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A study on urban development through land surface temperature by using remote sensing: in case of Ho Chi Minh City

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Abstract. In this research, remote sensing technology was used to evaluate urban development and its thermal characteristics through mapping impervious surfaces and evaluating thermal infrared images. The study is carried out in the northern part of Ho Chi Minh City, which is experienced an accelerated urban development since the end of 1980s. Landsat and Aster images were used to calculate the variation in urban impervious surfaces from 1989 to 2006. Thermal bands were processed to obtain land surface temperatures for investigating the urban heat island effect associated with increasing impervious surfaces both spatially and temporally.

*Keywords***:** Emissivity; Impervious surface; Land surface temperature; Surface urban heat island; Urban development.

1. Introduction

Urban development, as the major type of human activities leading to land cover change, has a great impact on the environment. In the process of urbanization, natural vegetation cover is largely replaced by impervious surfaces such as buildings, roads, parking lots, sidewalks and other built surfaces. Therefore, the impervious surfaces are important as a key for monitoring the urban development [1, 3, 9]. In urban environment, where vegetation is fairly sparse, build up or impervious surfaces are stronger absorbers. The absorbed radiation is gradually re-emitted as long-wave radiation that is responsible for warming up the boundary layer of the atmosphere within the urban canopy layer [8]. The temperature response and reflective properties of impervious surfaces are linked to the "urban heat island" (UHI) effect, which often makes cities several degrees warmer than the countryside. The hot climate of cities affects human comfort and health because of changes in sensible heat fluxes and the concentration of atmospheric pollutants [2]. Therefore, urban development has a great impact on the urban surface temperature. Urban areas developed in spatial and industrial activity context are considered as a factor contributed in the global climate change.

Measuring the urban development and the land surface temperature (LST) become essential for several environmental applications

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and the planning, as well as management of sustainable development in urban areas. There are many efforts to map the impervious surfaces and LST in urban environment, such as field measurement, visual interpretation of aerial photography. But they cost labor intensive, time consuming and expensive task to manually survey and map them. As a more cost-effective alternative, the remote sensing technology has been widely used in numerous applications in order to obtain much of the earth surface spatial information.

This paper has used remote sensing technology to study in Ho Chi Minh City for such objectives: (1) detecting the spatial urban development through impervious surface (IS); (2) deriving LST and analyzing its spatial and temporal distribution in the relationship with the urban IS and land cover; (3) examining the surface urban heat island (SUHI) measured by the urban-suburban LST differences. The time period happens from 1989 to 2006.

2. Study area and data sets

2.1. Study area

Ho Chi Minh City is located in the South of Vietnam and has a diversified landscape from the northern to the southern part by the natural elevation. The urban areas are mainly concentrated in the central of the city. The northern part is the agricultural land; the southern one is low land with dense mangrove forests. According to statistical data, the population density has increased from 552 pers/km^2 in 1985 to 3,067 pers/km^2 in 2006 (in urban areas about 10,905 pers/km^2, in rural areas about 648 pers/km^2). The population growth causes the spatial expansion being through encroachment into adjacent agricultural and rural regions, especially in the northern part of the city due to the advantages of landscape and relative high topography. Therefore, the study area is limited to this part. Here is the place where the urbanization process is happening fairly strong in the recent years (Fig. 1).

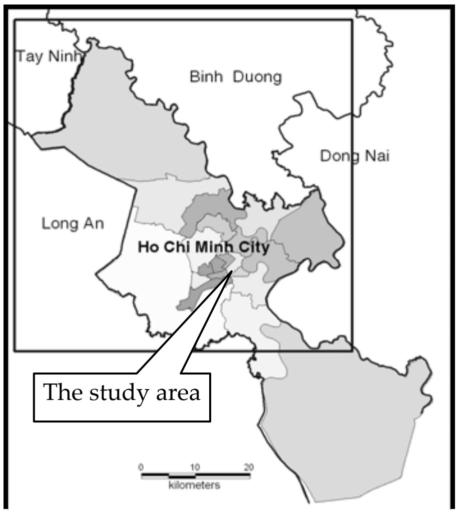


Fig. 1. The study area.

2.2. Data sets

Landsat TM and Aster images were used as the main data source in this research. Two Landsat TM images have seven bands, included six reflective bands in visible, near- and mid-infrared spectral region with 30-m pixel size and one thermal infrared band with 120-m pixel size, acquired on Jan 16, 1989 and Jan 25, 1998. One Aster image acquired on 25 Dec, 2006 has 14 bands with different spatial resolutions, i.e., three visible-near-infrared (VNIR) bands with 15-m pixel size, six shortwave infrared (SWIR) bands with 30-m pixel size and five thermal infrared (TIR) bands with 90-m pixel size. In the image processing stage, all Aster and Landsat images were converted from DN to radiance for further suitable calculation. The 2006 Aster image was then georeferenced in Universal Transverse Mercator projection based on the topographical map with RMS error less than 0.5 pixels. All Aster bands were resampled in 15m. An image-to-image registration was conducted between the Aster image and the TM images in order to keep registration errors to less than a pixel. The 15-m resampled interval was carried out for all bands of the two TM images.

3. Methodology

3.1. Measurement of the urban IS

The satellite sensors record the earth surface from the radiance value which depends on the land cover spectral characteristics. Urban areas are heterogeneous and complex with different kinds of the impervious construction materials, which have different reflective and absorptive capacity. So the IS will be one land cover category for indicating the urban area in this study. In digital interpretation, the confusion of the bare land, moisture land and urban IS in the satellite images usually happen. Therefore, detecting and interpreting IS from satellite images require the integrated techniques plus the expert knowledge for the high accuracy. In this study, the IS type will be retain as the main category distinguished with other non-IS types in the whole process of digital image. At first, the supervised classification was used for extracting 4 main types of land cover, including IS, bare land, vegetation and water. There is no unique classification method due to the data acquired from multi sensors in a long time from 1989 to 2006. Through investigation in this study, the Mahalanobis distance and Maximum Likelihood Classifications were carried out in dependence of the image characteristics and statistics. Supervised classification method shown that IS was excellently separated from water and moisture land, but some bare land was mixed into that one. The NDVI (Normalized Difference Vegetation Index: NDVI=(Red-NIR)/(Red+NIR)) image was then used for making a threshold, where the NDVI value less than "0" usually represents for urban IS and water types. Classified IS and threshold NDVI images were multiplied to remove the mix pixels. The final IS results was accepted for setting up the map of urban spatial distribution. For change evaluation of IS, the study carried out the post-classification comparison.

3.2. Measurement of LST in the study area

Satellite thermal infrared sensors measure radiances at the top of the atmosphere, from which brightness temperatures T_B (also known as blackbody temperatures) can be derived by using Plank's law [7]:

$$T_B = \left(\frac{hc}{k\lambda}\right)\left(\frac{1}{\ln\left(\left(2hc^2\lambda^{-5}\right)/B_\lambda + 1\right)}\right), \qquad (1)$$

where h is Planck's constant (6.62×10^{-34} J-sec), c - velocity of light (2.998×10^{8} m/sec), λ - wavelength of emitted radiance (m), B_λ – blackbody radiance ($Wm^{-2}\mu m^{-1}$).

In order to determine the actual surface temperature it is necessary to do atmospheric correction and know the emissivity of the surface land cover. Due to lack of atmospheric measures during image acquisition, the atmospheric correction was ignored. However, these images were acquired in dry season in the study area, so they appeared very clear. In this context, the atmospheric effects on these images were not significant. The emissivity (ε) was calculated by using the formula of Valos and Caselles [10]:

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s(1 - P_v), \qquad (2)$$

where ε_v, ε_s are the emissivities of the full vegetation and bare soil, P_v is the vegetation cover fraction. They can be calculated by NDVI. If land surface emissivity is known, the LST (T_S) can be calculated by using the Stefan Boltzmann law [6]:

$$B = \varepsilon\sigma T_S^{\,4} = \sigma T_B^{\,4}, \qquad (3)$$

therefore:

$$T_S = \frac{1}{\varepsilon^{1/4}} T_B, \qquad (4)$$

where σ is the Stefan Boltzmann constant ($5.67\text{x}10^{-8} Wm^{-2}K^{-4}$).

The Landsat TM images with one thermal band 6 in the atmosphere window of 10.4-12.5μm were used for deriving the LST. The Aster images have 5 thermal bands from 10 to 14 in the window 8.125-11.25μm, but 2 bands

13 and 14 with the same window as of Landsat images will be used for calculating LST. The choice is based on that approximately 80% of the energy thermal sensors received in this wavelength range are emitted by the land surface [4] and the maximum value of LST is usually obtained in this range [5]. The results gave the spatial distribution of LST in the whole study area. Then the SUHI was evaluated based on this LST distribution between urban and rural areas.

Besides that, historical climate information such as the data of annual mean air temperature from 1989 to 2006 are collected from the Southern Region Hydrometeorological Center. These in-situ data were recorded in only one observation meteorological station named Tan Son Hoa. They were used for evaluating the trend of the temperature in urban area.

4. Results and discussion

4.1. Urban development through IS

The results of image derived IS were obtained with a fairly high accuracy through confusion matrix. The overall accuracy and Kappa coefficient of all 3 years were greater than 96%. By history, the urbanization in the northern part of Ho Chi Minh City was rapidly developed after formation of the five new districts (districts 7, 9, 2, 12, and Thu Duc) in 1997. The IS map (Fig. 2) and results (Table 1) in 1998 year indicated that the development of IS area is approximately 2.5 times bigger than that in 1989. The IS area from 1989 to 2006 was extended in about 6.5 times. Investigation of the IS in 3 years (1989, 1998 and 2006) shows that the IS was concentrated and expanded from the central part of the city with a growing tendency to the North, West and East of the city and along the main roads. Fig. 3 shows the trend of urban IS development with a strong slope between 1998 and 2006, indicating that Ho Chi Minh City is becoming a mega city in the late years. It requires a reasonable urban management for sustainable development in the future.

Table 1. Total area of impervious surfaces in 1989, 1998, and 2006

Year	IS area (ha)	% total area
2006	46,488.38	31.98
1998	18,693.32	12.86
1989	7,147.42	4.92

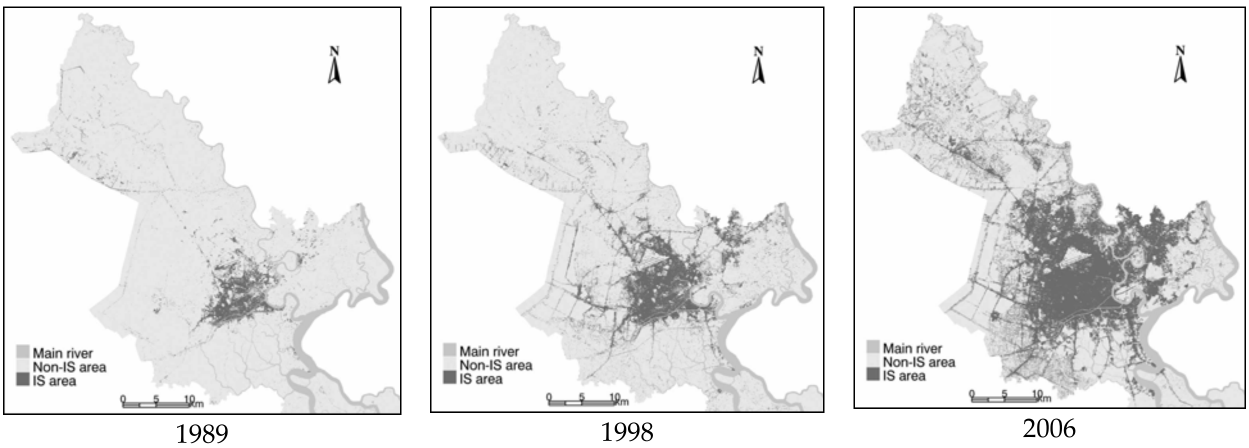


Fig. 2. IS distribution of Ho Chi Minh City in 3 years.

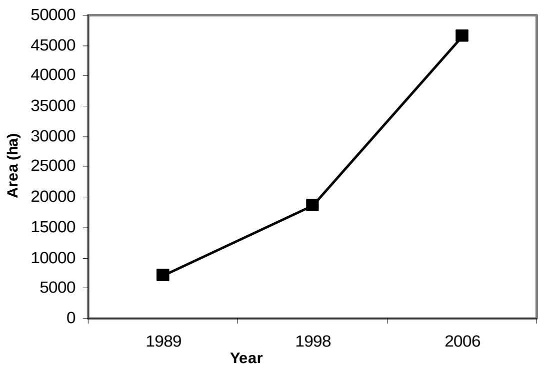


Fig. 3. The trend of urban IS development in Ho Chi Minh City.

4.2. LST distribution and impact of the urban development on surface temperature

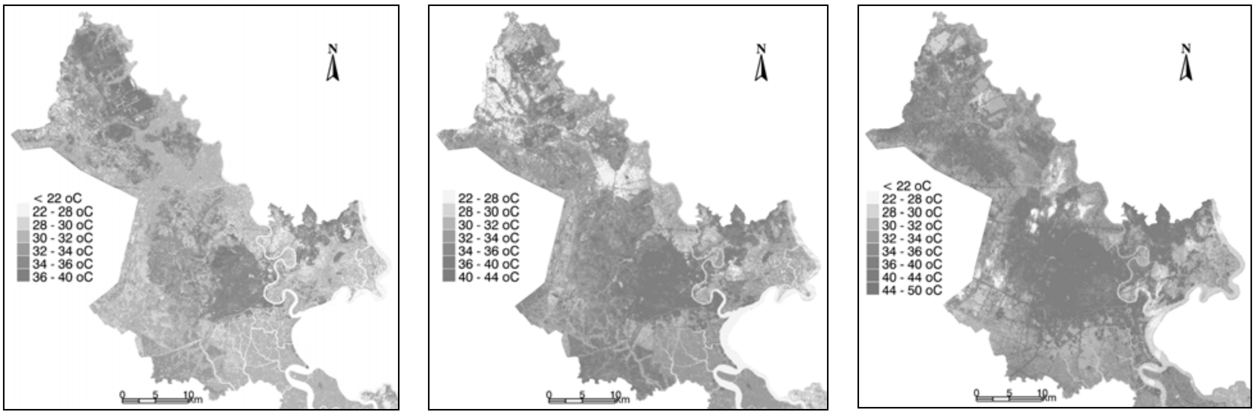
The LST measurements from the meteorological stations are recorded only in very sparse sites. Therefore, they can not tell us the temperature in somewhere we need. However, the remote sensing method can do it. The retrieved LST maps show the picture of LST distribution in an area. In this study, the accuracy of the satellite LST retrieval is determined by comparing the estimated LST from Aster image 2006 to the in-situ measurements in 10 observed points. It showed that the bias was less than 2^{o}C. The maps in Fig. 4 were produced to show the spatial distribution of emissivity-corrected LST in 1989, 1998 and 2006. The statistics of LST in Table 2 indicates that the highest temperature was increased from 39.8^{o}C in 1989 to 49.4^{o}C in 2006. It was only the instantaneous results in the time of image acquisition. But if it is considered that the 2006 image was recorded in the late of cool period of December, it could be think that the temperature was increased by time.

The remote sensing method provides not only a measure of the magnitude of surface temperatures of the entire city area, but also the spatial extent of SUHI effects. From Fig. 2 and 4 it is obvious that the IS distribution is proportional to the high LST one. The LST maps in 1989 and 2006 show the extension of the high LST areas with the expansion of developed urban areas. The heat islands were found in some hot spots over the study area. In the 1989 map, the high LST is shown in the bare land in the north of the city. There was not to be an extensive hot spot in the old urban areas. In this time the urban IS was not much in comparing to vegetation cover, so it was less effective to increase the LST.

The rapid process of urbanization after formation of the five new districts in 1997 caused the increase of the SUHI from 1998 to 2006. In the 2006 LST map, an extensive SUHI is concentrated in the central part city. One SUHI was developed in the north of the city in Cu Chi District. The third one was found in Thu Duc District of the eastern part. The highest LSTs (>45^{o}C) were found in the industrial zones, where the temperature was created from the production activities plus the received solar radiance. The urban areas have suffered the temperature within 36-40^{o}C. In addition, the wind circulation in urban areas is limited by the building elevation and structure. So with this temperature level human body always senses uncomfortable and requires air cooling. The more air conditions are used, the more heat is released, and the temperature is increased then. In spite of that, in the suburban and rural areas where the agricultural land still remains with the full vegetation cover the LST usually is lower.

Table 2. Statistics of LST at the time of satellite image acquisition

Year	Min	Max
1989-01-16	12.1	39.8
1998-01-25	22.3	43.5
2006-12-25	17.5	49.4



1989 1998 2006

Fig. 4. Distribution of land surface temperature in 1989, 1998 and 2006.

4.3. The relationship between LST and land cover types

The relationship between LST and land cover types was investigated for further understanding the effect of urban development. Table 3 and Fig. 5 show the average temperature of land cover. It is apparent that where the human is present, the heat is released and increased. The highest temperatures are always in industrial zones and urban areas. This implies that urban growth brings up surface temperature by replacing natural vegetation with non-evaporating, non-transpirating surfaces such as impermeable stone, metal and concrete. The agricultural land with grown crops in suburban areas has the lower temperature. Forest shows a considerable low surface temperature in 3 years, because dense vegetation can reduce the amount of heat stored in soil and surface structures through transpiration. By time with the same type of land cover their LST show a positive slope (Fig. 6). It tells us that the temperature tendency is increased, particularly when the process of industrialization and urbanization are developed by human demands. The graph in Fig. 7 exhibits the trend of in-situ air temperature measurement in meteorological station located in urban area of Ho Chi Minh City. The air temperature is the result of the process of atmosphere heat from the sun radiation and from the earth surface. So the high LST will contribute in high increase of the air temperature. This graph reflects the same picture from the remote sensing results.

Table 3. Average land surface temperature (^{o}C) by land cover type

Land cover type	1/16/1989			1/25/1998			12/25/2006		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Industrial zone	-	-	-	40.0	43.5	41.7	45.0	49.4	47.2
Built-up land	33.7	36.3	35.0	34.5	39.3	36.9	35.0	43.9	39.4
Bare land (construction site)	32.6	36.7	34.6	33.7	38.8	36.2	31.9	41.4	36.6
Land after crop	31.6	33.1	32.3	33.4	37.7	35.6	33.9	41.9	37.9
Land under crop	27.7	32.2	29.9	25.6	30.8	28.2	28.3	34.2	31.2
Forest	23.1	27.1	25.1	24.7	28.4	26.5	28.4	29.7	29.1
Water	20.3	24.9	22.6	23.9	29.8	26.9	26.8	33.5	30.1

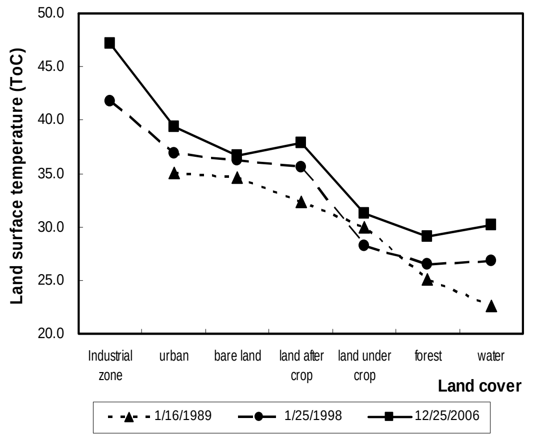


Fig. 5. Average LST by land cover in 1989, 1998, and 2006.

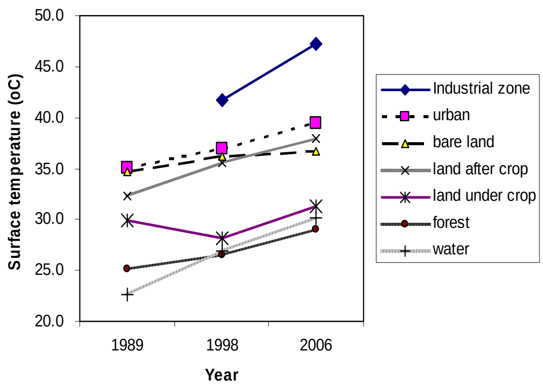


Fig. 6. The trend of average LST by land cover in 1989, 1998, and 2006.

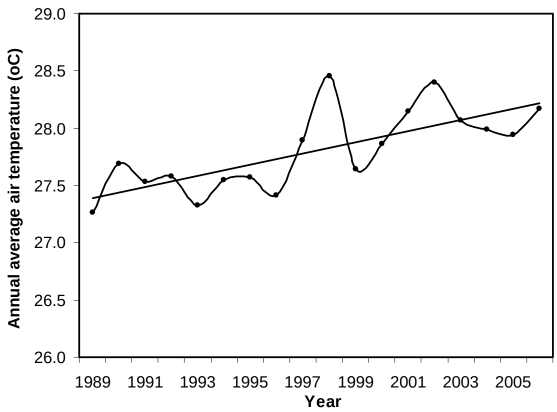


Fig. 7. Annual mean air temperature in the urban area of Ho Chi Minh City, 1985-2006.

4.4. Urban environment management with reasonable control of imperviousness and heat island effects

Urban areas are already remarkable concentrations of climate vulnerability and projected rates of urban development mean that vulnerability will increase at the same time as the impacts of climate change become increasingly manifest. Actions by planners, designers and infrastructure owners in sustainable management of urban environment are required in the short term if cities are to avoid becoming ever more vulnerable in the long term. These are already urgent problems.

Heat islands can amplify extreme hot weather events, which can cause heat stroke and lead to physiological disruption, organ damage, and even death - especially in vulnerable populations such as the elderly. Summer-time heat islands increase energy demand for air conditioning, raising power plant emissions of harmful pollutants. Higher temperatures also accelerate the chemical reaction that produces ground-level ozone, or smog. This threatens public health and the environment.

The above investigation shows that urban development relates to the impervious surface presence and affects on SUHI extension which can be detected from the satellite images. Therefore, in the urban management strategies it is necessary to control the urban development according to the plan. Moreover, vegetation plays an important role in making the urban climate equable. According to the information from the website of Ministry of Natural Resources and Environment in 2008, the green space in Ho Chi Minh City achieves on an average only 0.6m^2/person, which is 10 times lower than the standards. Hence, there are some steps that the community can take to lessen the impacts of heat islands, such as (1) installing cool roofs or vegetated green roofs, (2) installing green roofs, (3) switching to cool paving materials and (4) planting trees and vegetation.

However, some factors, such as land-use patterns, materials used in road and building construction, and the coverage of urban trees and vegetation,... can be directly affected by the decision makers. This is where policies and programs for reducing the impacts of heat islands (and achieving related environmental and energy-savings goals) can be most effective.

5. Conclusions

Urban development intensity and spatial extent can be characterized by using satellite remote sensing data through mapping the impervious surface distribution. This study has shown that different urban development intensities, defined by IS, have significant effects on LST. The urban and built-up area in the northern part of Ho Chi Minh City has expanded by 6.5 times from 1989 to 2006 year, and the urban development has altered the magnitude and pattern of SUHI. Application of satellite thermal infrared data to the study of LST suggests that different land cover types have distinctive responses. The conversion of natural and vegetated surfaces into urban development purposes will rise the temperature and increase the spatial variability of LST.

Temperature is an important meteorological factor in the process of forming the climate. The urban development and expansion lead to increase of LST and formation of extensive SUHI over the urban areas. This has impact not only on the local level but also on the global level if the temperature is increased more and more. If LST can be used as a surrogate for air temperature, then urban planners and managers can utilize satellite-derived measurements to indicate the need for new or revised urban design and landscaping policies for mitigating the UHI and SUHI effects on the climate condition.

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