Identifying Urban Heat Island Effects due to Urban Land Use Change

Dong-hoon Shin
Graduate Student, Dept. of Landscape Architecture, Sungkyunkwan Univ.
300 Chunchun-dong, Changahn-gu, Suwon 440-746, Kyunggi-do, Korea
wonboy@hotmail.com

Kyoo-seock Lee
Professor, Dept. of Landscape Architecture, Sungkyunkwan Univ.
300 Chunchun-dong, Changahn-gu, Suwon 440-746, Kyunggi-do, Korea
leeks@skku.edu

Abstract: The land use has changed rapidly since 1960s in accordance with urbanization in Seoul Metropolitan Region. As a result, the urban microclimate has undergone changes as well. This study aims to recognize trend of the urban heat island change which is caused by land use change during urbanization in large city. Thermal data of Landsat TM images in 1987 and 1999 were for land surface temperature change detection in the study.

Keyword: Land Use Change, Urban Microclimate, Surface Temperature Change, Urban Heat Island.

1. Introduction

At the threshold of the 21st century, urbanization occurs across all countries over the world. This urbanization has accompanied the economic growth and urban environmental problems. Since the 1960s, urbanization and industrialization were rapidly done in South Korea. As a result, cropland and forest area decreased and urban area increased. Also, the rapid urban expansion has resulted in a number of environmental problems (Yokohari, 2000) such as urban heat island, air and water pollution etc.

Urban heat island (UHI) results from the absorption and storage of solar energy by the urban artificial substratum, and also from the heat released into the atmosphere from industrial and communal processes (Janina, 1987). The interactions of urban surfaces with atmosphere are governed by surface heat fluxes, the distribution of which is drastically modified by urbanization (Dousset and Gourmelon, 2003).

Asphalt and concrete area compose most of city due to increase of urban area. Because such urban structure materials store heat in the daytime and are cooled slowly after sunset, it is main factor of urban heat island with auto exhausts and heating fever for residence. Satellite remote sensing thermal infrared data can capture a holistic view of such as urban heat island phenomena, especially for the rapidly expanded urban area. Therefore, this study aims to recognize trends of the urban heat island change due to land use change in a large city.

2. Materials and Methods

1) Study Site

The study site is Gangnam-gu, Seocho-gu and Songpa-gu located at south of Han River in Seoul City. From 1970s the population have grown rapidly mainly due to the urbanization. These areas are incorporated to Seoul according to Seoul Administrative District Expansion Plan in 1963. Currently Seoul has experienced rapid urbanization during the last four decades and has a population of about ten million. From the late 1960s, development began by purpose of constructing housing site. Former green landscape as rice paddy, cropland and forests have been converted into urban development sites. After development original landscape changed rapidly.

2) Thematic Data Used

For Remote Sensing (RS) data, Landsat 5 Thematic Mapper (TM) images were used (Table 1). For thematic data, 1:25,000 and 1:5,000 scale digital topographic maps were used to select ground control points (GCP's), also 1:3,000 scale Seoul Metropolitan Biotop Map was used for referring to land use classification. Tables 1 and 2 show RS and Geographic Information System (GIS) data and other thematic data used in this study, respectively.

Table 1. RS data used in this study.

Data source	Resolution	Date	Data type
Landsat 5 TM	Visible: 30m NIR : 120m	1987. 5. 20 1999. 5. 21	Digital

Table 2. Other thematic data used in this study

Data source	Scale	Date	Data type	Publisher
Topographic Map	1:25,000 1:5,000	-	Digital	National Geographic Information Institute
Seoul Metropolitan Biotop Map	1:3,000	2000	Digital	Seoul Development Institute

3) Methods

Landsat TM images taken on May 20, 1987 and May 21, 1999 were geometrically corrected into 30.0m resolution images using the second order polynomial transformation and nearest neighbour resampling. Then Land use classification was done using hybrid classification method by referring to Seoul Metropolitan Biotope Map made in 1999. The land cover classes are five classes. They are urban, agriculture, forest, bare soil and water.

Land Surface Temperature (LST) was derived from Landsat TM thermal infrared (TIR) band. The following equation (Eq. 1) was used to convert the digital number (DN) of Landsat TM TIR band into spectral radiance (Landsat Project Science Office, 2002).

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax}} \right) \times Q_{cal} + LMIN_\lambda \quad (1)$$

Where,

L_λ: Spectral Radiance at the sensor's aperture in W/(㎡.sr.㎛)

Q_{cal}: The quantized calibrated pixel value in Digital Number (DN)

Q_{calmin}: The minimum quantized calibrated pixel value(DN=0) corresponding to $LMIN_\lambda$

Q_{calmax}: The maximum quantized calibrated pixel value(DN=255) corresponding to $LMAX_\lambda$

$LMIN_\lambda$: The spectral radiance that is scaled to Q_{calmin} in W/(㎡.sr.㎛)

$LMAX_\lambda$: The spectral radiance that is scaled to Q_{calmax} in W/(㎡.sr.㎛)

For Landsat TM, $LMIN_\lambda$ is 1.2378 and $LMAX_\lambda$ is 15.303 (Chander and Markham, 2003).

The next step is to convert the spectral radiance. Thermal data from Landsat TM band 6 can be converted from spectral radiance to a more physically useful variable. This is the effective at-satellite temperatures of the viewed earth-atmosphere system under an assumption of unity emissive and using pre-launch calculation.

The conversion formula (Eq. 2) is (Landsat Project Science Office, 2002).

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)} \quad (2)$$

Where,

T: effective at-satellite temperature in K

K2: pre-launch calibration constant 2 in K

K1: pre-launch calibration constant 1 in W/(㎡.sr.㎛)

L_λ : spectral radiance at the sensor's aperture

For Landsat TM, K2 = 1260.56, and K1=607.76 were used.

3. Results and Discussion

1) Relation between LST and land use type.

Table 3 shows LST according to land use type in 1987 and 1999, and Table 4 shows LST change of each land use type in 1999.

As we can see in Table 3, water area shows the lowest mean LST followed by forest, agriculture, bare soil and urban area in 1999.

Table 3. LST of Land use type in 1987 and 1999.

(Unit: °C)

Value / Land use	Maximum value		Minimum value		Mean value	
	1987Y	1999Y	1987Y	1999Y	1987Y	1999Y
Urban	28.67	38.66	15.58	3.92	23.23	24.72
Agriculture	29.09	29.50	15.58	15.58	22.51	23.45
Forest	26.16	28.26	17.41	17.41	20.66	20.26
Bare soil	28.67	27.84	16.04	3.92	23.98	23.95
Water	27.42	27.42	13.25	14.18	15.74	16.60
whole study area	29.09	38.66	13.25	3.92	22.09	23.15

The study area LST increased 1.06°C overall from 1987 to 1999 as we can see in Table 4. In terms of LST change in each land cover class from 1987 to 1999, urban area increased highest (+1.49°C) followed by agriculture (+1.08°C), bare soil (+0.52°C), water (+0.49°C), and forest (+0.01°C) area.

Table 4. LST change of land use type in 1999.

(Unit: °C)

Value / Land use	Maximum value	Minimum value	Mean value
urban	+16.86	-23.40	+1.49
agriculture	+6.93	-5.32	+1.08
forest	+7.72	-3.09	+0.01
bare soil	+6.10	-24.34	+0.52
water	+4.71	-4.35	+0.49
whole area	+16.86	-24.34	+1.06

As expected, urban area shows the highest increase of LST. The highest value(+16.86°C) of LST increase occurred at Lotte World Complex, Songpa-gu which consists of department store, the amusement park and thermoelectric power plant. The power plant is believed to have influences on UHI. It is located at the downtown of Songpa-gu. The lowest value (-24.34°C) of LST difference occurred on the bare soil of ASEM Tower site, Gangnam-gu. Probably land cover materials during construction may make effects on the albedo difference. It needs to be investigated further. Particularly, LST difference of Teheran Road appeared lower (-0.5~+0.4°C) than surrounding urban area, relatively. However, it was due to the shade effects at 10:30 by tower block.

Forest area showed the lowest increase (+0.01°C) of LST. However, it shows the tendency that the core area in the forest decreased and increased in edge area. In edge area, it was affected by urban development while the inner part of forest was affected by more evaportranspiration due to vegetation growth.

Agriculture area showed relatively high value of LST difference (+1.08°C) relatively. It was judged due to seasonal factor (May), crop vegetation were not prosperous yet.

In the case of Yangjae stream, LST showed lower LST than surrounding area by about 1.3°C. It was considered by increase of vegetation and stream water volume after the mid 1990 natural style river restoration project. It should be investigated further.

4. Conclusions

This study was carried out for recognizing trends of the urban heat island change which is caused by land use change by urbanization in a large city.

As a result, land use changes so rapidly and urban temperature increased continuously in the study site. Landsat TM images were used for detecting land use change and LST change. Results of this study are as follows:

(1) Land surface temperature increased +1.06°C overall in the study site from 1987 to 1999.

(2) In terms of LST change, forest (+0.01°C) and water (+0.49°C) area increased less than that of urban (+1.49°C) and agriculture (+1.08°C) area. It means urban forest and urban stream make influences on urban heat island mitigation.

References

[1] Chander, G. and Markham B., 2003, Revised Landsat 5 TM Radiometric Calibration Procedures and Post-Calibration Ranges, p.4

[2] Dousset, B and F. Fourmelon, 2003, Satellite multi-sensor data analysis of urban surface temperatures and land cover, *Journal of Photogrammetry and Remote Sensing*, 58: 43-54.

[3] Landsat Project Science Office, 2002, Landsat 7 science data users hand book. URL: *http://www.gsfc.nasa.gov/ISA/handbook/handbook_toc.html*, Goddard Space Flight Center, NASA, Washington, DC.

[4] Janina, L., 1987, The Expansion of a Heat Island Resulting from the Development of a City, *Landscape and urban planning*, 14:219-224.

[5] Sohn, J. M., The Story of Urban Plan in Seoul - Introduction of Gangnam development plan (I), *Monthly publication Kook-Toh*, 205:87-99.

[6] Yokohari, M., *et al.*, 2000, Beyond greenbelts and zoning: A New Planning Concept for the Environment of Asian Mega-Cities, *Landscape and Urban Planning*, 47:159-171.