Identification of the impact of vegetation cover changes and the development of urban areas on Urban Heat Island using GIS and remote sensing: A case studies of Sleman regency, Province of Yogyakarta

B E B Dewantoro1,*, M A Khafid2, A D A Putra2, A P Wicaksono2 and F W Andita3

1 Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia
2 Department of Environmental Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta, DI. Yogyakarta, Indonesia
3 Department of Chemical Engineering, Faculty of Industrial Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta, DI Yogyakarta, Indonesia

*bayuelwantyo@mail.ugm.ac.id

Abstract. The phenomenon of urban area development both physically and socially as the center of government in Sleman can indirectly cause an impact on the atmosphere. One of the impacts of the atmospheric change, the urban heat island, which is influenced by the physical and social development activities, is expanding. The research focuses on the study of surface urban heat island (SUHI) aimed at knowing the spatial distribution of the UHI intensity in Sleman Regency. The methods used in this research are the integration of remote sensing techniques and geographic information systems (GIS) using thermal bands of Landsat 8 OLI/TIRS and image statistical analysis using Buffer Boundary Analysis to identify the potential occurrence of UHI in Sleman. The result of the processing shows the potential of high-intensity urban heat island in Depok subdistrict, Ngemplak subdistrict, Kalasan subdistrict, and part of Mlati subdistrict with the varying intensity of UHI. The highest UHI intensity is around the district of Depok and Mlati with an intensity of 2,001 – 6,000 °c during the period from 2014 to 2019.

1. Introduction
The dynamics of surface temperature constantly changing rapidly raises some of the problems against urban areas primarily related to hydro meteorological disasters impacts of climate change [1]. The physical and social development that took place in Sleman Regency as one of the areas supporting economic and educational activities in Yogyakarta province positively impacts economically and socially, but indirectly it raises Influence on the stability of urban microclimate conditions, particularly in urban heat island phenomena. Urban heat island that occurs in urban areas is caused by increasingly dense settlements, the more varied city transportation facilities that impact on the increased emissivity of the surface of urban areas. Increased surface emissivity in urban areas by motor vehicles causes urban areas to absorb more thermal energy than areas to increase the surface temperature in urban areas [2]. Sleman Regency is a district as the center of education and economics in Yogyakarta province. This
makes Sleman district with the population displacement or the largest transmigration in the province of Yogyakarta, especially from students from all over Indonesia who make the intensity of land change and transportation activities very high. Transportation activities produce gas emissions including hydrocarbons (HC), carbon dioxide (CO\textsubscript{2}), lead (PB) and Nitrogen (NO) which causes the atmospheric composition to change and increasingly thickened [3]. The change of land cover from meeting vegetation to buildings or buildings with low albedo can cause the Earth's surface temperature to become warmer. Remote sensing utilization for the study of urban heat island phenomena needs to be maximized given the ability to extract land surface temperature data (LST) in a short time and wide coverage [4]. The research seeks to integrate techniques and methods that have been widely used in urban heat island analysis by promoting the main focus of spatial distribution of urban heat island that occurs so that it is not only the visualization of temperature Surface (LST) course that is associated with urban heat island, but also a measurement through a series of extraction formulas. The results of the research are expected to be used by the local government of Sleman Regency as planning for regional and development for social and physical development that does not exacerbate the impacts of climate change and pay attention to aspects environment.

### 2. Methods

#### 2.1. Radiometric correction

The radiometric correction is done due to the interaction of electromagnetic waves with the atmosphere, causing the spectral reflectance of objects recorded by the sensor to be not optimal [5]. The radiometric using the following formula [6]:

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

where: \( L\lambda \) is TOA spectral radiance (Watts/( m\textsuperscript{2} * srad * μm)), \( M_L \) is Band-specific multiplicative rescaling factor, \( A_L \) is band-specific additive rescaling and \( Q_{cal} \) as a quantized and calibrated standard product pixel values (DN) is used to convert pixel value to spectral radiance at the Top of Atmosphere (TOA) level.

\[ \rho\lambda = M_\rho Q_{cal} + A_\rho \]  

Where \( \rho_\lambda \) is a TOA planetary reflectance, \( M_\rho \) band-specific multiplicative rescaling factor from the metadata, \( A_\rho \) band-specific additive rescaling factor from the metadata and \( Q_{cal} \) is a quantized and calibrated standard product pixel values (DN).

#### 2.2. Geometric correction

The image geometric correction is required to ensure the position of objects on the surface of the earth is in the actual position [5]. It takes a point of the form of Ground Control Point (GCP) either as a result of the primary measurement of geodetic GPS and maps of RBI used < 25 meters [7,8].

#### 2.3. Surface emissivity correction

Surface emissivity is needed to estimate the surface temperature with more precision and accuracy. According to Zha et al., [9] as follows:

\[ \varepsilon = 0.985P_V + 0.960(1 - P_V) + 0.06P_V(1 - P_V) \]  

#### 2.4. Converting spectral reflectance TOA to Land Surface Temperature (LST)

The formula used to convert spectral reflectance TOA value to land surface temperature (LST) utilizes a formula published by USGS (2015) as follows:

\[ T = \frac{K_2}{\ln(\frac{K_1}{L_{T,\lambda}}) + 1} \]
Equations (4) are used to convert spectral reflectance TOA values to brightness temperatures in Kelvin (K) units with the following formula:

\[ T_{\text{celcius}} = T - 273.15 \]  

(5)

2.5. Built-up area extraction techniques based on spectral transformation

Detection of built-up areas using Normalized Difference Built-up Index (NDBI) with the following formula [10]:

\[ \text{NDBI} = \frac{\text{SWIRBand} - \text{NIRBand}}{\text{SWIRBand} + \text{NIRBand}} \]  

(6)

Extraction dynamics of vegetation approached using a Normalized Difference Vegetation Index with the following formula [11]:

\[ \text{NDVI} = \frac{\text{NIRBand} - \text{RedBand}}{\text{NIRBand} + \text{RedBand}} \]  

(7)

Spectral confusion often occurs in a moist soil response to the central infrared wave, so as to suppress the spectral effect confusion used Modified Normalized Difference Water Index (MNDWI) which has the ability to detect against water on the surface with the following formula [12]:

\[ \text{MNDWI} = \frac{\text{GreenBand} - \text{SWIR2Band}}{\text{GreenBand} + \text{SWIR2Band}} \]  

(8)

The built-up extraction area uses a combination of NDBI, NDVI, and MNDWI to produce a sharper and easier built-up area feature to interpreted in the following formulas [13]:

\[ \text{BUAI} = \text{NDBI} - \text{NDVI} - \text{MNDWI} \]  

(9)

2.6. Statistical analytics using correlation and regression method

Statistical calculations on samples were conducted using correlation and regression analyses to identify influences between predictor variables (NDVI and BUAI) [14].

\[ \text{Cov}(i, j) = \frac{(Z_{ik} - \mu_i) - (Z_{jk} - \mu_j)}{N - 1} \]  

(10)

\[ \text{Corr}(i, j) = \frac{\text{Cov}(i, j)}{\sigma_i \sigma_j} \]  

(11)

Data correlation quality is tested using r test, while data significance is tested using T test, where data is rated significantly when T-count > T-table [15].

3. Results and discussion

3.1. Spatial distribution of NDVI and built-up area

The spatial distribution of NDVI values and built-up area as a parameter determining urban heat island phenomenon can be seen in Figure 1. The NDVI value is utilized as an approach to the extraction of vegetation objects, where the formula used in NDVI relates to vegetation density [16,17]. The NDVI classification is divided into 4 classes to facilitate and simplify the analysis process. The value of NDVI with a range of 0.401 – 1.000 dominates the study area in the period 2014 to 2019 with the estimate of percentage reached > 91% and the largest change reached 4.27%. The spatial distribution patterns on the NDVI values are relatively spread out across the entire study area at a value range of 0.401 – 1.000, while the < 4 NDVI values tend to be group-wide in urban areas [11]. The built-up area seen in Figure 1 shows a distribution pattern that is group with developments leading to the northeast and northwest.
The area of the built-up woke up in Sleman Regency is estimated at 31.01% of the total area of Sleman Regency in 2019 or around 17826.3 Ha.

Figure 1. Spatial distribution of NDVI (a) and built-up area (b) in Sleman regency.

3.2. Measure urban heat island effect in Sleman regency
The development of urban areas in Sleman Regency could potentially result in the phenomenon of urban micro climate phenomena called urban heat island (UHI) because the built-up material tends to absorb heat and radiate heat energy it thus increases the temperature in urban areas [18-20]. Based on data processing on land surface temperature, urban heat island effect occurred in Depok subdistrict, Ngemplak subdistrict, Kalasan subdistrict, and part of Mlati subdistrict with the varying intensity of UHI (see Figure 2). The highest UHI intensity is around the district of Depok and Mlati with an intensity of 2,001 – 6,000 °c during the period from 2014 to 2019. This is because the subdistrict has a higher building density than other subdistricts in Sleman Regency which resulted in increasing emissivity of surface and land surface temperature to enlarge the potential [21]. The lowest UHI effect is distributed in the Pakem subdistrict, Turi subdistrict, Cangkringan subdistrict, Tempel subdistrict and Sleman subdistrict with the intensity of the effect of UHI-10,000 – 0.001 °c, while other subdistricts experience the effect of UHI with intensity 0.001 – 4,000 °c. The dynamics of motor vehicles every year continue to increase resulting in the amount of gas in the atmospheric layer increases. It is also influenced by the level of migration that is at the intensity of Mlati, Depok, Ngemplak and Kalasan which is quite high at 1296, 1813, 908 and 1173 inhabitants. Measurement of air quality is carried out with three sampling located in the settlement, roadside, and industrial areas parameters CO, SO₂, NO₂, TSP, O₃ and PM10 showed the highest concentrations of 23.098, 11.828, 232.588, 162.984, 252.366, 0.769, and 98.68 μg/Nm³.
3.3. Statistical analysis of LST, NDVI, and built-up area

Statistical analysis is also performed to help identify predictor variable relationships (NDVI and BUAI) against the response variables (LST) (see Table 1 and 2). Based on a statistical test conducted on 141 samples, LST has a strong positive relationship with the built-up area that was approached with the Built-up Area Index (BUAI) with the highest correlation coefficient (r) of 0.739 and coefficient of determination (r²) of 0.544 or 54.4%. Based on the correlation coefficient, the built-up area can be used as the main parameter in LST study because it has strong relationship and positive direction. Increased built-up area density was able to influence the LST increase by 54.4%, while the remaining 45.6% was affected by other variables.

**Table 1.** Statistical test summary between LST and BUAI with 95% confidence level.

| Year | Samples | r²   | r-stat | t-stat | t-table | r-table | Sig-F | Direction | Correlation Strength | Description       |
|------|---------|------|--------|--------|---------|---------|-------|-----------|---------------------|-------------------|
| 2014 |         | 0.401| 0.636  | 9.69   | 1.977   | 0.176   | 3E-17 | Positive  | Strong              | Significance       |
| 2015 |         | 0.544| 0.739  | 12.9   |         |         |       | Positive  | Strong              | Significance       |
| 2016 |         | 0.357| 0.602  | 8.846  |         |         |       | Positive  | Strong              | Significance       |
| 2017 | 141     | 0.504| 0.712  | 11.92  | 1.977   | 0.176   |       | Positive  | Strong              | Significance       |
| 2018 |         | 0.42 | 0.648  | 9.998  |         |         |       | Positive  | Strong              | Significance       |
| 2019 |         | 0.459| 0.68   | 10.9   |         |         | 2E-20 | Positive  | Strong              | Significance       |
The statistical test is also conducted on the dynamic vegetation that is approached using NDVI values against the LST. Different results are found in this statistical test, where the value of NDVI tends to be negatively related to the LST. The correlation coefficient (r) is obtained by 0.508 with a coefficient of determination (r²) of 0.253 or about 25.3%. Based on these results, the NDVI values can be used in LST studies, but the relationship is not as strong as BUAI. The direction of the negative relationship and the coefficient of determination gained on the statistical test results show that the vegetation in general can affect the LST decline by 25.3%.

4. Conclusion
Spatial distribution of intensity of urban heat island (UHI) effect occurs in the center of the urban area of Sleman Regency with an intensity range of 2,001 – 6,000 °C. Administratively, the effect of UHI occurs in the Depok subdistrict, Ngemplak subdistrict, Kalasan subdistrict, and part of Mlati subdistrict due to physical development and massive building density. The lowest UHI effect is distributed in the Pakem subdistrict, Turi subdistrict, Cangkringan subdistrict, Tempel subdistrict and Sleman subdistrict with the intensity of the effect of UHI-10,000 – 0.001 °C, while other subdistricts experience the effect of UHI with intensity 0.001 – 4,000 °C.

Acknowledgment
This research was supported by Department of Environmental Faculty of Mineral Technology, Universitas Pembangunan Nasional “Veteran” Yogyakarta and Gadjah Mada University.

References
[1] Khafid M A 2019 Jurnal Meteorologi Klimatologi Dan Geofisika 6(1) 49-57
[2] Khafid M A 2019 IOP Conf. Ser.: Earth Environ. Sci. 399 012096
[3] Khafid M A, Aditya P W and Bayu E B D 2020 International Journal of Innovative Technology and Exploring Engineering (IJITEE) 9(3S) 177–181
[4] Ramanathan V, Lian M S and Cess R D 1979 J. Geophysical Research 84(C8) 4949 –4958
[5] Danoedoro P 2012 Pengantar Penginderaan Jauh Digital (Yogyakarta: Andi) p 89
[6] USGS 2015 Landsat Missions: Using the Landsat Level-I Data Product [online] retrieved from https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product
[7] Badan Informasi Geospasial 2016 Peraturan Kepala Badan Informasi Geospasial No. 6 Tahun 2018 [online] retrieved from https://jdih.big.go.id/hukumjdih/4477
[8] Fawzi N I 2014 Majalah Ilmiah Globe 16(2) 133-139
[9] Zha Y J and Gao S N 2003 International Journal of Remote Sensing 24(3) 583-594
[10] Shiyong Y, Ke S and Yi L 2019 Front. Earth Sci
[11] Xu H 2005 Journal of Remote Sensing 9(5) 511-517
[12] Bhatti S S and Nitin K T 2001 GIScience & Remote Sensing 51(4) 445–467
[13] Sarwono J 2006 Metode Penelitian Kuantitatif dan Kualitatif (Yogyakarta: Graha Ilmu) p 165
[14] Sugiyono 2008 Metode Penelitian Bisnis (Bandung: CV Alfabeta Press) p 124
[15] Tan K C, Lim H S, Jafari M Z M and Abdullah K 2009 Proc. of Sixth International Conference on Computer Graphics, Imaging and Visualization
[16] Tan J, Zheng Y, Tang X, Guo C, Li L, Song, G, Zhen X, Yuan D, Kakstein A J and Li F 2010
International Journal of Biometeorology 54 75-84

[17] Syuhada A S 2010 Kajian Tingkat Kemampuan Penyerapan Panas Matahari pada Atap Bangunan Seng Berwarna Prosiding pada Seminar Nasional Tahunan Teknik Mesin IX, Palembang, 2010

[18] Feizizadeh B and Blaschke T 2013 J. Selected Topics in Applied Earth Observations and Remote Sensing 6 1749-1756

[19] Mallick J, Rahman A and Singh C K 2013 Advances in Space Research 52 639-655

[20] Coseo P and Larsen, L 2014 Landscape and Urban Planning 125 117-129

[21] Debbage N and Shepherd J M 2015 The Urban Heat Island Effect And City Contiguity Computers, Environment and Urban System 54 181-194