Analysis of the impact of land cover on Surface Temperature Distribution: urban heat island studies in Medan and Makassar

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Abstract. The increasing number of an urban population in Indonesia causing Urban Heat Island (UHI) phenomenon that has to be the concern for the local government. Urban Heat Island is a phenomenon of the surface and thermal air climate that is warmer than the surrounding non-urbanized areas due to population density. This phenomenon is identified by the growing number of impervious surface area that can store heat energy better than any other surface area. A ground-based temperature monitoring system can observe this symptom but on a smaller scale. If we want to monitor the UHI in a larger spatial scale, we need to set up a much more ground-based temperature monitoring system, and that would cost too much money. Satellite-derived Land Surface Temperature (LST) may be the solution to this problem. In this study, the UHI phenomenon was examined in two cities in Indonesia: Medan and Makassar using Landsat 8 OLI/TIRS imagery. The Single Channel Algorithm (SCA) was used to retrieved LST data. Spectral indices such as Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI) and Visible Red–Near Infrared Build up Index (VrNIR-BI) were used. The mean LST in Medan and Makassar was 30.46°C and 30.76°C respectively. The study revealed that mean LST in the vegetation area was the coolest among the impervious and the mixing area. The Pearson Product Moment Correlation to analyze the relationship between land cover that is represented with NDVI values and LST in those study area shows that they have negative relationship. The correlation coefficient between NDVI values and LST in Medan and Makassar was -0.65; and -0.63. While the correlation coefficient between VrNIR-BI values and LST in Medan and Makassar was 0.65 and 0.63 respectively.

1. Introduction
Indonesia is the fourth most populous countries in the world with about 255 million peoples. In 2015, 53.3% of the population lived in urban areas, compared to the 2010 data, this number increased by around 3.5% [1]. BPS (Indonesian non-departmental government institute that is responsible for conducting statistical surveys) predicts that this number will grow to 66.6% in 2035. One of the effects of the increasing number of urban population is Urban Heat Island (UHI). UHI is a phenomenon of the surface and thermal air climate that is warmer than the surrounding non-urbanized areas due to population density [2]. This phenomenon was first discovered in 1818, and after that another research about UHI has been conducted in many other places [3] – [4]. UHI is indicated by a vast expanse of
impervious surface that can store heat energy better than any other surface areas [5]. This phenomenon induced heat stress, ozone formation changes, increased electricity demand, raises of pollution, greenhouse gas emission and in the more severe case, it can cause health problems.

A ground-based temperature monitoring system can observe this symptom in a smaller case. If we want to monitor the UHI in a larger spatial scale, we need to set up a much more ground-based temperature monitoring system, but that would cost too much money. Satellite-derived Land Surface Temperature (LST) may be the solution to this problem.

In this study, the UHI phenomenon was examined in two cities in Indonesia, Medan and Makassar, which have population density for about 8300 people/km$^2$ and 8200 people/km$^2$ respectively, in 2015. These cities have a very similar demographic and geographic condition, where both cities are located near the coastal area and have tropical climate. Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) were used to retrieve Land Surface Temperature (LST) and Land cover data. Various geospatial and statistical approaches were used for analysis. A statistical method to understand the correlation between LST and land cover using Pearson Product Moment Correlation was performed.

The goals of this research are to analyze the land cover of each study area using several spectral indices algorithm and to retrieve surface temperature distribution from Landsat data as well as to discover the correlation between land cover and LST in each of the study area. This research can help local governments to implement the appropriate policies in the planning and development of the city by taking into account environmental aspects.

2. Method

2.1. Research sites
This research was conducted in Medan, which is located at 3.4909° N – 3.8012° N and 98.5924° E – 98.7467° E and Makassar which is at 5.0623° S – 5.2335° S and 119.3779° BT – 119.5428° BT. Both cities are located near the coastal area and have same climate conditions, which is characterized by two seasons wet and dry. In Medan and Makassar, the wet season start from October until May and the dry season from June until September.

2.2. Data and equipment
The data used for this study are level 1 and 2 data product of Landsat 8 OLI/TIRS imagery covering the city of Medan and Makassar acquired on August 24, 2018, and July 14, 2018 respectively during the dry season. Landsat 8 OLI Level 2 data product were used to retrieve the land cover map; these data were used because it was atmospherically and terrain corrected. Level 2 products only consist of band 1 to band 7 that are in the OLI sensor. However, USGS doesn’t recommend the use of OLI bands 1 and 2 (coastal aerosol and blue bands, respectively) for analysis, as they already used within the algorithm making them unreliable [6]. The land cover map was performed using several spectral indices such as NDVI, MNDWI, and VrNIR-BI. Landsat 8 TIRS level 1 data product was used to retrieve LST data and the Single Channel (SC) algorithm were applied. Landsat 8 TIRS level 1 data product is consist of two bands: 10 and 11, but band 10 were used instead of band 11 because it has lower atmospheric absorbance compared to the band 11 [7].

In this research, the atmospheric condition parameter data were needed to perform atmospheric correction to the band 10 Landsat 8 TIRS. The data were collected from the weather station in those study area that can be accessed from https://www.wunderground.com/. This atmospheric correction was done using Barsi’s atmospheric profile modeling that can be accessed in https://atmcorr.gsfc.nasa.gov/.
2.3.  Land cover
The land cover map was retrieved using three spectral indices i.e. NDVI (Normalized Difference Vegetation Index), MNDWI (Modified Normalized Difference Water Index), and VrNIR-BI (Visible Red-Near Infrared Build up Index). NDVI was used to identify vegetation while VrNIR-BI were used to distinguish the impervious surface of the study area. To extract the bodies of water, we use MNDWI. The data used to make the spectral indices are Landsat 8 OLI level 2 which is atmospherically corrected so that it has produced surface reflectance data [8].

NDVI is one of the parameters used to analyze the condition of vegetation covered in the study area. The level of vegetation density can be assessed through the use of technology that is currently growing. NDVI calculations performed are as follows [9]:

\[
NDVI = \frac{\rho_{S(NIR)} - \rho_{S(red)}}{\rho_{S(NIR)} + \rho_{S(red)}}
\]

where:
\[\rho_{S(NIR)}\] = surface reflectance values of band 5 Near-Infrared
\[\rho_{S(red)}\] = surface reflectance values of band 4 red

MNDWI is performed to extract bodies of water. This spectral index was introduced as an improvement of the McFeeters Normalized Difference Water Index (NDWI) [10]. Unlike NDWI which uses reflectance values in near-infrared bands, MNDWI uses a shortwave-infrared band to distinguish water from other objects. For the case on the Landsat 8 OLI satellite, because there are two shortwave infrared channels, the research conducted by Du (2014) suggested to use SWIR-1 channel in band 6. The equation used to calculate MNDWI values is:

\[
MNDWI = \frac{\rho_{S(Green)} - \rho_{S(SWIR-1)}}{\rho_{S(Green)} + \rho_{S(SWIR-1)}}
\]

where:
\[\rho_{S(SWIR-1)}\] = surface reflectance values of band 6 Shortwave Infrared-1
\[\rho_{S(Green)}\] = surface reflectance values of band 3 green

Based on research by Estoque and Murayama, VrNIR-BI was able to separate impervious surfaces with open land such as dry agricultural land and dry grassland on Landsat ETM + and Landsat OLI / TIRS imagery. This index uses the values of surface reflectance red band and near-infrared bands to produce impervious surface areas. VrNIR-BI calculated using the following equation:

\[
VrNIR - BI = \frac{\rho_{S(red)} - \rho_{S(NIR)}}{\rho_{S(red)} + \rho_{S(NIR)}}
\]

Where:
\[\rho_{S(NIR)}\] = surface reflectance values of band 5 Near-Infrared
\[\rho_{S(red)}\] = surface reflectance values of band 4 red

Each of these spectral indices is given a threshold to distinguish between vegetation and non-vegetation land, water bodies with non-water bodies, and water-resistant land with water-absorbing land. Each of these thresholds is explained in table 1.

2.4.  Land surface temperature (LST) retrieval
The land surface temperature was obtained from band 10 Level-1 Landsat 8 TIRS imagery. Channel 10 was used because channel 10 has lower atmospheric absorption compared to band 11 [7]. Radiometric correction performed on channel 10 is to convert DN to radiance as in equation (4) [11].

\[
L_\lambda = M_\lambda Q_{cat} + A_\lambda
\]
where $L_{\lambda} = \text{Top of atmosphere (TOA) spectral radiance (W/m}^2\text{sr}\mu\text{m)}$, $Q_{\text{cal}} = \text{Quantized and calibrated standard product pixel values (DN)}$, $M_L = \text{Band specific multiplicative rescaling factor}$ and $A_L = \text{Band specific additive rescaling factor}$. All of the parameters were obtained from metadata. In calculating LST, the radians value is also used to generate the value of brightness temperature. The equation used utilizes the inverse of the Planck Law equation which assumes that the surface of the earth is a black body that has an emissivity value equal to one [4].

$$\mathcal{T} = \frac{k_2}{\ln\alpha_k}\left(\frac{L_{\lambda}}{l_{\lambda} + 1}\right)$$

where $T = \text{Brightness temperature (K)}$, $L_{\lambda}$ is TOA spectral radiance, $K_1$, and $K_2 = \text{Thermal conversion bands}$. LST retrieval using the Single Channel method is as follows [12]; [7]:

$$LST = \gamma\left[\frac{1}{T}\left(\psi_1 L_{\lambda} + \psi_2\right) + \psi_3\right] + \delta$$

where $\varepsilon$ is Land Surface Emissivity (LSE), $\gamma$ and $\delta$ are function parameters, while $\psi_1$, $\psi_2$, and $\psi_3$ are atmospheric correction functions. The parameters $\gamma$ and $\delta$ are calculated using equations (7) and (8) below,

$$\gamma = \frac{c_2 L_{\lambda}}{T^2} \left(\frac{L_{\lambda} + 1}{c_1}\right)^{-1}$$

$$\delta = -\gamma \cdot L_{\lambda} + T$$

$c_1$ and $c_2$ are Planck’s radiation constants, each of which is $1.19104 \times 10^8 \text{W} \mu\text{m}^4 \text{m}^{-2} \text{sr}^{-1}$ and $1.43877 \times 10^4 \mu\text{m K}$, while $\lambda$ is the effective wavelength for channel 10 Landsat 8 TIRS imagery which is $10,895 \mu\text{m}$.

Calculation of surface temperature using the SC method requires atmospheric correction parameter data obtained from the atmospheric profile modeling carried out by Barsi [13], this modeling can be accessed on the NASA webpage (https://atmcorr.gsfc.nasa.gov/). To do the modeling, we must enter some data on atmospheric conditions when the image is taken. These data are coordinate locations, acquisition time of the imagery, relative air humidity, air temperature, altitude, and air pressure. Atmospheric modeling will produce three parameters of atmospheric conditions, namely the band average atmospheric transmission ($\tau$), effective bandpass upwelling radiance ($L^\uparrow$) and effective bandpass downwelling radiance ($L^\downarrow$). This value needs to be converted to $\psi_1, \psi_2, \text{dan } \psi_3$ using the equation below:

Table 1. Threshold for determining land cover class

| Land Cover                          | Spectral Indices | Thresholds          |
|------------------------------------|------------------|---------------------|
| Vegetation                         | NDVI             | > 0.5               |
| Impervious surface                 | VrNIR-BI         | > -0.22             |
| Water Bodies                       | MNDWI            | Otsu’s binary Threshold |
| Mix Area (a mixture between        |                  |                     |
| impervious surface and             |                  |                     |
| vegetation, grassland,             |                  |                     |
| cropland, and bare land)           |                  |                     |

$$\psi_1 = \frac{1}{\tau}$$

$$\psi_2 = -\frac{L^\downarrow}{\tau}$$

$$\psi_3 = \frac{L^\uparrow}{\tau}$$
In this study, land surface emissivity (LSE) data was collected using the NDVI Threshold Method (NDVITHM). In NDVITHM, the threshold is determined to estimate the type of land cover found in the study area. NDVI which has a value of less than 0.2 (NDVIs) is considered as land and building so that it has an LSE value equal to 0.96 ($\varepsilon_{\lambda} = 0.96$). While the NDVI value exceeds 0.5 (NDVIV) are considered as full vegetation so that it has an LSE value of 0.99 ($\varepsilon_{\lambda} = 0.99$). NDVI values that are between 0.2 - 0.5 (mixed vegetation and soil or building) will have values as in the equation (12) [14]. LSE classification based on NDVI is explained in table 2.
\[ \varepsilon = \varepsilon_{\text{v,\lambda}} \cdot P_v + \varepsilon_{\text{s,\lambda}} \cdot (1 - P_v) + C_\lambda \]  

To get the LSE value in the mixed vegetation area, the value of the Proportion of Vegetation (PV) and Cavity Effect (C_\lambda) is needed. PV is the value of the proportion of vegetation from an area, some sources also refer to PV as FVC (Fractional Vegetation Cover) [4]. PV values can be determined based on the equation below:

\[ PV = \frac{N_{\text{NDVI}} - N_{\text{NDVI}_s}}{(N_{\text{NDVI}} - N_{\text{NDVI}_s})^2} \]  

While the value of the Cavity Effect is the value of the level of roughness of an area caused by the texture on the surface of the land recorded in the image. The value of the Cavity Effect is determined based on equation 14.

\[ C_\lambda = (1 - \varepsilon_{\text{s,\lambda}}) \varepsilon_{\text{v,\lambda}} \cdot \tilde{F}(1 - P_v) \]  

\( \tilde{F} \) is a geometric factor that depends on the surface geometric distribution, based on Sobrino [14] the value of \( \tilde{F} \) rough and heterogeneous surface mean is 0.55 and is also used for this study.

The LSE value must still be corrected based on land cover in the form of a water body. This is because the water body has a higher emissivity value of 0.995. LSE correction of water bodies was carried out using MNDWI by performing an otsu binary threshold to distinguish water bodies from the land.

3. Results and Discussion

In figure 1.a, the land cover of Medan and Makassar was divided into four classes, namely the Water Body symbolized in blue, the Mixed area symbolized in pink, Impervious Surface symbolized in brown, and Vegetation symbolized in green. In Medan, the Mixed land cover class dominates land cover, especially in the central part of the city. While most of the water body was in the northern part of Medan. The vegetation land cover class was widespread in the northern and southern parts of Medan. The majority of the impervious surface land cover class is located in the middle-east part of Medan, which is the economic and business center in Medan.

The Mixed land cover class dominates Medan land cover of 119.828 km² or 42.652% of the total area of Medan. While the vegetation has an area of 87.869 km² or equal to 31.277% of the total area of Medan. Meanwhile, most water bodies located in the northern part of Medan City have an area of up to 29.343 km². Impervious surface land cover has an area of 43.902 km² or 15.627% of the total area of Medan City.

Figure 1.b, featuring the land cover of Makassar, the land cover of Makassar City was dominated by green which was a vegetation area. Vegetation can be found in almost all parts of the city, but most gather in the middle-northeast to the east. In the south can also be found a collection of vegetation areas that are quite dominating. Impervious surface areas symbolized by the brown color in Makassar City was concentrated in the central part of the city extending diagonally to the southeast. Likewise with the mixed area symbolized by pink, it was also concentrated in the middle and extended to the southeast. However, in the north-eastern part of Makassar City, a mixed land cover class can be found even though the area was not as large as the vegetation land cover class. In other parts of the city, Mix land cover classes can also be found with areas that are not too large. The land cover class of the water body was symbolized in blue. The Water bodies were concentrated in the central part of the city in the northeast of the land cover class. The water body in Makassar was mostly river and pond areas. Water bodies can also be found in the southern part where two rivers were outfall into the Makassar Strait.
Table 2. LSE classification based on NDVI

| Land Cover                                      | NDVI   | LSE value |
|-------------------------------------------------|--------|-----------|
| Vegetation                                      | > 0.5  | 0.99      |
| Mix area (mixture of vegetation and soil or building) | 0.2 – 0.5 | Based on equation 12 |
| Building and soil                               | < 0.2  | 0.96      |

Figure 3. Correlation test between NDVI and LST.

The vegetation has a significant area of the total area of Makassar City. It was proven by the percentage of the total area which reached 40.668% with an area of 72.154 km² compared to the area of mixed land which reached 55.765 km² with a percentage reaching 31.430%. The impervious surface has an area of up to 35.381 km² or 19.941% of the total area of Makassar City. Meanwhile, the land area of the water body has an area of 14.125 km² with a percentage of up to 7.961% of the total area.

The LST retrievals for the two cities used as the case study in this study resulted in an overall average value that not much different, as seen in figure 2. The city of Medan has an average surface temperature of 30.46°C with maximum and minimum temperatures of 36.64°C and 20.77°C. Makassar which has the higher vegetation area than Medan has an average surface temperature of 30.76°C with a maximum temperature reaching 36.55°C and the minimum temperature reaches 24.38°C.

From the results of processing the spectral indices and LST, the two variables can be correlated using the simple Pearson product-moment correlation analysis. Extraction of spectral index data such as NDVI and VrNIR-BI was performed after first removing pixels detected as water by MNDWI. Correlation analysis performed on NDVI values and LST in Medan gave a correlation value of -0.652 with linear equation $y = -9.3529x + 34.429$. The correlation value of LST with NDVI that has been corrected with a water body shows a tendency to decrease the surface temperature of the land along with the increase in the NDVI value to produce a negative correlation coefficient. Similarly, the correlation value on the VrNIR-BI value with Medan City LST results in a correlation value of 0.652. The LST value tends to increase with the increase in the value of VrNIR-BI which has been corrected for the water body.

On the other hand, correlation analysis conducted on the NDVI value and LST value of Makassar City gave a correlation value of -0.636 with linear equation $y = -4.9798x + 33.02$. This value indicated that there was a correlation between the NDVI value and the LST value, where increasing the NDVI value, the LST value will tend to decrease. The correlation coefficient between VrNIR-BI and LST was 0.636. The LST value tends to increase with the increased value of VrNIR-BI which has been corrected for the water body. The correlation test graph can be seen in figure 3.
4. Conclusion
Land cover was made in this study using several spectral indices namely: NDVI, VrNIR-BI, and MNDWI with each threshold to determine land cover class such as NDVI >= 0.5 for vegetation land; VrNIR-BI >= -0.22 for impervious surface; 0.22<NDVI<0.5 for mixed area, and otsu’s binary threshold for MNDWI. LST retrieval using the Single Channel method produces the average surface temperature values for Medan of 30.46°C and Makassar 30.76°C. The correlation value between LST and NDVI in Medan and Makassar is -0.65 and -0.63 while between LST and VrNIR-BI each is 0.65 and 0.63, respectively. This value indicated that there was a correlation between the NDVI value and the LST value, where the increasing the NDVI value, the LST value will tend to decrease, on the other hand the positive value of correlation between LST and VrNIR-BI means that the increasing the NDVI value, the LST value will also tend to increase.

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