Spatial temporal analysis of urban heat hazard in Tangerang City

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Abstract. Urban heat is a natural phenomenon which might caused by human activities. The human activities were represented by various types of land-use such as urban and non-urban area. The aim of this study is to identify the urban heat behavior in Tangerang City as it might threatens the urban environment. This study used three types of remote sensing data namely, Landsat TM, Landsat ETM+ and Landsat OLI-TIRS, to capture the urban heat behavior and to analysis the urban heat signature of Tangerang City in 2001, 2012, 2013, 2014, 2015 and 2016. The result showed that urban heat signature change dynamically each month based on the sun radiation. The urban heat island covered only small part of Tangerang City in 2001, but it was significantly increased and reached 50% of the area in 2012. Based on the result on urban heat signature, the threshold for threatening condition is 30 °C which recognized from land surface temperature (LST). The effective temperature (ET) index explains that condition as warm, uncomfortable, increase stress due to sweating and blood flow and may causing cardiovascular disorder.

Keywords: land surface temperature, urban heat signature, spatial-temporal analysis, urban environment threat

1. Introduction

The IPCC 2007 report on the “Science of Climate Change” showed a small increase in temperature and rainfall for the Southeast Asia Region in the last 50 years or so. There is a general agreement amongst scientists that the changing behavior patterns of the el-Nino ENSO, Monsoons and to a certain extent the Indian Dipole Oscillation circulation systems are triggering extreme weather and variability to influence changing behavior patterns of hydro-meteorological and geomorphological events (floods, haze pollution and slope failures) in the region in general. The last half decade has showed that societies and their whole rubric of livelihood systems (that include low income economic systems and modern production systems) are becoming more threatened and more vulnerable to climate change induced hazards and their ability to adapt to these imposing conditions are becoming more demanding and would get worst in the near future. The significance of climate “variation” or “change” depends not only on the behavior of the change itself but also on the characteristics of society and systems exposed to the changes [1].
Asian cities are the most rapidly growing regions of the world nowadays and 16 of the world’s 24 mega cities (cities with more than 10 million people) will be located in Asia by the year 2015 [2, 3]. Urbanization including residential, commercial and industrial developments initiated one of the most dramatic human-induced change of a natural ecosystem: a natural landscape, often containing transpiring vegetation and a pervious surface, is converted to a built, largely impervious landscape made up of rigid, sharp-edged roughness elements [2]. Urban heating causes many problems for the inhabitants of some cities and areas, in particular those with a tropical environment. Urban heating could deteriorate our living environment, increase energy consumption, elevate ground-level ozone and even increase mortality rates. There are three billion people (48% of the world population) living in urban areas, they are directly exposed to urban heating problems and more people will be vulnerable to these problems as the number of people living in urban areas is expected to grow to five billion by 2030 [3].

With rapid urbanization, there has been a tremendous growth in population and buildings in cities. The rapid growth of a city has concluded that the urbanized areas had significantly higher day-time surface temp as compared to those of the surrounding rural with vegetated areas [2]. The accelerated rate of urban growth in tropical cities highlights the critical necessity of creating more outdoor spaces for leisure and recreation activities of citizens [4]. In Singapore, the primary root of heat island in cities is due to the absorption of solar radiation by mass building structures, roads, and other hard surfaces during daytime and it is doubtless that the UHI effect is aggravated mainly due to the loss of green areas in the urban environment as consequences of rapid population has led to demands for converting natural areas to public housing [5]. In Malaysia, number of factors contributes to the occurrence and intensity of heat island and these include weather, geographic location, time of day and season, city form and city functions [6]. The urban conurbation within urbanized in Selangor has a remarkable heat island despite the less urbanized area in 1988 compared to 1999. The urban land cover can be associated with buildings, road pavement, highways, green parks and also bare soil due to earthwork activities [7]. The urbanized areas had significantly higher day-time surface temperature as compared to those of the surrounding rural with relatively moist vegetated areas. In February 2002, the mean rural temperatures in Bangkok, Manila and Ho Chi Minh City were 29.5 °C, 26.5 °C, and 30 °C respectively. Bangkok has the highest daytime surface UHI intensity of 8 °C, followed by Manila (7 °C) and Ho Chi Minh City (5 °C) in dry season [2].

The condition is similar to temperature trends in Indonesia. The rise of temperature is a phenomenon caused by human activities such as land-use change. It means that changes in land-use are in line with human growth. This research is to identify those circumstances. The study took place in Tangerang City, one of the cities in Banten Province with fast growth, as it is near with Jakarta.

2. Material and method
As it has been explained in the first part of this paper, the urban heat is very much related with land-use and land-cover condition. This research is focusing on analysis on land surface temperature (LST), determine urban heat island (UHI) and its distribution and observation on the impact to urban environment. Tangerang City is chosen as study area, where the rate of urbanization is very rapid, hence the dynamic change of land-use/land-cover were seen.

2.1. Image processing
This paper used indirect data collecting by employing satellite data form Landsat TM, Landsat ETM+ and Landsat OLI-TIRS. The list of Landsat imageries used in this study is showed in Table 1. Thermal band from each data were collected and processed to generate LST. The pixel size is determined at 100 x 100 meter, accordance with [8] who measured UHI in Japan. The grid size is also determined based on spatial representative of land-use and land-cover. Land surface temperature is representing the heat from the land which generated by radiated sun energy [5, 9, 10, 11].
Table 1. List of Landsat imageries in this study

| Year | Path/row | Acquisition date | Remote sensing imagery |
|------|----------|------------------|------------------------|
| 2001 | 122/64   | 15-07-2001       | Landsat TM [15]         |
| 2012 | 122/64   | 27-06-2012       | Landsat ETM+ [15]       |
| 2013 | 122/64   | 12-10-2013       | Landsat OLI-TIRS        |
| 2014 | 122/64   | 15-10-2014       | Landsat OLI-TIRS        |
| 2015 | 122/64   | 18-10-2015       | Landsat OLI-TIRS        |
| 2016 | 122/64   | 13-05-2016       | Landsat OLI-TIRS        |

LST is generated through several steps. The thermal band of Landsat imagery is the main “ingredient” of LST. First, digital number (DN) of the thermal band needs to be converted to spectral radiance. The formula is represented in equation 1 and 2 (Eq. 1 is applied for Landsat TM and ETM+, eq.2 is applied for Landsat OLI-TIRS) [12].

\[
L\lambda = \left[ \frac{(LMAX - LMIN)}{(QCALMAX - QCALMIN)} \right] \times (QCAL - QCALMIN) + LMIN\lambda
\]  

\[
L\lambda = (M \times DN) + A
\]  

where, \(L\lambda\) is spectral radiance (\(\text{Wm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}\)), \(M\) is Multiplicative digital number value at thermal band, DN is digital number of Landsat’s thermal band and \(A\) is additive value of spectral radiance at thermal band.

Second, the spectral radiance resulted from equation 1 is being converted to estimate land surface temperature. The formula is represented in equation 2 [10, 11].

\[
T = K2/\ln((K1/L\lambda) + 1)
\]  

where \(T\) is the temperature at the satellite sensor (Kelvin), \(K1\) is the calibration constant 1 for Landsat, \(K2\) is the calibration constant 2 for Landsat, and \(L\lambda\) is the spectral radiance of band. The utilization of remote sensing imagery to collect urban heat signature have been performed in several studies [5, 11, 12, 13, 14, 15].

Finally, the estimate of LST is being transformed from Kelvin to Celsius by the following formula [11, 16].

\[
LST (\text{celcius}) = T - 272.15
\]  

Based on the equation, low value of LST will be seen in maximum vegetation cover, while minimum vegetation cover will be overlaid with high temperature value [9, 17-19].

2.2. Universal Thermal Climate Index (UTCI) and Effective Temperature (ET) Index

More people are affected by higher temperatures for longer period, higher temperature not only makes life uncomfortable for urban residents it is also adversely affecting people’s health [14, 16]. The comfort thermal for tropical area ranges between 22 °C to 27 °C [20,21,22].

An index called Universal Thermal Climate Index (UTCI) was developed to closely monitor the impact climatic condition on human [16, 23]. There are five categories of heat stress based on the level of temperature, such as Extreme Heat Stress (> +46 °C), Very Strong Heat Stress (+38 to +46 °C), Strong Heat Stress (+32 to +38 °C), Moderate Heat Stress (+26 to +38 °C) and No Thermal Stress (+9 to +26 °C) and In this study, the UTCI is being combined with effective temperature (ET) index to explain the relation between temperature condition and the level of sensation (very hot, hot, warm, slightly warm and neutral), comfort (very uncomfortable, uncomfortable and comfortable),
psychology (body heating, increasing stress due to sweating and blood flow, and normal regulation by sweating and vascular change), and health (circulatory collapse, increasing danger of heat stroke, cardiovascular embarrassment and normal health) [16, 23]. Those indices will determine the urban heat hazard in our study area. Spatio-temporal analysis of urban hazard based on LST have been performed by previous studies [2, 9, 17, 19, 24].

3. Result and discussion.

3.1. Spatial analysis
The distributions of urban heat signature (UHS) were different each year. This study categorizes UHS with high, moderate and low classes based on the LST. The moderate temperature (signed by yellow color) covered 30 to 60 % of Tangerang City in 2013 and 2014. The distribution and density were different in between these two years. For the high temperature (red color), the coverage was higher in 2014 compare to 2013. However, according to LST the maximum temperature was decreased from 37 °C in 2013 to 30 °C in 2014 and becomes 26 °C in 2015, however it increased back to 30 °C in 2016. The area with high temperature in 2013 is mainly agglomerated in the center then it is spread to the west part of Tangerang City. It becomes more equally distributed in 2014 and spread from the center to east part in 2015 and 2016 (Figure 1).

Figure 1. Land surface temperature of Tangerang City from 2013 to 2016
The +30 °C threshold is applied on LST to highlight the distribution of urban heat island (UHI) during 2013 and 2016 in Tangerang City. There is a slight adjustment for 2015, where the threshold is set to +28 °C, due to the maximum LST of 29 °C in 2015. The distribution of UHI in Tangerang City can be seen in figure 2 below. As we can see, the largest area of UHI was occurred in 2013, where it was mostly agglomerated in the southwest part of Tangerang City (Karawaci, Cibodas and Jatiuwung). It was significantly reduced in 2014, where only small area of UHI were gathered in north (Benda) and sparsely distributed in the southwest part of Tangerang City. The area of UHI were increased again in 2015 and mostly distributed in the north (Benda) and southeast part of Tangerang City (Larangan). The area of UHI were slightly reduced in 2016, where it is mostly found in southeast of Tangerang City (Larangan).

Figure 2. Urban heat island in Tangerang City from 2013 to 2016

Figure 3 shows the result from [15], who explained the distribution of UHI in Tangerang City in 2001 and 2012. Based on the result, the UHI were sparsely distributed in north and south part of Tangerang City. During 10 years period, it was greatly increased and found almost in every part of Tangerang City. We can assume that changes of land-use from vegetated area to built-up area as the main reason of these circumstances. If compared with the result from [15], it is known that the area of UHI were significantly reduced during 2012 and 2013.
3.2. Temporal analysis

Based on the LST, the trends show a declining in terms of surface temperature during 2013 and 2015 (Figure 4). The highest temperature was 38.3 °C and it was founded in 2012, while the lowest was 10.62 °C and it was founded in 2015. Based on the LST, we can safely say that 2012 is the warmest period in Tangerang City.

![Figure 3. Urban heat island in Tangerang City in 2001 and 2012](image)

![Figure 4. Temporal trend of urban heat signature in Tangerang City during 2001 until 2015](image)
3.3. Urban heat hazard
The urban heat hazards were determined by relating the temperature value from LST with UTCI. Based on the index, the hazards were occurred in 2012 and 2013, with stress category from strong heat stress to very strong heat stress. Fortunately, there is no extreme heat stress situation available in this study. The relations between temperature and heat stress category are presented in Table 2 below.

Table 2. Universal Temperature Climate Index (UTCI) in Tangerang City

| Range of maximum temperature | Stress category | Year |
|-----------------------------|----------------|------|
| Above 46 °C                | Extreme heat stress | -    |
| +38 to +46 °C              | Very strong heat stress | 2012 |
| +32 to +38 °C              | Strong heat stress   | 2012, 2013 |
| +26 to +32 °C              | Moderate heat stress | 2001, 2014, 2015, 2016 |
| +9 to +26 °C               | No thermal stress    | -    |

To observe more about the impact of urban heat to human body, the effective temperature (ET) index was employed. Based on the ET index, the urban heat were very dangerous in 2012, where high temperature mostly occurred, causing very uncomfortable condition due to the increasing stress caused by sweating and blood flow and increase the probability of heat stroke (Table 3).

Table 3. Effective Temperature (ET) index in Tangerang City

| Year    | Temperature (°C) | Sensation | Psychology | Health                          |
|---------|------------------|-----------|------------|---------------------------------|
|         |                  | Temperature | Comfort    | Body Heating, Failure of Regulation | Circulatory Collapse |
| >40     | Very Hot         | Very Uncomfortable | Increasing Stress Caused by Sweating and Blood Flow | Increasing Danger of Heat Stroke |
| 2012 and 2013 | 35 – 40          | Hot        | Uncomfortable | Cardiovascular Embarrassment |
|         | 32 – 35          | Warm       | Neutral    | Normal Regulation by Sweating and Vascular Change |
| 2014    | 30 – 32          | Slightly Warm | Comfortable | Normal Health |
| 2001, 2015 and 2016 | 25 - 30         | Neutral    | Comfortable | Normal Health |

4. Conclusion
The UHS on Tangerang City with temperature more than 30 °C would become a threat for urban environment. Based on effective temperature index, such condition will bring warm sensation in temperature, which is uncomfortable and might cause increasing stress due to sweating and blood flow and may damage the cardiovascular organ. This condition is dangerous and can be categorized as urban heat hazard for everyone living in urban area. This result addresses the dangerousness of urban heat hazard to the community and urban environment.
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