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Characteristics of Urban Thermal Environment from Satellite Remote Sensing Data in Ho Chi Minh City, Vietnam

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Abstract: The period of spontaneous development of Ho Chi Minh City in Vietnam has caused uncontrollably environmental problems occurred. Besides, the concrete surface caused increasing surface temperatures, reducing evaporation, consequently heating up urban space. This paper presents the results of the application of Landsat satellite images to study the urban thermal environment from the thermal infrared channel by capability of object surface emissivity for the northern part of Ho Chi Minh City. The Landsat satellite images was used for exploratory research to date 21-01-2014. The method to extract land surface temperature (LST) from thermal infrared bands with emissivity determined by the characteristics of Normalized Difference Vegetation Index (NDVI) values has created detailed results according to resolution of the reflectance bands. In addition, the relationship between the heating element and land cover variables (impervious surface, bare soil, vegetation and water) is also considered in order to find the relationship determining factor affecting the urban thermal environment. The study results showed that the developing urban area is where the high temperature exits. A giant heat island is formed on the central area of the city with temperature ranging from 32oC to 44oC and above. Besides, impervious surface is a major factor contributing in the warmth of the thermal environment in the city with the highest number of positive correlation (R = 0.87), whereas vegetation is factor that impact to reduce heat with the highest number of negative correlation (R = -0.84). In Ho Chi Minh City there is only one ground meteorological station, so its temperature number does not express the thermal environment in the whole city. These results are a good reference for local city authorities in urban spatial planning during climate change period nowadays.

Keywords: emissivity; land surface temperature; urban thermal environment; urban development; remote sensing

1. Introduction

The problem of urban heat environment is becoming more serious and prominent with the rapid development of urbanization process. Urban development alters natural landscapes such as shrinking water surface, changing agricultural land into construction land, developing more impervious surfaces. Impervious surface is a typical type of land cover in the urban environment that alters the thermodynamic properties of soil, surface energy budget of the Earth; changes the nature of the circulation of ambient atmosphere; creates a large amount of waste heat from human activities and leads to a series of changes in the system of the urban environment. Urban Development in Ho Chi Minh City has changed the appearance of the city today. However, the spontaneous development period made environmental problems occur uncontrollably. Besides, the concrete surface has also increased the lattent heat, reduced evaporation which makes the urban space become increasingly heated. Implementing spatially thermal environment measurement in details will enable managers and urban planners to orient rational distribution of construction work. Satellite image showing the surface with radiation energy received on image will reflect the distribution of biophysical condition of the surface.

This study conducted calculations on the database of satellite images for the northern part of HCMC to (1) determine land cover distribution for the variables: impervious surface, bare soil, vegetation and water representing surface condition; (2) determine the distribution of land surface temperature taking into account the corrected emissivity of the surface material; (3) then, evaluate the correlation between the variables of land cover and thermal environment for urban areas; (4) lastly, propose the solution for effective urban planning in the current warm trend.

2. Data and Methodology

Landsat 8 satellite image data was used in the study. This is a multispectral image with spectral bands in wavelengths from the visible to the thermal infrared with spatial resolutions from 30 meters to 100 meters respectively. Thermal infrared band has the ability to extract the temperature value based on the fundamental laws of radiation. Information collected on the satellite image is radiation emitted from the earth's surface into the atmosphere to get the satellite through the electromagnetic wave propagation.

Physical parameter "impervious surface" represents "Urban". This is the characteristic of urban development such as buildings, sidewalks, roads, park... built from waterproof materials. These materials absorb solar radiation. In turn, the solar radiation heats the surface and is trapped in a long time. Then, they emit radiation and heat the air layer above. This process results in no evaporation, so the heated dry air layer makes urban environment suffocated by the lack of steam.

Research methodology is the use of remote sensing techonology, including:

- *Multispectral remote sensing:* classifying objects according to the visible and near infrared bands, concentrated under 4 classes consisting of impervious surface (IS), bare soil (S), vegetation (V) and water (W)
- *Thermal infrared remote sensing:* extracting temperature values for each pixel, with emissivity values calculated from NDVI by 30m x 30m resolution across the study area. This is the real surface temperature, shown by the distribution of ground objects

At the same time, the statistical method will use Excel and SPSS software to find the relationship between temperatures and land cover variables above. Datasets shown in the average temperature and the percentage ratio of 4 variables present in an administrative unit of district level

Method of calculating the surface temperature and emissivity from satellite images

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 [1], 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}):

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

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 [4]. Therefore, correction for emissivity should be done. The emissivity (ε) was calculated by using the formula of Valos and Caselles [3]:

$$\varepsilon = \varepsilon_V P_v + \varepsilon_S (1 - P_v) \qquad (2)$$

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 [2]:

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

Therefore,

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

where σ is the Stefan Boltzmann constant (5.67 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 temperature .was estimated from the thermal infrared band. Landsat 8 has two thermal infrared bands 10 and 11 in the wavelength range from 10,60µm - 12,51µm. Band 11 is close to the wavelength range of 15µm in atmospheric zone absorbed by CO_2. It is easily influenced by the atmosphere rather than band 10. Finally, band 10 is used to calculate in this case

3. Results and Discussion

3.1. Distribution of land cover and surface temperature

Results shown on a satellite image is the current status of land cover, depending on the seasons and the characteristics of the land cover. Results of interpretation said distribution rate of 4 classes IS, S, V and W, shown in Figure 1 and Table 1. Calculated for the entire area north of Ho Chi Minh City, the percentage of vegetation cover accounts for 51.61% of the area, impervious surface layer accounts for more than 1/4 the area, nearly 28%. If the calculation is exclusive for the inner urban area with 19 districts, the impervious surface area will account for more than half the area, about 52.81% and vegetation will account for about 28.63% mainly distributed in District 9. In general, urban development is concentrated in the central part with sparse greeness.

There is a quite synchronized correspondent between the results of calculation of temperature distribution from satellite imagery and classification results (Figure 2). Urban development areas are the ones with high temperatures. A giant "heat islands" is formed on city center area with temperatures from 32^{o}C to 44^{o}C above. Due to the nature of the surface materials (concrete, stone, asphalt ...) (which are high thermal conductivity, effective heat absorption, but the process of evaporation is weak due to IS existence), latent heat flux on these areas is always higher than orthers with trees, moisture soil and water.

In general, the LST distribution concentrated high temperatures in the inner city districts, in settlement areas of Thu Duc and Cu Chi districts. Nha Be wetlands, planted forests of the north of Cu Chi and the green area of farmland belonging to Binh Chanh and Hoc Mon have lower temperatures. Considering the entire northern area of the city, the average surface temperature is 30.9^{o}C and the lowest temperature is 20.8^{o}C. If survey was done in 19 inner city districts, the average surface temperature would be about 31.4^{o}C, the lowest temperature is 22.3^{o}C (Table 2). This result was observed at 10am when the satellite passed study area.

Surveying thermal environment of each district by calculating the average temperature in the administrative boundaries, shows that Tan Phu district has the highest temperatures of 35.3^{o}C; with the proportion of urban land occupied 90.9% compared with the rate of green land and the water, respectively, 2.29% and 0.05%. Tan Binh and Go Vap are orderly ranked. Meanwhile, though District 1 is considered the central business district occupied with the commercial area, it results in quite low temperatures, around 33^{o}C, with the IS area receiving direct solar radiation around 80% and the remaining land is covered with trees about 11% and about 7.5% of the water. This shows that althought land surface covered with a dense layer of IS under urban development, but if vegetation layer is developed with a high dome on impermeable surface layer, only land under the sun received direct solar radiation will be heated. These are the features of District 1 with many roads covered with trees. Besides, District 1 also owns part of the Saigon River, its thermal environment is quite cool in compared to other districts. The result of this distribution said information between surface temperature and vegetation cover on a study region has spatial relationship to each other through the thermal characteristics of the objects.

Figure 1. Land cover of the northern part of HCMC on 21-01-2014

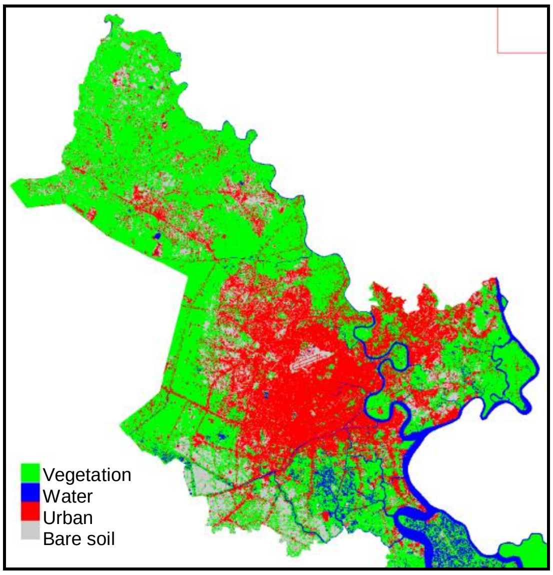

Figure 2. Distribution of LST of the northern part of HCMC on 21-01-2014 at 10am

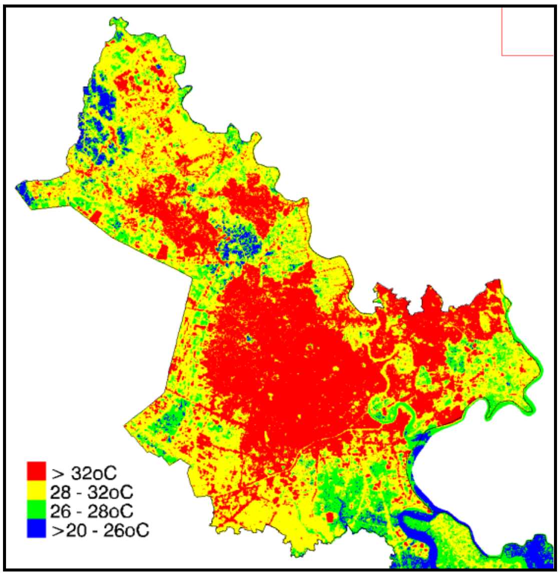

Table 1. Percentage distribution of land cover on 21-01-2014 from satellite image (%)

Land cover type	Percentage compared to northern HCMC	Percentage compared to 19 inner city districts
IS	27.81	52.81
V	51.61	28.63
W	6.85	8.07
S	13.73	10.49

Table 2. LST statistics on 21-01-2014 from satellite image (^{o}C)

Stastistics	LST of northern HCMC	LST of 19 inner city districts
Mean	30.93	31.42
Min	20.78	22.34
Max	44.85	44.85

3.2. Relationship between LST and land cover

On the charts of Figure 3 and Table 3, it shows the average data from administrative units in the district. They show the correlation between the LST distribution and the presence of different land cover. Temperature is strongly positively correlated with urban development with a correlation coefficient r = 0.87. For 3 variables remaining as vegetation, water and bare soil, the temperature tends to correlate negatively. In particular, vegetation has the strongest negative correlation r = -0.84 with temperature. Bare soil has the weakest correlation with temperature r = -0.37. This result shows that if there is good planning control in urban development issues, it will reduce the stuffy environment due to heat by increasing greenery and water.

Figure 3. Chart of corelation between LST and land cover

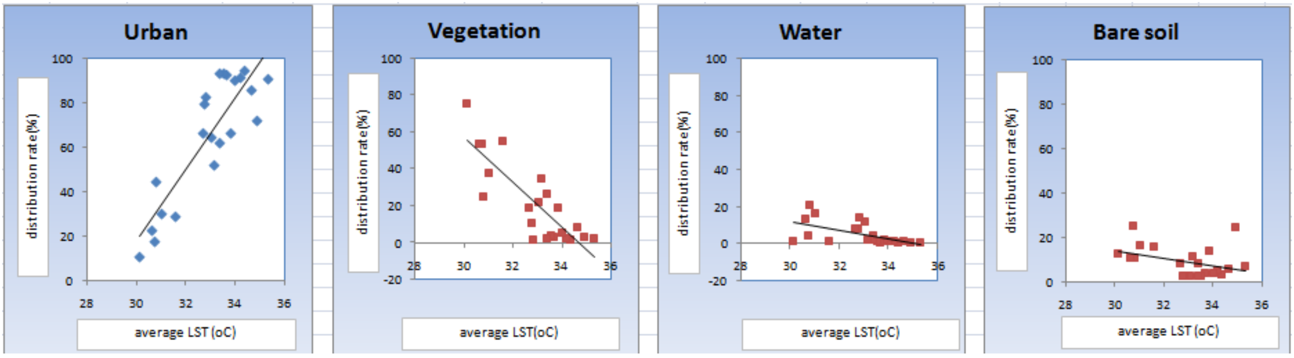

Table 3. Correlation coeficient between LST and land cover

Land cover type	Correlation coeficient
IS	0.87
V	-0.84
W	-0.58
S	-0.37

3.3. Solutions for urban thermal environment management

The urban development leads to impervious surface and building space increasing. This reduces the possibility of ventilation and cooling urban areas. Urban cooling should integrate both mitigation and adaptation measures with high temperature. Some general principles in the management of urban temperature are: (1) the larger surface area covered with trees, the cooler neighborhood become and the temperature at night will decreased, (2) better ventilation will drop the temperature, cooling efficiency will higher, (3) the greater open water, the higher cooling effect increases, (4) effectively integration of those three principles will make urban cooling capacity highly risen

Apart from the solutions to cool the urban, the management of solar radiation is indispensable. It is noted to enhance the reflection of solar radiation on the building and paving materials as: (1) using light-colored materials to reflect sunlight better and keep itself cool for as long, as to avoid direct radiation from the sun shining on the building, part of the building will be maintained cool; (2) When impervious surface increasing due to urban development process is inevitable, the shading solutions in public spaces with trees and buildings is a good solution to reduce heat. The purpose of shading is to reduce solar radiation directly into buildings and impervious surface.

Because temperature is inversely proportional with plant and water, the construction of a green park combined with regulatory lake and fountains, construction of urban green belt from the city to suburban are good approach for central urban areas, contributing to reduce the urban heat island phenomenon.

4. Conclusions

The results of the applied research of remote sensing data to consider the characteristics of the thermal environment of the north of HCMC under impact of urban development showed that surface temperature in urban areas increases by rising impermeable surface suffered directly solar radiation. Conversely, surface temperature decreases with rising water surface area and the green space. Remote sensing solution is a good support for the meteorological observation when we are unables to increase the number of in-situ stations over a large area. In addition, remote sensing method also makes it possible to evaluate close correlation between temperature and land cover distribution on the area in details.

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Conflicts of Interest

The authors declare no conflict of interest.

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