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EFFECTS OF URBAN DEVELOPMENT AND SPATIAL CHARACTERISTICS ON URBAN THERMAL ENVIRONMENT IN CHIANG MAI METROPOLITAN, THAILAND

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ABSTRACT: Chiang Mai Metropolitan Area (CMMA) is the largest city in northern of Thailand, experiencing rapid urbanization that has resulted in remarkable the urban heat island (UHI) effect which will be sure to influence the regional climate, environment, and socio-economic development. In this study, we review the use of thermal remote sensing in the study of urban climates, focusing primarily on the UHI effect and an integrated remote sensing-based approach to investigate the effects of urban development and spatial characteristics on urban thermal environment. The LANDSAT ETM+ images from 2000 and 2006 were utilized to assess the surface urban heat island (SUHI) which will be further analyzed by investigating the relationships with several urban environment and development indices including; the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Density of Building (DenBldg), Floor Area Ratio (FAR) and Building Coverage Ratio (BCR) in the urban area of CMMA. Results show that the SUHI effect has become more prominent in areas with rapid urbanization in CMMA. It was found that the average of SUHI (Mean±S.D.) in the center of CMMA was about 20.52±1.05˚C in 2000, but this difference jumped to 28.08±1.50˚C in 2006. This could lead to an intensified the UHI effect in the urban areas. In order to analyze the relationship between surface temperatures with the spatial characteristic indices, the results of the correlation can understand impacts of the configuration and composition of spatial characteristics on local thermal environment which was the basic information for finding the reduction methods of urban temperature and the establishment of environmentally friendly urban planning in the future. Overall, remote sensing technology was an effective approach for monitoring and analyzing urban growth patterns and evaluating their impacts on urban climates.

Keywords: Urban thermal environment, Surface urban heat island (SUHI), Remote sensing.

INTRODUCTION

The urban heat island (UHI) refers to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization (Voogt & Oke, 2003). It is characterized by a large expanse of non-evaporating impervious materials covering a majority of urban areas with a consequent increase in sensible heat flux at the expense of latent heat flux (Oke, 1982; Owen et al., 1998). UHI effects are exacerbated by the anthropogenic heat generated by traffic, industry and domestic buildings, impacting the local climate through the city's compact mass of buildings that affect exchange of energy and levels of conductivity. The higher temperatures in urban heat islands increase air conditioning demands, raise pollution levels, and may modify precipitation patterns. As a result, the magnitude and pattern of UHI effects have been major concerns of many urban climatology studies.

Nowadays there have been few studies of the UHI in Thailand and include the Chiang Mai Metropolitan Area (CMMA), which is the largest city in northern of Thailand and continue to rapidly grow in both population and physical size (Figs.1). Thus, the study of UHI to understand impacts of the urbanization on local thermal environment and assess the diurnal variation in the CMMA will become progressively more important for researchers and decision makers to understand climate effects of urbanization in order to contribute to sustainable urban development in the region.

Heat islands can be characterized for different layers of the urban atmosphere and for various surfaces and divided into three categories (Fig.2): canopy layer heat island (CLHI), boundary layer heat island (BLHI), and surface urban heat island (SUHI). The urban canopy layer extends upwards from the surface to approximately mean building height, whereas the urban boundary layer is located above the canopy layer (Voogt & Oke, 2003). The CLHI and the BLHI are atmospheric heat islands

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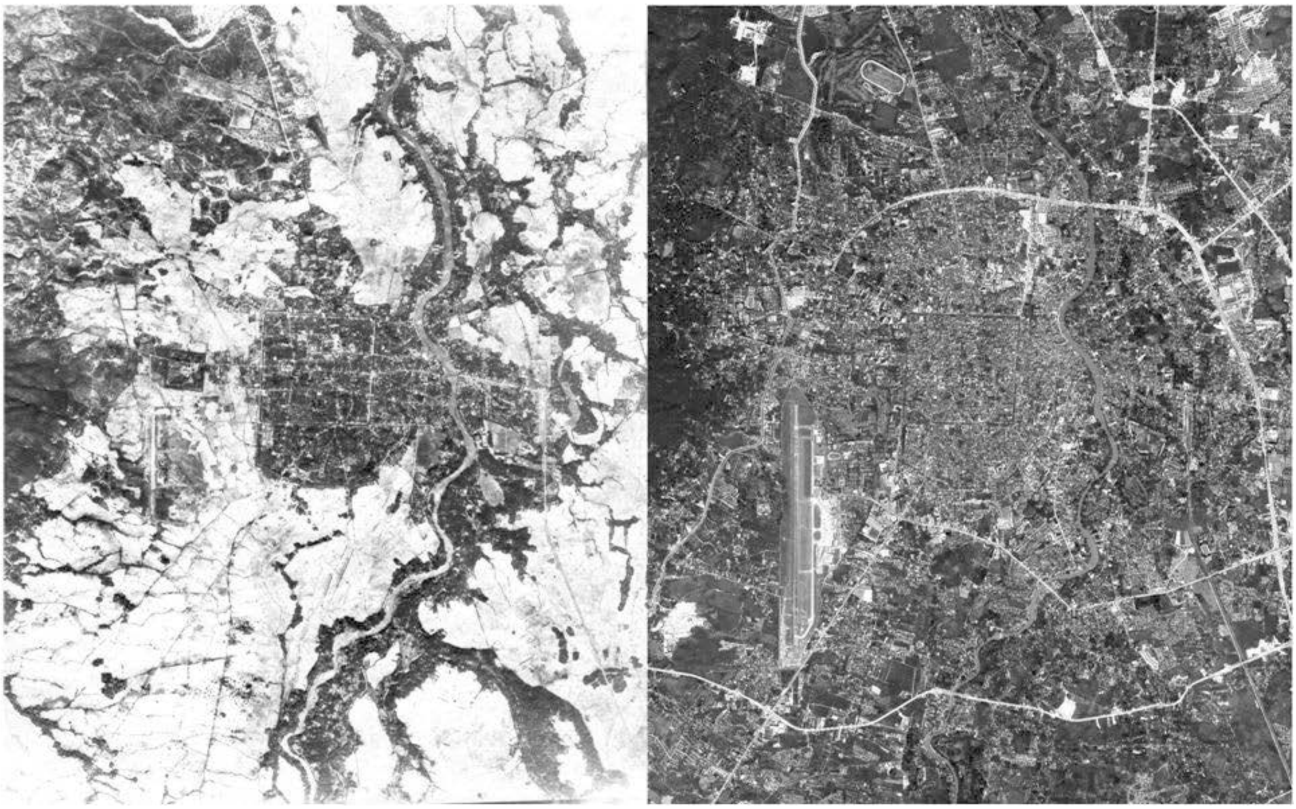
since they denote a warming of the urban atmosphere, whereas the SUHI refers to the relative warmth of urban surfaces compared to surrounding rural areas.

It is known that atmospheric UHIs are larger at night while SUHIs are larger during the day (Roth et al, 1989). While atmospheric heat islands are normally measured by in situ sensors of air temperature via weather station networks, the SUHI is typically characterized as land surface temperature (LST) through the use of airborne or satellite thermal infrared remote sensing, which provides a synoptic and uniform means of studying SUHI effects at regional scales. Satellite-measured LST has been utilized in various heat-balance, climate modeling, and global-change studies since it is determined by the effective radiating temperature of the Earth's surface, which controls surface heat and water exchange with the atmosphere. Voogt and Oke (2003) suggested two major applications of thermal remote sensing to the study of urban climates. The first, two of them focus on examining relations either between spatial structure of urban thermal patterns and urban surface characteristics or between atmospheric and surface heat islands; the second is centered on studying urban surface energy balances by coupling urban climate models with remotely sensed data. Our study addresses the first application area.



(a) TSD Aerial Photo in 1954 (b) QuickBird Satellite in 2008

Figs.1 Temporal change in the core area of the Chiang Mai city

In earlier thermal remote sensing studies, much emphasis has been placed on using the normalized difference vegetation index (NDVI) as a major indicator of urban climate studies (Lo et al., 1997; Gallo and Owen, 1999; Yuan and Bauer, 2007). However, the NDVI is subject to seasonal variations which may influence the results of SUHI analysis. The intensity of UHI is related to the spatial extent and composition of vegetation and built-up areas and their temporal changes. Quantitative studies of the relationship between spatial patterns and LST are important for land-use management and planning.

The aims of this study are to understand impacts of the urbanization on local climate and assess the diurnal variation of the SUHI measured from the thermal infrared of LANDSAT satellite images in CMMA using remote sensing images of different time periods and then analyzed the surface temperature retrieved from the thermal infrared band. In this paper, multi-temporal LANDSAT (ETM+) imagery of 2000, and 2006 were used to investigate the impact of such changes on the spatial patterns of SUHI effect in CMMA. In order to analyze the relationship between surface temperature and the spatial characteristics of CMMA, including the

Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Density of Building (DenBldg), Floor Area Ratio (FAR) and Building Coverage Ratio (BCR), the correlation coefficient of factors was analyzed using correlation analysis and prediction model of SUHI on spatial characteristics are established using linear regression analysis and scatter plot (linear plot). In the last part of the paper, the authors would share our viewpoint on research trends in thermal remote sensing of urban areas, and would provide updates on current and future TIR remote sensors.

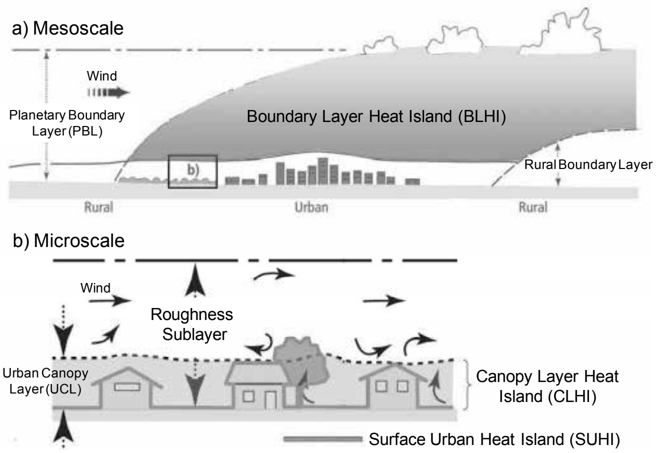
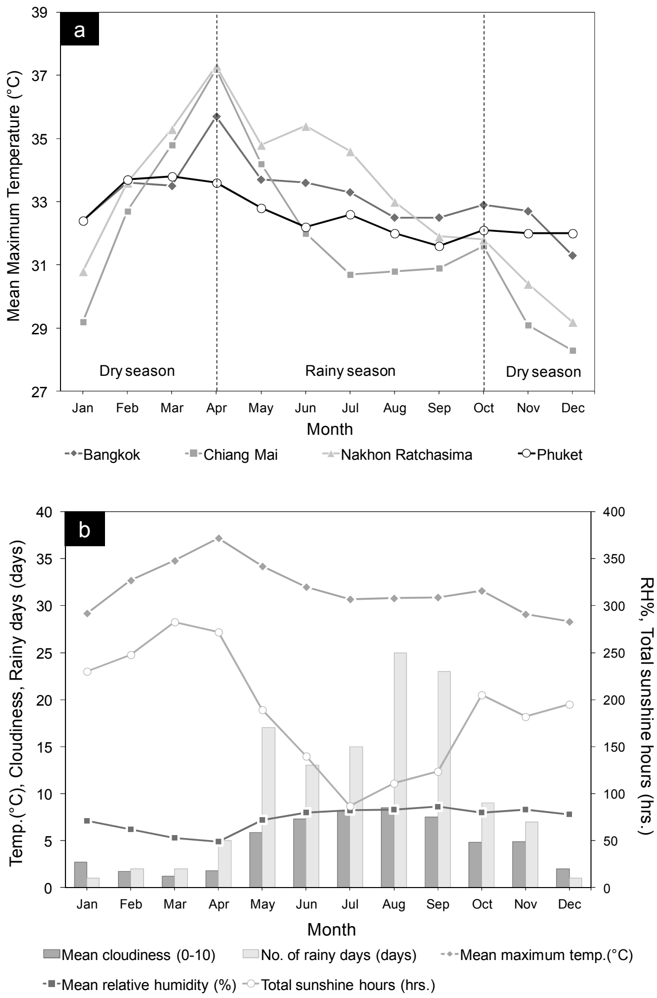


Fig.2 Schematic depiction of the main components of the urban atmosphere (Modified after Voogt, 2004)

THE STUDY AREA

Urban areas in Thailand have been developed as the dominant centers for economic activities that changing in populations and land use caused urban areas in Thailand are facing a high risk of UHI effect. The diurnal variation in monthly mean maximum temperature of the four major cities in Thailand was investigated by using data measured at urban meteorological observatories for the period 2000 to 2006, are illustrated in the Fig.3a. The results indicated that the monthly mean maximum temperature in Chiang Mai (the largest city in northern of Thailand) and Nakhon Ratchasima (one of the northeast cities of Thailand) were the greatest on the summer period of dry season in April (37.3˚C and 37.2˚C, respectively) and declined to a minimum during the winter period (is from November to February). During the dry season in Chiang Mai (during February to April) (Fig.3b), has highest solar intensity, longer sunshine days, the precipitation and cloudiness had the smallest values. So at that time, the SUHI effects were probably the strongest which could affect a community's environment and quality of life in Chiang Mai city. However, the local weather conditions and the local characteristics of Chiang Mai's urban areas (e.g. building density, open space) seem to be the dominating factors in the formation of UHI. Thus, the studies should to investigate the relationship between the SUHI and the local weather conditions.



Figs.3 (a.) Diurnal variation in monthly mean maximum temperature in large Thailand cities for the period 2000 to 2006, and (b.) The monthly mean urban climatic variations at the study site for the period 2000 to 2006

The study area covers the seven districts in CMMA of Thailand (Fig.4), an area of approximately 409 sq.km. Like many other Thailand cities, the population of CMMA is rapidly increasing leading to increased urban expansion. This urban growth is encroaching into the adjacent agricultural and other non-urban land. The city was also characterized by different density of urban developments in the central portion and several rural land-cover types; predominantly agricultural fields, forests, water and bare land in the surrounding landscapes. The built environment consists of buildings and roofs made up of concrete, brick tiles and metal plates, and majority of the roads are covered by asphalt and concrete. The CMMA is therefore ideally suitable for the analysis of UHI phenomenon due to its diversity of land-cover types and the rapid urbanization.

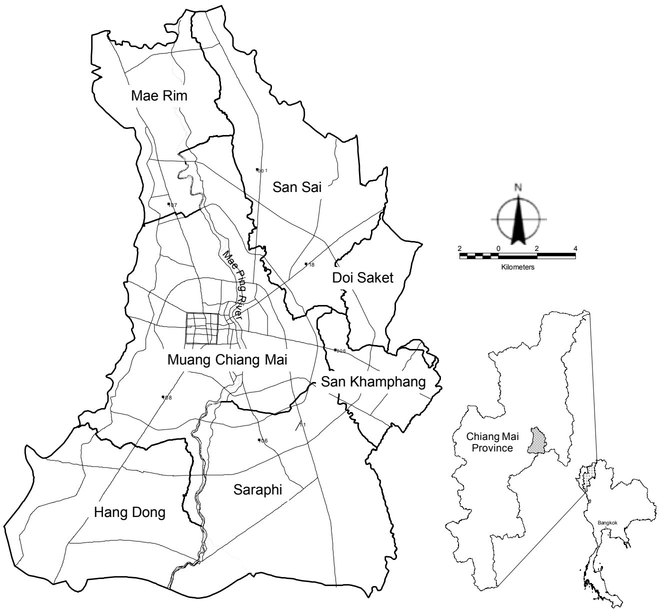


Fig.4 The study area of Chiang Mai Metropolitan Area (CMMA), Thailand

METHODS

Image pre-processing

LANDSAT data from two different years were obtained. LANDSAT enhanced thematic mapper plus (ETM+) images acquired on March 5th, 2000 (the early summer) and February 18th, 2006 (the late winter) were geo-referenced to a common UTM coordinate system based on the rectified high resolution QuickBird image, aerial photograph and the 1:50,000 scale topographic maps. Using the radiometric correction method propose by Schroeder et al. (2006), the original digital numbers of bands 1–5 and 7 images were converted to at-satellite radiance, at satellite reflectance, and further converted to surface reflectance. While bands 1 through 5 and band 7 are at a spatial resolution of 30 m., the thermal band (band 6) comes at an original spatial resolution of 60 m. for ETM+. In order to carry out further analysis on a common spatial resolution, bands 1–5 and band 7 of both LANDSAT imageries were resampled onto 60 m. using the cubical convolution algorithm.

Derivation of LST, NDVI and NDWI from LANDSAT ETM+ imageries

Derivation of land surface temperature

LST is the radiative skin temperature of the land surface, which plays an important role in the physics of the land surface through the process of energy and water exchanges with the atmosphere. The derivation of LST from satellite thermal data requires several procedures: sensor radiometric calibrations, atmospheric and surface emissivity corrections, characterization of spatial variability in land-cover, etc. As the near-surface atmospheric water vapour content varies over time due to seasonality and inter-annual variability of the atmospheric conditions, it is inappropriate to directly compare temperature values represented by the LST between multiple periods. Therefore the focus here is on the UHI intensity and its spatial patterns across the study region. UHI intensity is estimated as the difference between the peak temperatures (LST) of the urban area and the background non-urban temperatures (Chen et al., 2006). This UHI effect can be determined for the individual thermal images and then compared between two or more periods. However, before we compute UHI effect, we must first derive the LST based on methods for ETM+ images.

As described above, the ETM+ thermal infrared band (10.4–12.5 μm) data were used to derive the LST. Yuan and Bauer (2007) proposed a method of deriving LST in three steps: Firstly, the digital numbers (DNs) of band 6 are converted to radiation luminance or top-of-atmospheric (TOA) radiance (L_λ , mW/(cm^2 sr·μm) using (Eq. [1]) :

$$L_\lambda = \frac{(L_{max} - L_{\min})}{QCAL_{max} - QCAL_{\min}} \times (DN - QCAL_{\min}) + L_{\min} \quad [1]$$

Where *DN* is the pixel digital number for band 6, $QCAL_{\max}$ = 0 is Maximum quantized calibrated pixel value corresponding to $L_{\max}$, $QCAL_{\min}$ = 255 is Minimum quantized calibrated pixel value corresponding to $L_{\min}$, $L_{\max}$ = 17.04 (mW/cm^{2}sr·μm) is spectral at-sensor radiance that is scaled to $QCAL_{\max}$ and $L_{\min}$ = 0 (mW/cm^{2}sr·μm) is spectral at-sensor radiance that is scaled to $QCAL_{\min}$.

Secondly, the radiance was converted to surface temperature using the LANDSAT specific estimate of the Planck curve (Eq. [2]) (Chander & Markham, 2003):

$$T_k = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)} \quad [2]$$

Where T_k is the temperature in Kelvin (K), $K1$ is the prelaunch calibration of constant 1 in unit of W/(m^2

sr·μm) and $K2$ is the prelaunch calibration constant 2 in Kelvin. For LANDSAT ETM+, $K1$ is about 666.09 W/(m^2 sr·μm) and $K2$ is about 1282.71 W/(m^2 sr·μm) with atmospheric correction (Barsi et al., 2005). The final apparent surface temperature on Celsius (˚C) can be calculated the following equation:

$$T_c = T_k - 273.15 \qquad [3]$$

Where T_c is the temperature in Celsius (˚C), T_k is the temperature in Kelvin (K).

Derivation of NDVI and NDWI

Normalized difference vegetation index (NDVI) may be used as an indicator of biomass and greenness (Myneni etal., 2001; Boone et al., 2000; Chen and Brutsaert, 1998). When standardized, it may also be used as a method for comparing vegetation greenness between satellite images (Gillies et al., 1997; Weng et al., 2001). The index value is sensitive to the presence of vegetation on the Earth's land surface, and is also highly correlated with climatic variables, such as precipitation (Schmidt and Karnieli, 2000). In this study, NDVI was used to examine the relationship between LST and greenness. NDVI was calculated as the ratio between measured reflectance in the red and near infrared (NIR) spectral bands of the images using the following formula:

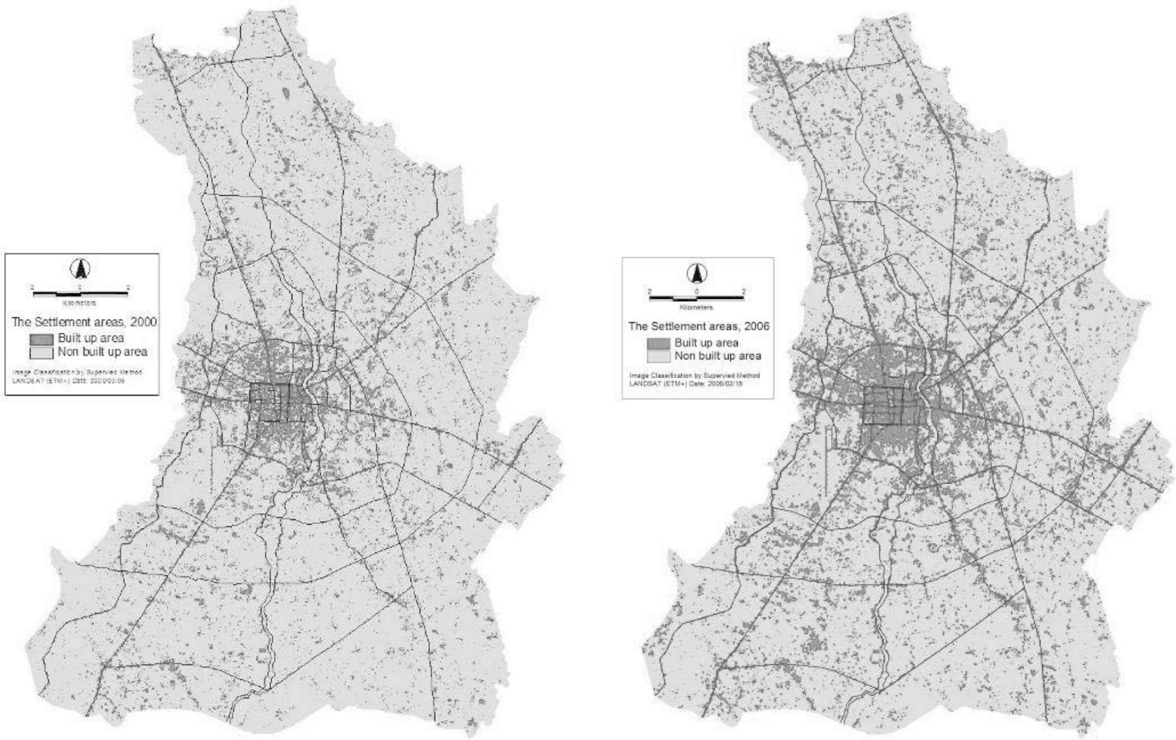
$$NDVI = \frac{R_{NIR} - R_{red}}{R_{NIR} + R_{red}} \qquad [4]$$

Where R_{NIR} and R_{red} are spectral reflectance in ETM+ red (band3) and near-infrared (band4) band, respectively. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.

NDWI is a Normalized Difference Water Index, also called leaf area water-absent index, which implied the water content within vegetation (Gao, 1996; Jackson et al., 2004; Zarco-Tejada et al., 2003) and water state of vegetation (Maki et al., 2004). This study showed that the NDWI was in direct proportion to the water content of vegetation.

$$NDWI = \frac{R_{NIR} - R_{MIR}}{R_{NIR} + R_{MIR}} \qquad [5]$$

Where R_{NIR} and R_{MIR} are spectral reflectance of near-infrared band (band4) and mid-infrared band (band5) of the LANDSAT ETM+ image, respectively.



(a) Built-up area in 2000

(b) Built-up area in 2006

Figs.5 Urban expanded in the study area from 2000 to 2006.

RESULTS AND DISCUSSIONS

Urban expansion detection and analysis

Land covers in urban areas tend to change more drastically over a short period of time than elsewhere because of incessant urbanization. Urbanization has led land covers to change especially frequently in peri-urban areas in CMMA as a result of rapid economic development. These changes can be ideally monitored and detected from remotely sensed images. The results are as follows (Figs.5). The red color indicates the built-up area (including barren land).

In 2000, the total area of built-up and barren land in CMMA was only 43.6 sq.km., accounting for 11% of the study area. However, in 2006, the total areas of built-up and barren land were 49.2 sq.km.; the percentages were 12% correspondingly. There has been a considerable increase in built-up area during the two periods (from 2000 t o 2006); the result found that the total changed area of built-up was increased about 5.6 sq.km. (Table 1). Urbanization transforms the natural landscape to anthropogenic urban land and changes surface physical characteristics. Of these effects, one of the most important is surface temperature variation, especially in the urban areas. Since 2000, many urban areas have expanded dramatically. The increased surface temperature in the CMMA was mainly a reflection of rapid urban expansion during the 6-year period.

Table 1 Built-up area change from 2000 to 2006

Statistics	Year		Changes
	2000	2006	2000 to 2006
Built-up area (sq.km.)	43.6	49.2	5.6
Percentage of the total study area (%)	10.9	12.3	1.4

The conversion of agricultural land into urban/built-up land has also contributed to the increased surface temperature. Moreover, the government policy has relocated many factories to industrial zones in the outskirts of the cities in order to make them more competitive. The new factories, along with supporting infrastructures, were frequently located in high-quality agricultural land while old factories were abandoned and the land remained unused afterward. This relocation has reduced the green area and increased surface temperature. In the past, agricultural areas could provide a buffer zone between the urban and rural areas to absorb excess heat generated by automobiles and factories. Their conversion into urban/built-up uses terminated this functionality. The changes in land use/cover have also widened the temperature difference between the urban and the surrounding areas. For example, average air temperature between Chiang Mai municipality (urban) and Doi Saket district (rural) was about 4˚C degree in 2000, but this difference jumped to 6˚C in 2006.

For the other conditions that affect the urban temperature changes including the ability of heat release by long-wave radiation in urban areas is low due to decreased sky view which results in heat storage in building structures. While the open spaces and green areas of the urban areas enhances radiative cooling because the areas cannot confine air which has been heated during the day. In addition, the urban areas release heat at daytime from human activities, traffic, etc. which play a significant role in increase the urban thermal effects at diurnal range.

Previous researches (Oke, 2004; Givoni et al., 1998; Manat et al., 2011) suggest that the physical profile including urban structure (e.g. dimensions of the buildings and the spaces between them, street widths and spacing) and urban cover (e.g. vegetated, bare soil and water) within the urban canopy layer significantly affects the physics of urban climatic environment. In this study, there are three significant controls on urban climate used in this study were including; density of building (DenBldg) is the ratio of the number of all buildings to the total area of the interest area, building coverage ratio (BCR) and floor area ratio (FAR) are used to estimate the building intensity of a city from three aspects, the buildings stretching on the surface and growing along the third dimension. The BCR is the means percentage ratio of the total standing area of all buildings (or building footprint) to the total area of the interest area, while the FAR is the ratio of the gross floor area of all buildings to the total area of the interest area. It is a building density parameter used in urban planning and design disciplines. It captures the impact of vertical frictional surfaces in urban land due to high-rise built surfaces and used in urban canopy parameterization of drag and turbulence production. On the other hand, it is a major parameter showing development intensity and refers to the intensity of activities taking place within a specified land area and obviously has implications on urban climate that reflects the number of prominent obstacles that affects air flow.

In order to analyze the relationship between surface temperature and the spatial characteristics of CMMA, exposure layers are together inside the GIS platform. Fortunately a geo-referenced building footprint map in the area of interest was made available in digital format by the Department of Public Works and Town &

Country planning (DPT), the government of Thailand. The footprints of the buildings had been extracted from aerial photographs that were taken only in 2006 and the number of floors on each building was counted and obtained by visual surveys. We used grid mesh (500m grid cell size), the resolution is sufficient to provide information regarding urban thermal environment patterns on a local scale to calculate the most important indicators that affect the urban thermal.

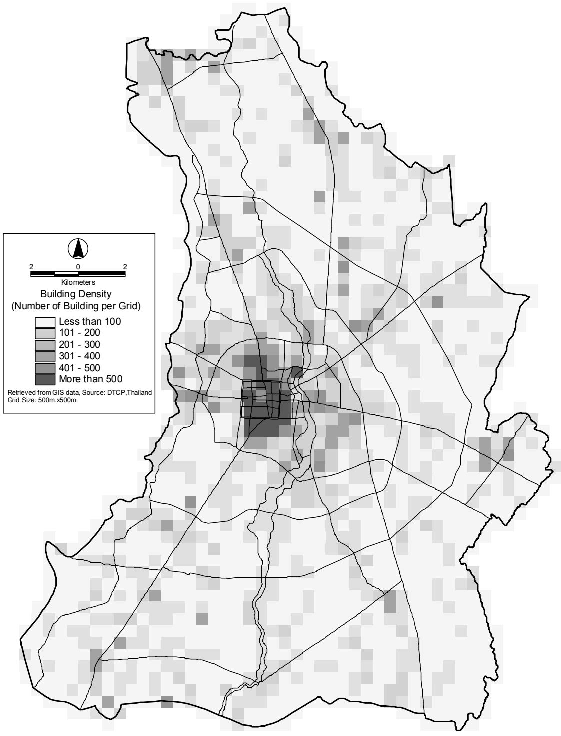
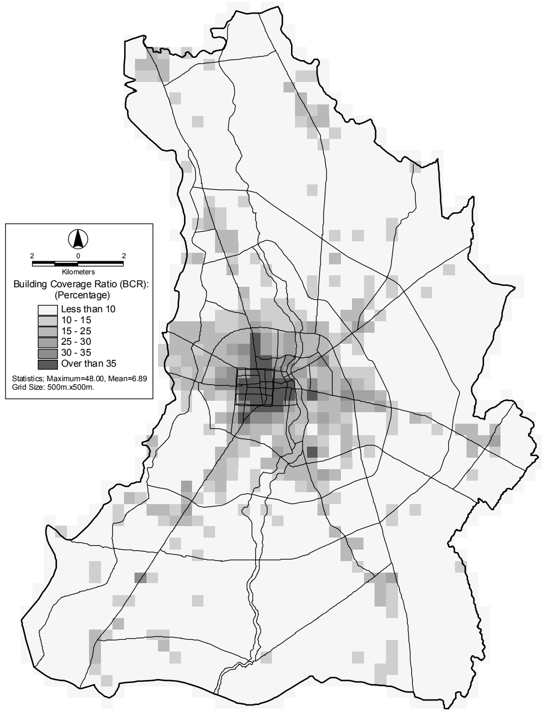
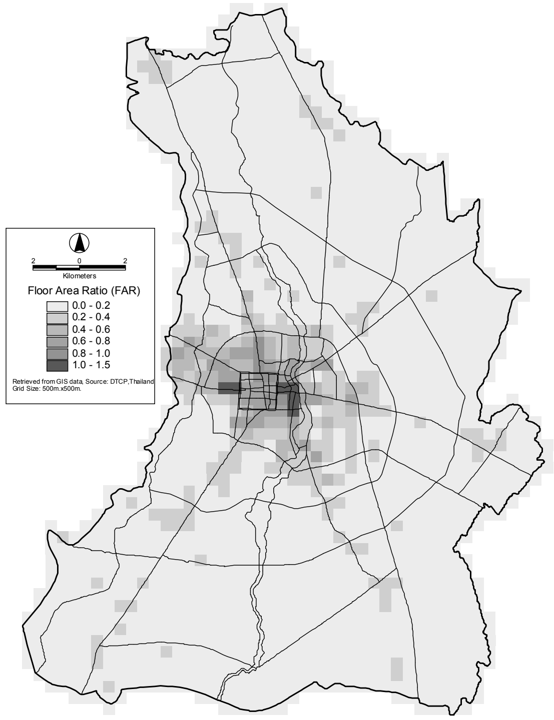


Fig.6 Density of building map (number of building per grid) in 2006

The distribution results of DenBldg, FAR and BCR are shown in Fig.6 and Figs.7, respectively. It shows that the higher the DenBldg and FAR areas are more aggregated, and locate in the center of the inner circle along the Mae Ping river, while the higher BCR areas are more scattered, and interlaced with the higher FAR areas in many places. The average the DenBldg, FAR and BCR value are 258 units, 0.11 and 6.89% respectively for the CMMA. At next step, it was assessed the relationship with thermal environment and if there is, It is thus crucial to identify the spatial characteristic factors amongst the many indicators available to investigate which ones are more important. A Pearson correlation was developed to examine the strength of bivariate associations between urban climate indicators and the variables of composition and configuration of urban morphology indicators.



(a) Building coverage ratio (BCR)



(b) Floor area ratio (FAR)

Figs.7 Distribution of building intensity in 2006

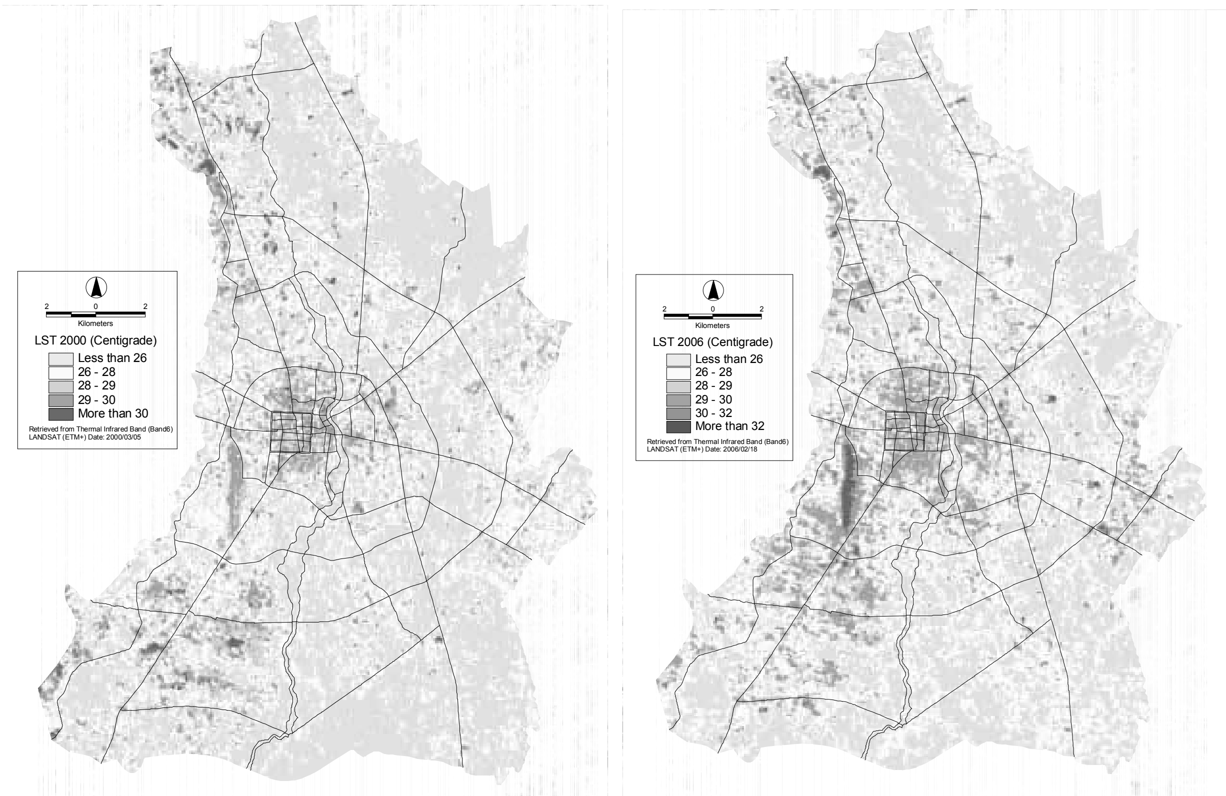
Changes in land surface temperatures (LST)

Summarized characters of LSTs on two dates are show in Table2. Herein, the retrieved land surface temperatures dated on March5, 2000 and February18, 2006 were taken in the mid-winter season, average land surface temperatures ranged from 19.57 ˚C to 25.79 ˚C.

Table 2 Descriptive statistics of land surface temperature in 2000 and 2006

Statistics	LST_{2000}	LST_{2006}
Minimum	12.73	14.88
Maximum	26.50	37.42
Mean	19.57	25.79
Standard deviation	1.39	2.17

Figs.8 shows the increasing extent of LST over the study period. In 2000, the areas with higher surface temperature were mainly located in the central urban area and the major towns, with a typical strip-shaped associated with the traffic road systems. Within the urban central area, numerous sub-centers of LST with higher surface radiant temperature were mainly located in the old and recently developed downtowns at middle section of the Mae Ping River. Southern of the study area, characterized with intensive traditional industries, was also a key contributor to LST distribution. At regional level, the bare lands had higher surface radiant temperatures, especially at the urban fringe areas. Not surprisingly, the water bodies had the lowest surface radiant temperatures, followed by the vegetated areas. Compared to the LST map of CMMA in 2000, the extent of LST in 2006 increased significantly (Figs.9). With the growing central urban area, the extent of SUHI dramatically expanded from the inner cycle highway to the outer one, linking the suburban areas and the substantially growing satellite towns, which were characterized with small and obvious sub-centers with higher surface radiant temperatures. On the other hand, at the northeastern and southeastern parts of CMMA, which cover most of the rural areas of Sansai, Sankhamphang and Saraphi districts, the detected hot spots in 2004 remarkably increased in 2006, except a new hot spot appeared at the recently emerging Hangdong new town at the southwestern.



(a) LST March5, 2000

(b) LST February18, 2006

Figs.8 Distribution maps of surface temperature in CMMA from 2000 to 2006

Changes in vegetative greenness and water content by NDVI and NDWI

The land surface or near land surface temperature can be affected by the nature of land surface cover, ranging from the bare ground to vegetation cover types of variable density. It is well known that NDVI can be used as a surrogate for the density and vigour of vegetation. Figs.10 and Figs.11 shows the distribution of NDVI values by categorizing them into six zones. This image displays a large gray area (low values) at the center of the study area corresponding to the Central Business District (CBD) of CMMA. Dark green areas of high NDVI values were found in the surrounding areas. The average NDVI value decreased from 2000 to 2006 at the center of CMMA (Chiang Mai municipality). The average NDVI value decreased to 0.022 and -0.037, with the standard deviation of 0.163 and 0.137 from 2000 to 2006 for CMMA respectively. This explains the fact that there was less vegetation cover interspersed within the developed areas in 2006 in comparison to 2000, because vegetation landscapes in urban areas are interspersed with the variegated developed urban structures.

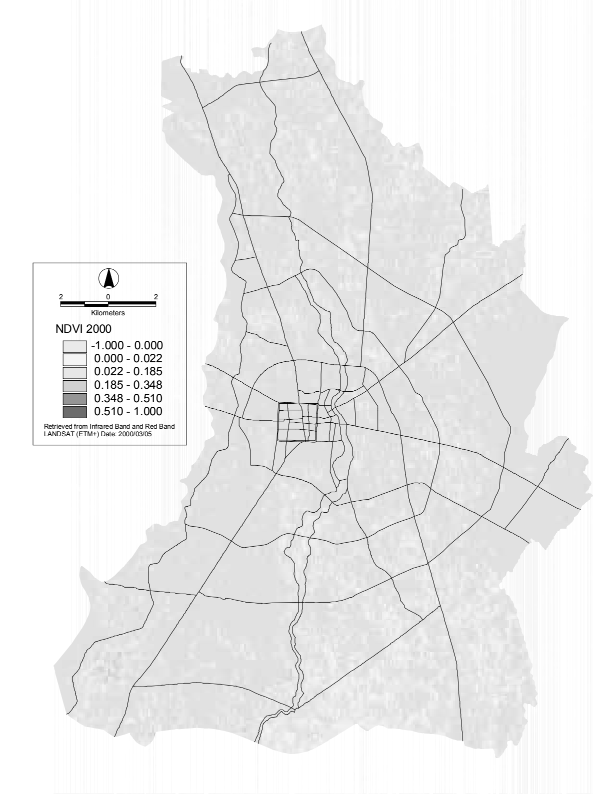
(a) LST March5, 2000 (b) LST February18, 2006

Figs.9 Distribution maps of surface temperature in the core area of the Chiang Mai city

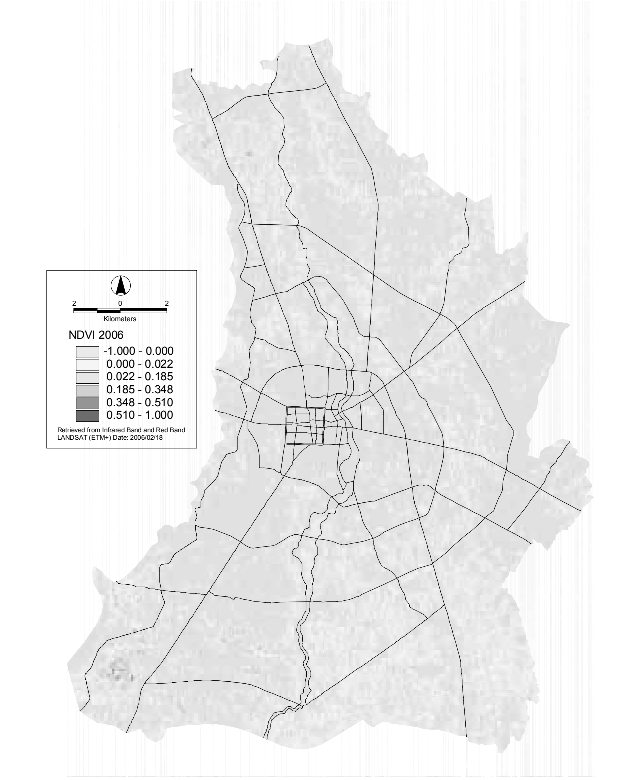
NDVI has been widely used as an indicator of vegetation abundance to estimate LST in studies of urban heat islands (Carson et al., 1994; Gillies and Carlson, 1995; Weng et al., 2004). NDWI was used to substitute for the surface moisture availability. In this study, NDVI, NDWI and LST were found to be closely correlated, especially in vegetated lands. Therefore, the impact of urbanization on LST may be examined by an analysis of the changes in NDVI and NDWI. From the difference between mean values for the two periods, conclusions are clear: arid and semi-arid areas have seen their LST, NDVI and NDWI mean values increase; temperate areas (Central CMMA) have suffered a slight increase in LST and a decrease in NDVI and NDWI mean values, where NDVI and NDWI values have decreased by less than 0.02 and 0.08 respectively.

Relationship between thermal environment and spatial characteristics

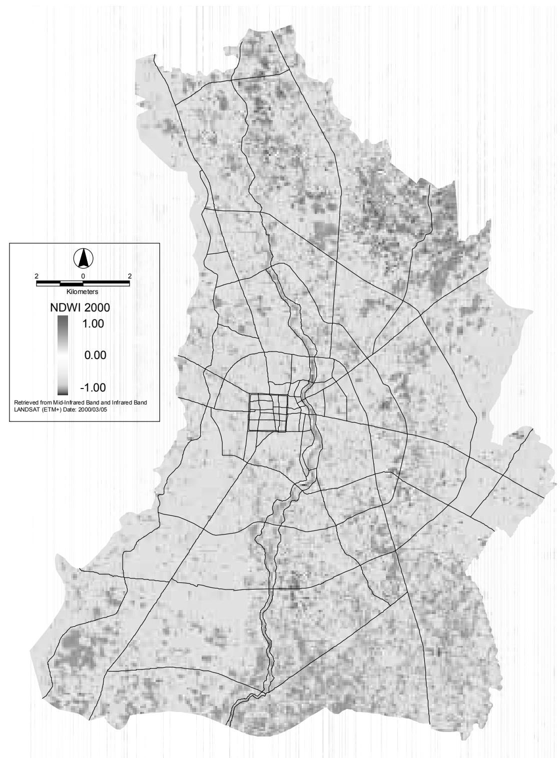
In order to assess the relationship between thermal environment and spatial characteristics of CMMA, correlation analysis was a zonal analysis which was carried out to evaluate the mean LST at the increment of percent building coverage from 0% to 100%, floor area ratio from 0 to 1 and the NDVI and NDWI from -1 to 1. Figs.12 shows relatively strong linear relationships (R^2 = 0.7565) between the mean LST and NDWI for 2006, suggesting that the variations in LST can be well accounted for by NDWI, especially during the dry season period (Fig.12b). On the other hand, the associations between the mean LST and mean NDVI are not straightforward but weak (Fig.12a).



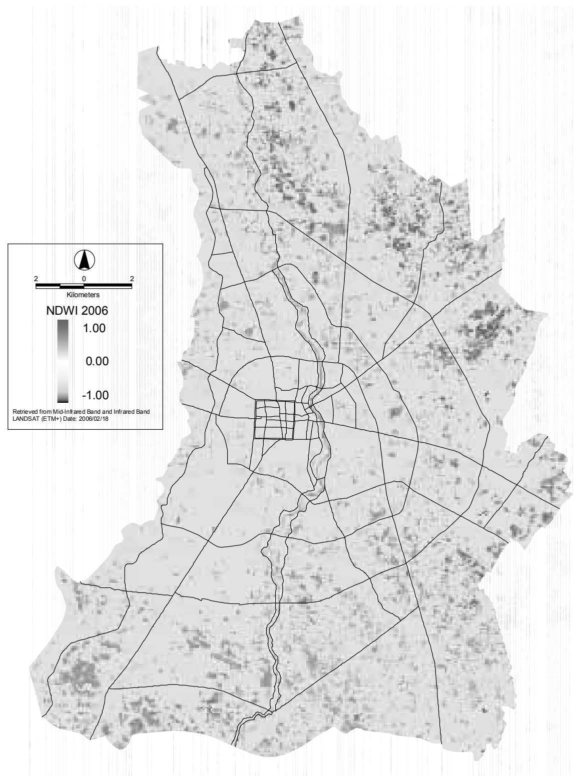
(a) NDVI March5, 2000



(b) NDVI February18, 2006



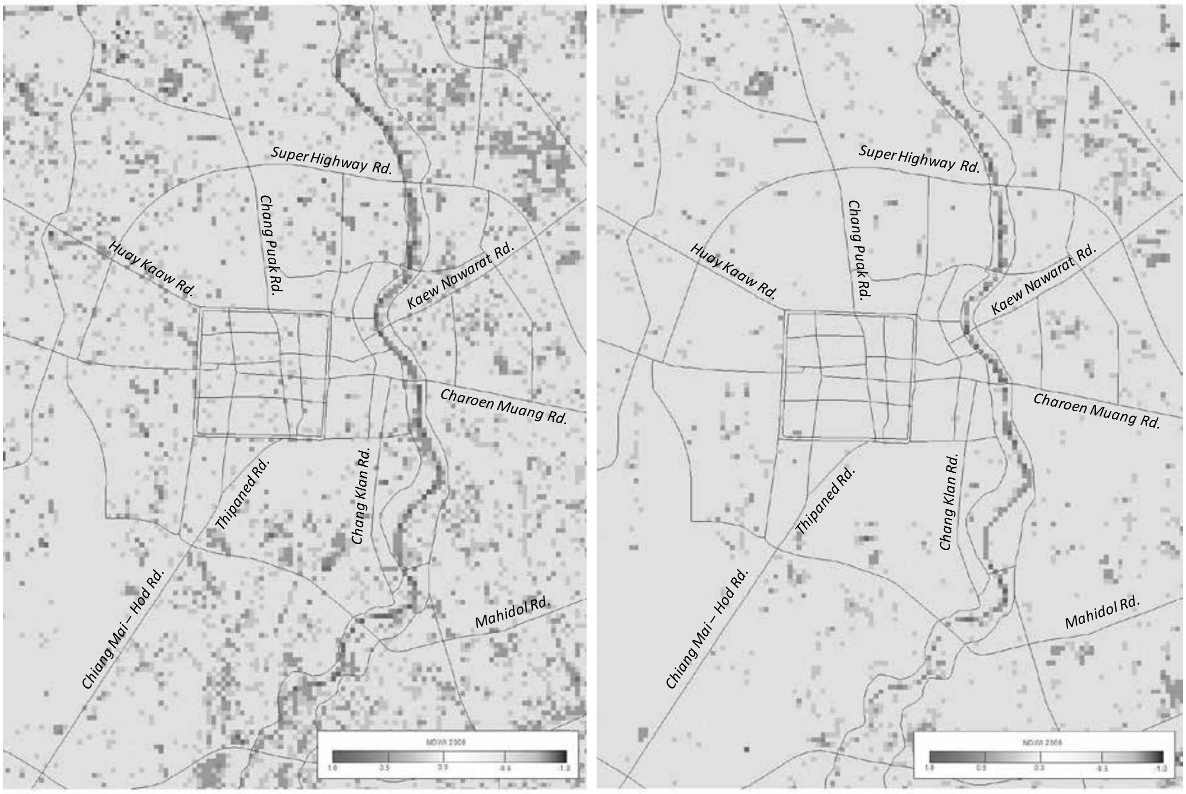
(c) NDWI March5, 2000



(d) NDWI February18, 2006

Figs.10 Distribution maps of NDVI and NDWI in CMMA form 2000 to 2006

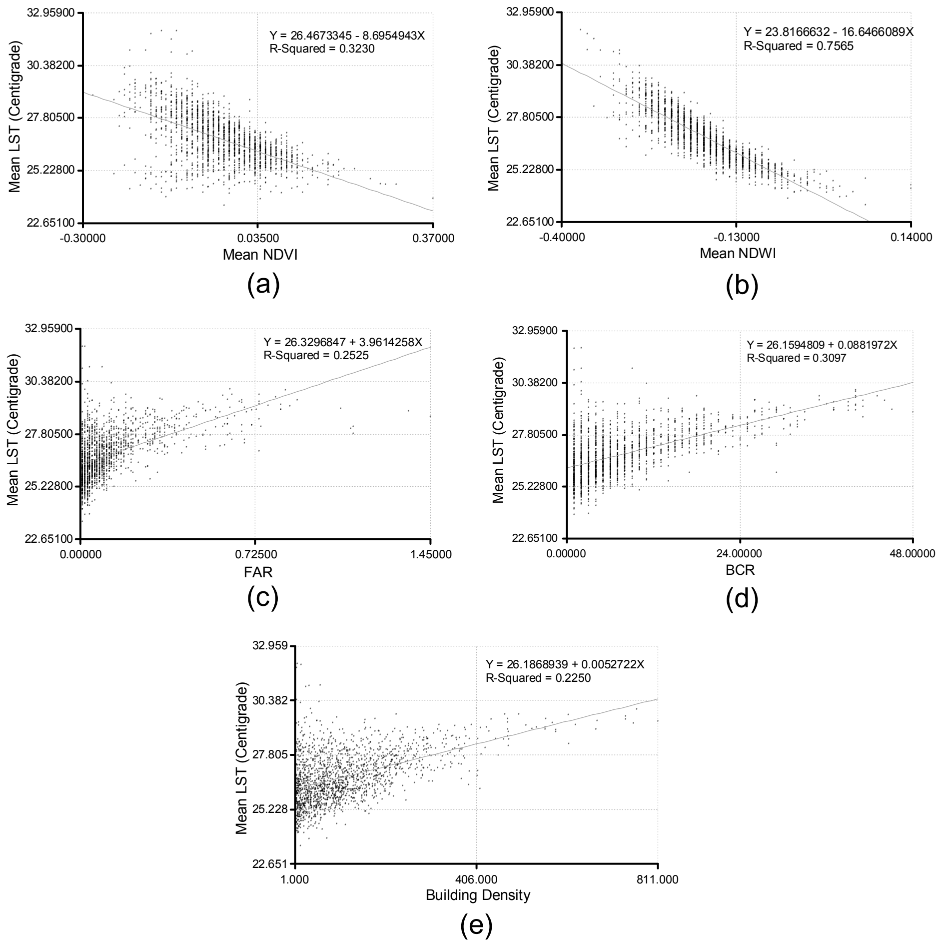
(a) NDVI March5, 2000 (b) NDVI February18, 2006



(c) NDWI March5, 2000 (d) NDWI February18, 2006

Figs.11 Distribution maps of NDVI and NDWI in the core area of the Chiang Mai city

In the urban areas, the vegetation and open water features (e.g. rivers and lakes, lagoons, wetlands, ponds, etc.) is little and the LST is high while it is contrary in rural areas. According to the results, the amount of vegetation and open water features can affect the LST. The reason may be the ecological function of vegetation in cooling down the surface from high evapotranspiration. To reduce urban heat island effect, increasing the vegetation and open water cover can be a very good method for CMMA. In order to quantitatively analyze the relationship between the intensity of building and its temperature, percentage of building coverage and corresponding temperature were used. The scatter plots of BCR and corresponding LST are shown in Fig.12d. The results indicate a statistically significance correlation (R^2 = 0.3097) between BCR and LST, and the resulting regression equation could be used to study the impact of built-up area on LST. The floor area ratio and density of building had positive correlation with LST by 0.2525 and 0.2250, respectively. Our results are consistent with those from previous research that land cover composition, or the percent cover of different types of urban canopy cover features, greatly affect the magnitude of surface temperature. Increasing vegetation and open water features cover could significantly decrease surface temperature, and thus help to mitigate excess heat in urban areas; whereas the increase of buildings and paved surfaces would significantly increase surface temperature, exacerbating the urban climatology phenomena on the diurnal range.



Figs.12 Linear plots of mean land surface temperature (LST) versus spatial characteristics on February 2006

CONCLUSIONS

This paper proposed the term surface urban heat island (SUHI) for a UHI that is measured with LST, has demonstrated the use of LANDSAT ETM+ thermal remote sensing to observing and assessing SUHIs in CMMA. Changes in urbanization were accompanied by changes in SUHI. From 2000 to 2006, the urban or built-up surface temperature increased in whole area of CMMA, and continued to increase. Moreover, temperature differences between the urban area and the surrounding rural areas significantly widened, especially in the core area of Chiang Mai city. This could lead to an intensified urban heat island effect in the urban areas.

This study, the spatial characteristics were defined as the configuration and composition of urban morphology features also significantly affects the surface temperature. A linear regression model in this study was built to determine specific contribution of NDVI, NDWI, DenBldg, FAR, BCR and were used as independent variables to motivate the average surface temperature which was a dependent variable rising on the diurnal range. These simple relationships between climate and spatial characteristic indicators could help decision makers and planners to take climate adaptation into account, to ensure climate neutral development from the beginning of a planning process.

In fact, our results showed that the average surface temperature can be significantly increased or decreased by different spatial compositions and configurations of those features. This is because the spatial characteristics including urban structure and urban cover (e.g. fractions of built-up, paved, vegetated, and open water features) within the urban canopy layer which influences obstruct urban wind flow and increase thermal mass of urban fabric that could heat up the local climate zone. Therefore, it is our recommendation that urban planners should try to control for the effects of their composition. Vegetation management, particularly increasing tree canopy, has been considered an effective means to mitigate excess urban heat and to alleviate the thermal discomfort in the outdoor environment for both highly urbanized areas and areas where urbanization is still in process.

All the analyses in this paper were based on the interpretation of remote sensing images and the results showed that remote sensing images are ideal for analyzing SUHI, by which we analyzed not only the phenomenon of SUHI but the impact factors of SUHI from the regional level to the local level. The surface temperature measurements taken by remote sensing have several limitations should be mentioned. First, they do not fully capture radiant emissions from vertical surfaces, such as a building's wall, because the equipment mostly observes emissions from horizontal surfaces such as streets, rooftops, and treetops. Second, remotely sensed data represent radiation that has traveled through the atmosphere twice, as wavelengths travel from the sun to the earth as well as from the earth to the atmosphere. Thus, the data must be corrected to accurately estimate surface properties including solar reflectance and temperature. In future studies, it is necessary to focus on: *(i)* the impact of the distribution pattern of different land use and land cover (LULC) types on UHI; *(ii)* more accurate estimation of the variable conditions of LULC types; *(iii)* comparison of UHIs estimated for cities of different sizes under different climatic conditions; and *(iv)* multi-temporal studies of UHIs of a single city over four seasons' using different satellite data.

REFERENCES

Barsi, J.A., J.R. Schott, F.D. Palluconi, D.L. Helder, S.J. Hook, B.L. Markham, G. Chander, E.M. O'Donnell, (2003). Landsat TM and ETM+ thermal band calibration. Canadian Journal of Remote Sensing, 29(2), 141-153.

Boone, R. B., K. A. Galvin, et al. (2000). Generalizing El Nino effects upon Maasai livestock using hierarchical clusters of vegetation patterns. *Photogrammetric Engineering & Remote Sensing,* 66(6): 737-744.

Carson, T. N., Gillies, R. R., and Perry, E. M. (1994). A method to make use of thermal infrared temperature and NDVI measurements to infer surface soil water content and fractional vegetation cover. *Remote Sensing Reviews*, 9, 161-173.

Chander, G., Markham, B., (2003). Revised Landsat-5 TM radiometric calibration procedures and post calibration dynamic ranges. *IEEE Transactions on Geoscience and Remote Sensing*, 41 (11), 2674–2677.

Chen, D. and W. Brutsaert.,(1998).Satellite-sensed distribution and spatial patterns of vegetation parameters over a tallgrass prairie. *Journal of the Atmospheric Sciences*, 55(7): 1225-1238.

Gallo, K. P., & Owen, T. W. (1999). Satellite based adjustments for the urban heat island temperature bias. *Journal of Applied Meteorology*, 38, 806-813.

Gao, B.-C., (1996), NDWI-A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment* , 58, 257-266.

Gillies, R. R., and Carlson, T. N. (1995). Thermal remote sensing of surface soil water content with partial vegetation cover for incorporation into climate models. *Journal of Applied Meteorology*,34, 745-756.

Gillies, R. R., Carlson, T. N., Cui, J., Kustas, W. P., and Humes, K. S. (1997). A verification of the 'triangle' method for obtaining surface soil water content and energy fluxes from remote measurements of the Normalized Difference Vegetation index (NDVI) and surface radiant temperature. *International Journal of Remote Sensing*, 18: 3145-3166.

Givoni, B. (1998). Climate Considerations in Building and Urban Design.Wiley.

Jackson, T.J., Chen, D., Cosh, M., Li, F., Anderson, M., Walthall, C., Doriaswamy, P., and Hunt, E.R., (2004).

Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans. *Remote Sensing of Environment*, 92, 475−482.

Lo, C. P., Quattrochi, D. A., & Luvall, J. C., (1997). Application of high resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. *International Journal of Remote Sensing*, 18, 287−304.

Maki, M., Ishiahara,M. and Tamura, M., (2004), Estimation of leaf water status to monitor the risk of forest fires by using remotely sensed data. *Remote Sensing of Environment*, 90, 441–450.

Manat and Hokao K. (2011). The Influence of urban morphology indicators on summer diurnal range of urban climate in Bangkok metropolitan area, Thailand. *IJCEE-IJENS*, 11(5), 34-46.

Myneni, R. B., Dong, J., Tucker, C. J. Kaufmann, R. K. Kauppi, P. E., Liski, J., Zhou, L., Alexeyev, V., & Hughes,M. K.,(2001). A large carbon sink in the woody biomass of Northern forests. *Proc. Natl. Acad. Sci. U.S.A*., 98, 14784-14789.

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108, 1−24.

Oke,T.R. (2004). Initial guidance to obtain representative meteorological observations at urban sites. IOM Report No. 81, WMO=TD No. 1250, Geneva: World Meteorol Organiz.

Owen, T. W., Carlson, T. N., & Gillies, R. R. (1998). An assessment of satellite remotely-sensed land cover parameters in quantitatively describing the climatic effect of urbanization. *International Journal of Remote Sensing*, 19, 1663−1681.

Roth, M., Oke, T. R., & Emery, W. J. (1989). Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International Journal of Remote Sensing*, 10, 1699−1720.

Schmidt and Karnieli,(2000), Remote sensing of the seasonal variability of vegetation in a semi-arid environment, *Journal of Arid Environments,* 45 (1), 43–60.

Schroeder et al., (2006), Radiometric correction of multi-temporal Landsat data for characterization of early successional forest patterns in western Oregon, *Remote Sensing of Environment*, 103, 16–26.

Voogt, J.A., Oke, T.R., (2003). Thermal remote sensing of urban climate. *Remote Sens. Environ*. 86, 370–384.

Voogt, J. A. (2004): Urban Heat Islands: Hotter Cities. http://www.actionbioscience.org/environment/voogt.html

Walsh, S. J., Butler, D. R., and Malanson, G. P. (1997) An overview of scale, pattern, process relationships in geomorphology: A remote sensing and GIS perspective. *Geomorphology*, 21, 183–205.

Weng, Q. (2001). A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in Zhujiang Delta, China. International Journal of Remote Sensing, 22(10), 1999−2014.

Weng, Q., Lu, D., and Schubring, J. (2004). Estimation of land surface temperature– vegetation abundances relationship for urban heat island studies. *Remote Sensing of Environment*, 89, 467-483.

Yuan and Bauer, (2007), Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery, *Remote Sensing of Environment*, 106, 375–386.

Zarco-Tejada., P.J., Borjon, A., Morales, A., Miller, J. R., Aguera, J., Cachorro, V., et al. (2003). Leaf biochemistry estimation on EU high-value crops with ROSIS and DAIS hyperspectral data and radiative transfer simulation. *3rd EARSeL workshop on imaging spectroscopy*, 597-602.