Spatial Patterns of Land Surface Temperature in Jakarta and Its Surrounding Areas

A B Raya and H S Hasibuan

1 School of Environmental Science, Universitas Indonesia, Jl. Salemba Raya No.4 Jakarta Pusat 10430

hayati.hasibuan@ui.ac.id

Abstract. Urban growth drastically changes the biophysical environment, including in the form of replacing the soil and natural vegetation with urban material, which causes urban areas to be warmer than the surrounding suburban and rural areas. This phenomenon which is commonly referred to as Urban Heat Island is regrettable because it increases energy consumption for the needs of air conditioners as well as thermally uncomfortable conditions for activities. This study aims to identify the phenomenon of Urban Heat Island in one of the largest metropolitan areas in the world, namely Jakarta, the capital of Indonesia, and the surrounding area. In this study, the UHI phenomenon was identified based on the spatial pattern of surface temperature obtained by processing the Landsat 8 OLI / TIRS remote sensing satellite image data. The results showed that the developed land has a higher temperature than the land with natural cover and land that is overgrown with plants, namely forests and agricultural land. The spatial pattern shows that land surface temperature decreases with increasing distance from the Capital City of Jakarta.

1. Introduction

Continuous urbanization and development without considering the environmental balance causes environmental problems in urban areas, including the issue of urban warming or termed 'Urban Heat Island' (UHI). The term was first introduced by Luke Howard in 1820, which examined that air temperature at night in London is warmer than the surrounding rural areas [1]. It refers to a phenomenon that urban areas experience warmer temperatures than the surrounding rural environment [2]. The UHI is caused by, among other things, low evaporation due to lack of vegetation, high absorption of solar radiation due to low albedo, high anthropogenic heat release, and winds blocked by buildings thereby reducing its ability to provide coolness [3]. In tropical climates, this is unfavourable because it causes more energy consumption to cooling, reduces human thermal comfort, and increases the concentration of air pollution [4]. Various research topics regarding this phenomena can be grouped in changes in surface material and urban ventilation, health and comfort, spatial and temporal variations of UHI, and building energy use [5]. This paper is intended to discuss the spatial variation of UHI by using Jakarta and its surroundings as a case study.

The mentioned phenomenon is categorized into two types: surface UHI and atmospheric UHI [1],[6]. Moreover, the Atmospheric UHI can be distinguished from Urban Canopy Layer Heat Island (UCL) and Urban Boundary Layer Heat Island (UBL). UCL lies between the surface of the...
land/buildings to under the roof of buildings or treetops, while the UBL occupied the roof of buildings or treetops to the atmospheric layer which is no longer influenced by urban landscape [2],[6]. UCL is generally detected in situ through sensors at the meteorological station or on a mobile traverse by installing sensors on the vehicle, while the UBL is observed through a unique sensor platform or a hot air balloon [2]. The surface UHI is generally seen through thermal remote sensing [2].

Remote sensing has long been used as a tool in urban climate research. The initial initiative of its potential to evaluate the surface UHI was carried out by Rao in 1972 [2],[7],[8]. Since then, various studies exploring remote sensing data (satellite, aircraft, ground-based) to observe city surface temperatures that contribute to UHI on various scales [2],[7],[1]. According to Voogt and Oke [2] there are three main categories of remote sensing utilization in assessing city temperatures: (1) evaluate the spatial structure of the city's temperature pattern and its relation to the surface characteristics of the city; (2) applying remote sensing to study energy balance; and (3) the application of remote sensing to study the relationship between the atmospheric and surface UHI.

Surface temperature is an important parameter in the study of the temperature of urban environments [7]. Surface temperature is closely related to the characteristics of land use and land cover [7][8], vegetation and water have the lowest temperatures, while settlements and industrial estates have high temperatures [8]. The study of the relationship between land use and surface temperature in various countries has been carried out by, among others, Aslan dan Koc-San [8], Su et al.[9], Rinner dan Hussain[10], Tursilowati.et.al.[11], Franco et al.[12], and Ali et.al.[13].

The UHI phenomenon also occurs in Metropolitan Jakarta, as shown through studies by Lestari et al. [14] utilizing data from meteorological stations. Besides, several studies are specific to one administrative boundary in this region with various methods. In the scope of the Capital City of Jakarta, research has been done by Tokairin et al. [15] with fixed-point observation method, Maru and Ahmad [16] with the traverse method, and Tursilowati.et.al. [11] and Estoque et. Al [17] that use satellite image data. In the administrative area outside the Capital, a study was conducted by Wibowo and Rustanto [18] in Kota Tangerang, and Nurwanda and Honjo [19] conducted a study in Kota Bogor. Both of them use remote sensing data. In addition to these studies, there are still some relevant research results but those written in Indonesian, including Effendy et.al.[20], Aditya et.al.[21] and Rushayati and Hermawan [22].

Previous studies on UHI in the Jakarta Metropolitan region were mostly still carried out in urban areas based on administrative boundaries whereas the observation of this phenomenon is intended to observe the difference in temperature between urban areas and the surrounding rural areas. The use of remote sensing data to identify UHI in Metropolitan Jakarta as a whole has never even been done. In this study, the identification of spatial variations in land surface temperature in Metropolitan Jakarta will be carried out, as an indication of UHI, using remote sensing data.

2. Study area

The research was conducted in the Jakarta Metropolitan area. This region is located in Java Island, Indonesia. Administratively it is in three provinces, namely the Special Capital Region of Jakarta, West Java Province and Banten Province, and covers 13 District / City Regions. Geographically located between 106° 19' -107° 30' E and 5° 18' -6° 48' S (figure 1). Located at the height of land ranging from 0-700 meters above sea level. This area has three characteristics of landforms, coastal areas in the north, lowlands in the middle, and hills and highlands in the south.

This region is the largest metropolitan in Southeast Asia and one of the largest metropolitan areas in the world. The total population in 2013 reached 26,746 million people. This area is called Jabodetabek, taken from the initial letters of the administrative units of Jakarta, Bogor, Depok, Tangerang, and Bekasi. The Metropolitan core is the Capital City of Jakarta, the inner edge of which covers four cities, namely Tangerang City, Tangerang Selatan City, Depok City, Bekasi City.
3. Data and methods

The data used in this study are Landsat 8 OLI / TIRS satellite data acquired on July 6, 2018. The image was obtained by downloading from the official website of the United States Geological Survey (USGS) Earth Resources and Science Center https://earthexplorer.usgs.gov/. Landsat 8 Satellite has two sensors, namely Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The OLI spectral sensor consists of 9 Spectral Bands (Band 1 to Band 9), while the TIRS Thermal sensor has 2 Bands (Bands 10 and 11). Two image data files are used, Path/Row 122/ and Path/Row 122/65. The Jabodetabek boundary used vector map at scale 1:25,000 issued by the Indonesian Geospatial Information Agency. Landsat satellite images and boundary map using the Universal Transverse Mercator (UTM) WGS 84 Zone 48 S projection coordinate system. In general, the research was conducted in two stages: (1) classification of land cover types using spectral composite bands; and (2) calculation of LST values and UHI effects using thermal bands.

![Study area location map](image)

**Figure 1.** Study area location map

3.1. Land cover classification

Land cover data were obtained from a composite of 3 bands OLI image to obtain natural colour. The bands used are Band 1, Band 2 and Band 3. The land cover classification uses the supervised
classification method that requires dataset training or classifier for each type of land cover. Training datasets were identified based on the appearance of land cover on IKONOS satellite imagery. The sample data used is 150 points. Classification of land cover class refers to class 2 land cover class according to Indonesia National Standard (SNI) 7654: 2010. This standard relates to LCCS-UNFAO and ISO 19144-1 Geographic Information Classification Systems-Part 1: Classification System Structure that has been adapted to Indonesian conditions. The system consists of 5 types of land cover, but in the study area only four types of land cover were identified, namely: (a) agriculture and open space; (b) forests and shrubs; (c) settlements and industries (including airports and ports; and (d) water bodies. Whereas former lava flows and beach sand types of land cover are not explicitly identified.

3.2. Land surface temperature calculation

Land surface temperature (LST) is generally defined as surface skin temperature which refers to soil temperature for land without vegetation (bare soil), canopy surface temperature for dense vegetation and combination of both if the vegetation is tenuous. Extraction of LST carried out from one of Landsat TIRS thermal bands namely Band 10. Band 11 is not used considering the uncertainty of calibration according to USGS recommendations [23]. No image correction was made regarding the influence of clouds and the height of the land.

Calculation of soil surface temperature using Band 10 was carried out in two stages. First, changes spectral values into radians. Second, change the radians' value to the temperature. The formula for calculating and converting the value refers to the LST calculation formula from Landsat 8 TIRS data provided by USGS and has been used among others by Aslan and Koc San [8], Ali et al.[13]. The calculation of radians is based on equation (1):

\[ L_\lambda = M_L Q_{\text{cal}} + A_L \]  

where: \( L_\lambda \) is the top of the Atmosphere (TOA) spectral radiance, \( M_L \) is band-specific multiplicative rescaling factor, \( A_L \) is a band-specific additive rescaling factor, \( Q_{\text{cal}} \) is the pixel value (Digital Number). The values of \( M_L \) and \( A_L \) are contained in the metadata of Landsat 8 imagery. Furthermore, the calculation of the temperature value is done by equation (2):

\[ T_b = K_2 / \ln (K_1 L_\lambda + 1) - 273.15 \]  

where: \( T_b \) is the temperature (°C), \( K_1 \) is the spectral radiance calibration constant, and \( K_2 \) is the absolute temperature calibration constant.

4. Results and discussion

Based on the results of the land cover classification (figure 2), it was identified that the dominant land covering was agricultural land with an area of 340,725 Ha (50.08%), followed by built-up land with an area of 176,353 Ha (25.92%), forest with an area of 137,364 Ha (20,19%) and water bodies with an area of 25,924 ha (3.81%).

The built-up land in the Capital city of Jakarta has reached 69.4% of the total area. In the suburbs of Metropolitan Jakarta, the percentage of built-up area to the administrative area is: (1) Tangerang City at 66.67%; (2) Bekasi City has reached 56.48%; (3) South Tangerang City is 40.37%; and (4) Depok City at 35.22%.
The lowest surface temperature in the study area was 14.2°C and the highest temperature was 44.4°C (figure 3). About 48.77% of the total land area has a temperature lower than 30 °C (table 1).

Figure 2. Land cover classification, 2018

Figure 3. Land surface temperature
In Jakarta and its surrounding cities directly adjacent, the percentage of LST above 30°C reaches more than 95% of its area (table 2). As for Bogor City, the rate of LST above 30°C reaches 79%.

Table 1. Area percentage of LST class

| LST °C | Area (Ha) | % Area | % Cumulative |
|-------|-----------|--------|--------------|
| 14-23 | 23857.83  | 3.51%  | 3.51%        |
| 23-26 | 37011.24  | 5.44%  | 8.95%        |
| 26-28 | 100484.64 | 14.77% | 23.72%       |
| 28-30 | 170485.92 | 25.06% | 48.77%       |
| 30-32 | 147850.56 | 21.73% | 70.50%       |
| 32-34 | 120185.55 | 17.66% | 88.17%       |
| 34-45 | 80492.13  | 11.83% | 100.00%      |
| 680367.87 |        |        |              |

In Jakarta and its surrounding cities directly adjacent, the percentage of LST above 30°C reaches more than 95% of its area (table 2). As for Bogor City, the rate of LST above 30°C reaches 79%.

Table 2. Percentage of the area in each class of LST in Jakarta and surrounding cities

| LST °C | Jakarta | Tangerang Ct. | Bekasi Ct. | Depok Ct. | Bogor Ct. | Tangsel Ct. |
|-------|---------|---------------|------------|-----------|-----------|-------------|
| 14-23 | 0.01%   | 0.00%         | 0.00%      | 0.00%     | 0.00%     | 0.00%       |
| 23-26 | 0.02%   | 0.01%         | 0.02%      | 0.00%     | 0.00%     | 0.01%       |
| 26-28 | 0.40%   | 0.14%         | 0.12%      | 0.03%     | 2.40%     | 0.01%       |
| 28-30 | 2.65%   | 3.51%         | 1.07%      | 4.64%     | 18.75%    | 2.70%       |
| 30-32 | 8.81%   | 16.35%        | 10.26%     | 26.07%    | 32.46%    | 17.48%      |
| 32-34 | 35.36%  | 38.40%        | 39.60%     | 41.93%    | 37.49%    | 49.15%      |
| 34-45 | 52.75%  | 41.59%        | 48.94%     | 27.32%    | 8.90%     | 30.65%      |

4.1. Relationship of land cover with surface temperature

The results of cross-tabulation between land cover types and LST (table 3) show that 98.4% of forest type land cover has LST less than 30°C, on the contrary, 64.70% of built-up land has LST values higher than 30°C. 95.8% of agricultural land has a temperature range between 26-34°C, and only 2.97% has a temperature higher than 34 °C. This shows that built-up type of land cover has a higher temperature than the natural and vegetation types of land cover such as forests and agriculture / open space. Thus confirms the findings of previous studies, including Weng [7], Aslan and Koc San [8].

Table 3. Cross-tabulation of Land Cover with LST

| LST °C | Forest     | Agriculture & Open Space | Water Bodies | Built-up area |
|-------|------------|--------------------------|-------------|--------------|
| 14-23 | 22.04%     | 0.00%                    | 0.00%       | 0.10%        |
| 23-26 | 27.84%     | 1.21%                    | 0.36%       | 0.93%        |
| 26-28 | 35.96%     | 17.79%                   | 75.37%      | 26.27%       |
| 28-30 | 12.56%     | 37.60%                   | 9.20%       | 8.00%        |
| 30-32 | 1.55%      | 27.80%                   | 4.14%       | 13.91%       |
| 32-34 | 0.04%      | 12.61%                   | 6.93%       | 24.71%       |
| 34-45 | 0.00%      | 2.97%                    | 4.00%       | 26.08%       |

4.2. Spatial pattern of land surface temperature

Transects were carried out from the Capital City of Jakarta to the East, South, and West to determine the spatial pattern of LST. Transect lines are chosen around the main transportation routes that connect Jakarta with the surrounding area, which is also an urban corridor dominated by built-up land. The results of the transect to the East (Bekasi) and South (Bogor) consistently indicate a pattern of decreasing LST values for each increase in distance from Jakarta. The results of the transect to the
West (Tangerang) indicate that a distance of 10-20 Km from Jakarta tends to increase the LST, but after a distance of 20 Km gradually returns a decrease in LST (figure 4).

5. Conclusion

The capital city of Jakarta and the suburbs in Metropolitan Jakarta (Bekasi City, Tangerang City, South Tangerang City, and Depok City) is dominated by a built-up type of land cover. In this area, 95% of the area has a surface temperature above 30°C. Spatially, the land surface temperature of metropolitan area of Jakarta decreases with the distance increases from the City of Jakarta.

Acknowledgments

This research is funded by thesis publication grants from Universitas Indonesia.

References

[1] Parlow E, Vogt R & Feigenwinter C 2014 The Urban Heat Island of Basel – seen from different perspective *J. of the Geographical Society of Berlin, Die Erde* 145 (1-2) pp 96-110

[2] Voogt J A & Oke T R 2003 Thermal Remote Sensing of Urban Climates *Remote Sensing of Environment* 86 pp 370-384

[3] Nuruzzaman M 2015 Urban Heat Island: Causes, Effects and Mitigation Measures - A Review *Int. J. of Environ. Monitoring & Analysis* 3 (2) pp 67-73

[4] Voogt J A 2002 Urban Heat Island In: Munn T Ed *Encyclopedia of Global Environmental Change* Wiley Chichester 3 pp 660-666

[5] Mirzaei P A 2015 Recent challenges in modeling of urban heat island *Sustainable Cities and Society* 19 pp 200–206

[6] Bhargava A, Lakmini S & Bhargava S 2017 Urban Heat Island Effect: It’s Relevance in Urban
Weng Q 2009 Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trend *ISPRS J. Photogrammetry Remote Sens.* 64(4) pp 335-344

Aslan N, Koc-San D 2016 Analysis of Relationship Between Urban Heat Island Effect and Land Use/Cover Type Using Landsat 7 ETM+ and Landsat 8 OLI Images *ISPRS - International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences* XLI-B8 pp 821-828

Su W, Gu C & Yang G 2010 Assessing the Impact of Land Use/Land Cover on Urban Heat Island Pattern in Nanjing City China *J. of Urban Planning & Development - ASCE* 136(44)

Rinner C & Hussain M 2011 Toronto’s Urban Heat Island—Exploring the Relationship between Land Use and Surface Temperature. Remote Sens 3 1251-1265

Tursilowati L, Sumantyo J T S, Kuze H & Adiningsih E S 2012 Relationship between Urban Heat Island Phenomenon and Land Use/Land Cover Changes in Jakarta – Indonesia *J. of Emerging Trends in Engng & Appl. Sci.* 3(4) pp 645-653

Franco S, Mandla V R., Rao K R M., Kumar M P & Anand P C 2015 Study of Temperature Profile on Various Land Use and Land Cover For Emerging Heat Island *J. of Urban & Environ. Enng*, 9(1) pp 32-37

Ali S B, Patnaik S & Maguni O 2017 Microclimate Land Surface Temperatures Across Urban Land Use/Land Cover Forms *Global J. Environ. Sci. Manage.* 3(3) 231-242

Lestari S, Moersidik S S & Syamsudin S 2015 Study on Heat Island Effect Induced by Land Use Change Increased Temperature in Metropolitan Jakarta *J. Math. Fund. Sci.* 47(2) pp 126-142

Tokairin T, Sofyan A & Kitada T 2010 Effect of land use changes on local meteorological conditions in Jakarta Indonesia: toward the evaluation of the thermal environment of megacities in Asia *Int. J. of Climatol* 30 pp 1931–1941

Maru R & Ahmad S 2014 Daytime Temperature Trend Analysis in the City of Jakarta Indonesia *World Appl Sci. J.* 32 (9) pp 1808-1813

Estoque R., Murayama Y & Myint S 2016 Effects of Landscape Composition and Pattern on Land Surface Temperature: An Urban Heat Island Study in the Megacities of Southeast Asia *Sci. of The Total Environ.* 577 pp 349-359

Wibowo A & Rustanto A 2013 Spatial - Temporal Analysis of Urban heatIsland in Tangerang City *Indonesian J. of Geography* 45(2) pp 101 – 115

Nurwanda A & Honjo T 2018 Analysis of Land Use Change and Expansion of Surface Urban Heat Island in Bogor City by Remote Sensing *Int. J. Geo-Inf.* 7(165)

Effendy S, Bey A, Zain A F M & Santosa I 2006 The Role of Urban Green Space in Harnessing Air Temperature and Urban Heat Island Exemplified By Jabotabek Area *J. Agromet Indonesia* 20(1) pp 23–33

Aditya H, Lestari S, & Lestiana H 2012 Studi Pulau Panas Perkotaan dan Kaitannya dengan Perubahan Parameter Iklim Suhu dan Curah Hujan Menggunakan Citra Satelit Landsat TM Studi Kasus DKI Jakarta dan Sekitarannya Jurnal Sains & Teknologi Modifikasi Cuaca 13(1) pp 19-24

Rushayati S B & Hermawan R 2013 Characteristics of Urban Heat Island Condition in DKI Jakarta *Media Konservasi* 18(2) pp 96–100

Avdan U & Jovanovska G 2016 Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data *Journal of Sensors*