepsilon s + (1 - \varepsilon s)\, F \varepsilon v \quad (5)$$

THERMAL FIELD VARIANCE INDEX

UTVI is an index for evaluating the impact of urban heat islands and evaluating urban ecology. UTFVI measures UHI intensity with environmental quality classification (Sobrino et al., 2020). Each of them is related to the UHI

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red} \quad (6)$$

$$PV = \left(\frac{(NDVI - NDVI_{min})}{(NDVI_{max} - NDVI_{min})} \right)^2 \quad (7)$$

A method (Sobrino et al., 2004) was used in this study to obtain the emissivity of the soil surface using equation 8:

$$\varepsilon = \text{mPV} + \text{n} \quad (8)$$

ε is calculated using values of 0.004 for m and 0.986 (Sobrino et al., 2004) The brightness temperature (TB) is then finally converted to degree Celsius (°C), used to compute the emission corrected LST using equation 9:

$$Ts = \frac{BT}{\left(1 + \left[\frac{\lambda BT}{\rho}\right]\right)} \quad (9)$$

Ts = LST in celius (K)
BT = Brightness of temperature
λ = wavelength of the radiant beam (10.8)
P = h × c/σ (1.438 × 10 - 2 m K)
σ = oltzmann constant (1.38 × 10 - 23 J/K)
h = Planck's constant (6.626 × 10 - 34 Js)
c = speed of light (2.998 × 108 m/s)

URBAN HEAT ISLAND

Heat islands can increase if the temperature in the city center is high compared to the temperature around it. To find out which areas are affected by heat with variations in heat in different years, we can use equation 10:

$$UHI = \frac{LST - LST_{mean}}{STD} \quad (10)$$

phenomenon and its impact on environmental quality Population. The UTFVI class is divided into 6 classes based on UHI strength ranging from class 1 (very good) to class 6 (worst), determined using equation 11:

$$UTFVI = \frac{TS - TS_{mean}}{TS} \quad (11)$$

Table 2. Urban ecological condition evaluation.

UTFVI Value	UHI	Ecological Evaluation Index
< 0	None	Excellent
0 – 0,005	Weak	Good
>0,005 – 0,01	Middle	Normal
>0,01 – 0,015	Strong	Bad
>0,015 – 0,02	Stronger	Worse
>0,02	Strongest	Worst

RESULTS

NDBI

Land use classification used the NDBI approach with a three-class classification including high, medium and low built-up areas to representation of the most dominant NDBI. The overall distribution of NDBI in Tegal City is presented in the figure 3. At a broad level, the study area was dominated by high built-up areas in the central to eastern parts of the study area. While most of the sparse built-up land classes were concentrated in the central to western areas of the study area, and the western to northern areas were dominated by sparse built-up land classes throughout the period (2013-2023) in particular the visibility of increasing dense built-up land (red color) can be easily observed during the study period which presents the growth of dense built-up land classes in Tegal city between 2013 and 2023. The results show that the dense building land class in tegal city increased from 14.41 km^2 in 2013 to 19.66 km^2 in 2023.

The sparse building land class experienced the same increase during this period. overall, tegal city experienced an increase in non-building land class shrinkage during the last 3 periods (2013-2017). The results show that the dense building land class in tegal city has decreased from 12.80 km^2 in 2013 to 12.06 km^2 in 2017, finally decreasing to 7.43 km^2 in 2023. These spatial-temporal land use results have important implications for land use policy Spasial-temporal LST (2017-2023).

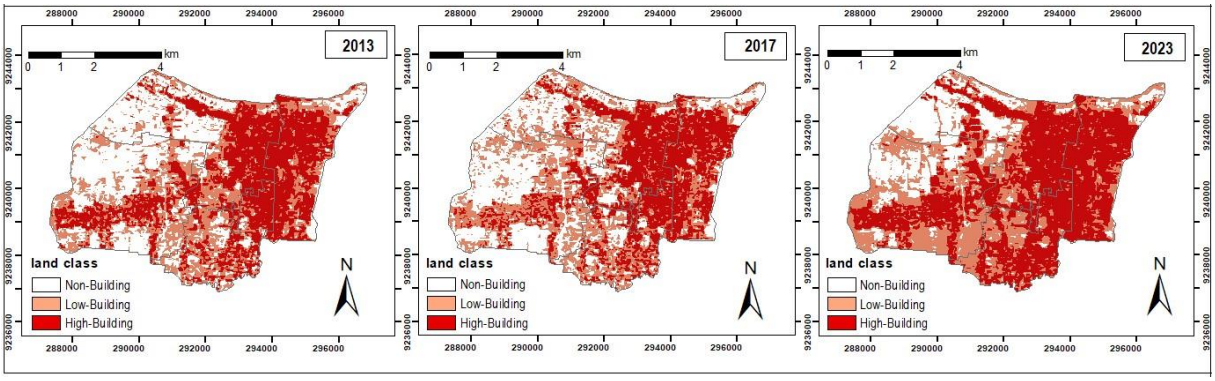

Figure 3. Spatial temporal map of land use (NDBI) of 2013, 2017, 2023.

LAND SURFACE TEMPERATURE

Based on the spatial distribution of LST, the eastern areas of the study area have the highest LST throughout the study period (2013-2023) as shown by the red color in Figure 4. This appears to make sense given that this high LST areas are mostly densely developed land areas. Similarly, the southern to western areas include areas with relatively more moderate LST. In overall, there is an increase in the spatial LST in the study area. At the city level, the highest maximum annual LST during the study period occurred in 2023 (40.69 °C). In contrast, the minimum annual LST was observed in 2013 (21.33 °C). In the meantime, it was noted that the observed maximum LST changed by 1.63 °C in Tegal city during 2013-2023. Spatial-temporal trends and patterns clearly showed that relatively higher LST was concentrated in the eastern Part of the City. Changes in land surface temperature when viewed in 3 periods (2013-2023) spatially showed that in the three images had the same pattern of low temperatures on the edge of the northern coastal city (Tegal Barat sub-district) increasingly to the center or the city center (Tegal Timur sub-district) the higher the temperature. This condition was caused by the eastern part of Tegal City had dense built-up land. While in the northern part of Tegal City has a border with the

sea and land use in this area has a large rice fields and other vegetation.

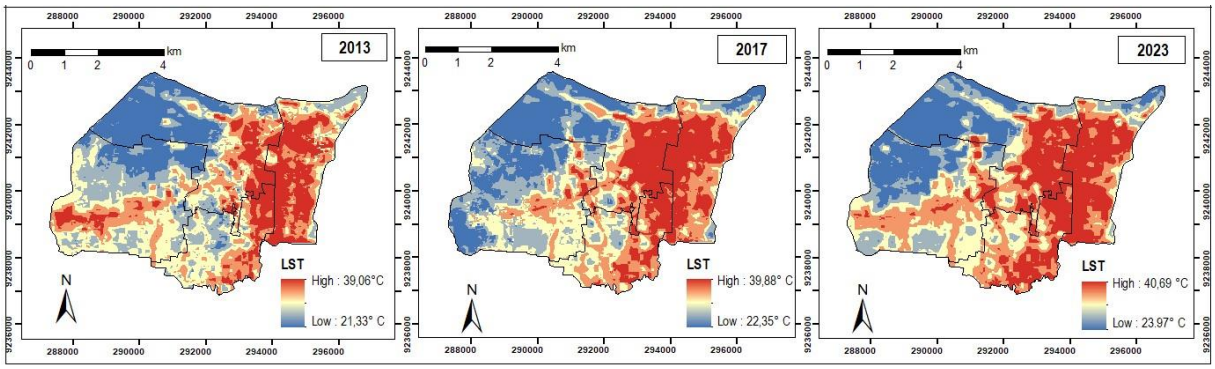

Figure 4. Spatial temporal map of Land Surface Temperature of 2013, 2017, 2023

URBAN HEAT ISLAND

UHI values are obtained from further processing of lst data, namely by involving the maximum value, average, and standard deviation values from lst processing. The results of the processing by involving these values will obtain a threshold value to obtain the UHI value. Temperature values that are above the UHI threshold will be categorized as UHI, and if the lst value is below the UHI value threshold, it will be categorized as non-UHI. Based on the results of data processing, the uhi area of the research area has a surface temperature threshold of 33.46°C in 2013, 34.23°C in 2017, and 35.34°C in 2023. Temperature values that are above the UHI threshold will be categorized as UHI, and if the lst value is below the uhi value threshold it will be categorized as non-UHI. The increase in UHI area in Tegal City was mainly triggered by changes in land use class. It is known that in 3 periods (2013-2017) the UHI area continued to grow. The results showed that the UHI area in 2013 amounted to 19.99 km^2, in 2017 it became 20.61 km^2 and increased again in 2023 to 24.58 km^2. As a result of the increase in the UHI area, the non-UHI area decreased from 2013-2023. The urban heat island phenomenon continues to experience an expansion of the UHI area with the same pattern, namely the UHI area in the city center (eastern sub-district) in Figure 5 and increasingly to the center of the UHI area from 2013, 2017 and 2023. UHI will appear in urban areas that are entirely covered by built-up land. The increase in UHI area in Tegal City was mainly triggered by land use change. One of the main causes of UHI characteristics is the form and function of the urban area itself. Land use change into buildings is accompanied by an increase in population and population activities such as traffic, industry, and urbanization.

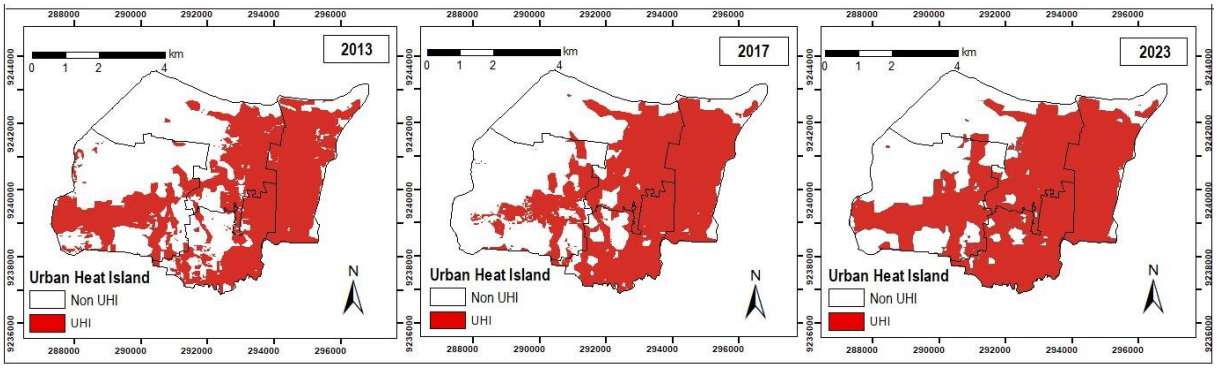

Figure 5. Spatial temporal map of Urban Heat Island of 2013, 2017, 2023

URBAN THERMAL FIELD VARIANCE INDEX

UTFVI represents the urban heat island effect and intensity. If the UTFVI value is high, the urban heat island intensity is high. The utfvi value of the non category represents very good urban ecological evaluation with an area of 7.15 km^2 in 2013, 8.05 km^2 in 2017, and 8.35 km^2 in 2023. This category is dominated by the distribution in the northern region. the category

of good urban ecological evaluation has decreased every year. In 2013 it had an area of 9.20 km^2, 8.77 km^2 in 2017, and 6.31 km^2 in 2023. The dominant distribution of the good ecology category is in the western region. While the value of medium utfvi representing the normal category has decreased similarly to good utfvi. In 2013 the area was 11.23 km^2, in 2017 10.38 km^2 and in 2023 10.08 km^2. Figure 6 High UTFVI values, greater than 0.0015, were spatially distributed throughout the regency, and were categorized as dense areas with poor urban ecological quality. This category dominated all areas of Tegal City in 2013. The area with poor urban ecology was 12.10 km^2 with a dominant distribution in the north, south, east and west, but only slightly in the west. In 2023, the area increased to 12.53 km^2 with the same distribution as in 2013, except that in the west the affected area was reduced so that the impact was very small. In 2023, it increased again to 14.94 km^2 with the same area distribution as the previous year, except that there was an expansion. The UTFVI value can provide an overview of urban ecological evaluation, an index derived from LST (Nguyen et al., 2019). In addition, the determination of UHI intensity and thermal comfort level in a region can use UTFVI (Singh et al., 2017).

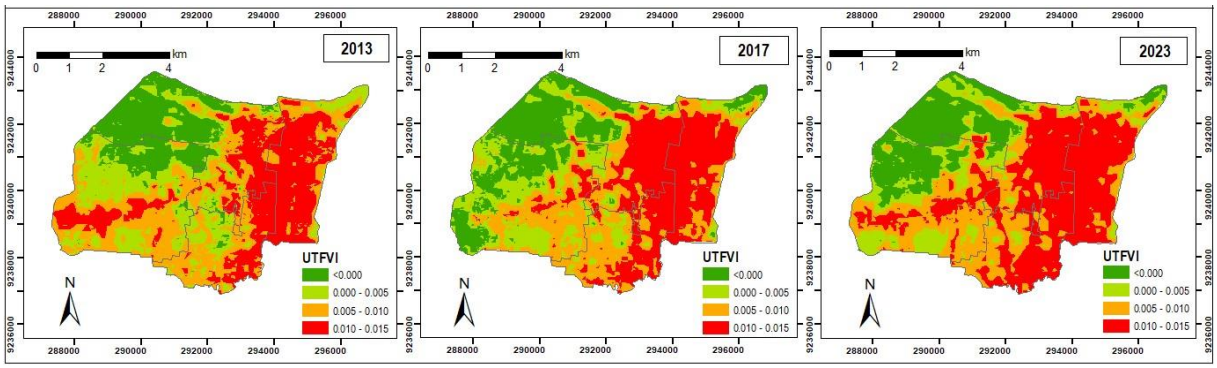

Figure 6. Spatial temporal map of Urban Thermal Field Variance Index of 2013, 2017, 2023

DISCUSSION

This increase in population will certainly be followed by an increase in demand for (built-up) areas as a place to live and work (Yuliastuti et al., 2012). The development of this built-up area then also affects the decline in the quality of the residential environment in the area (Saputra et al., 2023), due to the increasing density of existing buildings (Danardono et al., 2021). In addition, the increasing concentration of buildings has also resulted in the emergence of the UHI (Urban Heat Island) phenomenon in urban areas (Guha et al., 2018).

Previous research showed that the distribution of the UHI phenomenon contained in the 2014 and 2020 data was in the East Tegal District, and part of the West Tegal District (Nguyen et al., 2019). The results showed that the area of uhi in 2013 was 19.99 Km^2, in 2017 it became 20.61 Km^2 and increased again in 2023 to 24.58 km^2. The distribution of uhi area was dominant in the eastern and southern parts of Tegal city, but some western and northern areas of Tegal city were also affected by uhi. The spatial relationship between the eastern and southern parts of Tegal city and Tegal regency caused almost all of its areas to be included in the affected areas. In addition, the eastern Tegal area is the urban center where all economic concentrations, as well as the government center of education in Tegal City. This caused the area to have dense buildings.

Evaluation of urban ecological conditions on the aspect of land surface temperature based on UTFVI values showed the same pattern. on the results of the spatial temporal map (2013-2023) LST and UTFVI spatially showed that low temperatures / excellent ecology tends to be on the edge of the city of the northern coastal part (Tegal Barat sub-district) increasingly to the center has a warm temperature / normal ecology tends to be in the west and south (Margadana sub-district and south tegal) and the more to the east (Tegal Timur sub-district and part of Tegal Barat sub-district) the higher temperature / poor ecology. If an area is ecologically depressed then the area will have a higher than average LST (Hadibasyir et al., 2023) This is because the UTFVI value provides an index of urban ecological conditions derived from LST (Nguyen et al., 2019). In addition, the evaluation of urban ecological conditions using

UTFVI index in Tegal City can provide useful information in evaluating the quality of environmentally friendly urban environment. The existence of urban heat island phenomenon that is getting worse requires proper urban planning and development to protect the environment in the future plan of Tegal city as has been achieved in other similar cities.

CONCLUSIONS

The area of urban heat island continues to grow, the results show the area of uhi in 2013 amounted to 19.99 Km^2, in 2017 it became 20.61 Km^2 and increased again in 2023 to 24.58 km^2. As a result of the increase in the UHI area, the non-UHI area has decreased from 2013-2023. The urban heat island phenomenon continues to experience the expansion of the uhi area with the same pattern, namely the uhi area in the city center (eastern sub-district) and increasingly to the center of the uhi area spreading from 2013-2023. Such a severe urban heat island phenomenon requires better city management planning and the development of the city to protecting an environmentally friendly surrounding in the near term as has been achieved by other similar cities.

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