Spatial analysis of land cover fraction and land surface temperature in Jakarta, Indonesia

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Abstract: Vegetation cover is important to mitigate the effect of urban heat island. However, developments of city give a disproportionate impact on the decline of vegetation cover, causing surface temperature rise. This study aims to quantify the relationship between land cover fraction and land surface temperature. The result showed that land surface temperature is negatively and linearly related with vegetation fraction, while be positively related with impervious fraction.
Keywords: Urban vegetation, Land cover fraction, Land surface temperature, Urban heat island

1. Introduction

Indonesia is experiencing rapid urbanization with 55% of the total population lives in urban areas. The urban population has been heavily concentrated in Jakarta and Bandung, the two biggest mega-urban regions in Indonesia, and unplanned growth of these regions has led to urban environmental problems, such as surface urban heat island (UHI). Surface UHI refers to the phenomenon where urban areas have higher average land surface temperature (LST) in comparison to surrounding suburban area. The land surface temperature tends to be influenced by the complex of vegetation cover and evapotranspiration rate, and anthropogenic activities that significantly affect urban energy balance (Oke, 1982).

Many cities across the world struggle with issues of UHI. Commonly, urban green space development is considered as one of UHI mitigation strategies (Shishegar, 2014). However, understanding of the effect of the amount, the distribution, and the allocation of urban green space have not been fully sufficient. In this sense, satellite imagery is useful for mapping urban green covers. Linear spectral mixture analysis (LSMA) based on vegetation, impervious surface, soil (VIS) model often employed in this domain to identify sub pixel fractions by modelling a mixed spectrum as a linear combination of pure spectra (endmember) (Kärdi, 2007).

Previous study investigated the relationship of land cover and LST in Jakarta (Tursilowati et al., 2012), however, the study simplifies the land covers and overlooked the issues of mixed pixels. This study aims to quantify the relationship amongst land cover fractions based on VIS model on LST. We address the important role of the urban covers to alleviate the LST toward the UHI mitigation.

2. Materials and Methods

2.1. Study area

Jakarta, the capital city of Indonesia, is located in Java Island (Figure 1). With the area of 664.01 km^2, Jakarta has 10.4 million population and categorized as the most densely populated city (15.66 person/km^2). According to local government report, green spaces in Jakarta are 4.14% of the total in 2014, suggesting being far below the requirement of 30% as stipulated in the spatial planning law no. 26/2007.

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Figure 1. Study area

2.2. Method

2.2.1. Data collection and Image preprocessing

Sentinel-2 MSI level-1C data from August 1th in 2017 to July 31st in 2018 (in total 228 scenes) and Landsat 8 Surface Reflectance Tier 1 on July 6th in 2018 were used to generate land cover fractions and LST, respectively. Water body was masked out using Otsu threshold which was found by separating water and non-water pixels based on the observed distribution of pixel values (Otsu, 1979). The yearly cloud-free and water-masked image was produced by median values of temporal composite Sentinel-2 data after masking cloud covers identified by the quality assessment band, implemented on Google Earth Engine (GEE).

2.2.2. Linear Spectral Mixture Analysis (LSMA)

It was essential to select pure endmembers to the implementation of the LSMA. In this study, high-resolution satellite imageries found in Google Earth Pro was used to identify the location of pure spectral endmembers. Endmembers consist of low albedo (dark material), high albedo (light material), vegetation, and soil. Low and high albedos were considered as impervious surfaces. Spectral unmixing was applied to the processed Sentinel-2 imagery (7 reflectance bands) with selected 41 endmembers polygons. The fractional cover map represented proportions of the land cover in a pixel ranged from 0% to 100%.

2.2.3. LST calculation

LST was calculated using equation below (Avdan & Jovanovska, 2016):

$$LST = BT/(1+ (\lambda \times BT/\rho) \times In(\varepsilon)) \quad (1)$$

where BT is brightness temperature of Landsat-8, λ is the wavelength of emitted radiance (11.5 µm), $\rho = h \times c/\sigma$ (1.438×10^{-2} m K), h is Planck's constant (6.626×10^{-34} J s), c is velocity of light (2.998×10^{8} m/s), σ is Boltzmann constant (1.38×10^{-23} J/K), and ε is emissivity ($0.004 \times Pv + 0.986$). A method to generate the proportion of vegetation (Pv) was suggested using equation as follow:

$$Pv = \{(NDVI\text{-}NDVImin) / (NDVImax\text{-}NDVImin)\}^2 \quad (2)$$

Normalized Difference Vegetation Index (NDVI) is:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (3)$$

where NIR is reflection in the near-infrared spectrum and RED is reflection in the red range spectrum. As the last step, LST was subtracted by 273.15 for obtaining the result in Celsius.

2.2.4. Accuracy assessments

Accuracy of fractional cover was assessed by a mean absolute error (MAE) of the proportion of fractional cover map against the proportion of the reference pixel obtained from visual interpretation of imageries in Google Earth Pro for each class. 120 validation sample grids with the same grid size of Sentinel-2 imagery were randomly distributed. LST was compared with daily maximum air temperature (Tmax) in the same day as LST was observed, collected from National Oceanic and Atmospheric Administration (NOAA) and Meteorology, Climatology, and Geophysical Agency, Indonesia (BMKG) as a proxy.

2.2.5. Linear regression analysis

Linear regression between LST and land cover fractions was applied to estimate the relationships among them. 1000 reference points were collected by random sampling.

3. Result and Discussion

3.1. Land cover fraction

Figure 2 represented the mixture of fractions of impervious surfaces, vegetation, and soil. It was noted that low albedo and high albedo was combined to represent impervious surfaces fraction. We estimated Jakarta comprised of 69% of impervious surfaces, 23% of vegetation, and 6% of soil. The remaining 2% was water body that had been masked out throughout study area.

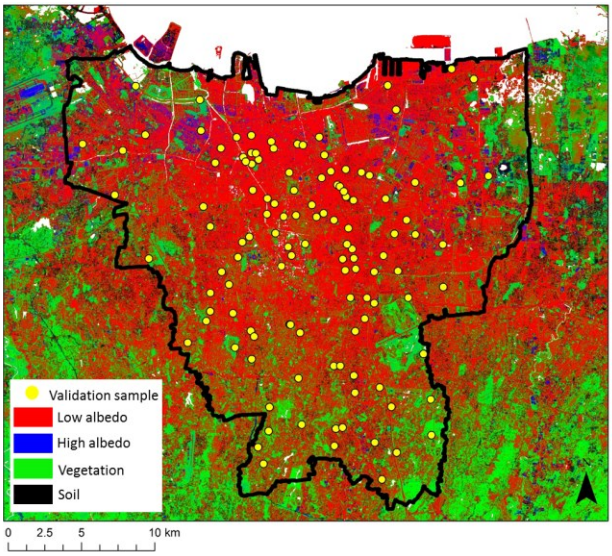

Figure 2. Fractional cover of Jakarta

Low albedo impervious surfaces was dominantly distributed over study area, while high albedo impervious surfaces was mainly presented in northern parts of Jakarta where majority of industrial areas were located. Soil fraction was dominantly seen only in construction sites. Relatively higher fractional rate of the vegetation cover was likely to be found in vegetated areas (70-90%), while lower in residential areas (6-10%), and less in industrial areas (5%). The accuracy of these land cover fractions were assessed with independent validation sample as the MAE of 0.08, 0.07, and 0.02 for impervious surfaces, vegetation, and soil, respectively.

3.2. Land Surface Temperature

Figure 3 showed the distribution of LST in Jakarta. The surface temperature within the boundary of Jakarta ranged from 24.85ºC to 41.75ºC, with the average temperature of 33.1ºC (Figure 3). The result showed, water body and vegetated area indicated relatively low LST, while high albedo and low albedo impervious surfaces indicated relatively high LST.

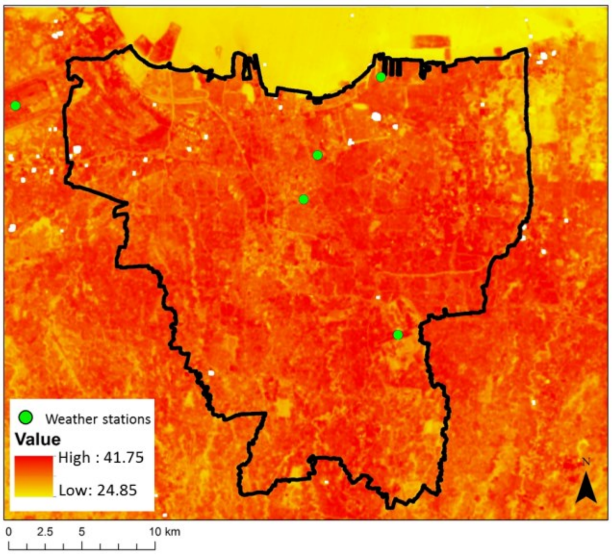

Figure 3. Land surface temperature (LST) of Jakarta

Table 1 showed the comparison of the LST and Tmax at weather stations. Gaps between them were reasonable due to the different observation approach to the temperature.

Table 1. Comparison with LST and daily maximum air temperature

Weather stations	LST (ºC)	Tmax(ºC)	Source
Tanjung priok	32.15	30.55	NOAA
Observatory	32.25	31.11	NOAA
Cengkareng	32.75	30	NOAA
Halim PK	37.25	33.88	NOAA
Kemayoran	31.65	28.1	BMKG

3.3. Relationship between land cover fraction and LST

The linear regression showed a significantly negative relationship between vegetation fraction and LST with correlation coefficient (R^2) of 0.75 and p-value less than 0.01 (Figure 4a). The negative regression coefficient (-0.063) suggested a relationship so that LST tend to decrease with the increase of the vegetation.

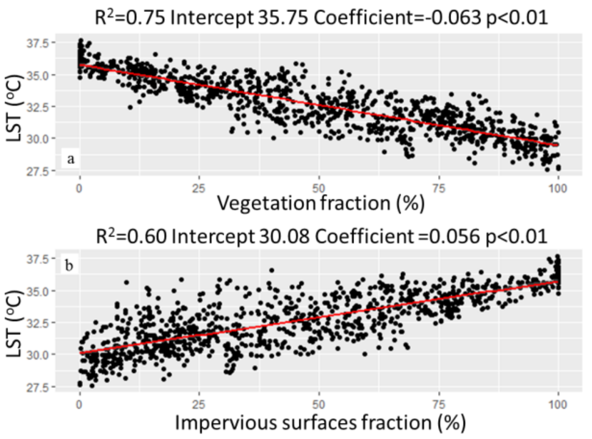

Figure 4. Linear regression model of (a) vegetation fraction and LST (b) impervious surfaces fraction and LST

The positive relationship was found between LST and impervious surfaces fraction with R^2 of 0.60 and p-value less than 0.01 (Figure 4b). A positive regression coefficient (0.056) suggested that LST tend to increase as impervious surface fraction increases. Our findings suggested that the degree of fraction of vegetation cover was linearly associated with the level of cooling effects. It may be because that vegetation cover gives relatively low reflectance of heat compared to impervious surface, with physical processes such as shading and evapotranspiration (Armson, Stringer, & Ennos, 2012).

4. Conclusion

The relationship between land cover fraction and land surface temperature (LST) is quantified. The finding addresses that vegetation fraction plays an important role in alleviating the UHI effect. Peramesti (2016) noted that the provision of green cover in urban areas has not been optimal due to weak supervision, high land prices, and lack of public dissemination. Further studies regarding mitigation strategies such as distribution and allocation patterns of green space will need to be explored.

Acknowledgement

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