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URBAN ENERGY MODELING USING REMOTE SENSING APPROACHES

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ABSTRACT: This research aims to discover the urban energy spatial pattern based on the analysis of urban heat island (UHI) and the land surface temperature (LST) in Yogyakarta city. The vegetation cover was analyzed using the vegetation index with the normalized difference vegetation index (NDVI) formula. The satellite imagery used Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), recorded on April 22, 2019, for the dry season images, and June 25, 2019, for the wet season images. The processing results showed that the maximum LST in the dry season was 34.09°C, and the minimum was 27.22°C; meanwhile, in the wet season, the maximum LST was 31.27°C, and the minimum was 23.67°C. The presence of vegetation indicated by NDVI values had a strong correlation with LST, i.e. R = 0.74 for the dry season and R = 0.60 for the wet season. The high NDVI had a low temperature, whereas the low NDVI had a high temperature. Based on the analysis results, UHI increases in temperature (7°C) from the temperature threshold. The difference in the spatial distribution of LST and UHI in the dry and wet seasons is strongly influenced by the image recording time and the atmospheric conditions. The percentage of non-UHI area is deficient at around 0.35% in the dry season and 0.59% in the wet season, indicating that the Yogyakarta city's energy needs are very high. Therefore, it requires urban planning that considers urban green space area.

Keywords: Urban heat island, Land surface temperature, Urban energy, Remote sensing, Yogyakarta

1. INTRODUCTION

Climate change has become one of the main issues discussed in scientific forums since it has a global impact on the environment and even the economy. Climate change has a greater impact on the city level, which is worsened by human activities that change land use into built-up land and cause the loss of natural resources on earth [1,2]. Cities contribute to global energy consumption and greenhouse gas emission since the population is more widely spread in cities [3]. The increasing urbanization is one factor supporting this [4]. In some countries, such as China, the urbanization contribution to heatwaves reaches 30 to 50% [5]. Land-use change, due to an urbanization process, affects the local hydrometeorology processes and alters the urban microclimate [6]. Complex urban structure and urban people lifestyles have controlled the surface energy exchange such as surface albedo, emissivity, and heat capacity [7,8]. The thermal characteristic of the urban building construction materials causes faster heat transfer and contributes to the city temperature increase [9].

The increasing urban temperature phenomenon is known as the urban heat island (UHI) in which the urban area temperature is higher than that in the surrounding area [10]. The establishment of UHI is closely related to the urban morphological characteristics, thermal and radiative responses of the building construction materials, regional characteristics, changes in land use/land cover (LULC), and the presence of green open spaces [8, 11,12]. UHI generally refers to a phenomenon in which the urban atmosphere is warmer than the surrounding. UHI is widely studied since it has harmful effects on various aspects, i.e. health, energy, and environment [9,13]. The main method in monitoring the urban thermal environment is analyzing the land surface temperature (LST) data that can be obtained from remote sensing imagery. The temperature observation mostly uses remote sensing since it offers better spatial resolution than the temperature observation at a weather station [10]. Remote sensing provides a good solution for obtaining LST values, monitoring UHI effects through thermal channels, basic information sources, and urban planning [8,14,15]. One of the UHI parameters, soil emissivity, can be estimated by remote sensing data using the normalized difference vegetation index (NDVI) approach [16]. NDVI can also be used to measure vegetation patterns, urban dynamics, and urbanization impact [17]. Remote sensing becomes a reliable method to understand the UHI phenomena and their effects [9]. This study relies on using the SEBAL method to generate information on land surface temperature that has not been applied in Yogyakarta city before.

Yogyakarta is one of the regions in Indonesia that does not have fossil energy potential, so it requires planning related to the urban energy policy that pays attention to environmental balance. The attribute of Yogyakarta City as an education city becomes people's attraction from various regions in Indonesia to study in Yogyakarta. This stimulates the population and economic activities to increase, which affects the higher urban energy needs. The UHI analysis in Yogyakarta City will contribute to the urban planning of Yogyakarta.

2. METHOD AND MATERIALS

2.1 Study Area

Geographically, Yogyakarta City is located at 110˚24'19" to 110˚24'19" East Longitude and 7˚15'24" to 7˚49'26" South Latitude, with an average altitude of 114 meters above sea level (Fig. 1) The average rainfall is 2,012 mm/year, with 119 raining days, and the average temperature is 27.2°C, with the average humidity of 24.7%. The monsoon wind blows commonly in the rainy season, with the the southwest wind blowing in the direction of 220°, and it is wet and brings the rain; while in the dry season, the southeast monsoon wind blows in the direction of ± 90° to 140°, and it is slightly dry [18]. The Yogyakarta City population growth is a quite high year by year; at the end of 2010, the population was 387,379, and in 2019, there it increased to 414,055.

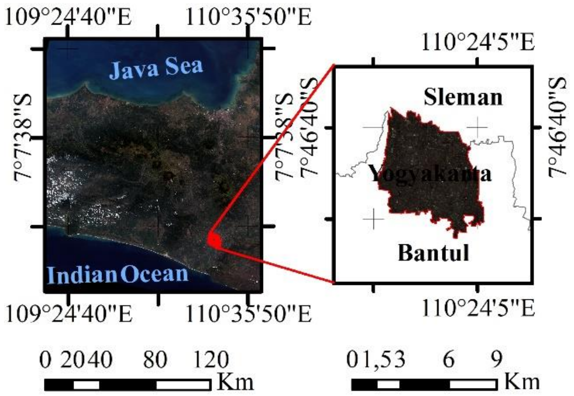

Fig.1 Study area – Yogyakarta city (Source: http://landsat.usgs.gov)

2.2 Data

The primary data used in this research were the Landsat 8 imagery from the wet season footage on April 22, 2019, and from the dry season on June 25, 2019, obtained from http://earthexplorer.usgs.gov/. The spatial coverage of each Landsat 8 pixel is 30 meters, with the radiometric resolution of 12 bits. Landsat 8 consists of two instruments: Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Landsat 8 was used for the vegetation index analysis, city surface temperature, and the UHI of Yogyakarta City.

The vegetation analysis was done using NDVI. It is assumed that low temperatures have high NDVI; conversely, high temperatures have low NDVI values [19]. The NDVI equation used the near-infrared image channel and red channel (Eq.1).

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \quad (1)$$

Note:
Band 5 = Near-Infrared channel of the Landsat 8 imagery
Band 4 = Red channel of the Landsat 8

The urban surface temperature was calculated using the SEBAL Model before identifying the UHI of Yogyakarta City [20] (Eq. 2).

$$Ts = \frac{K2}{ln(\frac{\varepsilon NB\ K1}{Rc} + 1)} \quad (2)$$

Note:
Ts = surface temperature (K)
K1, K2 = constants of the Landsat imagery
Rc = radian value of the corrected thermal
Celsius degree = °K – 273.15

The UHI analysis using the remote sensing approach can only identify the surface UHI; Eq. 3 is used for the area in which the UHI occurs, and Eq. 4 is used for the area in which the UHI does not occur [21].

$$Ts > \mu + 0{,}5\ \alpha Ts \quad (3)$$
$$0 < T \leq \mu + 0{,}5\ \alpha \quad (4)$$

Note:
T = urban surface temperature
μ = average temperature
α = standard deviation

3. RESULTS AND DISCUSSION

In this research, the NDVI formula was used to analyze emissivity and land cover. Statistically, the NDVI values are shown in Table 1. Spatially, the vegetation condition in Yogyakarta City has the same pattern, based on the results of the NDVI analysis in the wet and dry seasons, i.e low dominant and non-vegetation (Fig. 2 and Fig.3), respectively.

Table 1. The NDVI statistic values

NDVI Value	Dry season	Wet season
Minimum	-0.07	-0.05
Maximum	0.73	0.79
Mean	0.27	0.31
Std. deviation	0.11	0.11

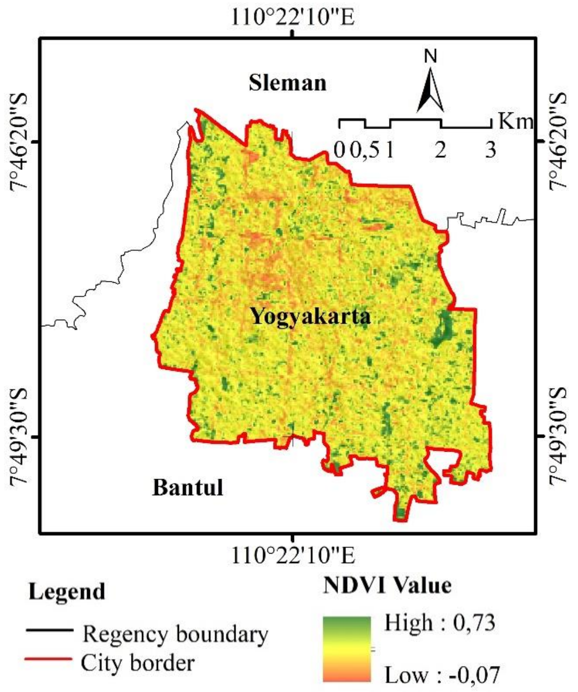

Fig.2 The NDVI map in the dry season

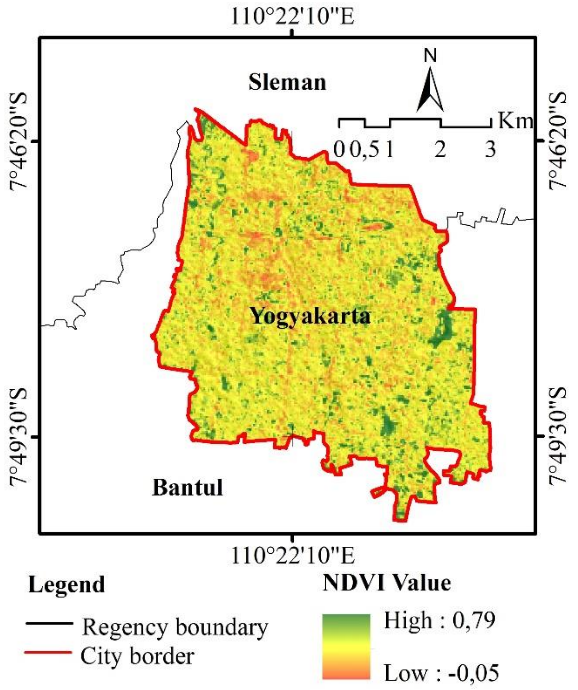

Fig.3 The NDVI map in the wet season

Fig. 2 shows the maximum NDVI value in the dry season image is 0.73, and the minimum is -0.07. Meanwhile, in the wet season (Fig. 3), the maximum NDVI value is 0.79, and the minimum is -0.05. Based on the NDVI statistic values in both images, Table 1 shows that the average NDVI value in the dry season is 0.27 and increases in the wet season with an average of 0.31. This proves that the NDVI trend is very susceptible to temperature changes [22]. Based on the image processing results, the spatial distribution of the Yogyakarta City LST in the dry and wet seasons is presented in Fig 4 and Fig 5.

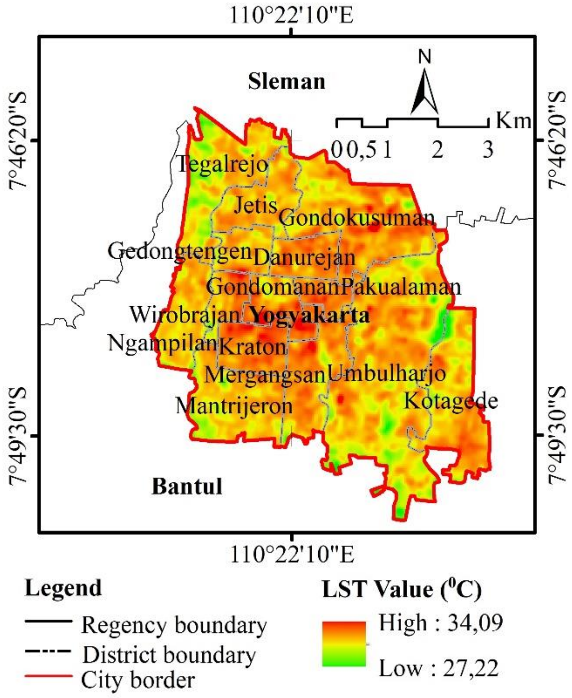

Fig.4 The LST map in the dry season

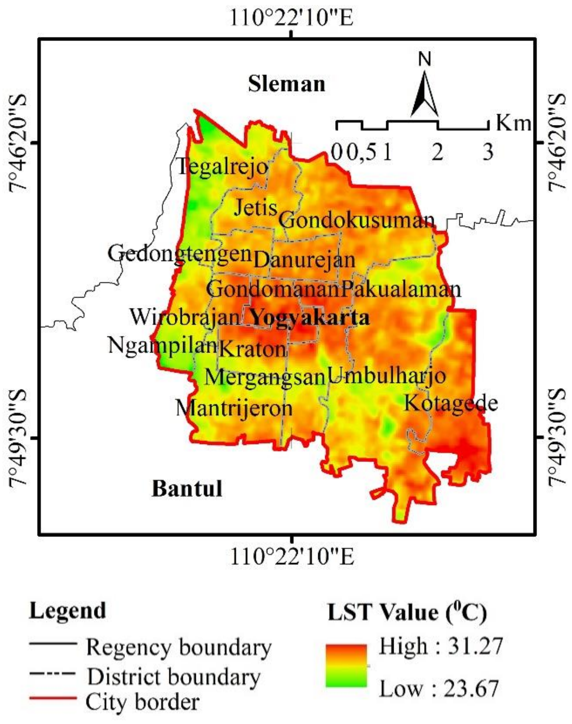

Fig.5 The LST map in the wet season

Spatially, NDVI and LST have the same pattern.

However, they are contrasted to each other, i.e. the image in the wet season has a higher LST value, whereas the image in the dry season has a lower LST value. The results of the NDVI and LST correlations are presented in Fig 6 and Fig 7.

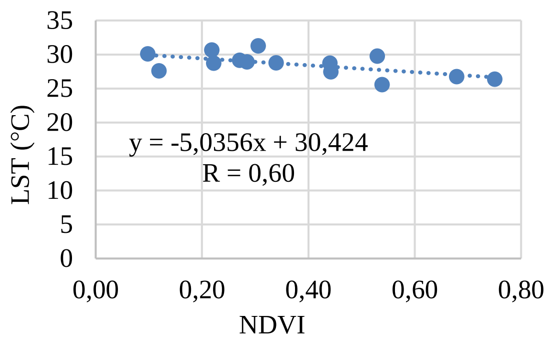

Fig. 6. LST and NDVI correlation in the wet season

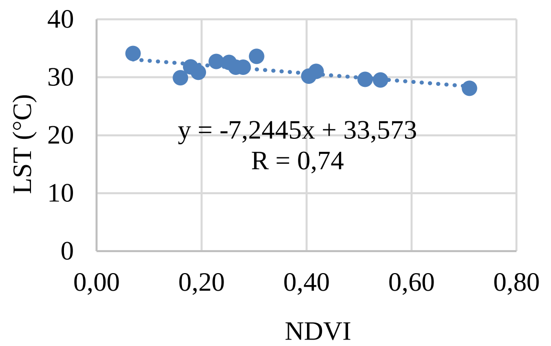

Fig. 7. LST and NDVI correlation in the dry season

The LST values in the dry season recorded by Landsat 8 imagery on June 29, 2019, were 34.09°C at maximum and 27.22°C at minimum (Fig. 4). The maximum LST was distributed in the sub-districts of the city centers, i.e. Kraton, Gondomanan, Pakualaman, and Danurejan. Meanwhile, the LST in the wet season recorded by Landsat 8 imagery on April 22, 2019, obtained a maximum value of 31.27°C and a minimum of 23.67°C (Fig. 5). High temperatures in the wet season occur in the sub-districts of Gondomanan, Pakualaman, Danurejan, Kotagede, and part of the Kraton. Spatially, the two images have almost the same pattern where high temperatures are grouping in the same area, and this area is the center of economic activities with the dominance of built-up land. The existence of Malioboro in Danurejan Sub-district has an impact on city development in the surrounding area, such as shops and hotel construction. Malioboro is a shopping center with various supermarkets, department stores, and traditional markets, becoming one of the tourist destinations in Yogyakarta [23].

LST and NDVI have a stronger correlation in the dry season (Fig. 7) with an R-value of 0.74 than that in the wet season with R-value of 0.60 (Fig. 6). Some previous researchers showed the same results that NDVI and LST had a strong negative correlation or an inverse relationship where the higher the LST value, the lower the NDVI value [24,25]. This proves that the vegetation presence affects the surface temperature decrease. The LST calculation results are used to measure the UHI intensity. The image statistics obtained for the UHI analysis are presented in Table 2.

Table 2. The image statistics to measure UHI

Image	μ (°C)	A	UHI Threshold
Dry season	27.27	1.82	28.18
Wet season	23.97	2.08	25.01

Table 2 shows that the temperature threshold for the area in which UHI occurred in the dry season is 28.18°C. This means that the area with temperatures more than 28.18°C is the location of UHI. Meanwhile, the UHI area in the wet season has temperatures above 25.01°C. The UHI distribution results in Yogyakarta City are presented in Fig. 8 (dry season) and Fig. 9 (wet season).

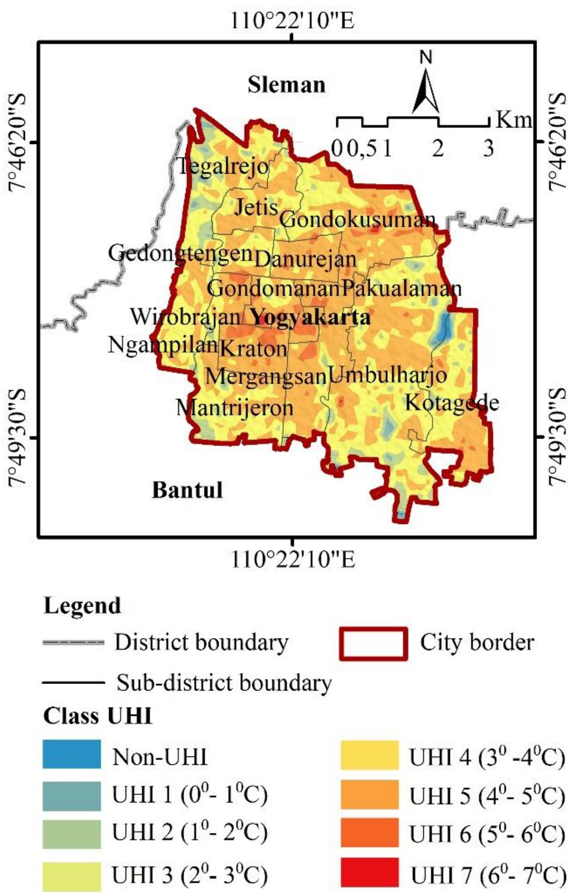

Fig.8 The UHI map in the dry season

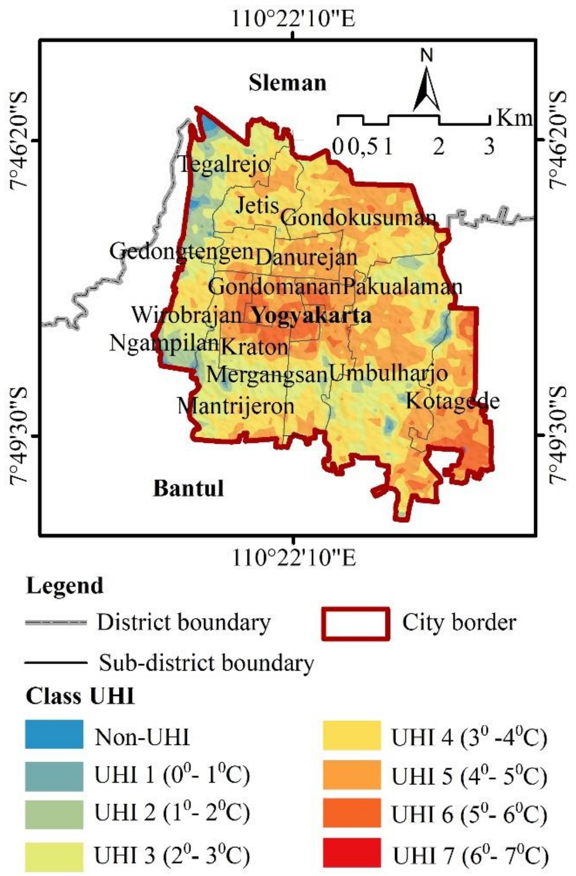

Fig. 9 The UHI map in the wet season

Based on the results of the analysis obtained, the temperature in the UHI areas increases up to 7°C. Fig. 8 and Fig. 9 show the areas with the highest UHI clustering in the subdistricts of Yogyakarta city, i.e. Gondomanan, Pakualaman, and Kraton. The small percentage of non-UHI areas is around 0.35% in the dry season (Fig.10) and 0.59% in the wet season (Fig. 11), which indicates that the energy needs of the Yogyakarta city are very high.

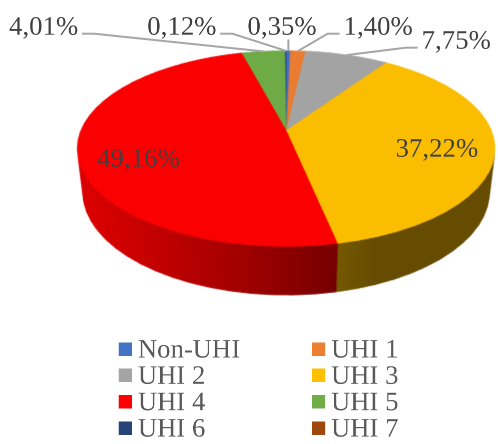

Fig. 10 Percentage of UHI distribution in the dry season

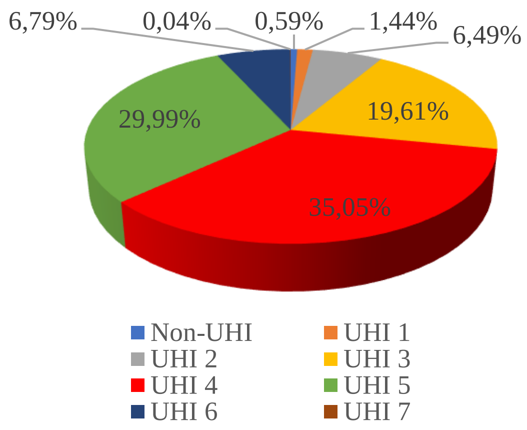

Fig. 11 Percentage of UHI distribution in the wet season

Figure 8 shows that the city of Yogyakarta is dominated by UHI class 4, which increases in temperature up to 4°C from the temperature threshold [23]. Spatially, the percentage of UHI 4 classes is greater in the dry season than in the wet season. It shows that temperature greatly influences UHI's intensity [9, 25]. LST and UHI measurements using remote sensing are strongly influenced by image recording time and atmospheric conditions.

4. CONCLUSION

The image processing results indicate that the NDVI has a strong negative correlation to the LST. The high NDVI has a low temperature, while the low NDVI has a high temperature. The UHI area spatially dominates Yogyakarta city compared to non-UHI areas. The percentage of non-UHI area is very low at around 0.35% in the dry season and 0.59% in the wet season. The results of the LST and UHI analysis show that the energy needed by Yogyakarta City is very high. Therefore, urban planning that focuses on the urban green space area is required because vegetation significantly influences the urban heat, energy requirements, and urban comfort.

5. ACKNOWLEDGMENTS

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