International Journal of Agricultural Technology 2018 Vol. 14(7): 1693-1708
Available online http://www.ijat-aatsea.com
ISSN: 2630-0613 (Print) 2630-0192 (Online)

The study of participatory monitoring of air quality and urban heat, case study Udon Thani province, Thailand

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Puansurin, K., Wongtragoon, U., Singchan, B. and Suwanmaneepong, S. (2018). The study of participatory monitoring of air quality and urban heat, case study Udon Thani province, Thailand. International Journal of Agricultural Technology 14(7): 1693-1708.

Abstract Urbanization in Thailand is a similar pattern. Land use planning, zoning and environmental safeguards are largely ineffective. Air quality and heat obviously affect environmental problem due to urbanization and harm to human health, especially respiratory disease. The lack of participatory planning process that citizens are limited ability to influence what is happening on the ground. The lack of public access to inform decision-making process is common across the country. Udon Thani municipality, Udon Thani province encountered this mentioned problems. The development of the simple method to monitor the concentration of Particulate Matter 2.5 µm (PM2.5) and urban heat in order to build social participation were investigated and providde the scientific information for decision-makers and key stakeholders of the community. The direct measurement was offered by using three devices as a mobile traverse method, for measurement; 1) a mobile visible light scattering device to measure PM2.5 concentrations, 2) a digital thermometer and 3) GPS device to obtain spatial data. The behaviors of air quality and urban heat island (UHI) was seasonally observed by day and night times from April 2017 to January 2018 in hot, rainy and cold seasons with five time intervals (16:00, 20:00, 00:00, 08:00 and 12:00) on a selected observation date of each season. The results indicated the peak spots of PM2.5 concentrations and UHI around the study area estimated to encounter the air pollution and urban heat occurrences in particular specific time interval and seasons. Finally, The simple method and scientific information were provided as a key stakeholders in the study area to monitor air quality and urban heat through workshop training and Shared Learning Dialogues (SLDs). It was obviously found that the participation of the key stakeholders were encouraged and their perception on social scientific information was well responded.

Keywords: Urban heat island, air temperature and air quality monitoring, mobile traverse, land surface

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Introduction

Urbanisation in particular Thailand is experiencing similar pace and patterns. Land use planning, zoning and environmental safeguards are largely ineffective. The lack of participatory planning process means that citizens have limited ability to influence what is happening on the ground. In fact, the lack of public access scientific information to inform decision-making process is common across this country. Growing cities in Thailand not effectively managed are faced with a suite of environmental issues (Arifwidodo and Tanaka, 2015; Rushayati *et al.*, 2015). Genuinely, infrastructure development caused by increasing population in growing cities has rapidly replaced open space area with ineffective infrastructure master plan. Such green areas and agricultural areas mostly replace and disappear. Consequently, local authorities have to tackle increasing issues of pollution, solid waste, wastewater, environmental degradation and contamination, which harm human health and life quality.

Air pollution is one of the major environmental issues in urban areas. Impacts of air quality on human health in urban areas are well researched and recorded. According to WHO and the United State Environmental Protection Agency (the US EPA), they encourage the use of Particulate Matter 2.5 µm (PM2.5) Air Quality Index (AQI), rather than Particulate Matter 10 µm (PM10) AQI because it would be more significant and related to health implication. The major sources of PM2.5 are from open burning and transportation (The Pollution Control Department and Ministry of Energy, 2018). The Pollution Control Department and Ministry of Energy of Thailand indicates that PM2.5 concentrations over 100 $\mu g/m^3$ are unhealthy while the concentrations between 51-100 $\mu g/m^3$ are moderate which can harm sensitive people, and the concentrations less than 50 $\mu g/m^3$ are considered as good air quality.

Table 1. PM2.5 concentrations in the major regional cities of Thailand

Province	Max. in 2016 ($\mu g/m^3$)	Mean PM2.5 Concentrations ($\mu g/m^3$)				
		2017	2016	2015	2014	2013
Bangkok	103	37	43	37	36	35
Chiang Mai	144	30	32	44	33	35
Lampang	156	19	29	31	30	26
Khon Kaen	112	30	43	31	30	N/A
Ratchaburi	136	22	27	29	26	N/A
Saraburi	68	36	35	34	39	38
Rayong	82	35	23	42	22	19
Song Khlan	-	15	-	-	20	20
Udon Thani	N/A	N/A	N/A	N/A	N/A	N/A

Note: N/A means not available with no station; and Null means system failure
Source: The Pollution Control Department and Ministry of Energy (http://air4thai.pcd.go.th/)

Table 1 shows the mean of PM2.5 concentrations in the major regional cities of Thailand between 2013 to 2017. Many major cities faced unhealthy state causing PM2.5 concentrations over 100 µg/m3. Moreover, air quality information is not regularly provided, not widely monitored and not easily accessible in many cities in this country.

Urban heat island (UHI) effect is an important aspect of urbanization. Urban growth and sprawl have drastically altered land use and land cover, changing the land surface characteristics, by replacing soil and vegetation with man-made structure. In Figure 1, it is evident that urban centers experience higher surface temperatures than surrounding less urbanized suburban and rural areas. During the day, urban land surfaces (building, pavement, and parking lot, etc.) absorb heat from the sun, so the heat exposes from urban surfaces higher than the air temperatures. On the other hand, the temperatures of moist rural land surfaces are closed to the air temperatures. The heat explosion behavior of land surfaces in urban and rural areas during the night is as same as occurring during the day even it is cooler. Urban heat island has negative impacts on the well-being of city communities from the aspects of energy and water consumption, air and water quality, and human health. Climate change intensifies the effect of urban heat island and exacerbates negative health impacts on local communities.

This study proposed the development of a simple method for monitoring PM2.5 concentrations and urban heat in order to build social participation and provide the scientific information that is well perceived for decision-makers and key stakeholders of the community.

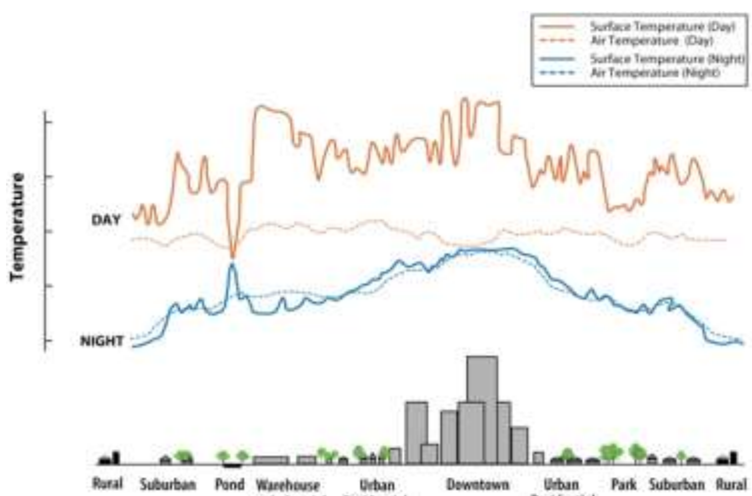


Figure 1. The cross-section of UHI formation
Source: https://www.epa.gov/heat-islands/learn-about-heat-islands

Materials and Methods

The study area was located in latitude 17°24'54.0"N, longitude 102°47'12.0"E as shown in Figure 2 which located in the northeast of Thailand and considered as one of the four major cities of the northeast, Udon Thai province. Udon Thani municipality, Udon Thani province which plays important role in the economic gateway to Laos PDR, northern Vietnam and southern China. The study area has a population of approximately 399,535. The climate of Udon Thani municipality is fairly dry and warm during cool season while the average daily maximum temperature in hot season is at 36.3 °C. The annual average relative humidity is 71%. Unfortunately, Udon Thani municipality has no fixed air quality station to monitor air quality and there is no urban heat information to provide in public.

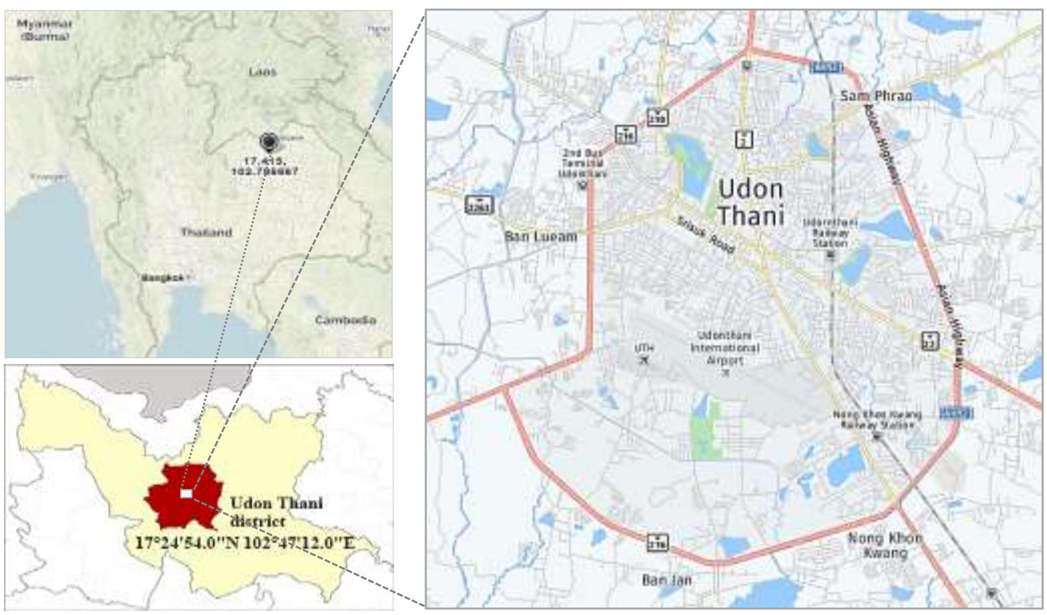


Figure 2. Geographic feature of the study area

The objective of this study was to build social science participation and provide the geographic information for decision-makers in order to reach its comparison to 3 mechanisms: (1) to understand the seasonal pattern of the air quality (PM2.5) and the urban heat island (UHI) formation in Udon Thani municipality in each time interval, (2) to understand the change of UHI and the change of PM2.5 concentrations in each season, and (3) to provide the practice for driving the social participation.

The methods for monitoring urban heat are classified into three groups; remote sensing measurement, numerical modelling measurement and direct measurement. The aircraft and satellite thermal infrared data was used in the category of the remote sensing method (Arifwidodo and Tanaka, 2015). Remote-sensing techniques provided a high geographic resolution and easy repeatability, but the derived temperature may be different from the true surface temperature. However, it was expensive cost and not available in some areas. Computer simulation model is used to study the effect of thermal differences such as regression (Ningrum, 2017). The air temperatures data were recorded from remote sensing method or direct method to estimate the urban heat formation in the study area.

The direct measurement or ground-based measurement were known as the urban-rural weather stations which the primary approach to measure the thermal differences, but the estimation of the urban heat formation were recorded the weather stations to measure the thermal differences in a large area. The auto-traverse technique or the mobile traverse technique was used to improve the urban-rural weather stations. The mobile traverse method was the simplest and most frequently used method which inexpensive device for air temperature measurement such as digital thermometer and global positioning device.

Mobile traverse: the direct measurement was used a mobile traverse technique. The monitoring devices to measure air quality and urban heat based on community participation, mobility and portability were recorded. There were three selected devices combined into the mobile traverse technique as shown in Figure 3.

(a) Airbeam device (b) Digital thermometer (c) GPS device

Figure 3. Devices for measurement

PM 2.5 Concentrations was monitored by following the United States Environmental Protection Agency (the US EPA) which declared five devices for particle measurement as mass and mass equivalent, visible light scattering, visible light absorption, electrical mobility and electrical technique. The airbeam device was used as a visible light scattering device as shown in Figure 3(a). The environmental measurement device used which based on the open-source Air Casting platform to collect, display and share the environmental data by using an android mobile device. The airbeam used a light scattering method to measure PM 2.5. Air was drawn through a sensing chamber and light from a laser scatters off particles in the airstream. This light scatter was registered by a detector and converted into a measurement that estimated the number of particles in the air. The airbeam is communicated to the AirCasting Android app via Bluetooth during record data. The collected data is sent to the AirCasting website, where the data is crowdsourced.

The air temperature was monitored using the digital temperature data logger as shown in Figure 3(b). It is type sensor K/J thermometer displaying °C or °F measurement unit and its accuracy is ±0.8 °C or ±1.5 °F. It is the external memory real time recorder. Four kinds measurement are combined into one meter with easy operation. After execute data logger, measured values and time information were downloaded into the spreadsheet directly.

The spatial locations were observed the points along a traverse route, the Global Positioning System (GPS) device is operated. It is a satellite-based navigation system device working in anywhere, anytime and any weather conditions in order to identify the location of measuring air temperature (Figure 3(c)).

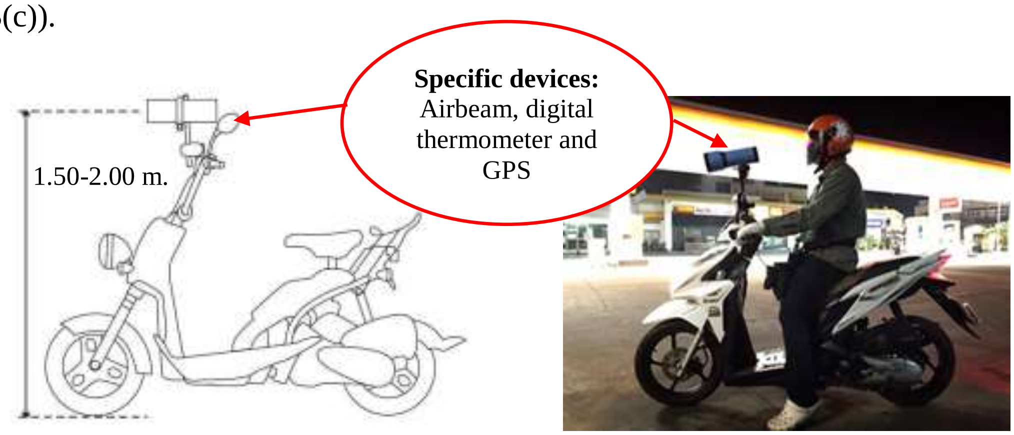


Figure 4. Mobile traverse technique

The mobile traverse technique with installing three specific devices was shown in Figure 4. The height to install the devices is limited between 1.50-2.00 m. from the ground surface. In order to prevent measuring errors, the protection is required and the airbeam and digital thermometer was installed away from the vehicle's engine and intake, and the GPS was installed on the vehicle to capture coordinates during measuring PM 2.5 concentrations and air temperatures (Yokobori and Ohta, 2009) .

The research objectives were to fix weather station and install to monitor air temperatures cooler than urban air temperatures, to observe the points along the traverse route in Udon Thani municipality, to measre air quality and urban heat, to measure the time intervals for seasons, to record the air quality and air temperature, to analyse data and isothermal mapping and to participate the building for key stakeholders to monitor air quality and urban heat through Shared Learning Diglogues (SLDs). On the basis of seasonal observation, the research activities were used as the same procedures as described below.

Fixed weather station installation: the thermal differences were various temperatures between the observed air temperatures along the traverse route and the air temperature at the fixed weather station, which was the air temperature cooler than the air temperature in urban area. Therefore, the UHI formation is simply simplified. In this study, the location of the fixed weather station (latitude 17°24' 22.25"N, longitude 102°48'38.06"E) is shown in Figures 5.

Figure 5. Location of the fixed weather station at Udon Thani municipality

Observed points along the traverse route: the method was followed many studies who demonstrated the features of UHI and the effects of different surface characteristics (Saito *et al.*, 1991; Eliasson, 1996; Upmanis and Chen 1999; Unger *et al.*, 2001; Jonsson, 2004; Bottyán *et al.*, 2005 and Hart and Sailor, 2009). The influence of land use and surface characteristics was recorded the existence of different thermals. The surface characteristics and the air temperatures were observed to relate the seasonal observation. Therefore, the traverse route under the concept of the various surface characteristics was observed such as government center, green and water areas residential and commercial buildings and park. The distance of this route was around 30 km. in Udon Thani municipality as shown in Figure 6.

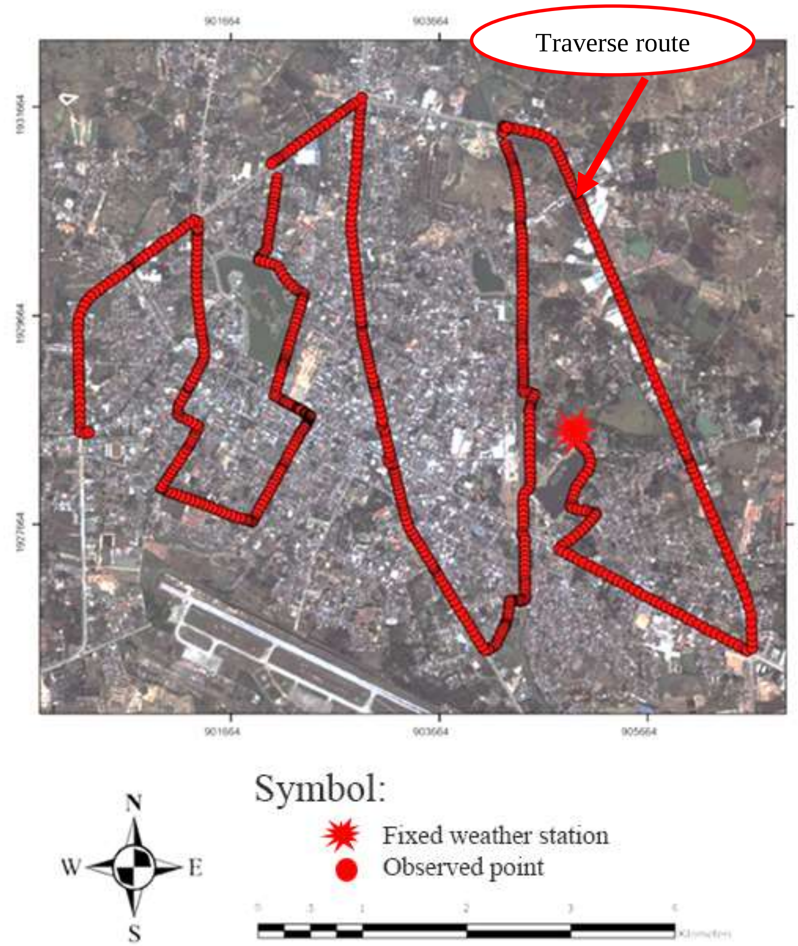


Figure 6. Location of the fixed weather station and traverse route

Air quality and urban heat measurement: the air quality associated with the effect of land cover on air temperatures were investigated, the mobile traverse was used to measure PM2.5 concentrations and air temperatures. Due to the mobile traverse and the mobility of measurements, the spreading PM2.5 concentrations and the air temperatures in the study at the specific time is concerned. To minimize the observation errors, the averaged data at every 5 seconds was done 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 changed by time and the change of PM2.5 concerations at the time (Yokobori and Ohta, 2009).

Time intervals for seasonal measurement: the method was followed Unger *et al.* (2001) and Bottyán *et al.* (2005) who indicated the relationship between green area and air temperatures on the basis of seasonal observations and dayt ime and night time observation. The air quality and air temperature measurements seasonally were recorded in hot, rainy and cool seasons from April 2017 to January 2018. On a selected date of each seasonal measurement, there were five time intervals in a day (starting at 16:00, 20:00, 00:00, 08:00 and 12:00).

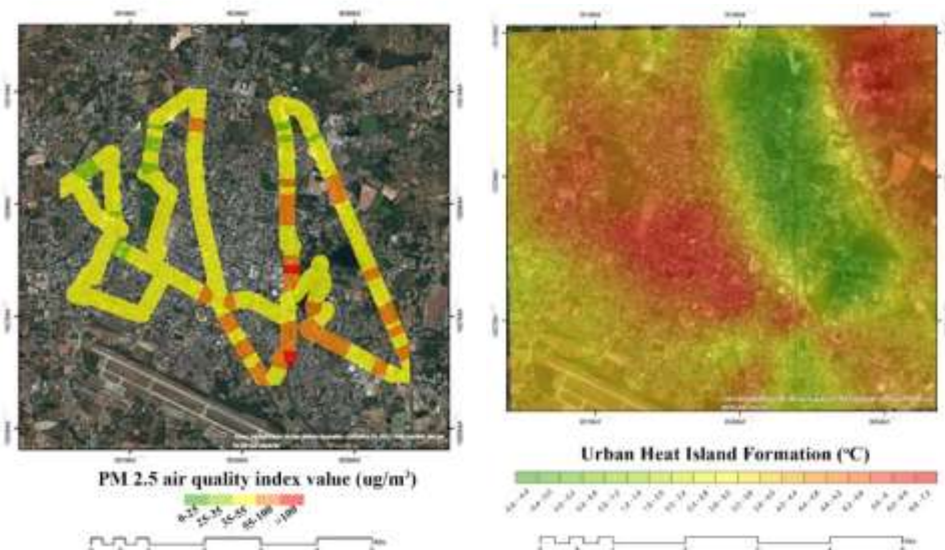
Collecting air quality and air temperature: the airbeam device monitoring air quality was set up and synchronized with the aircasting application in order to record PM2.5 concentrations in every 5 seconds and uploaded on the aircasting website. Simultaneously, before measuring the air temperatures, the digital temperature data loggers installing at both the fixed weather station and the mobile traverse were set up and prepared for measurement including the GPS device at the mobile traverse, which was set up to record the coordinates along the traverse route in every 5sec. In particular, the mobile traverse measured with nonstop driving during the measurement.

Data Analysis and Isothermal mapping: after the measurement, the spreadsheet was arranged all recorded data of PM2.5 concentrations and the data of different thermals into a suitable pattern. The data of different thermals were calculated from the collected temperatures of the digital temperature data loggers at the fixed weather station and at the mobile traverse referring to the recorded time (every 5 seconds). The coordinates, time, the data of air quality and different thermals in a spreadsheet format were imported into ArcGIS version 10.3. With the functions of Arc GIS software, the collected PM2.5 concentrations illustrated on the land use map of Udon Thani municipality. The data of the different temperatures using the kriging method were interpolated to estimate heat island from a scattered set of points and drawing the isothermal map.

Participatory building for key stakeholders to monitor air quality and urban heat through Shared Learning Diglogues (SLDs): key stakeholders in the community influence participatory building was obsreved. The social scientific information on air quality and air temperature were recorded to study the important role on community participation building. The spatial or geographic information was studied on human perception and descriptive information. The data collection, analysis and interpretation of geographic information from the study on air quality and urban heat were provided to local multi-stakeholders (community leaders and members, NGOs, municipalities, government agencies and departments business and private sector) through training workshops and SLDs.

Results

The proposed method was provided to understand the seasonal variations of air quality and UHI formation as well as the better practice for driving the social participation, the results are revealed as follows:



(a) PM2.5 concentrations at 20:00 (b) UHI formation at 20:00

Figure 7. Air quality and urban heat (21st – 22nd April 2017) in hot season

The air quality at 20:00 on 21st April 2017 in hot season in Udon Thani municipality was recorded. The maximum of PM2.5 concentrations was over 100 µg/m^3 appearing in business area of Udon Thani. In addition, on average PM2.5 concentration was between 33-55 µg/m^3 affecting sensitive people and limiting activities (Fig.7a). The UHI formation was shown that the hottest spot (light red color) was in business area its temperature was higher than the fixed station about 7 ℃. The temperatures surrounding business area were cooling down to 3 ℃. For the green area, it was the location of the fixed weather station. Its land surface was mostly lake, forest and vegetation (Fig.7b).

Air quality

The seasonal behavior of PM2.5 concentrations with five time intervals found that the air quality in rainy season was good and unharmed for human health because PM2.5 concentrations which less than 35 µg/m^3. In hot season, the air quality was dangerous for human because PM2.5 concentrations over 55 µg/m^3 at 08:00 and 20:00 in orange color and over 35 – 55 µg/m^3 showed in yellow color. In cool season, the air quality at 20:00 was also dangerous for human health due to above 100 µg/m^3 of PM2.5 concentrations. In conclusion, the stress of PM2.5 concentrations was serious in both hot season and cool season. PM2.5 concentrations at 00:00 in cool season reached a peak (Table 2, Fig.7a).

Table 2. Seasonal air quality between April 2017 – January 2018

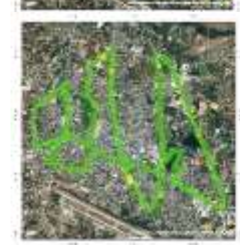
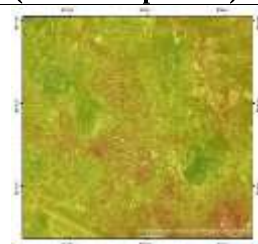
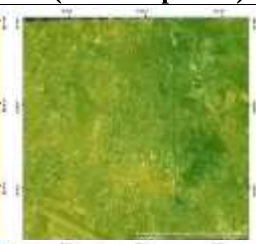
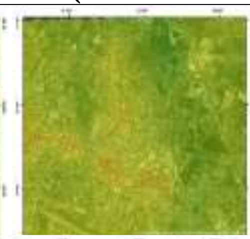
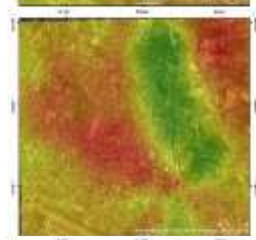
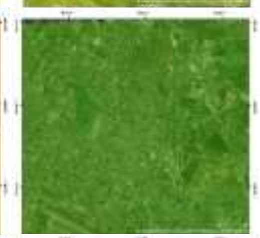
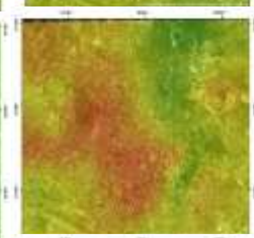
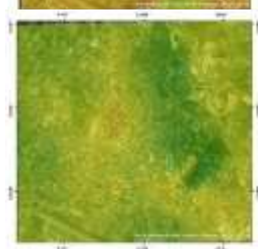
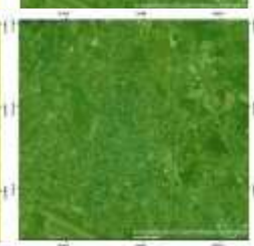
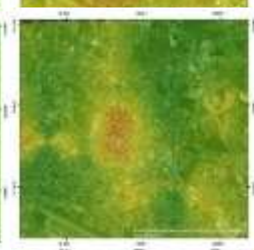
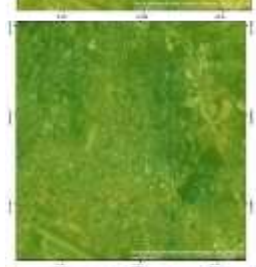
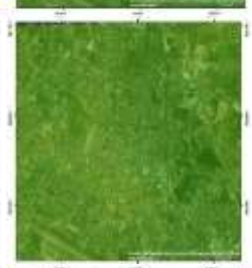
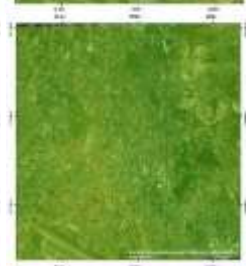
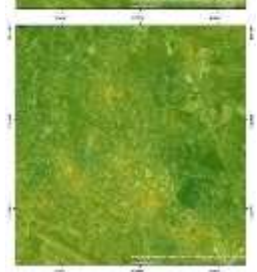
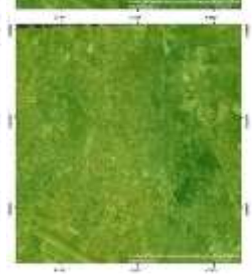
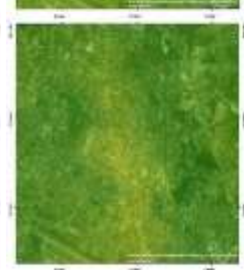
Season / Time interval	Hot season (21st-22nd Apr 2017)	Rainy season (7th-8th Sep 2017)	Cool season (5th-6th Jan 2018)
16:00			
20:00			
00:00			
08:00			
12:00			

Table 3. Seasonal urban heat island formation between April 2017–January 2018

Season / Time interval	Hot season (21^{st}-22^{nd} Apr 2017)	Rainy season (7^{th}-8^{th} Sep 2017)	Cool season (5^{th}-6^{th} Jan 2018)
16:00			
20:00			
00:00			
08:00			
12:00			

Urban heat

The seasonal behavior of UHI formation revealed that the UHI formation in rainy season did not appear. On the other hand, in hot season and cool season, the UHI phenomenon started forming from 16:00 to 20:00. Then, it was cooling down at 00:00 (Table 3, Fig 7b). It was obviously shown that UHI formation was intensive after sunset (Fig.8). In addition, the UHI phenomenon during hot season was more intensive than cool season, and the highest different thermals between the fixed weather station and the sample points along the traverse route was 7.0 ˚C with the average different thermal around 3.5 ˚C.

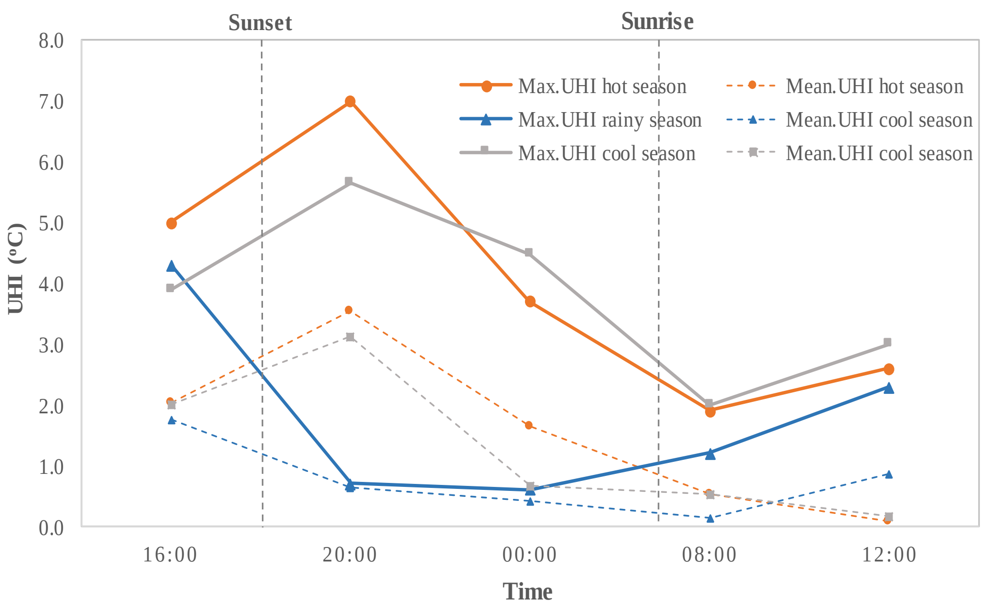


Figure 8. Seasonal variation of the urban heat formation

Social participatory building

The social participatory building for key stakeholders to monitor air quality and urban heat was implemented through training workshops and SLDs. The key stakehtolders joined and shared ideas and experiences. The simple method and the geographic information on monitoring air quality and urban heat, the stakeholders' perception and participation were encouraged as shown in Figure 9.

Figure 9. Social participatory building on monitoring air quality and urban heat

Discussion

Air quality

The stress on the air quality throughout the year was severe at 20:00 in cool season, found above 100 μg/m^3 which can harm sensitive people (The Pollution Control Department and Ministry of Energy, 2018; The United State Enviromental Protection Agency, 2018). It can be noticeable that PM2.5 concentrations at 20:00 in the study area in cool season as in Figure 7(a), for example, were "it is captured at 20:00". Technically, it was only the sample of PM2.5 concentration at the specific time around the city. However, the scatter of PM2.5 over the city is dynamic due to the movability (wind) of the dust. Therefore, the air quality should be measured by a fixed station as a network in order to estimate the scatter of PM2.5.

Urban – rural differences in thermal behaviour

The different thermals causing UHI formation relied on the differences of urban and rural land cover surfaces. The variations of land cover surfaces and soil moisture were previously cited as key factors in UHI intensity and dynamics (Oke, 2004) and it was explained in this study (Table 3 and Figure 8). The highest UHI intensity in Udon Thani municipality appeared during drier periods of the year similar to the results from other studies (Arifwidodo and Tanaka, 2015; Yokobori and Ohta, 2009). Consequently, the relationship between land cover surface and the UHI formation should be deeply studied and analyzed in order to propose the better city plan under the assumption "different land cover surface characteristics affects the different formations of UHI phenomenon". The relationship between energy consumption and UHI formation should be studied in order to manage or improve the efficiency of energy use. The relationship between traffic and UHI formation should be considered in order to manipulate the pollution.

Acknowledgement

This research project is granted by the Urban Climate Resilience in Southeast Asia Partnership (UCRSEA) project, which is funded by the Social Sciences and Humanities Research Council of Canada (SSHRC) and the International Development Research Centre (IDRC). The completion of this research project could not have been possible without the participation and the supports from Thailand Environment Institute (TEI) and Dr. Pakamas Thinphanga, Co-director of UCRSEA, TEI.

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(Received: 9 September 2018, accepted: 31 October 2018)