Contribution of urban heat island on landscape composition and its impact to the land surface temperature (case study on Palembang City-Indonesia)

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Abstract. Palembang is the capital of South Sumatra Province with the development carried out through the diversion of land functions into built-up land causes an increase in surface temperature which triggers the urban heat island (UHI) phenomenon. This study aims to discuss the phenomenon of UHI in Palembang City and its relation to land composition and population density on surface temperatures obtained from the processing of multi-temporal Landsat Images in 1989, 2001, 2018, with the specification of clear sky using the LST algorithm and guided classification. The distribution of the UHI phenomenon is obtained by classifying LST to obtain the UHI threshold. The value of the determinant coefficient (R²) between the relationship of changes in surface temperature which is directly proportional to the increasing population, the increase in the area of each open land and built-up land reached 62.6%, 86.3%, and 55.0%. Conversely, there is a negative link between surface temperature and dense vegetation with R² reach 90.4%. The affected area of UHI is located in the centre of Palembang, reaching 33.5 km² of the total area. It is necessary to have ideal city mitigation and arrangement by calculating the green area with the increasing population in Palembang City.

1. Introduction

Urban Heat Island (UHI) is included in the micro-scale urban climate which is characterized by an increase in urban temperatures compared to the surrounding area. This can occur along with human activity increase and various infrastructure developments in the region. UHI is described as a hot surface air island which is centered in urban areas and surrounded by a temperature decrease on the urban edge [1]. An increase in the human population, coupled with the high density of transportation and changes in building construction have an increasing impact on temperature and air pollution which causes the UHI effect.

The UHI phenomenon is a type of environmental degradation could also significantly reduce air quality which affects human health, energy use, and climate change [2]. The subsequent of the UHI effect in the latest research results have showed that climate change will have an impact on health and reduce vulnerability to heat waves. There are two important reasons why UHI is suspected to be responsible for increasing surface temperature and air temperature in recent decades. The first reason is related to the decrease in diurnal temperature and the second is the lower level of warming observed in the lower troposphere compared to the surface.
There are 2 types of methods in the measurement of UHI, such as the UHI atmospheric layer, through the measurement of the urban canopy layer (UCL) and the urban boundary layer (UBL), as well as the urban surface of the UHI which is measured by measuring land surface temperature (LST) [3]. Research on UHI phenomena using satellites in LST measurements has been used with NOAA-AVHRR data utilization [4]. In addition, several studies using Landsat Thermal Mapper (TM) using TIR (thermal infrared) were also carried out in analyzing surface temperatures, correlated the relationship between LST and NDVI (Normalized Difference Vegetation Index) using Landsat Enhanced Thematic Mapper Plus (ETM +) located in the City of Indianapolis, IN, the USA on June 22, 2002 [4]. It is known that unmixed vegetation value has a direct influence on humidity, temperature, and radiation that determine LST values. [5] examined the correlation between LST to green space and water bodies in the Southeast Asian region by taking 3 metropolitan cities, such as Bangkok (Thailand), Jakarta (Indonesia), and Manila (Philippines) by utilizing Landsat-8 satellite data Operational Land Imager and Thermal Infrared Sensor (Landsat-8 OLI / TIRS). This study proves, the average LST in a body of water is around 3°C higher than a green space. In general, the results highlight the important role of green space in reducing the effect of UHI.

Another research has tested the UHI phenomenon analysis and its mitigation in the city of Semarang [6]. The results showed the relationship between changes in LST with land cover and population density. UHI mitigation that can be done is the physical modification of the building, such as the use of materials with a high albedo, the application of green walls, green roofs, greening parking lots, and increasing vegetation around the building and along the road. In addition, it is also necessary to supervise changes in land use and its suitability with the establishment of Semarang City. Research conducted an analysis of the impact of urban composition on LST as a contribution from UHI in Guangzhou, China using the Landsat TM satellite with a cloud-free system. By using a regression model to test the nonlinear relationship between LSTs using satellite-based indexes in the UHI group: Normalized Differential Vegetation Index (NDVI), Normalized Differential Build-Up Index (NDBI), and Normalized Difference Bareness Index (NDBaI) showed a strong correlation between NDVI and NDBI with LST variations while NDBaI has a weaker correlation compared to LST.

Remote sensing technology is one of the technologies which can be used to analyze UHI phenomena. By using a processing algorithm, it can be used to determine changes in land cover and LST distribution. Therefore, this study does research on land cover and LST climatologically at selected times by taking locations in Palembang City, one of the largest cities after Medan on Sumatra Island, Indonesia. The results of this study will increase understanding of variations in increasing LST over time along with population growth and regional infrastructure.

2. Data and Method

2.1. The Study Site

The study area include Palembang City, Indonesia. The study area covers 385.55 km² landscape. According to data from the Central Statistics Agency of South Sumatra Province, the population density value in Palembang City in the year of 2018 reached 1,651,857 people as shown in figure 1.

Characteristics of Palembang City climatology conditions generally is the monsoonal type that has a clear difference between rainy season and dry season also included in the humid tropics with an average air temperature reached 21-32°C and rainfall records ranging from 22-428 mm/year (based on observations from the Indonesian Meteorology, Climatology and Geophysics Agency). There is a tendency of a significant increase in average monthly surface temperature conditions in Palembang City based on the results of the Palembang City Meteorological Station observation record [7]. Palembang City has a diverse relief consisting of soil in the form of alluvial layers and sandy clay. Palembang City covers a variety of landscape conditions such as forests (5.68%), swamps (3.83%), agricultural land, bodies of water such as the Musi river (width reaching 504 m), residential areas with low density, and settlements with low/high densities, diversity and spatial heterogeneity of the land surface conditions make it an ideal study area for UHI research.
2.2. Study Area

The research location was taken in Palembang City (figure 2), which is one of the metropolitan cities in Indonesia. Geographically located between $2^\circ 52' - 3^\circ 5' S$ dan $104^\circ 37' - 104^\circ 52' E$ with an average height of 8 meters above sea level.

Figure 1. Conditions of population density change in Palembang City (2010-2018)

Figure 2. Geographical location of Palembang City
2.3. Data
In this study, the data used are satellite imagery of Landsat TM and Landsat ETM + (Band 6) and Landsat OLI / TIRS (Bands 10 and 11) with cloud-free (clear sky) specifications (Table 1). Data were obtained from the GloVis USGS Earth Resource Observation Systems Data Centre by taking multitemporal time in 1989, 2001, and 2018. The area was taken in Palembang City which had 1) 1984 WGS datum with 48 S zone (Southern Hemisphere).

| Location          | Time                  | Season | Acquisition date and time (GMT)   |
|-------------------|-----------------------|--------|-----------------------------------|
| Palembang City    | Saturday, April 15, 1989 | Dry    | Thursday, March 2, 2017           |
|                   | Friday, July 13, 2001  | Dry    | Sunday, April 2, 2017             |
|                   | Saturday, November 17, 2018 | Wet    | Friday, December 14, 2018         |

2.3.1. LST calculation from Landsat ETM + satellites. The standard method for determining LST values requires the conversion of DN (digital number) values on the thermal band for Band 6 on Landsat TM and ETM + and Bands 10 and 11 on Landsat 8 OLI / TIRS. The DN value is then converted to a radiance value. The next step is converted into brightness temperature which will be obtained LST values [8]. In converting DN values to radiance values for Landsat TM and ETM + satellite types, the formula is used:

\[
L_{\lambda} = \frac{L_{\text{MAX}} - L_{\text{MIN}}}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}} \times (DN - Q_{\text{CALMIN}}) + L_{\text{MIN}}
\]

where \(L_{\text{MIN}}\) and \(L_{\text{MAX}}\) are spectral radiance from each band at DN values of 1 and 255. \(DN\) is the pixel value of DN, and \(\lambda\) is the wavelength. To convert the radiance value to the brightness temperature value, the calculation is performed:

\[
T = \frac{K_2}{\ln \left(\frac{K_1}{L_{\lambda}} + 1\right)}
\]

where \(K_1\) and \(K_2\) are determined from the wavelength of the satellite sensor. The LST value produced has Kelvin units. To obtain the LST value on Landsat 8 OLI / TIRS, like do the same thing on Landsat TM and ETM+, the first thing to do is convert to a radiance value, then the conversion calculation is calculated into the brightness temperature value. After converting the value of brightness temperature into Celsius (°C), an emissivity correction calculation is performed in the LST calculation. The following is the formula for determining LST values using Landsat 8 OLI / TIRS [9]:

\[
\text{LST (°C)} = \frac{T_B}{1 + \left(\frac{\lambda \times T_B / \rho}{\ln \varepsilon}\right)}
\]

\(T_B\) is the brightness temperature of Band 10 of Landsat 8, \(\lambda\) is the wavelength of Band 10 which is 10.8 µm, \(\varepsilon\) is LSE (land surface emissivity), while \(\rho\) is obtained by:

\[
\rho = h \times \frac{c}{\sigma} (1.438 \times 10^{-2} \text{ mK}), \sigma = 1.38 \times 10^{-23} J/K; h = 6.626 \times 10^{-34} Js; c = 2.998 \times 10^8 \text{m/s}
\]

2.3.2. NDVI Calculation. NDVI of the so-called normalized difference vegetation index is an image calculation to determine the level of vegetation density of an area which later in this study will be determined in several green level classes. NDVI calculations are performed using Band 4 (Red) and Band 5 (NIR) with the following formula [10]:

\[
\text{NDVI} = \frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}}
\]
\[ \text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \]

2.3.3. UHI Phenomenon Identification. In analysing UHI phenomena, the method is based on the results of the LST calculation threshold. From the surface temperature data, the UHI phenomenon is then identified by subtracting the UHI threshold value \[[11]\].

\[ T > \mu + 0,5\alpha \\
0 < T \leq \mu + 0,5\alpha \]

where \( T \) is the LST value, \( \mu \) is the average value of surface temperature and \( \alpha \) is the standard deviation of surface temperature which can be determined through statistical LST processing on satellite imagery.

3. Result and Discussion

3.1. Result

From the results of the LST value display obtained from the ECMWF model, it can be shown that during 1982-2018 the LST condition continued to increase as shown figure 3. This can be proven by a linear surface temperature regression graph that shows the value of a positive equation. The increase is quite high in certain years, as in the case of 1998, where the LST reached 28.6°C due to the El Nino phenomenon, which is caused by high sea surface temperature in the central and eastern Pacific pushing the formation of clouds that will increase rainfall around the region. Air pressure in the western part of the Pacific Ocean has increased so that it has hampered the growth of clouds over the ocean in the eastern part of Indonesia, as a result, some areas of Indonesia experienced a decrease in rainfall that is far from normal and affects temperatures in Indonesia \[[12]\], include Palembang City.

![Land Surface Temperature (℃)](image)

**Figure 3.** Changes in LST during 1982-2018 in Palembang City

From the results of the air temperatures analysis in Palembang City also shows a positive trend which can be seen through the value of the equation in figure 4. Generally, the condition of the air temperature shows a trend that is almost the same as the condition of the average LST graph on the previous graph in Palembang City.
Development is carried out by converting land from non-built up the land into built-up land. This will certainly have an indirect impact on environmental conditions, one of them is the change in LST in the region. The change in LST will have an impact on changes in the ambient air temperature. Changes in the land cover which reduce the area of green outdoor are estimated to be one of the main triggers of increased surface temperature and air temperature. Vegetation conditions can be used as an indicator of surface temperature dynamics in urban areas. The more vegetation cover, the surface temperature value will be lower (cooler), conversely, the lower vegetation cover will produce higher or lower surface temperature values [13].

\[ y = 0.0237x - 19.272 \]

\[ R^2 = 0.1772 \]

![Air Temperature (°C)](image)

**Figure 4.** Changes in surface temperature during 1982-2018 in the Palembang City

![Proportion of LST](image)

**Figure 5.** Description of the surface temperature proportion in Palembang City during 1989, 2001 and 2018
Furthermore, the change values in average surface temperature throughout 1989, 2001, and 2018 are indicated by the graph in figure 5. On the graph, it can be seen that the average LST value in 1989 is dominated by temperatures in the range of 21°C - 24°C. In 2001, the average surface temperature was generally dominated by a temperature range of 24°C - 27°C, whereas in 2018, the average surface temperature was generally in the range of 21°C - 24°C and 24°C - 27°C. The results of the analysis in general show that the average surface temperature conditions have increased from year to year.

The land cover area is divided into 4 types, such as water bodies, rocks/high-density population, low-density population, vegetation in the form of the field area, and dense vegetation dominated by forest areas (figure 6). The graph above shows the condition of changes in the land cover area based on the years of research namely, 1989, 2001, and 2018. From year to year, the area of water bodies and dense vegetation has decreased the percentage of the total area. This is different from residential areas, both dense and low density continuing to increase. For the vegetation space, it can be seen an increase in open land until 2001, however, towards 2018, the area of vegetation has decreased. The highest increase in land cover conditions from year to year can be seen in the increase in population residential, both with high and low population density. This can be said also as the effect of increasing population in the Palembang City from year to year. More will be explained in the next section.

![Proportion of Land Cover Categories](image)

**Figure 6.** Description of land cover conditions in Palembang City

Figure 7 shows the spatial changes in LST conditions and land cover from year to year based on the time of the research. The analysis, results show that the effect of the green space on LST is smaller than the residential areas with both high/low density. In 1989, the green land area had the biggest ratio compared to residential areas, which was 42.0% of the total Palembang City, when compared to the condition of residential land which was only around 16.0% and only had highest scale LST around 28.77°C. Whereas in 2018, with the development which led to a reduction in green land and has caused the greater ratio of residential than green land, which is 44.2% vs 6.0% shows the condition of LST in Palembang City reached 32.38°C. This shows the necessity of developing green land compared to residential areas in mitigating the effects of UHI in urban areas. The results of this analysis are also consistent with studies relating to the effect of UHI in Phoenix, AZ, USA [14].
Figure 7. Condition map a) land cover area and b) LST in Palembang City using Landsat TM, Landsat ETM +, and Landsat OLI / TIRS.
Through the calculation results using LST data, obtained UHI values in the scale of the Palembang City area. From the analysis results, it was recorded in 2018, around 9.14% or as much as 33.5 km² of the total Palembang City area was detected as experiencing UHI phenomena, which is a condition that indicates the existence of urban surface air temperature which is higher than the surrounding temperature. Palembang City is one of the cities that is centered on infrastructure development which is increasing every year. This has resulted in an increase in the area affected by UHI (figure 8). The Palembang City has experienced changes in infrastructure which are mostly carried out for the development of residential and the economy along with the increase in population in the region. For example, the average rate of conversion of the Musi river area stockpiled for the benefit of residential and economic center activity is estimated at 6% per year (taken from Statistics Agency of South Sumatra).

3.2. Discussion
The table below is the values that show the land conditions are based on the distribution of water bodies, rocks/high-density residential, low-density residential, fields, forests, as well as population and average LST values in the city of Palembang. From this table, it can be seen that there is an increase in the number of populations which is directly proportional to the increase in LST. It is also necessary to do a comparative test to get the relationship between each parameter. In this study, the relationship, condition between land cover and LST are analyzed and divided into 3 parts, such as open land, built-up land with dense vegetation. All three factors are compared with the population number of Palembang City area and the average LST value per study year, ie 1989, 2001 and 2018 using linear regression tests.

Table 2. Simple linear regression test data

| Year | Water (Km²) | Rock/High Density Residence (Km²) | Low Density Residence (Km²) | Fields (Km²) | Forest (Km²) | Population (Population/Km²) | LST (°C) |
|------|-------------|----------------------------------|-----------------------------|--------------|--------------|-----------------------------|---------|
| 1989 | 20.29       | 16.00                            | 42.14                       | 132.59       | 153.04       | 3078.00                     | 26.61   |
| 2001 | 13.70       | 25.25                            | 73.45                       | 202.76       | 51.74        | 3718.00                     | 27.71   |
| 2018 | 13.50       | 53.40                            | 107.47                      | 170.95       | 20.98        | 4463.00                     | 27.60   |

Figure 8. Results of UHI phenomenon detection in Palembang City in 2018
From the results of linear regression, a positive value equation can be identified, meaning that there is a directly proportional relationship between LST between open land and built-up land (figure 9). This indicates that from year to year there is an increase in land use which also causes an increase in the average LST value. In addition, the results of the linear regression test between the population and the LST value also showed a positive value, meaning that the greater population increasing, the LST value will also increase. On the other hand, the regression equation result between dense vegetation and LST are negative so that they have an inverse connection.

It can be concluded, if the area of dense vegetation decreases and an increase between the number of population densities and land-use area, namely open land and built land, the average LST will increase. The most influence changes factor in the average LST value can be shown by the magnitude of the determinant coefficient (R2) in a row, namely dense vegetation ranges from 90.4%, open land 86.3%, population ranges from 62.6%, and built-up land around 55.0%.

Figure 9. Results of UHI phenomenon detection in Palembang City in 2018
3.2.1. Palembang City Review. From the study results, we compared the research studies that have been carried out with the real condition of the Palembang City. From figure 10, it can be seen the appearance of the land cover condition around the Musi river. It appears that the area has been classified as an area with built-up land and has a low to high population density. This condition is in accordance with the study conducted by the author which shows that this area is classified in terms of land cover with characteristics of low density residential and rocks/high-density residential. This area is included in the UHI area with LST higher than the surrounding area. From the results of this review, an urban planning system is needed to avoid this condition. For this reason, it is very important to plan and mitigate the spatial distribution of the urban environment to minimize and control UHI changes in Palembang.

**Figure 10.** (a) Spatial distribution in one of study area based on the characteristic conditions of UHI Palembang City in 2018 and (b) Spatial distribution of Palembang City

**Figure 11.** Spatial distribution of Palembang City
Based on spatial distribution data taken from the Statistics Agency of West Sumatra Province data in 2018, it can be seen that the urban environment condition of Palembang City which is quite dense with high-density population is generally located in the Musi River waterside area precisely in Ilir Village (figure 11). For this reason, a review of Palembang's spatial distribution system and UHI mitigation is needed in terms of social, energy use, water use, and air pollution. In addition, there is a need for UHI mitigation counseling by a related institution to the society so that the impact of UHI can be reduced.

4. Conclusion

Based on the research that has been done, the following conclusions can be drawn the area affected by the spread of UHI is located in the center of Palembang City with an area of 33.5 km² of the total area of Palembang City in 2018. Temperature changes based on LST processing respectively in 1989, 2001, and 2018 were 26.61°C, 27.71°C, and 27.60°C. Changes in land cover based on guided classification processing from year to year indicate a decrease in the area of water bodies, dense vegetation, and on open land, but an increase in 2001 which then decreased in 2018. In addition, an increase in residential areas with high or low density. This is concurrent with an increase in the population density of Palembang City from year to years such as 3078 people/km² in 1989, 3718 people/km² in 2001, and 4463 people/km² in 2018. There is a trend of warming the LST that increases from year to year which is directly proportional to the increase in population, an increase in the area of open land and built-up land with the coefficient of determination reaching 62.6%, 86.3%, and 55.0%. Conversely, a negative relationship is shown by a decrease in dense vegetation with a coefficient of degradation reaching 90.4%. It is necessary to have ideal city mitigation and arrangement by calculating the green area with the increasing population rate in Palembang City.

References

[1] Badriyah I U 2014 Jurnal Meteorologi dan Geofisika 5 167-176
[2] Fawzi N I 2017 Measuring Urban Heat Island using Remote Sensing, Case of Yogyakarta City, Majalah Ilmiah Globe 19 195-206.
[3] EPA (US Environmental Protection Energy) 2008 Reducing Urban Heat Island: Compendium of Strategies US Environmental Protection Energy: Washington D C
[4] Weng Q, Dengsheng L and Jacquelyn S 2004 Remote Sensing of Environment 89 467-483
[5] Estoque R C, Yuij M and Soe W M 2016 Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia, Science of the Total Environment.
[6] Darlina S P, Bandi S and Bambang D Y 2018 Jurnal Geodesi Undip 3 77-87
[7] Subarna, D., 2010, Monthly Surface Temperature Variability Analysis in Indonesia Continent on One Last Century, Prosiding Seminar Nasional Sains Atmosfer, 142-147.
[8] Ghulam A 2010 Calculating Surface Temperature Using Landsat Thermal Imagery Department of Earth & Atmospheric Sciences and Center for Environmental Sciences
[9] Artis D A and Carnahan W H 1982 Remote Sens. Environ 12 313-329
[10] Rouse J W, Haas R H, Schell J A and Deering D W 1974 Monitoring vegetation systems in the Great Plains with ERTS
[11] Ma Y, Kuang Y dan Huang N 2010 International Journal of Applied Earth Observation and Geoinformation 12 110–118
[12] Haryanto U 1998 Keterkaitan Fase SOI Terhadap Curah Hujan Di DAS Citarum, available at http://repository.ipb.ac.id/bitstream/handle/123456789/401 6/1998
[13] Jatmiko R H 2015 Disertation: Penggunaan Citra Saluran Inframerah Termal Untuk Studi Perubahan Liputan Lahan dan Suhu Sebagai Indikator Perubahan Iklim Perkotaan di Yogyakarta. Yogyakarta: Program Pasca Sarjana, Fakultas Geografi, Universitas Gadjah Mada
[14] Myint S W, Brazel A, Okin G and Buyantuyev A 2010 GISci Remote Sens 47 301–320