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A study on the relationship between urban heat island phenomena and land use: a case study of Chiang Rai Municipality, Thailand

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Abstract The Urban Heat Island (UHI) has never considered as an issue in urban planning for Chiang Rai municipality where is considered an rapid economic growth with urban development. According to the result, at 15:00 h, it was found that the temperatures at some moving observed points was slightly increased and higher than the temperatures at the fixed weather station about 3–4 ℃ while, at 20:00 h. It was found that the temperatures at most moving observed points was obviously higher than the surrounding areas, especially in business areas which were 5–6 ℃. The thermal differences (Urban Heat Island: UHI) varied directly with the man-made structures but they were inversely affected with the natural areas following $Y = 0.0393X_1 – 0.7533$ ($R^2 = 0.8996$) and $Y = -0.0393X_2 + 3.1765$ ($R^2 = 0.8996$) equations.

Keywords: Urban heat island, Direct thermal measurement, Mobile traverse, Land cover surface, Least squares analysis

Introduction

Urban Heat Island (UHI) phenomena is an important aspect of urbanization that has drastically altered land use, land cover, changing the land surface characteristics, by replacing natural areas with man-made structures. In Figure 1, it clarifies that central business district deals with higher surface temperatures than surrounding areas; suburb areas and rural areas. This raises the question on what is the relationship between UHI and land covers, so the finding will be useful for better understanding of urbanization management including providing the appropriate policy for urban development (Harlan *et al*., 2006).

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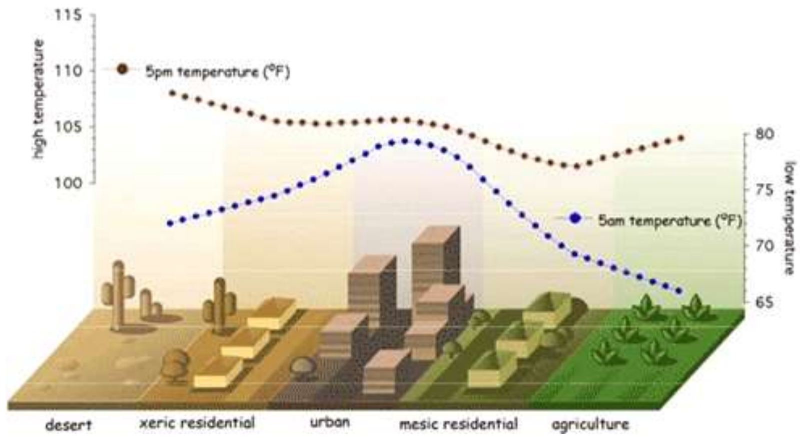


Figure 1. The cross-section of UHI formation The cross-section of UHI formation (Harlan *et al*., 2006)

During the day light, urban land cover surfaces (building, pavement, parking area, green area, river, pond, soil area, etc.) absorb heat from the sun and the energy consumption. A consequent increasing in urban heat surfaces is higher than the air temperatures in surrounding areas. Moreover, the heat explosion behavior of land cover surfaces in urban and rural areas during the night is similar to the heat explosion behavior during the day even it is cooler. Urban heat island phenomena affect the well-being of urban communities from the various aspects (energy and water consumption, air and water quality, and human health). Climate change intensifies the urban heat island behavior and it also exacerbates negative health impacts on urban communities (Harlan *et al*., 2006; Singchan, 2013).

The methods for urban heat measurements are generally classified into three types: remote sensing measurement, numerical modelling measurement (computer simulation model) and direct thermal measurement. The remote sensing measurement relates to aircrafts and satellites using thermal infrared remote sensing to collect the thermal data (Arifwidodo and Tanaka, 2015). Remote-sensing technique provides a high geographic resolution and easy repeatability. However, the derived thermal data may not be as actual as the true surface temperature. In addition, it is expensive cost and not available in restricted or rural areas. The computer simulation model is used to simulate the effect of thermal differences such as regression analysis and least square analysis (Ningrum, 2017). The derived thermal data are from remote sensing or direct thermal measurements to predict the urban heat behavior in the focus area. The direct thermal measurement or ground-based measurement is well known as the urban-rural weather stations that measure the thermal differences between both stations in order to estimate UHI phenomena in the study area.

The study area was Chiang Rai municipal area, located in Chiang Rai province (19°54'30.89" N 99°49'57.00" E) which considered as one of the major cities in the northern part of Thailand as shown in Figure 2. The population of Chiang Rai municipality has approximately 75,890 (Department of Provincial Administration, 2018). The climate of Chiang Rai municipality is fairly dry and warm during cool season while the average daily maximum temperature in hot season is at 36.3 °C (Climatological Data of Thailand for 30 - year period (1961 - 1990)). The annual average relative humidity is 71%. Moreover, Chiang Rai plays important role in the economic gateway, called the North-South Economic Corridor, connecting to the Lao People's Democratic Republic, the Republic of the Union of Myanmar and the southern China. Consequently, Chiang Rai city is growing and developing. Recently, urbanization in Chiang Rai has been exerting pressure on resources, in particular water supplies, the rising of temperatures, more variable rainfall, and water scarcity pose major risks for the city agricultural sectors.

This study aimed to identify the relationship between urban heat island phenomena and land covers in Chiang Rai municipality as the study area. The direct thermal measurement was used to measure the thermal difference between the heats at the fixed weather station and the heats at the moving points along the traverse route.

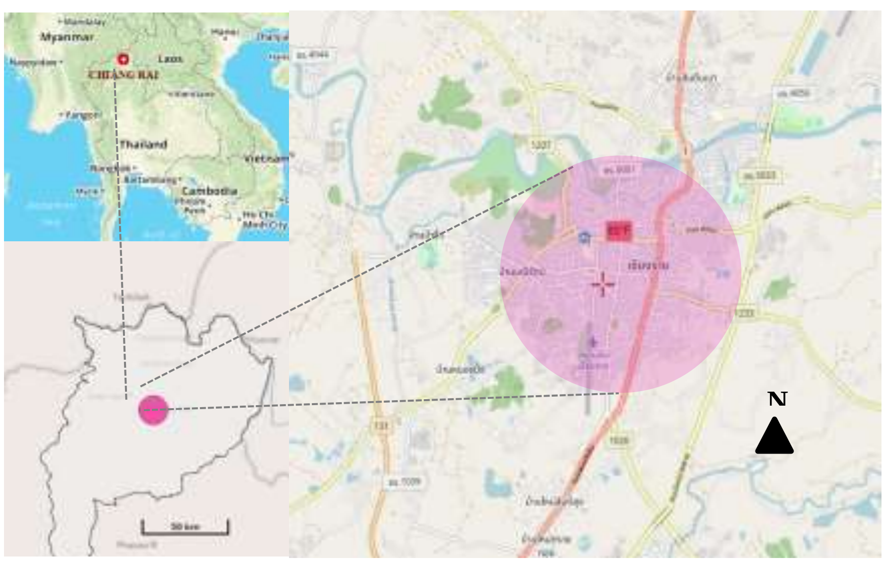


Figure 2. Geographic feature of the study area (Chiang Rai municipality)

Materials and methods

The air temperatures were monitored using the digital thermometer (Puansurin *et al*., 2018; Yokobori and Ohta, 2009) as shown in Figure 3b. After measurement the recorded air temperatures and time information were transferred into the spreadsheet. On the other hand, the spatial locations were also observed in order to record the observed moving points along a traverse route. The Global Positioning System (GPS) device, a satellite-based navigation system device, was used to identify and capture the required spatial locations (Figure 3c). In order to measure, all devices needed to be synced and installed on a vehicle as shown in Figure 3a). Therefore, the processes of mornitoring air temperature using the digital thermometer named as the direct thermal measurement and these processes were applied to this study in order to collect the air temperatures.

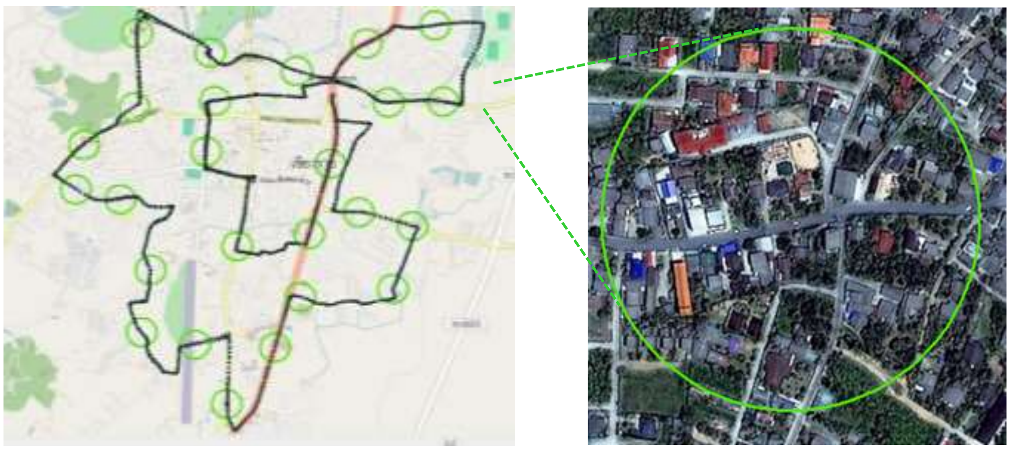
(a) Installed devices on a vehicle (b) Digital thermometer (c) GPS device

Figure 3. Mobile traverse

The methods for the study is divided into three parts as follows: the route and fixed weather station selection, the measuring time period and the recording time identification, and the data analysis and isothermal mapping.

The route and fixed weather station selection

The route and fixed weather station selection was the first part, it was illustrated in Figure 4. The black dots line showed the observed moving points along traverse route. In order to select the traverse route, we mainly considered the various land cover surface characteristics, based on the studies on the land cover surface classifictions (Hart and Sailor, 2009; Bottyán *et al*., 2005; Jonsson, 2004; Unger *et al*., 2001; Upmanis and Chen 1999; Eliasson, 1996; Saito *et al*., 1991) because the different land cover surface characteristic influenced the existence of different thermals. Consequently, the surface characteristics and the air temperatures were observed in the different seasonal observations. Therefore, the traverse route based on the various surface characteristics was a government center, green and watery areas, residential and commercial buildings and park. The distance of the traverse route was around 30 km. in Chiang Rai municipality.



(a) Traverse route (b) Magnification of a point

Figure 4. Traverse route and land cover surface analysis

On the other hand, the fixed weather station and installation is required in order to monitor the air temperatures, which are cooler than the urban air temperatures measured at the observed moving points along the traverse route in Chiang Rai municipality. The fixed weather station was installed in the suburb area, located on the south of Chiang Rai municipality with 30 km.

The measuring time period and the recording time identification

In addition, the recording time during the experiment was recorded in every 5 seconds (as the moving points) along the traverse route with the maximum speed up to 30 km/hr and 40 min of measuring time in order to prevent an error of the air temperature changing by time (Yokobori and Ohta, 2009).

Data analysis and isothermal mapping

Data were recorded every 5 second following the measurements at the observed moving points along the traverse route and at the fixed weather station.

The coordinates, date and time, the air temperatures at the observed moving points along the traverse route, the air temperatures at the fixed weather station, and the different thermals were imported from the mobile traverse to a spreadsheet format. After synchronized all data, they were imported into GISwith using the functions of GIS software in order to combine between spreadsheet data and spatial data. The different thermal data using the kriging method were interpolated to estimate heat island from a scattered set of points and drawing the isothermal map.

Land cover surfaces analysis, it was divided into 25 circles diameter 150 m covering the study area as shown in Figure 4 a. For example, a circle represented the selected areas, which classified according to land cover surface characteristics (man-made structure and natural area) as shown in Figure 4b. The first classification was man-made structure, building and pavement and the second classification was the natural area, river, pond, green area and soil surface. There were 70% of man-made structures and 30% of natural area as shown in Figure 5.

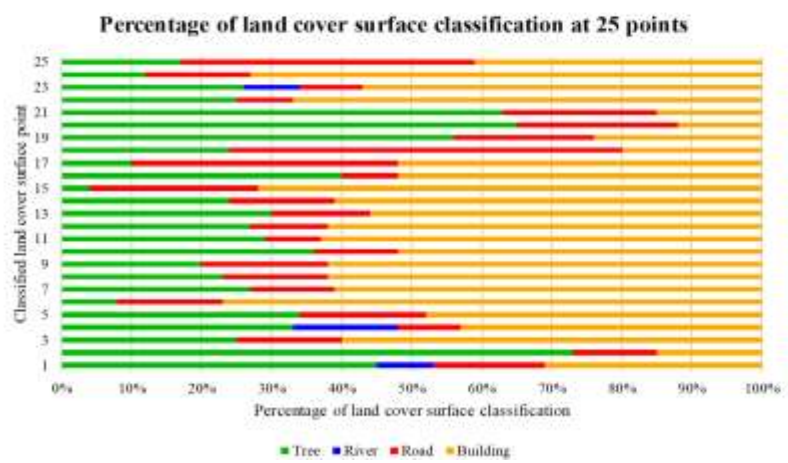


Figure 5. Percentage of land cover surface classification at 25 points

The data analysis was done as mentioned above, all necessary data were available for data analysis to identify the relationship between the thermal differences (UHI) and land cover surfaces by using the least squares analysis. This technique predicted the linear relationship for the best to fit for a set of existing data. The linear relationship was shown as the line called the regression line and the equation is $y = mx+c$ with the reliability (R^2).

Results

The result format of the Urban Heat Island (UHI) phenomena in the study area in April 2018 were shown in Figure 6ab, which were the UHI phenomena at 15:00 h and 20:00 h, respectively. In fact, it was found that the UHI phenomena, in particular in summer, started forming at 12:00 h and and slightly increased. Then, it reached a peak at 20:00 h. After that, it became less intense since midnight. Therefore, on April, the UHI phenomena at 15:00 h and 20:00 h represented as day time and night time, respectively.

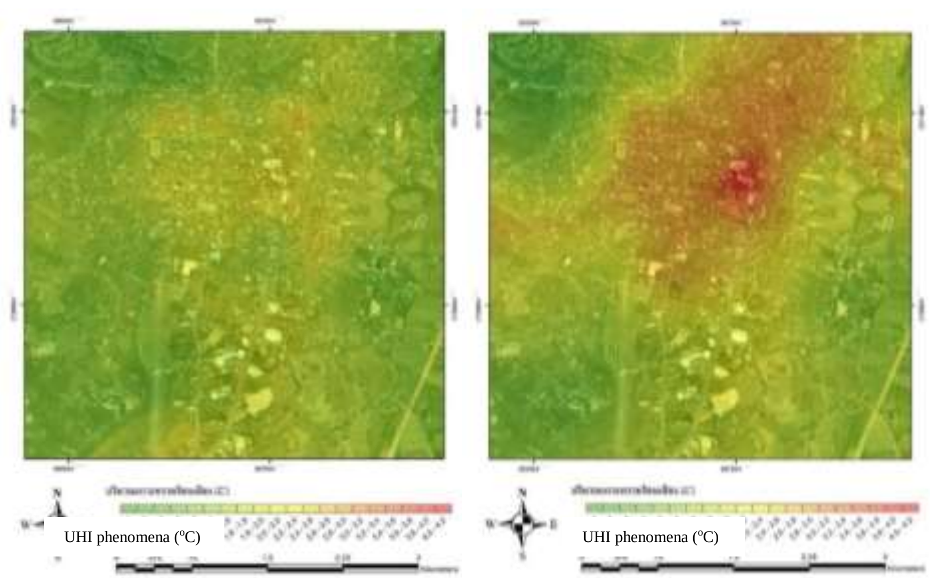
Based on the big data collecting from the field observation and data analysis by using kriging method, the highest different temperatures at 15:00 h between the observed points aand the fixed weather station were about 3 – 4 ℃ (Figure 6a) while they were about about 5 – 6 ℃ at 20:00 h, especially in business area (Figure 6b).

The least squares analysis was used to predict the relationship between the thermal differences (UHI) and land cover surfaces, which were classified to man-made structure, building and pavement) and natural area, river, pond, green area and soil surface. As a result, it was predicted that the UHI varied directly with man-made structure, but it was predicted that it was inversely with natural area as shown in Figure 7 with following $Y = 0.0393X_1 – 0.7533$ ($R^2 = 0.8996$) and $Y = -0.0393X_2 + 3.1765$ ($R^2 = 0.8996$) equations, where:

Y is the thermal differences at the fixed weather station and the moving observed points along the traverse route

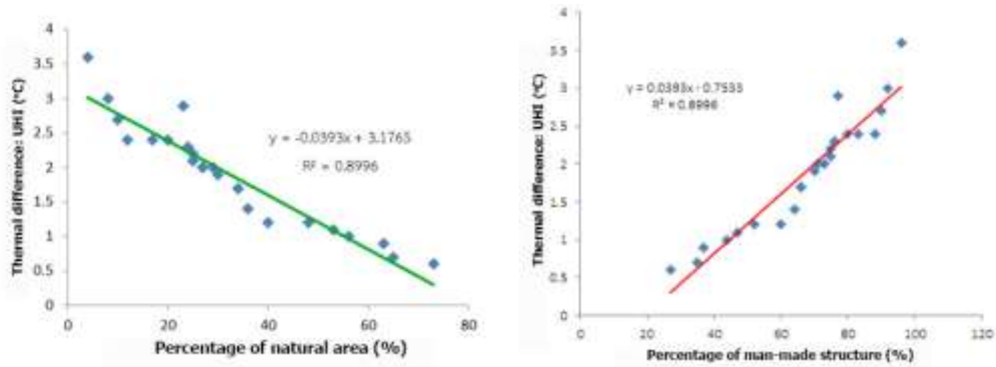
X_1 is the percentage of man-made structure area (building and pavement)

X_2 is the percentage of natural area (river, pond, green area and soil surface)



(a) Time15 :00 h - 16:00 h (b) Time 20:00 h - 21:00 h

Figure 6. Urban Heat Island phenomena in the Chiang Rai municipality



(a) UHI and natural area (b) UHI and man-made structure

Figure 7. The relationship between the thermal differences (UHI) and land cover surface

Discussion

Urban Heat Island (UHI) phenomena is defined as the dome of heat that the air temperature in urban area is normally higher than surrounding and rural areas. It raises the question on what is the relationship between UHI and land covers, which the finding will be useful for better understanding of urbanization management including providing the appropriate policy for urban development as explained by Harlan *et al*. (2006); Singchan (2013) and Puansurin *et al.* (2018).

The Urban Heat Island (UHI) phenomena can be simply captured by using the direct thermal measurement with the method called mobile traverse. At 15:00 h , it was found that the temperatures at some moving observed point along the traverse route was slightly higher than at surrounding area and the fixed weather station about 3 – 4 ℃ while, at 20:00 h, the temperatures at most moving observed point along the traverse route was more intense than surrounding area and the fixed weather station particulary the business area for 5 – 6 ℃. It was found that the thermal differences (UHI) varied directly with man-made structure while it was inversely with natural area following $Y = 0.0393X_1 – 0.7533$ ($R^2 = 0.8996$) and $Y = -0.0393X_2 + 3.1765$ ($R^2 = 0.8996$).

The porportation of land cover surfaces in the Chiang Rai municipality was found that man-made structure (building and pavement) was 70% and 30% for natural area. In addition, for natural area, there are only two parks in the Chiang Rai municipality and the Kok river while pond and soil surface are not obviously found. It is because most area of the the Chiang Rai municipality is the business area, residence and government office. The thermal differences between urban and rural area had the obvious relationship with land cover surface. It was found if land cover surface of man-made structure, increased for 20%, can cause the increase of the thermal differences for 1℃. On the other hand, if land cover surface of natural area, increased for 30%, can decrease the thermal differences for 1℃. This study is in the early stage to simply identify the relationship between Urban Heat Island phenomena and land cover surface. Therefore, the complicated factors for analysis are not considered such as humidity and wind speed. For the future step, we suggested that the factors affecting the changing temperature as mentioned should be further studied.

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