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Spatial analysis on urban heat island in Ho Chi Minh City

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Abstract

The urban heat island (UHI) is a temperature difference between the inner city and the suburbs. This is characteristic of the process of urbanization with the increase of impervious surface, increasing the temperature of the inner city. Measurements from the ground observation stations can not detect spatial distribution of UHIs due to limitation on station density. This paper presents the results of research and application of Landsat satellite images to survey the distribution and spatial variation of the surface urban heat island (SUHI) for the northern region of Ho Chi Minh City. The study results showed that, in the period 1995-2015, the trend of urban heat island formation surface shows clearly the difference between the surface temperature of urban areas and rural areas with space expansion of heat island in 4 times in 2015 compared to 1995. The study results can be used to support the planning and management of the urban environment, and to ensure better living for urban residents

Keywords: impervious surface, land surface temperature, urban heat island, urbanization

1. Introduction

Urban development is the development of urban economy, culture, ecology, infrastructure and urban management. A corollary of this development is the change in environmental quality, specially created differences in microclimate conditions of the urban environment. Urban development alters the natural landscape, shrinking water surface, making conversion of agricultural land into construction land, leading to the appearance of more and more impervious surfaces, which is a specific type of coating representing urban environment, changing the thermal properties of the soil, surface energy budget in the earth, changing the properties of circulation of surrounding atmosphere, creating a large amount of heat emitted from the human activities and led to a series of changes in the system of the urban environment. The impact of urban development on the thermal environment is creating the effect of "urban heat island" (UHI - Urban Heat Island). This effect most originated near the Earth's surface and the first causes surface temperature anomalies. The land surface temperature anomalies will spread upwards into the atmosphere (Jone *et al,* 1990; Kanay *et al,* 2003). In the context of climate change increasing evident as today, along with rapid and complex urbanization, deep understanding of the UHI is intended to support the management of the urban environment effectively and aims to protect public health under their impact.

Ho Chi Minh City (HCMC) is the most populous city in Vietnam. The increase in population and socio-economic development has led to increased traffic, housing area extending to the suburbs more than before. The

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higher building density, the higher surface radiant temperature. Meanwhile, the green area of the city was narrowed. The natural balance within the city are broken, strongly impact on the change of climate, due to the rise of urban temperatures than surrounding areas, forming UHI, making the city transformed into "fireball" heated people (Van, 2011).

This paper presents the research and application of remote sensing technology from the Landsat image exploitation, with reflectance spectral and infrared bands to examine environmental changes, reflected by the surface urban heat island (SUHI), which proposes solutions to minimize their impact on the environment and the health of urban residents in HCM City.

2. Methodology

Satellite thermal infrared sensors measure radiances at the top of the atmosphere, from which brightness temperatures T_B can be derived by using Plank's law (Markham *et al.* 1986), where h is Planck's constant (6.62 $\times 10^{-34}$ J-sec), c – velocity of light (2.998 $\times 10^{8}$ m sec^{-1}), λ – wavelength of emitted radiance (m), B_λ – blackbody radiance (Wm^{-2} μm^{-1}):

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

In order to determine an actual surface temperature it is necessary to carry out atmospheric correction and know the emissivity of the surface land cover. Due to lack of atmospheric measurements during image acquisition, the atmospheric correction was ignored. However, these images were acquired during the dry season in the study area, so they appeared very clear. In this context, the atmospheric effects on these images were not significant. Emissivity of natural surfaces may vary significantly due to differences in soil and vegetation cover characteristics (Van De Griend *et al,* 1993). Therefore, correction for emissivity should be done. The emissivity (ε) was calculated by using the formula of Valos and Caselles (1996):

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

Where ε_v, ε_s are the emissivity of the full vegetation and bare soil, and P_v is the vegetation cover fraction. They can be calculated by NDVI. With the known land surface emissivity from formula (2), the emissivity-corrected land surface temperature (LST) (T_S) can be calculated by the Stefan Boltzmann law (Gupta, 1991):

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

Therefore,

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

Where σ is the Stefan Boltzmann constant (5.67 x 10^{-8} Wm^{-2} K^{-4}), B – total amount of radiation emitted (Wm^{2-}), T_S – land surface temperature (K), T_B – brightness temperature (K), ε – emissivity varied between 0 and 1.

Satellite images taken in this study is Landsat TM, Landsat ETM +, Landsat / OLI & TIRS, be obtained free of charge from the website of the United States Geological Survey. Data and image acquisition time is as follows: LANDSAT / TM - 02/02/1995; LANDSAT / ETM - 04/01/2005; LANDSAT / OLI & TIRS - 24/01/2015

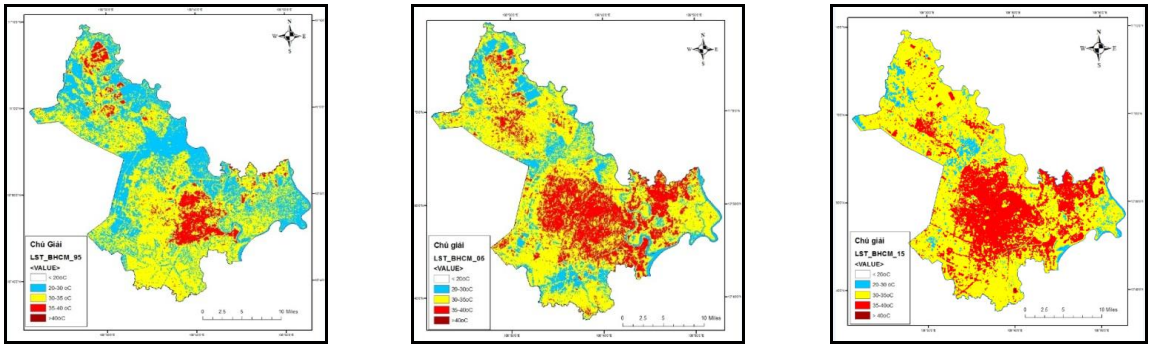
3. Results and Discussion

3.1. Change of surface urban temperature period 1995-2015

3.1.1. LST distribution

The result of the LST distribution on 3 image acquisition times (Fig. 1) showed that higher temperatures generally concentrated in the urban districts with values ranging from 21^{o}C to 47^{o}C. According to spatial distribution, the region where the LST values > 40^{o}C, scattered in industrial areas or areas with production activities. Northern area of HCMC with values from 35^{o}C to 40^{o}C LST mainly concentrated in urban areas, residential areas where there is no greenery or trees with sparse density, and the bare land, respectively with a decline in vegetation cover in the districts 10, 11, Tan Binh, Tan Phu... This can be explained, because urban areas have surface coatings or building materials in concrete, stone, asphalt ... with properties of high thermal conductivity, absorption of radiation reaching good and fast but low reflectivity. Meanwhile, the process of evaporation of impervious surface made by this type of material is less than the surface covered with vegetation, trees or wet soil.

Range of LST values from 30°C to 35°C concentrated in areas with trees, pasture and farmland, mainly in Cu Chi, Binh Chanh and part of Hoc Mon. These areas with production operations are mainly agriculture, rice and food crops. Regions with lower values LST 30°C falls in the forests and the water area along the Saigon River. LST value of the water is usually constant to range from 30°C to 20°C. Meanwhile, in any month of the year as well as the period of 10 years separated the inner city has always shown a higher temperature than the surrounding.



02-02-1995 04-01-2005 24-01-2015

Fig. 1. LST distribution on satellite images at acquisition times of period 1995-2015

3.1.2. Trend of LST in period 1995-2015

Temperature trend analysis is reviewed according to the range of LST values. The total area of study area is 129,116.52 ha. Overall, the distribution area of range of LST value 20°C to 30°C decreased from 38.4% in 1995 to 6% over the whole area in 2015. Meanwhile, the area of range of LST value above 35°C increased from 7.8% in 1995 to nearly 30% by 2015. This represents an area of range of LST value 20-30°C turned to the area of range of LST value above 35°C (Table 1).

In 1995, large parts of the region is dominated at 30-35°C accounting for 53.8% whole area, next is the region with 20-30°C accounted for 38.4% from the whole area. The two regions with these LST ranges concentrated in suburban areas. The area with LST ranges from 35°C concentrated mainly in urban areas and scattered very little in the suburbs accounted approximately 7.8% of the whole area.

In 2015, large parts of the region is dominated by the LST range at 30-35°C accounted for 64.1% the whole area, increased up 10.3% compared to 1995, and decreased down 7.5% in 2005. The area with LST range at 20-30°C accounted 6% of the whole area, down 32.4% compared to 1995, and down 11.6% compared to 2005. The area of LST range above 35°C accounted 29.9%, increased up 22.1% compared to 1995 and increased 19.1% compared to 2005. Finally, the area with LST range at 20-30°C turned to the range at 30-35°C and above 35°C. This shows the variation in temperature from area with cool LST range at 20-30°C into areas with warm and hot LST range above 30°C.

Table 1. Percent of area (%) according to LST ranges in 3 acuisition times in period 1995-2015

T (°C)	Năm		
	1995	2005	2015
20-30	38.4	17.6	6.0
30-35	53.8	71.6	64.1
35-47	7.8	10.8	29.9

3.2. Change of SUHI in period 1995-2015

According to the acquisition of satellite images in 3 times, by the spatial structure, the shape of SUHI shows the change and expansion significantly from dot type or small dispersed regions in 1995 to concentrated large areas style gradually from 1995 to 2005 and from 2005 to 2015, especially in urban areas, if we eliminate the high LST in the agricultural vacant land of Binh Chanh district in the southwest and the Cu Chi district in the north of HCMC. Figure 2 shows the location of typical SUHI on research areas.

To verify the magnitude of SUHI, threshold values greater than 35°C LST as divided as in the figure, we identified four distinct SUHI formed in the study area. The SUHI tend to expand in size and are shown in Table 2 on their spatial distribution. The total area of citywide SUHI was extended from 7,972 ha in 1995 to 24,464 ha in 2005, i.e. increased 3 times and increased 31,495 ha in 2015, equivalent to 4 times compared with 1995.

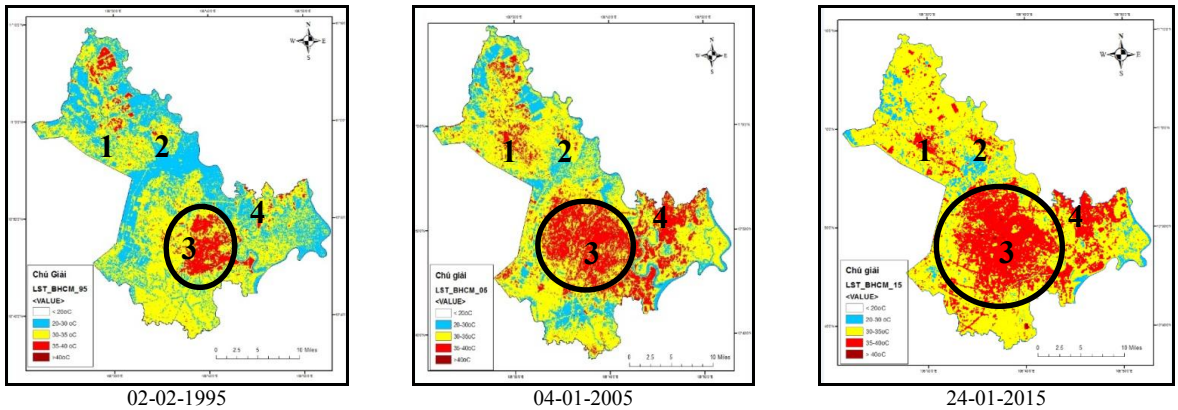
LST above 35°C reflected quite clearly the nature of SUHI for the difference between urban and rural areas for HCMC. Besides, the LST from 35°C quite clear impact on community life, causing muggy weather, discomfort and increase the cooling operation, which generated environmental pollutants. So LST value> 35°C was selected to evaluate the status of SUHI. Expansive area of LST > 35°C in the downtown area during the period from year 1995 to 2005 shows the changing status of land use and the increase of impervious surface area due to urbanization. According to statistics from 2001 to 2005 shows that there were over 8,000 hectares of farmland in the new districts such as District 2, District 7, District 9, District 12 and Thu Duc is converted to residential land and to some uncontrolled spontaneous urban areas at this stage. On the other hand, the process of urbanization has been rapid in many new districts of HCMC as 2,7,9,12 District, Binh Tan, Tan Phu, Thu Duc and many new urban areas such as Phu My Hung, Thu Thiem, South Saigon, Phuoc Hiep, setting up in 2003, showed the development and rapid transformation of urbanization in the period 1995-2005. This may explain the relatively large changes in the expansion of SUHI area towards suburban districts.

Regions SUHI_1 and SUHI_2 in Cu Chi District was formed and expanded with the area of a minor between 1995 and 2005. The rate increased 1.3 times. This stage was not much activity from the industrial zone Tay Bac Cu Chi and has not expanded residential areas in the town center in Cu Chi. In the period from 2005 to 2015, these SUHIs have been a significant expansion of the area, in details SUHI_1 has increased from 782 ha up 2,094 ha and SUHI_2 from 172 ha up to 800 ha. At this stage, the expansion of the industrial area of Tay Bac Cu Chi phase 2 in 2012 went into operation. On the other hand, the policy of building new rural areas in the 2012-2015 periods, the government was improving the system of roads into asphalt instead of unimpervious pathway. Therefore, the temperature at the center of the district and surrounding area has increased significantly.

A huge SUHI_3 areas in the metropolitan area was formed from an area of 6,637 ha in 1995, to 2005 the area of this zone has risen to 19,696 ha, with an increase of 3 times and in 2015 expanded to the 23,757 ha, with an increase of up 3.6 times compared to 1995. The expansion of the area with LST above 35°C reflected the correspond to an increase of impermeable surface areas, plus rapid urbanization rate of the inner city and the population growth during this period. SUHI_4 region was formed in Thu Duc District, where there was activity of Linh Trung industrial parks and high-tech zone District 9, with expansion of 9 times from 1995 to 2015

Table 4. Space area of SUHI (ha)

SUHI	Area with LST > 35°C		
	02/02/1995	04/01/2005	24/01/2015
SUHI_1	668	782	2,094
SUHI_2	128	172	800
SUHI_3	6,637	19,696	23,757
SUHI_4	539	3,814	4,844
Total	7,972	24,464	31,495



02-02-1995 04-01-2005 24-01-2015

Fig. 2. Location of typical SUHIs in northern part of HCMC in the image acquisition time

4. Solution for reduction of SUHI formation and influence

HCMC is a metropolis, lively, as the economic center - culture - society of the country. For years, the city is continuing to expand into urban and suburban rapid development. Therefore, there is the need for urban management strategies in the balance because of a good living environment for the community.

The purpose of these measures is to promote cooling of the urban environment to reduce the impact of UHI. On the other hand, they also bring benefits such as energy consumption reduction, emissions of greenhouse gases and air pollution reduction. The result of the study showed that higher temperatures found in places

covered by building materials, concrete, roads and places where lack of density of trees, shade, water and the lack of work human activities. Therefore, a number of measures are proposed to mitigate the impact on the urban temperature increase as: (1) the larger the surface area covered with trees, the more cooling the surrounding area, and it will make the night temperature dropped, (2) better ventilation, the temperature will drop, and will increase the cooling efficiency, (3) the larger open water, the higher the cooling efficiency, (4) the integration of the three principles on efficiency will make urban cooling capacity increases

5. Conclusion

The formation and development of UHI is derived from urban development. Many studies have demonstrated that UHI has negative impacts affecting the quality of life in urban environments. Application of remote sensing to study the characteristics of the UHI shows clear picture of the distribution as well as the magnitude and level of detail on the distribution of SUHI across the region. This study demonstrates that the UHI is formed by the action of the man, from the urban development process. Finally, from the above results, the study also came up with some solutions to reduce the temperature rise in the urban development process, towards sustainable urban development. The study results also demonstrated the ability of the advantages of remote sensing methods in environmental monitoring, especially urban areas

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