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The Role of Vegetation in Controlling Air Temperature Resulting from Urban Heat Island

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Abstract. Urban Heat Island (UHI) is a phenomenon exhibited by many worldwide cities. Cities, which exhibit UHI, possess higher air temperature as compared with air temperature in the surrounding areas. However, existing UHI profiles are those occurring in subtropical areas which are, of course, very much different from those in tropical cities. Therefore, the objectives of this study are to describe the UHI's profile and the role of tree vegetation in controlling and reducing air temperature in a tropical region's urban areas and, particularly, in DKI Jakarta. In this study, we carried out a spatial analysis of land cover and the distribution of air temperature. In this regard, we based our analysis of the potency of tree vegetation in reducing air temperature in UHI's profile on the distribution of air temperature in various types of land cover which extended from north to south and from east to west. The ranges of air temperature in land cover in the form of built-up areas were 29.2-39.5 ^{0}C, non-tree vegetation 28.6-35.6 ^{0}C, and tree vegetation 27.0-35.7 ^{0}C. Accordingly, tree vegetation has the highest potential to reduce air temperature and to overcome the phenomenon of UHI.

Keywords: air temperature, built-up area, land cover, tree vegetation, Urban Heat Island.

Abstrak. *Urban Heat Island (UHI) merupakan fenomena yang dialami oleh banyak kota di dunia. Kota-kota yang mengalami UHI memiliki suhu udara yang lebih tinggi dibandingkan suhu udara di sekitarnya. Namun profil UHI yang ada saat ini merupakan profil UHI kota yang berada di wilayah subtropis yang tentunya sangat berbeda dengan kota-kota di tropis. Oleh karena itu penelitian ini bertujuan untuk menggambarkan profil UHI dan peran tree vegetation in controlling air temperature di perkotaan wilayah tropis khususnya DKI Jakarta. Penelitian ini bertujuan mengkaji profil UHI di DKI Jakarta serta potensi vegetasi pohon dalam menurunkan suhu udara. Metode yang digunakan adalah dengan melakukan analisis spasial tutupan lahan dan distribusi suhu udara. Profil UHI dianalisis berdasarkan distribusi suhu udara berdasarkan tutupan lahan yang membentang dari arah utara-selatan dan barat-timur. Potensi vegetasi pohon dalam menurunkan suhu udara dalam fenomena UHI dilakukan dengan menganalisis suhu udara berdasarkan jenis tutupan lahan. Kisaran suhu udara pada jenis tutupan lahan berupa lahan terbangun yaitu 29.2-39.5 ^{0}C vegetasi non pohon 28.6-35.6 ^{0}C, vegetasi pohon 27.0-35.7 ^{0}C. Vegetasi pohon berpotensi menurunkan suhu udara dan dapat mengatasi UHI.*

Kata Kunci: *lahan terbangun, suhu udara, tutupan lahan, Urban Heat Island, vegetasi pohon.*

1. Introduction

Conversion of vegetated area to an impermeable surface is caused by the Urban Heat Island (UHI) phenomenon which occurs in many worldwide cities such as in China (Chen *et al.*, 2006; Li *et al.*, 2012)Shanghai city, the biggest city in China, was selected as the case for quantifying the impact of land-use/land cover (LULC and in other Asian cities (Aflaki *et al.*, 2017). As one of Indonesia's largest cities, Jakarta has experienced the UHI phenomenon which causes urban air temperature to be higher than those of the surrounding areas. This condition reduces environmental convenience. This UHI phenomenon is caused by a high concentration of air pollutants and, more particularly, greenhouse gases. This high concentration of greenhouse gases is not followed by sufficient presence of open green space (particularly in the form of tree vegetation). On the other hand, there is a very high percentage of built-up areas in urban areas. Rushayati *et al.* (2015) identified that DKI Jakarta's built-up area is increasing rapidly based on a study of time series data. In 2000, the size of the built-up area was 39,026.54 ha and, in 2012, it was 46,404.76 ha.

UHI is a common problem of cities worldwide. Mohan *et al.* (2012) explain that UHI occurs in urban areas with infrastructures and commercial centres. According to Akbari (2008), an urban centre's high air temperature is due to the strong absorption of radiation by roofs and pavements. High air temperature occurs, also, during the summer months in large international cities such as London, Los Angeles, China, and in large Indonesian cities such as DKI Jakarta, Surabaya, Semarang, and Bandung.

The presence of UHI will be higher in highly populated cities with a low percentage of green open spaces. This is due to a high concentration of greenhouse gases, a high percentage of a built-up area and a low percentage of green open spaces (particularly those in the form of tree vegetation). This condition creates the greenhouse effect that traps the emission of longwave radiation and causes air temperature to increase. Besides increasing air temperature, the negative impacts of UHI in a tropical area reduce air humidity and environmental convenience. An unpleasant urban microclimate reduces the productivity of the people working there.

Several studies on UHI were conducted in sub-tropical regions such as in the cities of Guangzhou, Los Angeles, Phoenix, Houston, Atlanta, New York and Mexico. The climate and weather conditions in those regions were different from those in tropical regions. Although the problems of urban areas are probably similar, the different climate and weather conditions of weather create different UHI profiles. Therefore, the analysis of a tropical region's UHI profile is critical in serving as a basis to overcome the negative impacts of UHI.

The negative impacts of UHI can be resolved by reducing greenhouse gas emissions and by increasing green open spaces particularly in the form of tree vegetation. Rushayati *et al.* (2015) explain that, although urban areas have high air temperatures, green open spaces can reduce air temperature more significantly than built-up areas. Therefore, green open spaces have a great role to play in reducing air temperature. Based on the important role of the green open space and due to the presence of UHI in urban areas, the objective of this research is to study the potency of green open space, particularly in the form of tree vegetation, in controlling high air temperature. In this study, we performed a spatial analysis of the distribution of surface temperature which was overlaid with land cover and land use map so that they could describe DKI Jakarta's UHI profile and the role of tree vegetation in controlling air temperature resulting from UHI.

2. Research Method

2.1. Location and Time of Research

This research was conducted in DKI Jakarta, with geographic position of 5^0 19'12''-$6^0$23'54'' S and $106^0$22'42''-$106^0$58'18'' E, and with an area size of 661.52 km^2. The study area included administrative municipal of North Jakarta, Central Jakarta, South Jakarta, East Jakarta and West Jakarta. Java Sea borders the northern part of the area with Bekasi Municipal and Bekasi District on the east, Depok District on the south, and Tangerang Municipal and Tangerang District on the west. Figure 1 describes the research location.

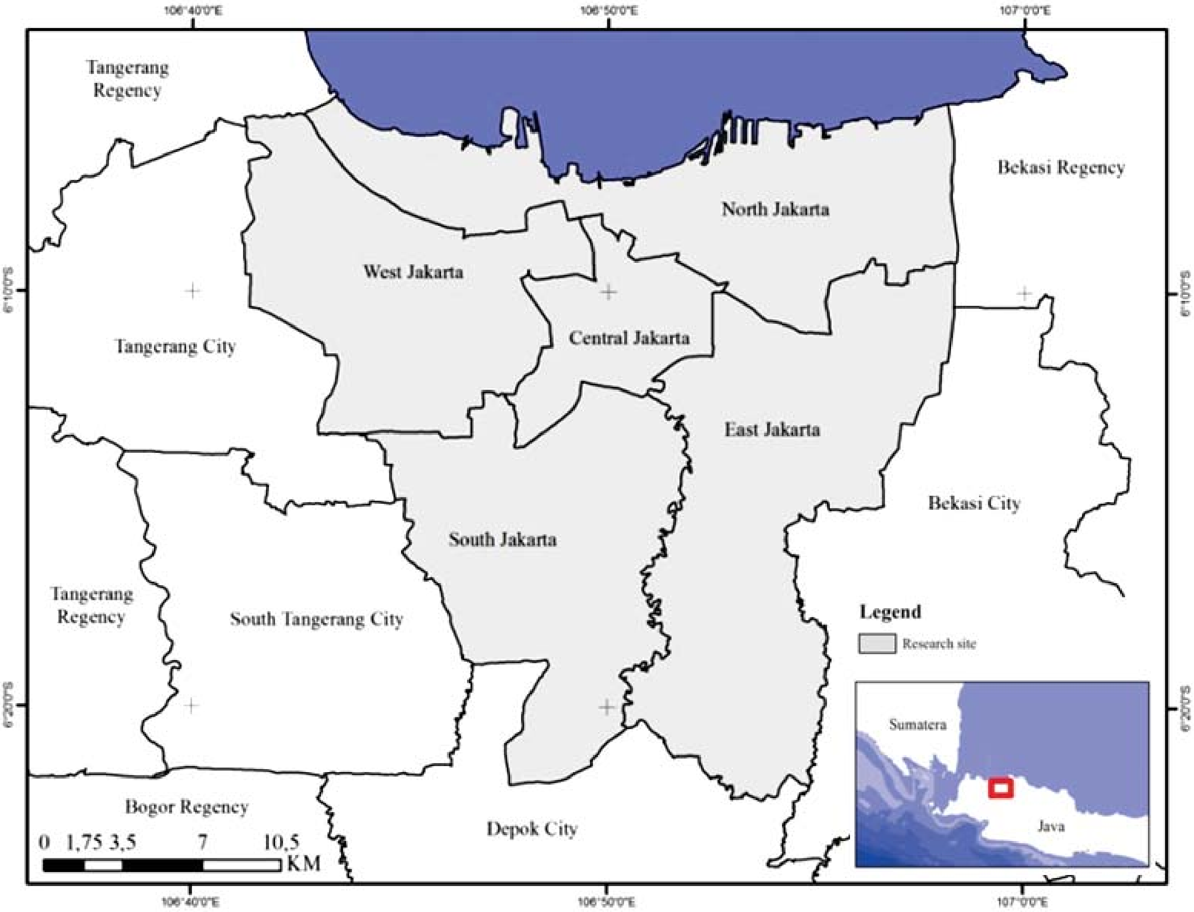

Figure 1. Research location in DKI Jakarta.

2.2. Data Collection and Source

Erdas Imagine 9 was used to analyse the remote sensing data images. Meanwhile, we used ArcGIS 10.3 for spatial analysis. We obtained Landsat 8 imagery (Path/Row: 122/64) with an acquisition date of 13 September 2014 by downloading from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). The ground check was conducted by using GPS to locate the coordinates supported by secondary information generated from Google Earth.

2.3. Data Analysis

Spatial analysis procedures were used to analyse remote sensing data in obtaining the information. We conducted spatial data analysis of types of land cover and constructed the distribution of air temperature which we used afterwards to analyse the phenomena of DKI Jakarta's UHI and to study the potency of tree vegetation in overcoming the phenomena of UHI and, more particularly, in terms of the reduction of air temperature.

2.4. Spatial Analysis of Land Cover

We conducted spatial analysis of land cover by classifying the obtained land cover from imagery processing through using Google Earth of 2014 for supervised imagery classification. We classified land cover as water bodies, built-up areas, tree vegetation cover, and non-tree vegetation cover.

2.5. Air Temperature

We used the following procedure to get the air temperature value from spectral data (USGS, 2013). There are several formulae (Equation 1 to 12) used in this procedure to obtain the temperature value. Mainly, the air temperature was calculated based on Equation 1.

$$T_a = T_s - \left[\frac{H\, r_{aH}}{\rho_{air}\, C_p}\right] \qquad (1)$$

where,

Ta : air temperature (K).
Ts : surface temperature (K) (see Equation 2).
H : sensible heat fluxes kj(Wm-2 (see Equation 3).
raH : aerodynamic resistance (sm-1).
ρair : moist air density (1.27 Kg m3).
Cp : air specific heat at constant pressure (1004 JKg-1 K-1).

Equation 2 was used to determine the value of surface temperature (T_s) which is required by Equation 1.

$$T_S = \frac{T_B}{1+\left(\frac{\lambda T_B}{\delta}\right) x \ln(\varepsilon)} \qquad (2)$$

where,

T_S : surface temperature (K).
T_B : satellite brightness temperature (K) (see Equation 4).
λ : wavelength of the emitted radiation (Landsat 5=11.5 μm; Landsat 8=10.8 μm).
δ : hc/σ (the figure is 1.438 10^{-2} m K).
h : Planck's constant (6.62 10^{-34} J sec).
c : speed of light (2.998 10^{8} m.sec^{-1}).
σ : Stefan-Boltzmann constant (1.38 10^{-23} JK^{-1}).
ε : object emissivity (water body =0.98; GOS=0.95; non-GOS=0.92).

While the following formula was used to obtain the value of sensible heat fluxes (H),

$$H = \frac{\beta(R_n - G)}{1+\beta} \qquad (3)$$

where,

H : sensible heat (Wm-2).
β : Bowen ratio.
Rn : net radiation (Wm-2).
G : soil heat flux (Wm-2) (see Equation 6).

The following formula (Equation 4) was used to determine the value of satellite brightness temperature (T_B) as required by Equation 2,

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \qquad (4)$$

where,

T_B : satellite brightness temperature (K).
K_1 : Calibration constant.
K_2 : Calibration constant.
L_λ : value of spectral radiance (see Equation 5).

Value of spectral radiance (L_λ) for above formula (Equation 4) was calculated based on the following equation,

$$L_\lambda = \left(\frac{L_{MAX(i)} - L_{MIN\,(i)}}{QCal_{MAX} - QCal_{MIN}}\right) x\, (QCal - QCal_{MIN}) + L_{MIN\,(i)} \qquad (5)$$

where,

L_λ : spectral radiance value (Watts/(m^2 * srad * μm)).
QCal : digital number.
$L_{MIN(i)}$: minimum spectral radiance.
$L_{MAX(i)}$: maximum spectral radiance.
$QCal_{MIN}$: minimum pixel value.
$QCal_{MAX}$: maximum pixel value.

Soil heat flux (G) of Equation 3 was determined using Equation 6:

$$G = \frac{T_s}{\alpha}(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98NDVI^4)(R_n) \qquad (6)$$

where,

G : soil heat fluxes (Wm-2).
Ts : surface temperature (°C).
α : albedo (see Equation 7).
Rn : net radiation (Wm-2) (see Equation 8).
NDVI : Normalized Differential Vegetation Index. Equation 9 is used to calculate this value.

Albedo (α) value for Equation 6 is the ratio between reflected short wave radiation and incoming short wave radiation. Equation 7 was [illegible] alue:

$$\alpha = \frac{\pi\, x\, L_\lambda\, x\, d^2}{ESUN\, x \cos\theta_s} \qquad (7)$$

where,

L_λ : radiation spectral value (Watts/(m2 * srad * μm)).

d : astronomic distance between sun and earth (astronomy).

ESUN : average value of spectral solar irradiance.

θs : solar zenith angle (rad).

Net radiation (Rn) value of Equation 6 was calculated using the following formula:

$$\mathrm{Rn} = \mathrm{Rs_{in}} - (\mathrm{Rs_{out}} + \mathrm{Rl_{out}}) \quad (8)$$

where,

Rn : net radiation (Wm-2).

Rs_{in} : incoming shortwave radiation (Wm-2) (see Equation 10).

Rs_{out} : reflected shortwave radiation (Wm-2) (see Equation 11).

Rl_{out} : reflected longwave radiation (Wm-2) (see Equation 12).

Meanwhile, for the NDVI, the following formula is used for the calculation:

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}} \quad (9)$$

where,

NIR : near infrared canal reflectance.

Red : red canal reflectance.

Equation 10 shows the formula to calculate incoming shortwave radiation (R_{sin}) of Equation 8:

$$\mathrm{Rsin} = \frac{\mathrm{Rs\ Out}}{\alpha} \quad (10)$$

where,

Rsin : incoming shortwave radiation (Wm-2).

Rsout : reflected shortwave radiation (Wm-2) (see Equation 11).

α : albedo (see Equation 7).

Equation 11 shows the formula to calculate reflected shortwave radiation (R_{out}) of Equation 8:

$$\mathrm{Rsout} = \pi \times L_\lambda \times d^2 \times \frac{1}{\mathrm{band}} \quad (11)$$

where,

Rsout : reflected shortwave radiation (Wm^{-2}).

Lλ : spectral radiance value (Watts/(m^2 * srad * μm)).

d : astronomic distance between sun and earth (astronomy).

1/band : Half-Amplitude Bandwidth.

Equation 12 shows the formula to calculate reflected longwave radiation (Rl_{out}) of Equation 8:

$$\mathrm{Rlout} = \varepsilon \times \sigma \times \mathrm{Ts}^4 \quad (12)$$

where,

Rlout : reflected longwave radiation (Wm-2).

ε : emissivity (water body =0.98; GOS=0.95; non-GOS=0.92).

σ : Stefan Boltzmann constant (5.67 x 10-8 Wm-2K-4).

Ts : surface temperature (K).

2.6. Profile of UHI

We locate the cross-section profile of air temperature on the air temperature map which was overlaid with land cover in DKI Jakarta and the surrounding areas (Tangerang, Tangerang Selatan, Bekasi, Depok, and Bogor). These points were taken in accordance with the 4 geographic direction from the central point, namely, Jakarta's National Monument (Monas). We analysed the role of vegetation in amelioration of climate, particularly the parameter of air temperature, by comparing the air temperature in an area with tree vegetation with that of an area which did not have tree vegetation. Figure 2 presents the construction method of the UHI profile.

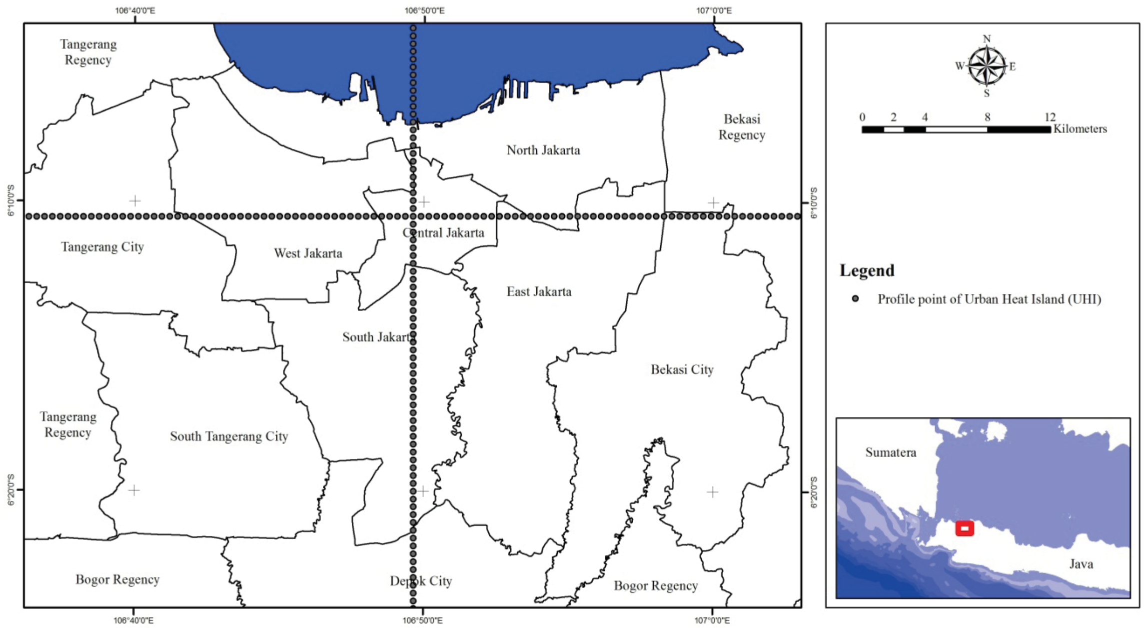

Figure 2. Method of construction of UHI Profile.

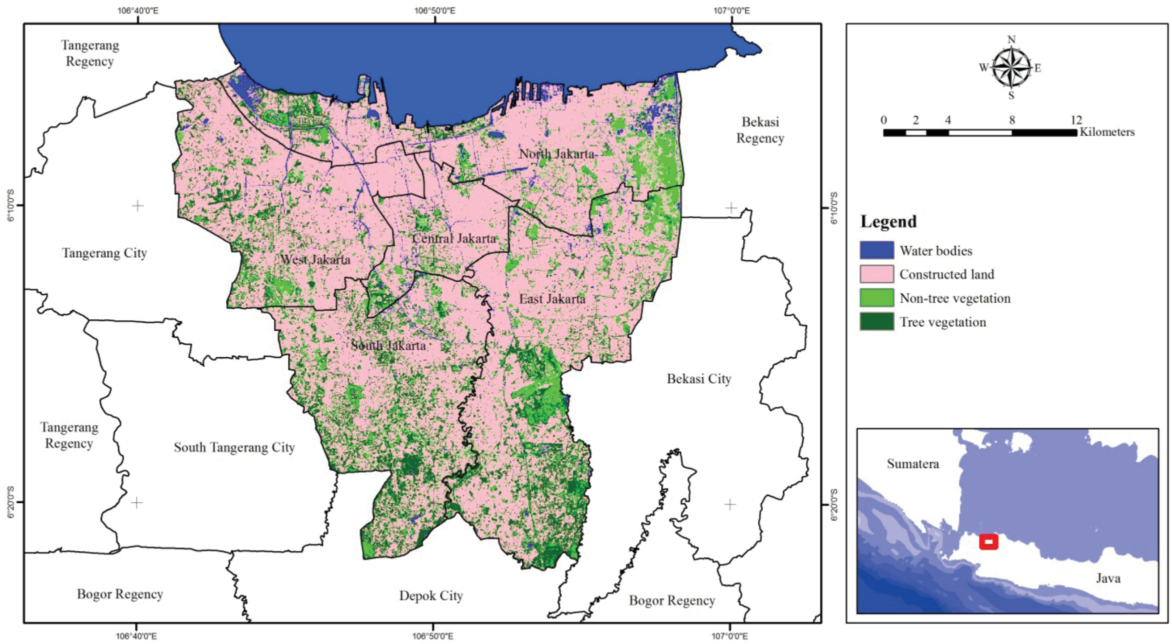

Figure 3. DKI Jakarta's Land Cover in 2014.

3. Results and Discussion

3.1. Land Cover

The spatial analysis results of land cover in 2014 showed that built-up areas dominated the land cover in DKI Jakarta's five territories (North Jakarta, South Jakarta, West Jakarta, East Jakarta, Central Jakarta). The built-up areas in North Jakarta were 74.5%, 69% in South Jakarta, 70.3% in East Jakarta, 82% in West Jakarta and 82.7% in Central Jakarta. The green open space, particularly that of tree vegetation, was 10% in North Jakarta, 22.8% in South Jakarta, 12.7% in West Jakarta, 18.9% in East Jakarta and 9.7% in Central Jakarta 9.7%. Non-tree vegetation was 9% in North Jakarta, 7.5% in South Jakarta, 4% in West Jakarta, 10% in East Jakarta and 5.4% in Central Jakarta. High percentages of built-up areas were due to the size of DKI Jakarta's human population. According to the 2014 census, the residents of DKI Jakarta reached 10.08 million people (BPS, 2016). Figure 3 presents DKI Jakarta's land cover.

Figure 4. Profile Diagram DKI Jakarta's UHI of in 2014 (North to South direction).

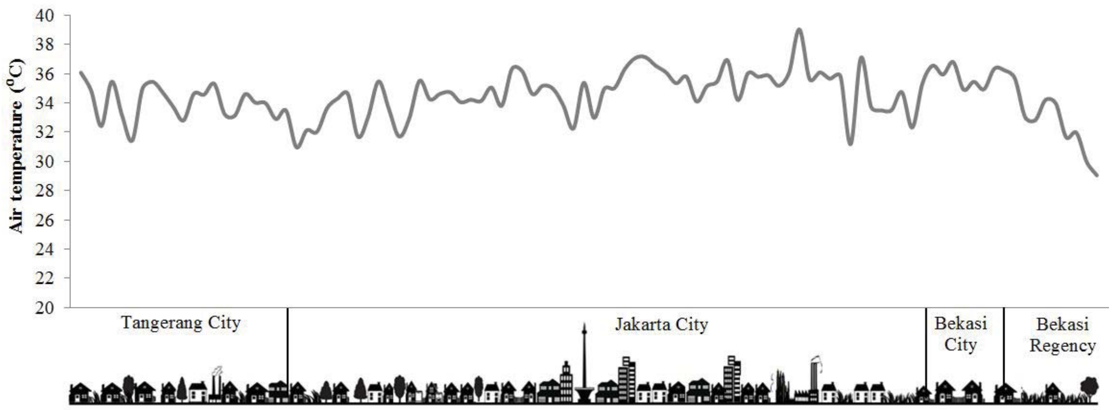

Figure 5. Profile diagram of DKI Jakarta's UHI in 2014 (west to east direction).

Rushayati *et al.* (2015) explain that DKI Jakarta's development has caused an increase of built-up area from year to year. The size of the built-up area was 39,026.54 ha in 2000 increased to 46,404.76 ha in 2012. Based on this research's spatial analysis, the size of the built-up area increased again to 47, 559.3 ha in 2014. Continuous increases in the size of the built-up area have the potential to increase the negative impact of UHI, namely, through the increase of air temperature.

Besides being affected by the built-up area, the condition of UHI is also affected by green open space which can reduce air temperature and the negative effects of UHI. Rushayati (2015) explains that an increase in the size of the built-up area and a reduction in green open space causes the air temperature to increase. This finally affects to the presence of UHI.

DKI Jakarta has experienced an increase in built-up area and a reduction in green open space; this creates a worrying situation. Therefore, there is a need to control the conversion of land from green open space to the built-up area. Areas, which are still in the form of green open spaces, should be maintained because green open space can reduce air temperature and the negative effects of UHI. Ballinas and Barradas (2016) explain that 24 large trees can reduce air temperature by two degrees Celsius. The reduction in air temperature by large trees occurs through the evapotranspiration process. Evapotranspiration uses net energy so that it can reduce the surface temperature and the surrounding air temperature.

3.2. Profile of UHI

During the occurrence of UHI in the year 2014, DKI Jakarta's average air temperature was 34.1 ^{0}C. The largest area size occurred at air temperature range 33-<36 ^{0}C, namely 33 which covers 160.1 ha (52%). Air temperature of >36 °C occurred in East Jakarta and North Jakarta, where there were industries in those areas there. The profile diagram of air temperature for the north to south direction extends to a distance of 37.5 km (Figure 4). The average air temperature of this profile was 34.2 °C.

In the west to east direction with a distance of 50 km, the average air temperature was 34.7 °C. Figure 5 shows the UHI's profile from the west to east direction. Based on the profile diagram of UHI, air temperature is determined very much by the types of land cover. The type of land cover in the form of a built-up area creates a high air temperature. On the other hand, the type of land cover in the form of tree vegetation creates an urban microclimate with lower air temperature. Weng and Yang (2004) explain that the City of Guangzhou's problem was the UHI which was due to progressive increases in the city's built up area. Depending on weather conditions, the difference in air temperature between that at the centre of the city and rural areas ranged from 0.2 to 4.7°C. Rushayati (2011) explains that based on research in the regency of Bandung, it is known that with the progressive increase in the built-up area and the progressive reduction in green open space, the surface temperature increases progressively.

3.3. The Role of Tree Vegetation in the Reduction of Air Temperature

Based on the spatial analysis of land cover and the distribution of air temperature and the profile of UHI which were analysed across north - south and west-east direction, it was known that land cover in the form of tree vegetation was proven to reduce air temperature. The ranges of air temperature, categorised into types of land cover, were as follows: various types of land cover in the form of built-up areas exhibited air temperature between 29.2 and 39.5 ^{0}C; that of non-tree vegetation between 28.6 and 35.6 ^{0}C; that of tree vegetation between 27.0 and 35.7 ^{0}C; and that of water bodies between 24.0 and 33.7^{0}C.

Tree vegetation is very important in reducing air temperature. Ballinas and Barradas (2016) explain that 24 large trees can reduce air temperature by up to 2 °C. The reduction of air temperature by tree vegetation occurs through evapotranspiration process which uses net energy so that it can reduce surface temperature and the surrounding air temperature. Haashemi *et al.* (2016) reported on the role of tree vegetation in the agricultural area of Tehran, Iran between September 2013 and September 2015. This showed a difference as large as 8.2 °C in surface temperature between the urban area and the agricultural area. The agricultural area exhibited lower surface temperature as compared with that of urban area.

This research results showed that air temperature in the built-up area, which was surrounded by tree vegetation, was 2.4 ^{0}C lower as compared with that of the built-up area without tree vegetation. The average air temperature of non-tree vegetation, occurring around tree vegetation, was also 0.1 ^{o}C lower as compared with air temperature without tree vegetation. Based on such analysis, it was known that tree vegetation possessed the potential to reduce air temperature and is able to overcome the negative impact of UHI.

The role of tree vegetation in reducing air temperature was observed, also, in the analysis of air temperature in the built-up area with tree vegetation and in a built-up area without tree vegetation. The air temperature, in the built-up area surrounded by tree vegetation, was 2.4 ^{o}C lower than that in the built-up area without tree vegetation. The average temperature of non-tree vegetation, occurring around tree vegetation, was, also, 0.1 ^{o}C lower as compared with non-tree vegetation occurring around non tree vegetation. This phenomenon proved that tree vegetation was very important in reducing air temperature in the surrounding areas. A study by Effendy *et al.* (2006) support the results of this study. This explained that the presence of tree vegetation had the ability to retain water and caused 53% of the net radiation to evaporate water so that land cover with tree vegetation tended to be wet and to create cooler air temperature.

Rushayati *et al.* (2015), explained that the difference in surface temperature between green open space and that of built-up areas reached 2.8 ^{0}C. Based on Ramdoni *et al.*'s (2015) research, it was known that from 2001 until 2014 there was a 13 % increase in built-up areas and a 5.1% decline in tree vegetation. Such conditions caused the surface temperature to increase by 2-4 ^{0}C and the air temperature to increase by 2-3 ^{0}C.

Xiao and Weng (2007) conducted research in Guizhou province, South China, based on Landsat Thematic Mapper (TM) images of November 7, 1991, December 5, 1994, and December 19, 2001. Based on this research, it was known that there was a reduction in agricultural land, an increase in urban areas, a slight increase in forestation, barren land increased from 1991 until 1994, afterwards, declined from 1994 to 2001. This change widened the temperature difference between urban areas and the surrounding areas. This research proves, also, that vegetation can reduce the trend of increasing air temperature in urban areas.

Weng and Yang's (2004) research in the city of Guangzhou, South China, showed that the type of land cover affected greatly surface temperatures. The lowest measured surface temperatures was found in forest land cover (29.88°C), followed by agriculture (30.96°C) and the highest surface temperature was measured in the Badlands (32.94°C). Besides intercepting solar radiation, tree vegetation can reduce air temperature through absorption of greenhouse gases and, more particularly t CO_2 through the photosynthesis process. Purbaya *et al.* (2017) explained that *Tamarindus indica, Adenanthera pavonina, Samanea saman,* and *Ceiba pentandra* tree vegetation had great ability to absorb CO_2 is. Some of these researches proved that vegetation, particularly the tree vegetation, was very influential in reducing surface temperature and air temperature either through interception of solar radiation by tree crowns or absorption of CO_2 through photosynthesis process, consequently, the negative impact of UHI can be overcome.

The size of built-up area and green open space (tree vegetation) determines the condition of UHI in urban areas very much. Based on a simulation by Fu and Weng (2017) which used the scenario of land use in the summer time, it can be shown that UHI responds to a various change in land uses. Consequently, we recommend that managers and policymakers consider the potential impact of the policy of urban growth in creating the thermal environment.

Knight *et al.* (2016) reported that UHI increased intensity and frequency of heat-waves, especially in urban areas. UHI can be overcome by establishing tree vegetation. Evapotranspiration by plants can reduce their absorption of radiation and reduce heat retention so that air temperature can be reduced.

4. Conclusion

The ranges of air temperature in land cover in the form of built-up areas were 29.2-39.5 ^{0}C, non-tree vegetation 28.6-35.6 ^{0}C, tree vegetation 27.0-35.7 ^{0}C, and water bodies 24.0-33.7^{0}C. Besides water bodies, tree vegetation has a significant role in overcoming UHI, because both can reduce air temperature. The air temperature in built-up areas, surrounded by tree vegetation, was 2.4 ^{0}C; this was lower when compared with air temperature in built-up areas without tree vegetation. The average temperature of non-tree vegetation, occurring around tree vegetation, was, also, 0.1 ^{o}C lower than the air temperature of non-tree vegetation.

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