Analysis of Urban Heat Island Phenomenon as A Global Warming Control Based on Remote Sensing in Jember Urban, Indonesia

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Abstract. Global warming is a world problem because it has a significant impact on the survival of the earth, which is the Urban Heat Island (UHI) phenomenon. Jember Regency is a district with a relatively high population growth rate. Total population growth per year is 0.55\% in 2020. In general, increasing the urban population increases the need for built-up land to support human activities and can affect surface temperatures, producing the urban heat island phenomenon. This study analyses the UHI phenomenon in 3 sub-districts in urban Jember using the Landsat 8 OLI remote sensing image processing method and TIRS Multispectral Imagery to obtain surface temperature values and high-resolution aerial photos from 2013 to 2021, which will be used to identify surface temperatures through several methods. Extraction is the use of supervised classification (supervised), NDVI (Normalized Difference Vegetation Index), and LST (Land Surface Temperature). The study results illustrate that the UHI value in 2013-2021 tends to fluctuate with decreasing temperatures. The Non-UHI classification dominates the urban area of Jember, where the majority are in the suburbs. Meanwhile, the highest UHI class value spreads in the downtown area.

Keywords: urban heat island, landsat image, land cover

1. Introduction

Global warming is currently the biggest problem that will never run out to be discussed by the world community. Global warming causes climate change in various parts of the world and is a worldwide problem written on the agenda for all countries to tackle. United Nations Environment Program [1] states that fossil energy has a significant role in increasing carbon emissions that cause global warming. The increase is 32.1 million tons since 2009. The rise in carbon emissions is dominated by the Asia and Pacific continents, where the resulting emissions will increase the number of emissions in the world. This increase in emissions causes a high concentration of CO2 in the atmosphere, so that it will increase global temperature [1].

One of the causes of carbon emissions is burning fossil fuels for industrial activities, heating, and transportation. Fossil fuels are the energy that dominates the world's energy needs and will continue to increase along with the increase in population. Deforestation and land-use changes also affect the
number of carbon emissions that cause global warming [1]. Several studies say global warming is caused by the Urban Heat Island (UHI) phenomenon. UHI is analogous to an "island" where the surface temperature of hot air is concentrated in urban areas, and the temperature will decrease further in the surrounding suburban/rural areas. Studies related to UHI are critical because UHI significantly affects air quality, influences human health, and involves energy use. As a result of increasing electricity consumption, it encourages the further use of fossil fuels which causes global warming [2].

Jember Regency is one of the districts that have high population growth. Where according to BPS 2020 data, population growth reaches 0.55% per year. This relatively high population growth has a high correlation with an increase in the conversion area from undeveloped land to built-up land to respond to the community's demands. In addition, infrastructure development continues to increase with various dynamics of land-use change. According to Delarizka [3], land cover changes correlate with an increase in surface temperature. To realize sustainable development in Jember Urban, the control of this global warming phenomenon is very important to do.

The background of these problems became the basis for the research "Analysis of the UHI phenomenon as an Effort to Control Global Warming Based on Remote Sensing in Urban Jember." This research was conducted in several stages—first, a literature review to formulate indicators, variables, characteristics of land cover. Second, Landsat image data collection and as a reference for land-use change analysis and as a basis for ground checking surveys. Third, ground checking survey/observation in three sub-districts included in the urban area of Jember Regency regarding the survey design compiled. The last stage, the analysis process, uses remote sensing. This study uses the range from 2013 to 2021 in analysing surface temperatures. The base year starts from 2013 because Landsat 8 imagery is available starting in 2013. Surface temperature extraction from Landsat 8 imagery uses the Split Window Algorithm (SWA) method, where this SWA method requires Band 10, band 11, Band 4, and band 5 from Landsat 8 imagery.

Based on the points above, urban heat island is a topic of urgency that deserves to be researched. The goal in the future is that with the implementation of this research, it can be input for the policymaking process by the district government of Jember related to land surface temperature control.

2. Data and Methods

2.1 Remote Sensing

NASA pioneered satellite remote sensing technology in the United States to launch the first natural resources satellite, called ERTS-1 (Earth Resources Technology Satellite), on July 23, 1972. Following ERTS-2 in 1975, this satellite carried the RBV (Retore Beam Videcin) and MSS (Multi-Spectral Scanner), with a spatial resolution of 80 x 80 m. The ERTS-1 satellite, ERTS-2, renamed Landsat 1, Landsat 2, continued with the following series, namely Landsat 3, 4, 5, 6, 7, and finally Landsat 8, which was orbited in February 2013.

The type of land use affects the surface temperature recorded by satellite sensors [4]. Thermal remote sensing provides a mechanism for observing the surface temperature of an area. Satellite imagery allows for a much larger and more uniform sampling method than in situ surface temperature measurement data. Thermal remote sensing provides an excellent spatial overview of the urban landscape for its temporal variability in time, allowing a comparative analysis of areas of high surface temperature [5]. Thermal infrared images record the radian value of an object/material to measure the object's temperature. Recording the radian value means that what is recorded by the sensor is radiant energy, while what is measured is kinetic energy. The radiant energy of an object is always less than its kinetic energy [6].

2.2 Urban Heat Island

Urban Heat Island (UHI) is a phenomenon where urban areas have higher temperatures than rural areas. UHI is like a giant dome that traps heat in a city. This giant dome is formed from several elements contained in the city. City surfaces consisting of asphalt and concrete are generally hotter during the day than vegetated areas. Several factors that can trigger the occurrence of UHI in urban areas include the
degree of heat of high building materials and the distance between buildings, and the level of air pollution [7].

UHI analysis is one of the analyses to assess the impact of changes in land cover and surface temperature due to urbanization. The main potential of remote sensing is to produce maps of its spatial distribution and intensity. Based on research conducted by Fawzi and Naharil [8], UHI analysis should get UHI intensity and be able to know its spatial distribution. This method helps identify warmer areas to determine mitigation measures. The use of remote sensing imagery for UHI analysis must use cloud-free imagery because UHI occurs in clear skies (without clouds) and without wind or with low wind speeds. If the image used contains many clouds, UHI analysis cannot be performed. Clouds block thermal sensors from recording objects and affect UHI more than wind (Huang et al., 2016; Levermore et al., 2016 in [9]). The presence of clouds can also distort the temperature of the ground surface with shadows on some surfaces. Cloud shadows give the false impression of differences in relative surface temperatures between surface types.

2.3 Research Site

The research location is in Urban Jember, Jember Regency (see Figure 1). Urban Jember is a sub-district administrative area included in the urban area with a tendency for massive activity and land use centers, consisting of Patrang Sub-District, Kaliwates Sub-District, and Sumbersari Sub-District.

![Figure 1. Research Delineation Map (Analysis Result, 2021)](image)

2.4 Analysis Method

The data used in this study are as follows:

a. Landsat 8 OLI/TIRS Level 1 image of the urban area of Jember, which was acquired on 17 June 2021
b. Jember Regency Administrative Boundary Shapefile digital data
c. The software used includes image processing and spatial data, Microsoft office 365

Stages of Data Processing:

a. Image Selection
   Landsat 7 and 8 Levels 1 and 2 images, selected with a cloud cover criterion of 10%, then cropped based on the Jember Regency Urban shapefile data.
b. Radiometric Correction
The calculation formula is as follows [10]:

\[
L_\lambda = MLQ_{cal} + AL
\]

Description:
L_\lambda : TOA spectral radiance
ML : Band-specific multiplicative rescaling factor from the metadata
AL : Band-specific additive rescaling factor from the metadata
Q_{cal} : Quantized and calibrated standard product pixel values (DN)

c. Calculation of Brightness Temperature
Convert the spectral radiance value to brightness temperature using the equation [10]:

\[
TB = \frac{K2}{\ln\left(\frac{K1}{L_\lambda + 1}\right)}
\]

Description:
TB : Brightness temperature (K)
L_\lambda : TOA spectral radiance
K1 : Band-specific thermal conversion constant from the metadata
K2 : Band-specific thermal conversion constant from the metadata

d. Calculation of the Normalized Difference Vegetation Index (NDVI)
Band 4 (red) and band 5 (near-infrared) are used to obtain the NDVI value with the following formula [11]:

\[
NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}
\]

Description:
NDVI : Normalized Difference Vegetation Index
Band 4: Red channel on Landsat 8
Band 5: Near-infrared channel on Landsat 8

e. Determine the value of the Proportion Of Vegetation (Pv)
The Pv values were obtained by scaling the NDVI to minimize disturbance from moist soil conditions and surface energy fluxes.

\[
Pv = \left(\frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}\right)^2
\]

Description:
Pv = Proportion of Vegetation
NDVI = NDVI processing result
NDVI_{soil} = NDVI value of bare soil
NDVI_{veg} = NDVI value of 100% vegetize fraction
f. Determine the Emissivity value ($\epsilon$)

After getting the vegetation cover fraction, the emissivity value of an area can be calculated.

$$\epsilon = 0.985Pv + 0.960(1 - Pv) + 0.06Pv(1 - Pv)$$

Description:
- $\epsilon$ = Emissivity
- $Pv$ = Proportion of Vegetation
- 0.985 = Vegetation Emissivity
- 0.960 = Soil Emissivity
- 0.06 = 4x$d\epsilon$ (mean value)

g. Calculating the value of the surface temperature (Land Surface Temperature)

$$TS = \frac{T}{(1 + \frac{\lambda T}{\partial \ln \epsilon})}$$

Description:
- $TS$ = Surface temperature
- $T$ = Brightness temperature
- $\lambda$ = Central wavelength of thermal band (Landsat 5 = 11.45 m; Landsat 8 = 10.8 m)
- $\partial$ = Constant 1.438 x 10-2mK
- $\epsilon$ = emissivity value

h. Identify the Urban Heat Island Phenomenon

UHI phenomena are identified using remote sensing methods based on the 2021 surface temperature processing (LST) threshold. UHI phenomena are identified from the surface temperature data by subtracting the UHI threshold value according to Ma et al. (2010) in [9].

$$T > \mu + 0.5\alpha$$
$$0 < T \leq \mu + 0.5\alpha$$

Description:
- $T$ = Surface temperature (LST)
- $\mu$ = Average surface temperature value
- $\alpha$ = Standard deviation of surface temperature

$$UHI = T_{mean} - (\mu + 0.5\alpha)$$

Description:
- $UHI$ = Urban Heat Island
- $T_{mean}$ = Land Surface Temperature (°C)
- $\mu$ = LST mean value (°C)
- $\alpha$ = LST standard deviation value (°C)

The result is a positive temperature difference value indicates that the area is experiencing UHI. If it is negative, then the area does not occur UHI phenomenon.

2.5 Research Flow

Figure 2 is a research flow where this research starts from collecting shapefile data on the administrative boundaries of Jember Regency and Jember Urban, which consists of 3 sub-districts, namely Sumbersari Sub-District, Patrang Sub-District, and Kaliwates Sub-District. Furthermore, data collection of Landsat imagery from Urban Jember. After the two data were obtained, the image was changed into the form of temperature (LST analysis) followed by temperature classification and calculation of UHI values in the range of 2013 to 2021. The last step was to provide recommendations for temperature control from the results of UHI values.
3. Results and Discussion

Based on the calculation results, it produces varied LST data. In the statistical data produced, the Jember Urban LST trend in 2013-2021 is fluctuating but tends to decrease (Table 1). The temperature distribution in urban areas is also dynamic and can change at any time. This condition can be influenced by natural, physical, climatic, weather, and hydrological conditions. The spatial distribution of LST in urban Jember is centered in the downtown area where the existing condition is in the form of built-up land which has very massive growth which is in line with the increase in the population of Jember Regency every year (Table 2).

Table 1. LST Calculation of Jember Urban

| Description               | Land Surface Temperature °C |
|---------------------------|-----------------------------|
|                           | 23/09/2013* | 24/05/2015* | 18/09/2017* | 20/06/2019* | 05/08/2021* |
| Maximum LST               | 34.29        | 30.31        | 34.83        | 27.73        | 31.37        |
| Minimum LST               | 17.96        | 21.57        | 20.60        | 18.98        | 22.59        |
| Average LST               | 28.61        | 25.48        | 29.47        | 23.17        | 26.62        |
| Standard deviation        | 2.27         | 1.73         | 2.00         | 1.61         | 1.70         |
| Tmean (Threshold)         | 29.74        | 26.34        | 30.47        | 23.97        | 27.46        |
| Maximum UHI               | 4.55         | 3.96         | 4.36         | 3.76         | 3.90         |

*data collection date
Table 2. Area of LST Result

| Year | 17-21°C | 21-25°C | 25-29°C | 29-33°C | 33-37°C |
|------|---------|---------|---------|---------|---------|
| 2013 | 56.70   | 336.53  | 5393.26 | 3946.73 | 136.64  |
| 2015 | 0.00    | 4511.58 | 5144.03 | 214.81  | 0.00    |
| 2017 | 1.48    | 32.18   | 4523.28 | 4911.02 | 401.22  |
| 2019 | 568.73  | 7716.12 | 1585.36 | 0.00    | 0.00    |
| 2021 | 0.00    | 1767.93 | 7065.42 | 1037.12 | 0.00    |

Analysis Result, 2021

In the maximum UHI graph, the distribution of UHI in Jember urban from 2013 to 2021 does not show a significant change, but the trend tends to decrease (see Figure 3). Although the trend of UHI values is decreasing, it does not significantly impact global warming in the Jember urban. The LST value varies from the lowest temperature of 17°C to the highest of 34°C.

Figure 3. Graph of the maximum value of UHI in 2013-2015 (Analysis Result, 2021)

Figure 4 shows a map of the spatial distribution of UHI from 2013 to 2015 in urban Jember. UHI values are divided into four to five classes of temperature differences and areas classified as Non-UHI, depending on the results of the UHI calculation from each year. The existence of the majority of Non-UHI classifications is in the suburbs of Jember Urban.

Based on the analysis results in Figure 4 (a-e), it shows that the distribution of UHI with the highest temperature is in the City Center and then spreads spatially to the suburbs of Jember. It can be seen in the figure that the trend of the location of the highest UHI distribution from 2°C to 5°C tends to cross diagonally from southwest to northeast. This phenomenon happens because the existing condition is that a collector road connects the bordering districts, namely Lumajang Regency and Bondowoso Regency. Land use development tends to follow the collector road, which causes high surface temperatures compared to suburban areas. The UHI classification 0°-1°C is mainly located on the suburb of Jember. Meanwhile, the UHI classification 1°-2°C and 2°-3°C has a spreading area. In addition, the 3°-4°C and 4°-5°C UHI classifications tend to be in the downtown area with a small area, even only in the form of location points.

According to [8], efforts to minimize UHI’s effect are the use of vegetation as a means to restore natural functions in the urban environment. In controlling global warming in Jember City, it can be done based on the results of the UHI classification. Areas with high UHI values can be a priority for handling global warming by providing public and private green open space in every building, both settlements and existing facilities, buildings with environmentally friendly concepts, and the application of a vertical garden or green roof system.
4. Conclusion

The spatial distribution of LST and UHI values in Jember Urban from 2013 to 2015 shows a fluctuating trend but decreases with a dynamic area. The classification of the highest UHI value is in the city center with the most massive activity and the dominance of built-up land, which is spread out following the primary collector road, which runs diagonally from southwest to northeast. The Non-UHI classification dominates the surface temperature area, where the majority are in the suburbs of Jember. Recommendations for controlling global warming can be done by providing public and private green open space in every building, both settlements and existing facilities, buildings with environmentally friendly concepts, and the application of a vertical garden or green roof system. These control efforts are focused on areas with the highest UHI classification.
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