Correlation Analysis of Urban Development and Land Surface Temperature Using Google Earth Engine in Sleman Regency, Indonesia

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Abstract. The development of urban areas in Sleman Regency occurs continuously along with an increase in population, encourages changes in any kind of land cover to be built-up area to meet the needs of citizen housing. The objectives of this study were to analyse changes in land cover and its correlation with Land Surface Temperature (LST) and to determine the direction of regional development that occurs in Sleman Regency. The methods used in this research were multispatio-temporal data analysis that contained spectral transformations and supervised classification of Maximum Likelihood on Google Earth Engine, statistical analysis of Landsat 8 OLI/TIRS imagery from 2014 to 2019, and accuracy assessments to determine the accuracy of the results. The results showed there were the increase in built-up area by 1713.374 ha from 2014 to 2019 and supported by the increase in population density of 2038 inhabitants/km2. There was an increase in LST in the converted areas from 2014 to 2019 with an estimated increase of 2.73°C. The distribution of built-up area that indicated as the direction of urban area development has a tendency to head north and northeast of Sleman regency, such as to Ngemplak sub-district, Kalasan sub-district, and Berbah sub-district. The correlation between building density and LST showed the correlation coefficient of 0.61 which was considered as a strong correlation and the determination coefficient of 0.38 also regarded as significant, based on the t-Test. The accuracy assessment was done on the land cover map, generating the overall accuracy of 88.42%.

Keywords: urban development, building density, land surface temperature

1. Introduction

The phenomenon of land conversion is now very massive, both on local-scale and regional-scale. Land conversion carried out due to the increasing demands for housing needs driven by increasing population and increasing population density. The rapid and massive development of urban areas theoretically influences environmental quality parameters which include air quality, surface humidity, vehicle and industrial exhaust emissions, as well as land surface temperature dynamics. Land surface temperature conditions are continuously increasing due to the increase in the amount of vehicle, industrial exhaust emissions, and land cover changes [1]. They also affect the climatic conditions especially the microclimate such as causing urban heat island [2].

Detection and estimation related to the urban area development is important to monitor the resulting impacts, especially the environmental impacts of the development. Monitoring the direction
of urban development is also important to prepare good and sustainable development plans. The spatio-temporal aspect is very useful and can be maximized for urban studies including the urban microclimate by using remote sensing and geographic information system [3].

2. Materials and Method

2.1 Location Area
Sleman Regency is one of the regencies in the Special Region of Yogyakarta Province that is located between coordinates 110° 33′ 00″ to 110° 13′ 00″ Eastern Longitude and 7° 34′ 51″ to 7° 47′ 30″ Southern Latitude [4]. Sleman Regency located between 100-2500 meters above the sea level [4]. Sleman regency has a total area of 57.482 ha which is divided into 17 sub-districts with a population of more than a million inhabitants [4]. This regency has a tropical climate with an average temperature of 26.74°C and average rainfall of 11.91 mm/day [5].

2.2 Retrieval Data Source
The extraction of Land Surface Temperature (LST) and built-up area data was performed using Landsat 8 OLI/TIRS imagery from USGS. The images used were from 2014 until 2019, with cloud cover conditions, data availability, spectral resolution, and spatial resolution as the acquisition parameters. Landsat 8 was considered ideal for use in city-scale and easily accessible. Band 10 was used for the extraction of Land Surface Temperature data after resampling was applied from a spatial resolution of 100m to 30m. Band 10 and band 11 of the Thermal Infrared Sensor (TIRS) were combined with the bands of the Operational Land Imager (OLI) for cloud masking. Detailed information about the Landsat 8 OLI/TIRS is shown in (Table 1). Built-up area data was obtained from the combination of several index transformations particularly Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), and Normalized Difference Built-Up Index (NDBI). Sleman population density data from 2014 to 2018 were obtained from Statistics of Sleman Regency data, while the building density data were obtained from field activities. The building density data was used for correlation analysis between building density and LST in Sleman Regency.

Table 1. Specification of Landsat 8 OLI/TIRS Imagery.

| Sensing Time | Spectral Band | Spatial Resolution | Acquisition Parameters | Source |
|--------------|---------------|--------------------|------------------------|--------|
| 05 May 2014  | Band 1 – Coastal aerosol | 30 m | AOI, (Minimum Cloud Cover < 5%) | USGS |
| 14 July 2015 | Band 2 – Blue | 30 m | | |
| 13 May 2016  | Band 3 – Green | 30 m | | |
| 01 June 2017 | Band 4 – Red | 30 m | | |
| 04 June 2018 | Band 5 – NIR | 30 m | | |
| 07 June 2019 | Band 6 – SWIR 1 | 30 m | | |
|              | Band 7 – SWIR 2 | 30 m | | |
|              | Band 8 – Panchromatic | 15 m | | |
|              | Band 9 – Cirrus | 30 m | | |
|              | Band 10 – Thermal | 100 (30) m | | |
|              | Band 11 – Thermal | 100 m | | |

2.3 Techniques for Obtaining and Analyzing LST, NDVI, MNDWI, NDBI and Land Cover Map
Analysis of land cover changes especially into the type of built-up area and its relation with LST is important to do. This is related to urban microclimate phenomenon such as urban heat island
2.3.1 Land Surface Temperature Extraction. The Digital Number was converted to Top of Atmosphere (ToA) Radiance [7] with the equation formula:

\[ L_{\lambda} = ML \times Q_{cal} + AL \]  

(1)

Where \( L_{\lambda} \) = ToA spectral radiance, \( ML \) = band-specific multiplicative rescaling factor from the metadata, \( Q_{cal} \) = quantized and calibrated standard product pixel values (DN), and \( AL \) = band-specific additive rescaling factor from the metadata.

ToA Radiance was converted to kinetic temperature (LST) in Kelvin with the equation formula:

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

(2)

Where \( T \) = Top of Atmosphere brightness temperature (in Kelvin), \( L_{\lambda} \) = ToA spectral radiance, \( K1 \) = band-specific thermal conversion constant from the metadata, and \( K2 \) = band-specific thermal conversion constant from the metadata.

Conversion of kinetic temperature in Kelvin to Celsius with the equation formula:

\( (T \text{ kinetic Celsius} = T - 273.15) \)  

(3)

Where \( T \) = kinetic temperature (in Kelvin) and \( T \text{ kinetic Celsius} \) = kinetic temperature (in Celsius).

2.3.2 Spectral Transformation of Landsat 8 OLI/TIRS Imagery. The vegetation density value was determined by Normalized Difference Vegetation Index (NDVI) with its formula [8]:

\[ NDVI = \frac{\text{dBand}}{\text{dBand} + \text{Re dBand}} \]  

(4)

Reduction of soil moisture effects was done by utilizing Modified Normalized Difference Water Index (MNDWI) with its formula[9]:

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

(5)

Built-up area detection was done by utilizing Normalized Difference Built-Up Index (NDBI) with its formula[10]:

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

(6)

Built-up area (BUA) extraction was done by using a combination of NDBI, NDVI, and MNDWI [11]:

\[ BUA = NDBI - NDVI - MNDWI \]  

(7)

2.3.3 Land Cover Classification. Land cover map was made using supervised Maximum Likelihood classification on Landsat 8 OLI/TIRS imagery recorded in 2019 with consideration that the supervised classification method is most ideal classification method and is suitable for various applications[12].

2.3.4 Correlation Analysis. Calculation of LST and built-up area density correlation values refers to the following formula [13].

\[ Corr(r) = \frac{n \sum XY - (\sum X)(\sum Y)}{\sqrt{n \sum X^2 - (\sum X)^2} \sqrt{n \sum Y^2 - (\sum Y)^2}} \]
Where $\text{Corr}(r) = \text{Pearson Correlation Coefficient}$, $n = \text{number of data pairs}$, $\sum XY = \text{sum of products of the paired variables}$, $\sum X = \text{sum of the x values}$, $\sum Y = \text{sum of the y values}$, $\sum X^2 = \text{sum of the squared x values}$, $\sum Y^2 = \text{sum of the squared y values}$. Data significance test was performed using T-Test method. Data is considered as significant when $t_{\text{Stat}} > t_{\text{Table}}$ [13] and/or significance $F < \text{confidence level}$. The $t_{\text{Table}}$ was obtained from the $t_{\text{Table}}$ by considering the level of significance used.

3. Results and discussion

3.1. Land Cover Change, Land Surface Temperature, and Built-up Area Dynamics

Spatial distribution of land cover in Sleman Regency can be seen in (Figure 1). Land cover in the map was classified into four type of land cover: vegetation, built-up, bare soil, and water body. Most of the built-up areas were located in the southern part of Sleman Regency, with a relatively higher population density than other regions.

![Land Cover Map of Sleman Regency 2019](image)

**Figure 1.** Land cover map of Sleman Regency 2019.

The highest population density in Sleman Regency was in Depok sub-district, followed by Mlati sub-district and Gamping sub-district because there are many education institutions in the form of universities, academies, and high schools in those area. The high population density was dominated by students. Based on population density data from Statistics of Sleman Regency 2013 to 2019, there was an increase in population density of 2038 inhabitants/km$^2$ in Sleman.

![Population Density of Sleman Regency](image)

**Figure 2.** Population density graph of Sleman Regency.
Spatial distribution of LST showed patterns that tend to increase in each district (Figure 3 and Figure 4). The high temperature variations were in the southern and southeastern regions of Sleman Regency, where those areas were dense built-up area that were still undergoing development. Therefore, in accordance with [14] that explained that built-up area has a higher emissivity which has the potential to increase the surface temperature, the wider and denser the built-up area, the higher surface temperature might be higher.

Theoretically, the lowest surface temperature should occur in 2014 and the highest temperature in 2019, but this did not happen in Sleman Regency. This was influenced by rainfall conditions, surface humidity conditions, aerosol content, and cloud cover, since the parameters that affect surface temperature are not only land cover alone. However, an interesting thing can be seen in (Figure 2) that relatively high surface temperature was consistently agglomerated in the southern part of Sleman Regency with a built-up land composition of more than 6000 ha.

Spatial distribution of LST and built-up area can be seen in (Figure 3). The growing built-up area that was indicated as the urban area development in Sleman Regency is heading to north and northeast. Based on (Figure 3), built-up area was detected reddish with clustered distribution in the southern part of Sleman Regency. Detection of built-up area was based on [11] which stated that built-up area is detected at DN value of higher than -0.20, while the rest is another land cover.

Integration of remote sensing data with statistical data showed that during the period of 2014 to 2019 the development of urban areas headed north and northeast instead of south because the southern part of Sleman Regency is directly adjacent to the center of Yogyakarta City, which is already very dense. The development of urban areas towards those directions was the results of the development of shopping centers and services that were spread in Ngemplak Sub-District, Ngaglik Sub-District, Prambanan Sub-District, Berbah Sub-District, Gamping Sub-District, and Depok Sub-District.

![Figure 3. Spatio-temporal distribution of LST and Built-up Area in Sleman Regency](image)

| Table 2. Data of minimum, maximum, average and standard deviation values for each LST and Built-up Area Extraction |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Years | Min | Max | Average | St.Dev | Min | Max | Average | St.Dev |
|-------|-----|-----|---------|--------|-----|-----|---------|--------|
| 2014  | 14.4| 32.42| 24.29   | 2.06   | -1.37| 0.65| -0.23   | 0.32   |
| 2015  | 15.04| 31.63| 24.87   | 1.73   | -1.32| 0.60| -0.24   | 0.35   |
| 2016  | 14.01| 28.13| 21.91   | 1.76   | -1.40| 0.51| -0.35   | 0.36   |
| 2017  | 14.63| 29.17| 23.21   | 1.47   | -1.34| 0.68| -0.24   | 0.37   |
| 2018  | 15.37| 30.72| 23.62   | 1.58   | -1.34| 0.68| -0.20   | 0.35   |
| 2019  | 15.74| 31.85| 24.64   | 1.88   | -1.39| 0.65| -0.19   | 0.36   |
Figure 4. Various dynamics of LST and Built-up Area in Sleman Regency.

The lowest surface temperature occurred in 2016 with an average surface temperature of 21.91°C covering 38891.07 ha or 67.21% of total area of Sleman Regency. The highest temperature occurred in 2015 with an average surface temperature of 24.87°C covering 46976.57 ha or 81.18% of total area of Sleman. The dynamics of built-up area from 2014 to 2019 increased (Figure 4). The increase in 2014 to 2017 was not significant. There was a drastic increase in built-up area from 2017 to 2018 by 1240.68 ha.

3.2. Correlation and Accuracy Assessment

3.2.1. Correlation between LST, NDVI, MNDWI, and NDBI.

Utilization of NDVI, MNDWI, and NDBI indices based on the sensitivity of each index to objects on the surface of the earth. Built-up area detection has used the MNDWI index to reduce the effect of surface humidity so that the built up area detected more clearly detected. Correlation value of MNDWI and NDBI was -1 so that the contrast of built-up area compared to other objects can be improved. Detailed correlation values and the R-Test can be seen in (Table 3 and 4). The NDVI index was used to provide more contrast in vegetation cover and open-land cover classes, so it was hoped that the combination of NDVI and NDBI would be able to provide a better built-up area detection results.

| Table 3. The Correlation between LST, NDVI, MNDWI, and NDBI. |
|------------------|------------------|------------------|------------------|
|                  | LST              | NDVI             | MNDWI            | NDBI             |
| LST              | 1                | -0.55811         | -0.782           | 0.782003         |
| NDVI             | -0.55811         | 1                | 0.84868          | -1               |
| MNDWI            | -0.782           | 0.84868          | 1                |                  |
| NDBI             | 0.782003         | -0.84868         | -1               | 1                |

| Table 4. R – Test Summary between NDVI, NDBI, MNDWI, and LST. |
|------------------|------------------|------------------|------------------|
| Indices          | R Stat           | R Table          | Description     | Direction       | Strength          |
| NDVI             | 0.56             | 0.32             | Significance    | Negative        | Intermediate-Strong |
| NDBI             | 0.76             | 0.32             | Significance    | Positive        | Strong             |
| MNDWI            | 0.78             | 0.32             | Significance    | Negative        | Strong             |
3.2.2. Correlation and Regression Analysis Between Building Density and LST

Correlation between building density as a predictor parameter and LST as a response parameter was built to determine whether there was a relationship between the two parameters and also to know the strength and direction of the relationship. According to [13], statistical results showed a strong correlation between building density and LST with a correlation coefficient of 0.61 and a coefficient of determination of 0.339. This showed that there was a strong and positive relationship between building density and LST. In other words there was a strong relationship between the increase of building density and the increase of LST.

The T-test was conducted to assess whether the statistical analysis produced was significant or not. According to [13], the results showed enough evidence to conclude that there was significant linear relationship between building density and Land Surface Temperature since the absolute value of the test statistic (t Stat) was greater than the critical value (t Table). The statistical results in (Table 5) showed a t Stat of 3.199 and the critical value was 2.10092 based on the 95% confidence level used. The probability value (Significance F) is less than the chosen significance level (0.05) so there was a significant relationship between the predictor and the response parameter. The results of the significance test carried out were significant so that the coefficient of determination can be used to predict the contribution of building density to LST. LST was influenced by building density with an estimate of 33.9%, while the remaining 66.1% was influenced by other factors. The results of the linear regression of the two parameters is shown in (Figure 5). The regression equation between building density and LST obtained was \( y = 0.0199x + 24.333 \) with LST in Celsius degree as the y variable and building density in percent as the x variable. Based on the regression equation, an increase in building density of 1% in the study area can increase the LST by 0.0199 °C. However, in other areas, the influence may vary.

Table 5. Statistical Summary between LST and Building Density.

| Regression Statistics   |       |
|-------------------------|-------|
| Multiple R              | 0.613 |
| R Square                | 0.376 |
| Adjusted R Square       | 0.339 |
| Standard Error          | 0.895 |
| Significance F          | 0.005 |
| t Stat                  | 3.199 |
| t table                 | 0.456 |
| t table                 | 2.101 |

![Figure 5. Linear regression.](image)
3.2.3 Accuracy Assessment of Land Cover Map
Accuracy assessment was done to measure the percentage of accuracy of the land cover map. The sample distribution was calculated using the Slovin formula and distributed using the stratified random sampling method with a land cover classes of 4 classes: built-up area, vegetation, bare soil, and water body. The accuracy test activities in the filed had various obstacles including various terrain conditions, the distance between samples that were quite far, difficult to access several sample points limited in human resources who performed the accuracy test, difficulty in measuring the polygon of samples that should meet the minimum mapping units both on the tentative map or when conducting the accuracy test. Based on the accuracy test using Confusion Matrix table, an overall accuracy of 88.42% was obtained.

Table 6. Confusion Matrix.

| Tentative Map | Field Survey | Vegetation | Built-up | Bare soil | Water body | Total row | User Accuracy (%) |
|---------------|--------------|------------|----------|-----------|------------|-----------|-------------------|
| Vegetation    | 28           | 0          | 3        | 0         | 31         | 90.32     |
| Built-up      | 2            | 44         | 3        | 0         | 49         | 89.80     |
| Bare soil     | 2            | 1          | 10       | 0         | 13         | 76.92     |
| Water body    | 0            | 0          | 0        | 2         | 2          | 100       |
| Total column  | 32           | 45         | 16       | 2         | 95         |           |
| Producer      |              |            |          |           |            |           | 87.5             |
| Accuracy (%)  |              |            |          |           |            | 97.78     | 62.5             |
| Overall       |              |            |          |           |            | 100       | 88.42            |

4. Conclusion
The development of urban areas in Sleman Regency has led to the conversion of land cover into the type of built-up area. The urban area in Sleman Regency was in the southern part of the district where there were many educational institutions. This urban area was developing towards the north and the northeast. Building density has a strong positive correlation with Land Surface Temperature with a correlation coefficient of 0.61 and a coefficient of determination of 0.339. There was significant linear relationship between building density and Land Surface Temperature. Land Surface Temperature in study area was influenced by building density with an estimate of 33.9% and the remaining 66.1% was influenced by other factors. The regression equation obtained was $y = 0.0199x + 24.333$. The increase in building density of 1% in the study area can increase the LST by 0.0199 °C. This influence may differ in other areas.

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