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Measuring Urban Heat Islands Using Landsat 8 TIRS and Investigating the Variety of Landuse Proportion in Yogyakarta City

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Abstract: Urban Heat Islands (UHIs) are one of the challenges that have emerged from urbanization and climate change in Yogyakarta. As the city grows more urbanized, the buildings and population also become denser which therefore reduces the availability of open space including green areas. This research aims to determine the variety of Land Surface Temperature (LST), UHI intensity distribution, and the proportion of landuse (vegetation and non-vegetation area) based on UHI intensity class. The LST and UHI intensity was derived from Landsat 8 Thermal Infra-Red Sensor (TIRS) satellite image of 2018 processed by LST algorithm method. The landuse proportion was obtained by analyzing the pixel samples (30x30m) on google earth image, UHI intensity class, and LST map. The results show that Yogyakarta is dominated by the high surface temperature (37° - 42°C). In general, non-UHI areas are located on the outside of the city bordering the Regencies of Sleman and Bantul, while the high intensity of UHI is in urban activity centers which are dominated by non-vegetated areas. The highest UHI intensity, 5.41°C, indicates the high-temperature difference between UHI and the non-UHI surrounding areas. The high intensity of UHIs is caused by the dominance of built-up areas (settlement, public building, and road). The results of sample identification in the non-UHI intensity class showed the proportion of 43.91% vegetation and 56.09% non-vegetation (roads). Meanwhile, the high UHI intensity class showed a proportion of 100% non-vegetation (built-up area).

Keywords: image processing, land surface temperature (LST), Landsat 8 TIRS, landuse proportion, Urban Heat Island (UHI).

Introduction

Globally, more people live in urban areas than rural areas, with 54 % of the world's population living in urban areas (UN, 2014). The effect of climate change in cities might be even more extreme because of population growth. The urban climate can affect the local temperature while the temperature itself depends on land surface proportion, such as the existence of buildings and vegetation. Built-up areas in cities have high thermal conductivity thereby saving more thermal energy than rural areas (Husna, et al., 2018). This in turn causes urban areas to have a slow rate of cooling of the surface temperature at night. Since there are more buildings in the city, the green areas have less impact on the environmental quality.

Many studies have identified adverse effects of UHIs. These effects lead to increased temperatures of cities, which then contribute to global warming, initiate storms, or precipitation events, increase energy demand of cities, and contribute to heat-related mortality (Deilami K. et al., 2018). USEPA (2008) has said that UHIs will elevate emissions of air pollutants and greenhouse gases and impair water quality. The effects of this will be devastating in the summertime, especially in the tropical and arid regions (Nuruzzaman, 2015). Tropical regions such as Indonesia, which experience anthropogenic heat, will have more and more increases in temperature in the years ahead.

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Yogyakarta, as one of the big cities of Indonesia, is facing climate change. As the city becomes more urbanized, the buildings and population also become denser, which reduces the availability of open spaces that could be turned into green areas. In 2013, Wicahyani et al. found that Yogyakarta City is dominated by temperatures ranging between 30-35 °C in settlement areas. The study of Vina et al. (2018) determined that the average temperature of Yogyakarta is 34.41 °C. The research was followed by Zahro et al. in 2018 who showed the highest temperature range in 2015 was 28.99 - 41.85 °C, while in 2017 the highest temperature range was 24.72 - 37.54 °C. These findings show that temperatures are high and dynamic in Yogyakarta city and, thus, it creates UHI in urban activity centers.

This research aims to measure UHI and investigate the landuse proportion in Yogyakarta City. Measuring UHI leads to identifying the area which needs heat mitigation. It will show the UHI intensity distribution in Yogyakarta City. In addition, investigating landuse proportion can give benefits in assessing the area which needs more vegetation. Landuse proportion shows the percentage of a vegetated and non-vegetated area which will vary based on the UHI intensity class chosen.

Materials and Methods

Study area

The research location is in Yogyakarta Municipality, the capital city of Daerah Istimewa Yogyakarta (DIY) Province, Java Island, Indonesia. Yogyakarta is located between 110° 24′ 19′′ to 110° 28′ 53′′ Longitude East and 7° 15′ 24′′ to 7° 49′ 26′′ South Latitude. Based on the Municipality Government of Yogyakarta, the area is 3,250 ha which comprises 14 sub-districts, 45 villages, 617 RW, and 2,351 RT habited by 428,282 people and the density population is 15,197 people per km². Yogyakarta Municipality is bordered by other regencies such as Sleman and Bantul. The area of Yogyakarta City can be seen in the picture below.

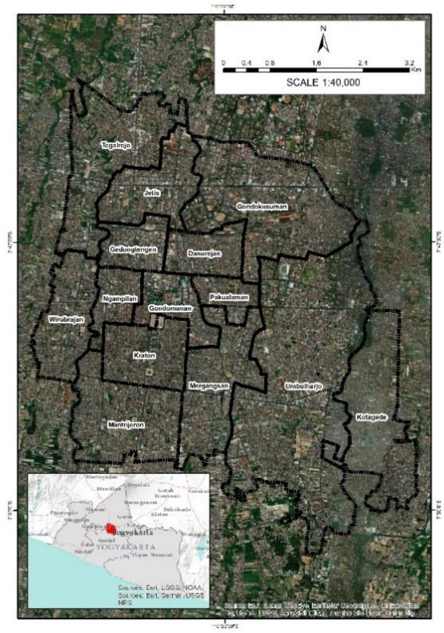


Figure 1. Map of Yogyakarta City from Google Earth (2021).

Materials

Land Surface Temperature (LST) and Urban Heat Island (UHI) are generated by the processing of Landsat 8 satellite imagery. Landsat 8 is satellite imagery operated by NASA. During the revolving time, Landsat 8 carrying OLI (Operational Land Imagery) sensors that record the electromagnetic energy from Visible to Shortwave Infrared wavelength and TIRS (Thermal Infrared) sensors that record Thermal infrared wavelength and plotted as band 1 to band 12. LST and UHI are extracted from Landsat 8 by utilizing red, infrared, and thermal wavelengths.

Table 1. Landsat 8 Band Designation.

Bands	Wavelength (μm)	Resolution (meters)
Band 1 - Coastal aerosol	0.43 – 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 – Near Infrared (NIR)	0.85 – 0.88	30
Band 6 – SWIR 1	1.57 – 1.65	30
Band 7 – SWIR 2	2.11 – 2.29	30
Band 8 – Panchromatic	0.50 - 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30
Band 10 – Thermal infrared (TIRS) 1	10.60 – 11.19	100
Band 11 – Thermal infrared (TIRS) 2	11.50 – 12.52	100

Source: USGS, 2021

This research used Landsat 8 Path 120 Row 65 which covered central Java including Yogyakarta on August 5th, 2018. Pre-processing is a necessary step to use Landsat 8. This research utilized image processing software to do the pre-processing. It included radiometric correction which converts the pixel sensor value to the actual electromagnetic value reflected and emitted by the object's surface.

Procedures

Radiometric Correction

1. *Spectral Radiance Conversion (TOA Radiance)*
   Spectral radiance correction is a correction that converts pixel value to spectral radiance value or Top of Atmosphere Radiance value. Spectral Radiance Conversion is for selected bands that are band 4 (red wavelength), band 5 (infrared wavelength), and band 10 (Thermal wavelength). The equation is provided by USGS (2019) which is used to do the conversion.

$$L_\lambda = (M_L \; x \; Q_{cal}) + \; A_L$$

   where:
   L_λ = Spectral radiance on Landsat sensor (W/m^2-sr.μm),
   $Qcal$ = Pixel value (DN),
   M_L = Rescaling constant (RADIANCE_MULT_BAND_x, where x is selected band used),
   A_L = Adding constant (RADIANCE_ADD_BAND_x, where x is selected band used).

2. *Spectral Reflectance Conversion (TOA Reflection)*
   Spectral reflectance conversion is a step to convert radiance value to actual reflectance value or real reflection value of an object on the earth's surface. These values are used to extract object characteristics to analyze various information related to objects on the earth's surface. This research used reflectance values of red and infrared wavelength (band 4 and 5) to calculate vegetation index and then surface temperature. Spectral reflectance conversion equation is published by USGS (2019) and uses pixel rescaling value which is provided in a metadata file.

$$\rho_\lambda' = (M_\rho \; x \; Q_{cal}) + \; A_\rho$$

   where:
   ρ_λ' = Spectral reflectance on Landsat sensor,
   $Qcal$ = Pixel value (DN),
   M_ρ = Rescaling constant (REFLECTANCE_MULT_BAND_x, where x is selected band used),
   A_ρ = Adding constant (REFLECTANCE_ADD_BAND_x, where x is selected band used).

Data Processing

1. *Normalized Difference Vegetation Index (NDVI)*
   The normalized difference vegetation index is one of the vegetation indexes that is widely used to calculate surface temperature. The usage of vegetation index is one of the alternatives to gain land surface emissivity. This vegetation index uses red and infrared wavelengths (bands 4 and 5).

$$NDVI = \frac{Band\,5 + Band\,4}{Band\,5 - Band\,4}$$

2. *Proportion of Vegetation/ Fractional Vegetation Cover (Pv)*
   Pv is fractional vegetation cover and the value is on 0,00 to 1,00 scale (Carlson & Ripley, 1997; Fawzi, 2014). Pv requires scaled NDVI to reduce noise on LST caused by soil moisture and surface flux energy. Hereby the Pv equation (Carlson & Ripley, 1997; Fawzi, 2014).

$$P_v = \left[\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right]$$

   The equation used NDVI value of bare soil and 100% dense vegetation based on Jiménez-Muñoz et al. (2009). Jiménez-Muñoz et al. (2009) define 0,15 for bare soil NDVI value and 0,801 for vegetation NDVI value.

3. *Land Surface Emissivity (ε)*
   Emissivity is energy emitted from an object. Landsat thermal sensor sense and record this energy so that the temperature of the object could be acquired. In Fawzi (2014), Valor and Caselles (1996) investigate the emissivity of an object related to the calculation of LST. They

modified the basic emissivity equation so that it includes the emissivity of vegetation and soil. The final equation is stated below.

$$\varepsilon = 0{,}985P_v + 0{,}960(1 - P_v) + 0{,}06P_v\,(1 - P_v)$$

where:

P_v = Fractional Vegetation Index calculated before

ε_v = 0,985 (Emissivity of vegetation),

ε_g = 0,960 (Emissivity of soil),

$d\varepsilon$ = effect of the geometry of the object and internal object reflection. In heterogeneous and rough surfaces, the effect is about 2%. In the equation, this value is multiplied by 4, so it resulted from 0,06 as above.

4. *Top of Atmosphere (TOA) Correction*

Top of Atmosphere correction is used to omit atmospheric interference during sensor recording. This interference affects the object's radiation energy that is sensed by the thermal sensor. Coll et al. (2010) in Fawzi (2017) developed an equation to apply the atmospheric correction. Hereby is the equation used in this research.

$$L_{sensor,\lambda} = \frac{L_\lambda - L_{atm}^{\uparrow}}{\varepsilon\,\tau_\lambda} - \frac{1-\varepsilon}{\varepsilon} L_{atm}^{\downarrow}$$

where:

L_{sensor} = Radiance sensor value on Top of Atmosphere (W/m^2-sr.μm),

ε = Land surface emissivity,

$L_{atm}^{\uparrow}$ = Atmospheric radiance upwelling value (W/m^2-sr.μm),

$L_{atm}^{\downarrow}$ = Atmospheric radiance downwelling value (W/m^2-sr.μm),

τ_λ = Atmospheric transmittance

The value of $L_{atm}^{\uparrow}$, $L_{atm}^{\downarrow}$, and τ_λ is provided by NASA website https://atmcorr.gsfc.nasa.gov/. The website requires the acquisition date and coordinates of the research location.

5. *Land Surface Temperature (LST)*

Based on USGS (2019), the equation to calculate the LST using corrected spectral radiance emissivity can be seen below.

$$T_{rad} = \frac{K_2}{\ln\left(\frac{K_1}{L_{sensor,\lambda}} + 1\right)} - 273{,}15$$

where:

T_{rad} = Radiance Temperature / Land surface temperature (^{0}C),

$L_{sensor,\lambda}$ = Emissivity corrected spectral radiance,

K_1 = 774,8853 = Spectral radiance calibration constant for band 10 (provided in Landsat 8 metadata),

K_2 = 1321,0789 = Absolute temperature calibration constant for band 10 and 11 (provided in Landsat 8 metadata).

6. *Urban Heat Island (UHI) Threshold Temperature*

Lima Alves and Loes (2017), Ozdemir et al. (2012) in Fawzi (2017) defined UHI by the following equation:

$$\Delta T_{\mu-r} = T_\mu - T_r$$

T_μ is the surface temperature of the urban area and T_r is the surface temperature of the urban peripheral area. This equation needs to be modified to be compatible with the remote sensing data extraction technique. Ma et al. (2010) in Fawzi (2017), identified an equation to elucidate a threshold temperature for UHI and non-UHI areas. To calculate this threshold, the statistic value of LST was needed to obtain mean (μ) and standard deviation (α) values.

$$T > \mu + 0{,}5\alpha \text{ For UHI area,}$$
$$0 < T \le \mu + 0{,}5\alpha \text{ For non-UHI area,}$$

If the result shows 34^{0}C for UHI area, then the area which has a temperature of more than 34^{0}C will be considered as UHI area, and vice versa. This threshold temperature is used as the classification reference which can be seen in Table 2.

Table 2. Classification of UHI Intensity Value.

Class	UHI Intensity Value
Non-UHI area	0 (T < 34⁰C)
UHI 1	0 - 1
UHI 2	1 - 2
UHI 3	2 – 3
UHI 4	3 – 4
UHI 5	4 – 5

7. *Urban Heat Island (UHI) Maps*

Urban Heat Island is a geographical phenomenon affected by the temperature of the surrounding area. LST is generated by remote sensing technology or a pixel-based analysis. It is different from UHI which uses an area-based analysis. Thus, adjusting the LST map with UHI map could be conducted by a spatial filtering technique. By using remote sensing processing software, this research applied 3 x 3 lowpass filtering. The result was used to produce the distribution map of UHI by the following equation.

$$Distribution\ of\ UHI = T_{mean} - (\mu + 0{,}5\alpha)$$

The threshold temperature equation explained in the previous section, will be also applied in this step. The equation description would be μ as the LST mean value and α as the standard deviation value from filtered LST data.

Data analysis

To see the significance of UHI phenomena in Yogyakarta, we compare the LST in a specific UHI class with the actual landcover. We separate the landcover into two, that is vegetation and non-vegetation. This consideration is chosen because a vegetated area is considered a colder area than the non-vegetation area. Non-vegetated area (mostly a built-up area) which is the surface reflecting the sun rays and emitting more energy, produce warmer temperature to the surrounding areas.

This research took 6 samples, a 30 x 30-meter square area, that represent non-UHI and UHI areas. Non-UHI had 2 samples; UHI 1 had 2 samples, and UHI 5 had 2 samples. This research will focus on UHI 1 and UHI 5 as the UHI area samples to compare between the minimum and maximum UHI area conditions, 'do they shows an extreme difference?'. Each sample was delineated into the polygon of vegetated and non-vegetated areas. Then the area proportion was calculated to obtain the percentage of vegetated and non-vegetated areas. In the end, the descriptive analysis was conducted to explain the relationships between LST and the proportion of landuse-landcover.

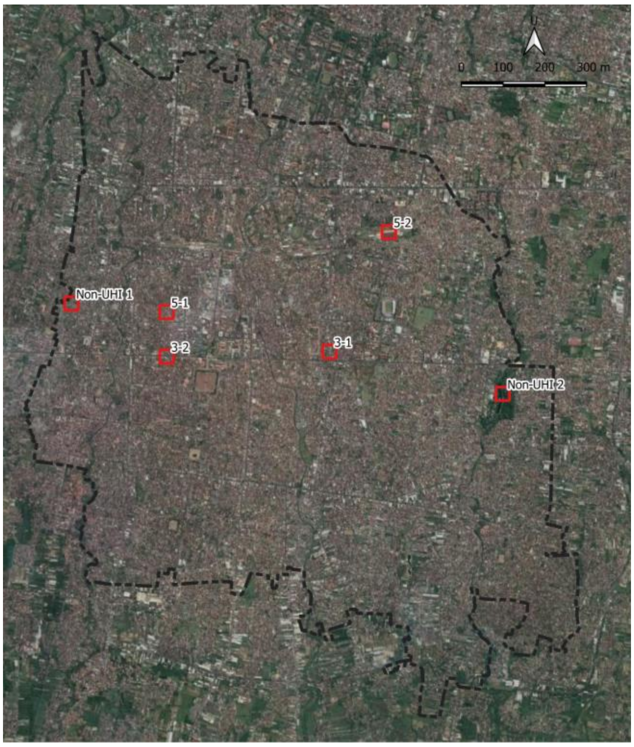


Figure 2. Location of samples from Google Earth (2021).

Results and Discussion

UHI Intensity Class

The results of the measurement of UHI in Yogyakarta City indicate that the city has a fairly high temperature (Table 3). It is shown in the UHI threshold value of a temperature is 37.51°C. Although T mean is lower than the UHI threshold, the average temperature is considered high according to Physiological Equivalent Temperature (PET). PET set the comfort temperature for human is below 29°C (Matzarakis, et al., 2016). In addition, the temperature of 37° - 42°C is distributed dominantly in the city area (Figure 3). Based on the LST map, the high LST is presented by the darker color of red while the lighter color reflects the lower LST. The high surface temperature can lead to high UHI. The UHI intensity of 5.41 °C indicates the temperature difference between UHI and the non-UHI. This result has been obtained by considering the area of the city of Yogyakarta and its surroundings with a buffer of 2 km. This buffer is included as a comparison of the urban area of Yogyakarta with rural areas. The urban temperature needs to be compared with the rural temperature so that the UHI will only focus on the city phenomenon.

Table 3. Results of Measuring UHI.

Area	Temperature (°C)				UHI Threshold (°C)	UHI Intensity (°C)
	Min	Max	Mean	Std Dev		
Yogyakarta + Buffer 2 km	28.76	44.11	36.29	2.45	37.51	5.41

The map of UHI intensity shows six classes with different colors (Figure 4). The high UHI intensity is presented in red color while the non-UHI are presented in dark green. The class between them is moderately presented by orange, yellow, and light green. High UHI intensity reflects high human activity, high building density, and low green area, while low UHI reflects a larger green area. The distribution of UHI intensity class shows that areas outside the city of Yogyakarta have low UHI values along with reduced building density. The UHI intensity shows the areas which have a temperature difference from their surrounding areas. UHI 5 means there is 4°-5°C difference with the surrounding area.

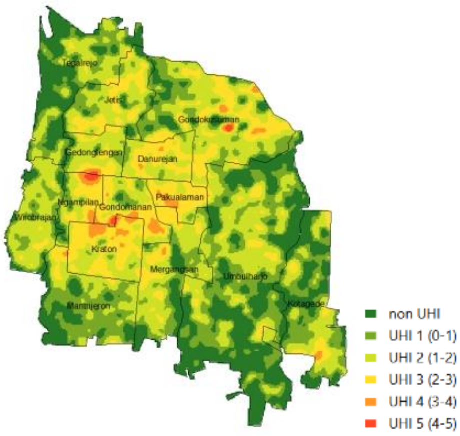


Figure 4. UHI intensity.

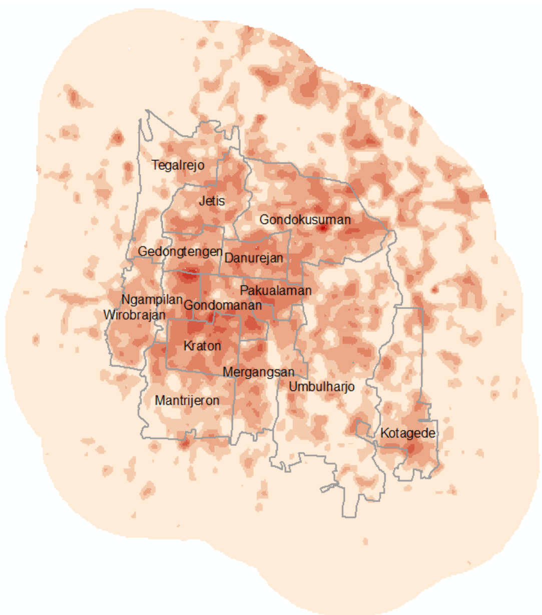
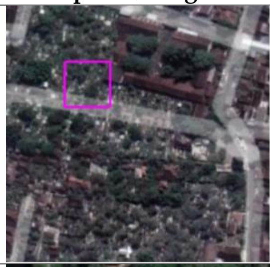
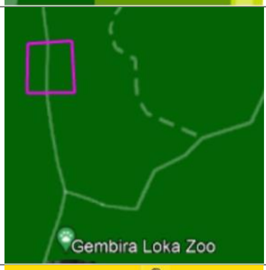
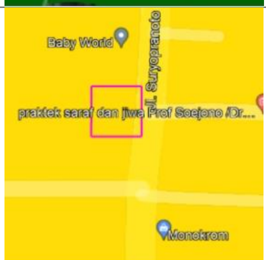
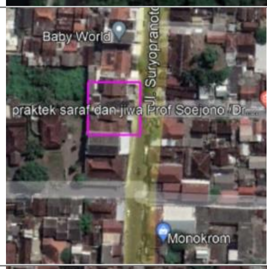
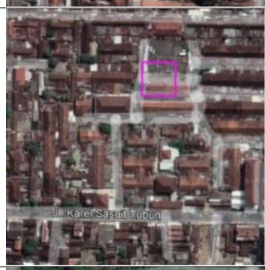
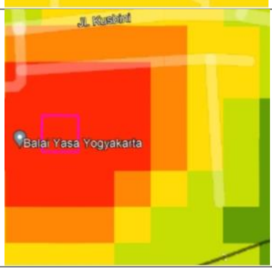


Figure 3. LST with 2 km buffer.

Landuse proportion

Based on the sampling results on the UHI intensity map, the proportions in each sample pixel are shown in Table 4. This table shows the percentage of vegetation area and non-vegetation area in a pixel-based on UHI class and LST. The non-UHI class shows lower temperatures than other classes due to the relatively high percentage of vegetation. In the non-UHI1 class, the percentage of vegetation was 15.33% which caused the temperature to be 37.64°C while the non-UHI2 class showed a lower temperature of 31.48 °C. This decreased temperature is affected by the increase in vegetation area. Various forms of vegetation are distributed over different landuses, such as zoos and cemeteries. Then in the UHI3 class, the temperature is around 41°C. A fairly high temperature indicates the proportion of built-up area that dominates the pixel sample. Pixels with a temperature of 41.37°C are entirely non-vegetation areas or built-up areas, while pixels with a temperature of 41.15°C have a vegetation percentage of 13.27%. The landuse types commonly found at high temperatures are settlements, commercial buildings, and roads.

Table 4. Analysis of Landuse Proportion.

UHI Class	Map of UHI Intensity Class	T (°C)	Empiric (Google Earth)	Landuse Proportion
non-UHI 1		37.64		Cemetery Vegetation: 15.33% Non-vegetation: 84.67%
non-UHI 2		31.48		Gembiraloka Zoo Vegetation: 43.91% Non-vegetation: 56.09%
3-1		41.37		Commercial building and settlement Non-vegetation: 100%
3-2		41.15		Road and commercial building Vegetation: 13.27% Non-veg: 86.72%
5-1		43.31		Road and governmental office building Non-vegetation: 100%
5-2		44.11		Train warehouse (KAI) Non-vegetation: 100%

The UHI5 class or the highest class shows very high temperatures at around 43.31°C in the UHI5-1 class and 44.11°C in the UHI5-2 class. Based on Table 4, the temperature of 44.11°C is the highest in the Yogyakarta City whose landuse type is a train warehouse from *Kereta Api Indonesia* (PT KAI). This warehouse has a zinc roof so it can absorb heat from sunlight massively. Meanwhile, the temperature of 43.31°C is on the road and governmental buildings. In these two sample pixels, the percentage of non-vegetation is 100%. This indicates that there is no cooling effect from the vegetation to the surrounding area.

Discussion

Looking at the map of LST (Figure 3) and UHI intensity (Figure 4), the UHI intensity classes distribute in sub-districts in Yogyakarta. Sub-districts showing high LST are the sub-districts that have high human activities. The high LST will lead to a higher UHI. The sub-districts which have high activities are the Sub-districts of Gedongtengen, Danurejan, Gondokusuman, Gondomanan, Ngampilan, Kraton, Pakualaman, and Kotagede. These sub-districts are centers of densely populated settlements which are also interspersed with public and commercial buildings. Sub-districts located in the peripheral area have a lower temperature so it becomes low UHI class.

The UHI condition indicates that Yogyakarta City is dominated by built-up areas. Yogyakarta with all its uniqueness has invited many people to have activities in it. The denser the population of an area, the more space is needed to facilitate more activities and continue the development. Various public facilities, accommodation, and shopping centers are increasingly crowded in Yogyakarta. Although Yogyakarta is already dominated by built-up areas, there is potential to change the UHI intensity classes through an intervention of government policies. Thus, the results of this UHI intensity map can be used as a guideline for the government in making plans for reducing the adverse effects of UHI.

The results of the landuse proportion in the class of non-UHI1 and UHI3-2 show interesting facts. The landuse proportion especially for the percentage of vegetation, in both of the classes, shows a small difference percentage at 15.33% and 13.27% respectively. This small difference can create a significant temperature difference (around 3°C). In another word, the vegetation area is matters despite it being only a small area. The vegetation area can influence the surrounding area and give a cooling effect.

Conclusions

Yogyakarta City is facing climate change and urbanization so these create UHI effect. This research tried to measure UHI intensity and investigate the proportion of landuse in Yogyakarta through spatial analysis. The first result of this research shows the distribution of UHI intensity class. It also informs the LST distribution in Yogyakarta City which is dominated by the high surface temperature (37° - 42°C). In general, non-UHI areas are located on the peripheral of the city, while the high intensity of UHI is in urban activity centers distributed in some sub-districts. The second result is the proportion of landuse based on UHI intensity class. The results of sample identification in the non-UHI intensity class showed the proportion of 43.91% vegetation and 56.09% non-vegetation (roads). Meanwhile, the high UHI intensity class showed a proportion of 100% non-vegetation (built-up area). The high intensity of UHIs is dominated by built-up areas such as settlements, public buildings, and roads. On other hand, the low intensity of UHIs is caused by the vegetation area such as forests and parks.

The results of UHI measurement could be more detailed by adding more samples in each UHI intensity class. More samples give the detailed proportion for analyzing at the subdistrict level. In addition, further investigation regarding the effect of vegetation and urban landscape are needed. Both of the research can help planners or decision-makers to formulate public policy in reducing urban temperature.

Conflict of Interest: The authors have no conflicts of interest concerning the publication of this article.

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