EVALUATE URBAN THERMAL ENVIRONMENT BY REMOTE SENSING METHOD TO PROVIDE ADDITIONAL SOLUTIONS FOR URBAN PLANNING IN HOCHIMINH CITY

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ABSTRACT

This paper presents the research on application of remote sensing to detect the impervious surface in reflective spectra and to retrieve the surface temperature of the urban objects in the thermal infrared spectra from satellite images. Based on these parameters, the urban growth, urban heat island effect and the relationships of urban surface temperature to other biophysical parameters (impervious surface, vegetation and water) have been analyzed. A long term study for Hochiminh City, located in the South of Vietnam, was carried out on a mid scale level in stage of 1989-2010. It is found that the relationship of the temperature and impervious surface had the strongest correlation. These findings are helpful for understandings urban landscape as well as land use planning to minimize the potential environmental impacts of urbanization.

Keywords: *impervious surface, remote sensing, surface temperature, urbanization, urban thermal environment*

1. INTRODUCTION

In frame of global warming, the problem of urban thermal environment is becoming more serious and remarkable with the rapid development of urbanization process. The impacts of landscape patterns in the urban thermal environment also become one of the hot topics and key issues in urban ecosystems. Observations from the meteorological stations is limited by the sparse distribution of stations in space, while remote sensing technology take the picture of the Earth's surface from a distance and allow to convey information into useful value, including meteorological parameters. Radiation derived from satellite images in thermal infrared remote sensing will be extracted into the surface temperature values with the suitable methods of processing and calculating. Understanding the nature, causes and changes of thermal regime occurs in urban environment in space and time with the support of the modern monitoring methods and computing is a scientific needs and studying them has a great significance for the direction of sustainable urban planning in the trend of global warming today, to minimize the impact of urbanization on the social issues and the environment.

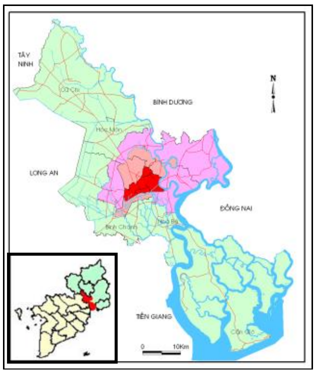


Fig. 1. The study area

This study was aimed to build the scientific basis to propose application of earth observation in the monitoring of urban thermal environment and to propose solutions to mitigate the urban heat stroke increases with the case study in Ho Chi Minh City. This city is located in the South of Vietnam. 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. 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 (Fig. 1).

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.

The biophysical parameters such as impervious surface (IS), vegetation cover and water body were detected by classifying satellite image. Urban areas were expressed by IS/non-IS map. This is a specific property representing for urban as well as a factor contributing the global warming. Sun radiance reaches and heat the earth surface. In turn, the earth surface emits the own radiance into the above air layer. Impervious surface receives lot of sun heat and emits radiance in latent heat. The more impervious surface is existed, the less vegetation cover is being remained. This leads to the urban thermal environment more inclement.

3. RESULTS AND DISCUSSION

Landsat TM and Aster images were used as the main data source in this research. Four 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, Jan 25, 1998, Feb 13, 2002 and Feb 11, 2010. 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 pixel. 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.

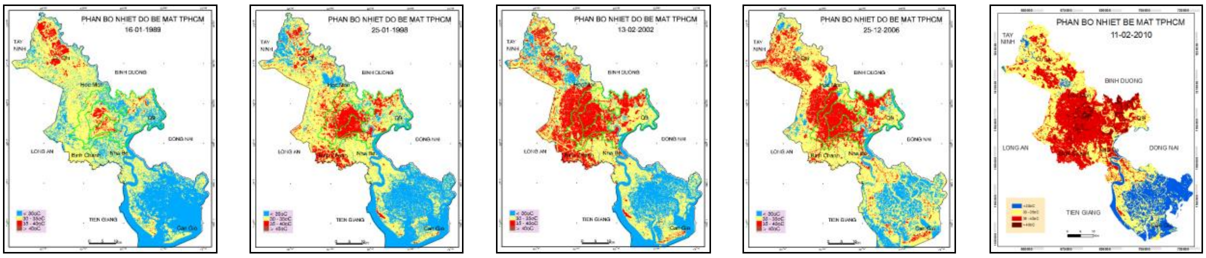
The only one thermal band 6 of the Landsat TM and ETM+ images in the atmosphere window of 10.4–12.5μm was used for deriving the LST. Aster has five thermal bands from 10 to 14 in the window 8.125–11.25μm, but two bands 13 and 14 with the same window as that from Landsat used for calculating LST. Because approximately 80% of the energy thermal sensors received in this wavelength region is emitted by the land surface (Czajkowski, 2004), maximum LST is usually obtained in this region (French, 2008). The results gave the spatial distribution of LST for the whole study area.

3.1. Change of LST and impact of urbanization

The maps in Figure 2 were produced to show the spatial distribution of emissivity-corrected LST in 1989, 1998, 2002, 2006 and 2010. The calculated statistics from images indicate that mean LST of the whole city has the increased trend from 29.4^{o}C in 1989 to 33.3^{o}C in 2010. The highest LSTs greater than 45^{o}C were found in the industrial zones, where high temperatures were caused by production activities as well as solar radiance. The urban areas have experienced maximum temperatures ranging between within 35^{o}C and 40^{o}C. Otherwise, in suburban and rural areas where agricultural land still remains with full vegetation cover, the LST is usually lower.

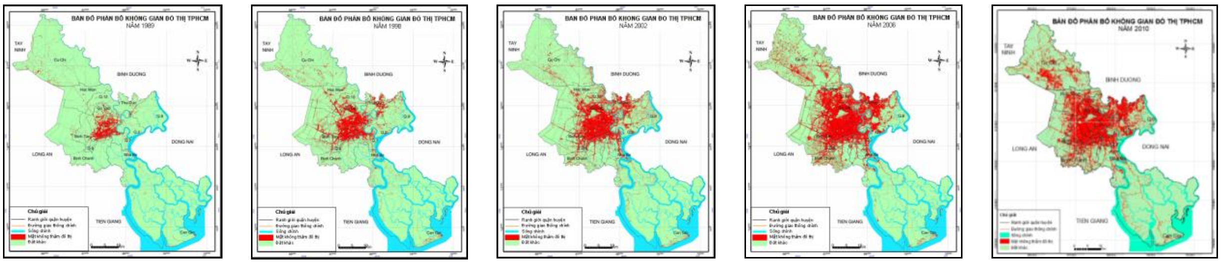
Besides, we found that the IS area from 1989 to 2010 increased more 7 times. Investigating the IS in the 5 years 1989, 1998, 2002, 2006 and 2010 showed that the IS was concentrated and expanded from the central part of the city with a growing tendency to the North, West and East and along the main roads (Fig. 3). The urban IS development, with particularly rapid development between 2002 and 2006 (Fig. 4), indicates that Hochiminh City was becoming a mega city in the latter years.

The impact of the urbanization on LST was expressed by the appearance of surface urban heat island (SUHI) effect, where the LST in urban is higher than in suburban and rural areas. On the figure 2, the SUHI was found in some hot spots of the entire study area. In the 1989 map, there was no an extensive hot spot in the old urban area located in the centre of the map. At this time the urban IS was minor in relation to vegetation cover, so it was less effective in increasing LST. Some was found in only the bare land and impervious runways of the airport. However, the rapid process of urbanization with the IS-area extension after the time of separating the city into five more new districts in 1997 increased the SUHI from 1998 to 2010. In the 2010 LST map, an extensive SUHI was concentrated in the central part of the city with the magnitude extended in 31 times compared with 1989 SUHI. This showed that SUHI intensity has the tight correlation to the IS extension.



(a) 16-01-1989 (b) 25-01-1998 (b) 25-01-1998 (d) 25-12-2006 (e) 11-2-2010

Figure 2. LST distribution at the acquisition time of satellite images from 1989 to 2010



(a) 16-01-1989 (b) 25-01-1998 (b) 25-01-1998 (d) 25-12-2006 (e) 11-2-2010

Figure 3. Urban spatial distribution in Hochiminh City in period 1989-2010

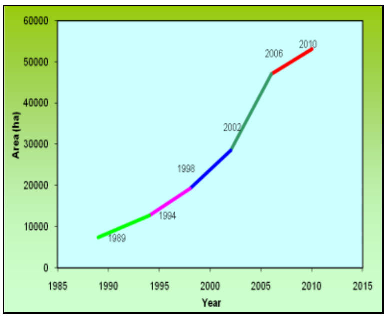


Figure 4. The trend of urban IS development in period 1989-2010

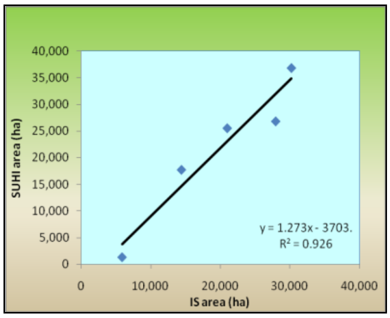


Figure 5. The correlation of SUHI and IS

3.2. The correlation between LST change and biophysical factors in Hochiminh City

The correlation between LST change and biophysical factors was investigated for further understanding the effect of urban development. We identified biophysical factors by the surface land cover measured on the same satellite images retrieving the LST. They were the IS, vegetation cover and water body in percent scale within the district administration border (IS, ND and WA). Pearson correlation coefficients (r) is used to measure this relationship. This is a statistical index to quantify the level of strict linear relationship between two quantitative variables and values from -1 to +1. The correlation coefficient is 0 (or nearly 0) means that the two variables are not related to each other; vice versa if this coefficient equal to -1 or +1, means two variables have an absolute relationship, in opposite directions or other positively . The results clearly show, the best correlation found between Ts and IS, followed by between Ts and ND with the absolute value of coefficient $|r| > 0.8$. Lowest correlation occurred between variables Ts and WA with $|r| = 0.689$. Consider the signs, it indicate the direction of the relationship. It is found that the relationship between the variables Ts and IS is positive, i.e. Ts tends to increase as these variables increase, while the relationship between Ts and variable ND, WA is the inverse relationship, i.e. Ts tends to decrease as they increase. The linear regression equation is estimated for each pair of single variables as follows:

$$Ts = 31{,}976 + 0{,}051*IS \quad (5)$$

$$Ts = 36{,}737 - 0{,}072*ND \quad (6)$$

$$Ts = 36{,}229 - 0{,}126*WA \quad (7)$$

This regression equation identified that LST has the positive relation with the IS area percent. The negative relation was found between LST and percent of area of the vegetation cover and water bodies.

3.3. The solutions to effective urban thermal environment management

Urban thermal environment is greatly influenced by the shape of each city, so the planning of new urban development or urban renew need to pay attention to the solution of climate and ecology in order to cool the city and mitigate heat islands. For the efficient management of urban thermal environment, the following general strategies can consider. The first is the use of surfaces with reflectance properties, light-colored on the new construction or replacement for existing dark surfaces (roofs, pavement, road...)

The second strategy is to plant trees in urban areas. This is a simple and effective way. Plant trees around the house will cool directly inside the building, reducing the cost of air condition and energy. In addition, trees also improve air quality, reduce CO_2 emissions, reduce runoff, improve community life and enhance many other benefits.

To reduce impervious surface area causing heat island effect, the problem is not to stop urban development that is developed with a better model. Integrated solution to the problem might be to build public multifunctional construction serving communities entertainment with planting many trees, grass and building reservoirs. HCMC is overloaded by the pressure of population density and not all control development activities. So there are many steps necessary for the community participation in the implementation of solutions to urban planning in order to mitigate the heat island effect and the environmental problems

4. CONCLUSIONS

This study has shown that the different urbanization intensities, defined by IS, have significant effects on urban thermal environment. Application of satellite thermal infrared data to the study of urban thermal environment suggests that different land cover types have distinctive responses. The conversion of natural and vegetated surfaces to urban development purposes will rise the temperature and increase the spatial variability of LST. This not only has an impact at the local urban level but it also has global implications if the temperature continues to increase. If LST can be used as a surrogate for air temperature, then urban planners and managers can use satellite-derived measurements to indicate the need for new or revised urban design and landscaping policies to mitigate the UHI and SUHI effects under present climatic conditions.

5. ACKNOWLEDGEMENTS

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