AN APPLICATION OF REMOTELY SENSED DATA TO LAND SURFACE TEMPERATURE ESTIMATION

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ABSTRACT: Global warming is the significant environmental problem which currently and greatly affects the humanity. All countries realize such a problem and try to find solutions. Remote sensing technology has become an effective supporting tool for researching and monitoring the problem. The satellite data are exploited to apply to estimate land and water surface temperature changes as well as global changes measuring. Since satellite data are available for large areas, multi-temporal data and multi-spectral bands. The purpose of this research is to apply band 6 of Landsat-5 Thematic Mapper (TM) data to estimate Land Surface Temperature (LST) by using Single-Channel algorithm and band 3, 4, 5 are used for land use classification by using maximum likelihood algorithm. Estimated LST data was overlaid on classified land use data to examine the Urban Heat Island (UHI) phenomenon. The result of LST showed that the urban LST was higher than suburban temperature which demonstrated clearly UHI phenomenon in Khon Kaen Province.

1. INTRODUCTION

Global warming is the significant environmental problem which currently and greatly affects the humanity. All countries realize such a problem and try to find solutions. Remote sensing technology has become an effective supporting tool for researching and monitoring the problem. The satellite data are exploited to apply to estimate land and water surface temperature changes as well as global changes measuring. Since satellite data are available for large areas, multi-temporal data and multi-spectral bands. Landsat-5 TM satellite is the most widely-used satellite in environmental research applications and the band 6 of TM (TM6) data can be used to analyze land surface thermal radiation and LST. Spatial resolution of TM6 is higher than other thermal data, so TM6 data is a better choice than ones when higher spatial resolution is required in an application (Zhangyan, Yunhao, & Jing, 2006). There are three types of methods which have been developed to retrieve LST from at-sensor and auxiliary data: Single-Channel method, Split-Window Technique and Multi-Angle Method. Because the last two methods require at least two channels, Single-Channel method is the only method that can be applied to the Landsat platform, with one thermal channel (Rong-bo et al., 2007).

2. OBJECTIVE

The first objective of this study is to estimate LST in various types of land use in Khon Kaen using Landsat-5 TM acquired in January 1990, December 1999, and November 2006. The second objective is to examine the Urban Heat Island phenomenon.

3. STUDY AREA

The study area is Khon Kaen which is the second-largest of the North-Eastern provinces of Thailand. This site covers approximately 10,886 square kilometers and is subdivided into 26 districts. It is the central of education, commerce and transportation in Northeast Thailand, so it has undergone intense urbanization.

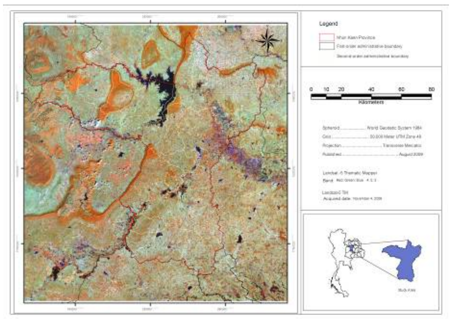


Figure 1 Location of the study area.

4. METHODOLOGY

4.1 Data Use

Band 3, 4 and 6 of Landsat-5 TM data acquired in January 1990, December 1999, November 2006 , December 2008, January 2009 and February 2009 were used to estimate LST as band 3, 4 and 5 of Landsat-5 TM were applied to classify land use.

4.2 The Procedures of Image Processing

The digital image processing was performed using PCI Geomatica software. Maximum Likelihood was processed for land use classification and Single-Channel algorithm was processed for LST estimation. The procedures of LST estimation as shown in Figure 2, are as follows:

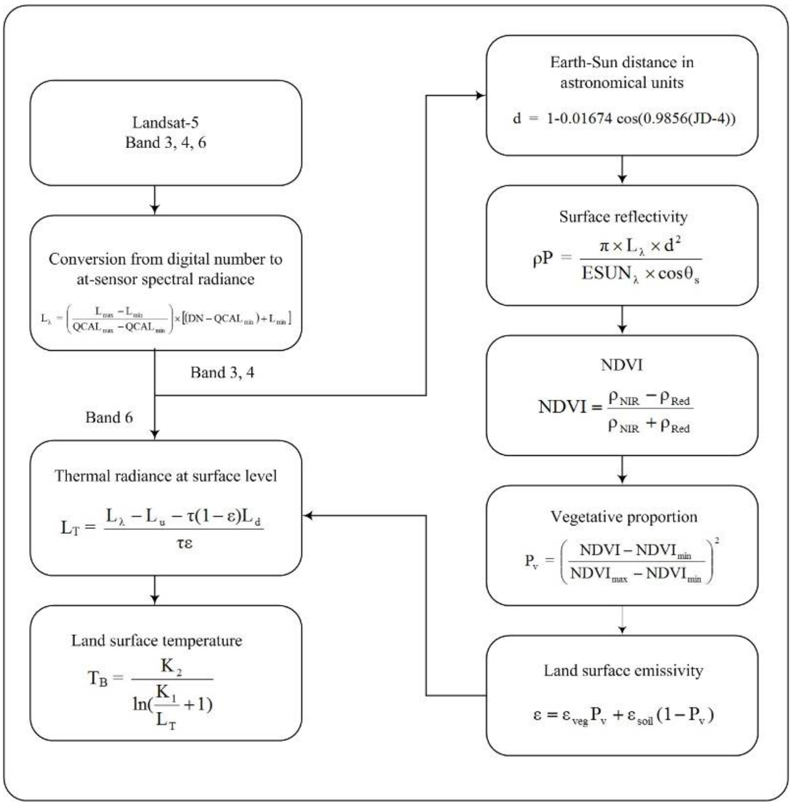


Figure 2 The procedures of LST estimation.

Firstly, the digital number (DN) of band 3, 4 and 6 were converted to space reaching radiance or top-of-atmospheric (TOA) radiance (at-sensor spectral radiance) by using the equation 1.

$$L_\lambda = \left(\frac{L_{max} - L_{min}}{QCAL_{max} - QCAL_{min}}\right) \times \left[(DN - QCAL_{min}) + L_{min}\right] \quad \text{(Chander \& Markham, 2003)} \quad (1)$$

Where; L_λ is TOA radiance at sensor's aperture in W /(m^2.sr.µm).

$QCAL_{max}$ is the highest point in DN.

$QCAL_{min}$ is the lowest point in DN.

L_{max} is the TOA radiance that is scaled to $QCAL_{max}$ in W /(m^2.sr.µm).

L_{min} is the TOA radiance that is scaled to $QCAL_{min}$ in W /(m^2.sr.µm).

The Landsat-5 data acquired from March 1, 1984 to May 4, 2003, the values of L_{max}/L_{min} in Band 3, 4 and 6 are 204.30/-1.17, 206.20/-1.51, and 15.303/1.2378 W /(m^2.sr.µm) respectively, while data acquired after May 5, 2003, the values of L_{max}/L_{min} in Band 3, 4 and 6 are 264.0/-1.17, 221.0/ -1.51, and 15.303/1.2378 W /(m^2.sr.µm) respectively.

Secondly, at-sensor spectral radiance was then converted to surface-leaving radiance by using following equation.

$$L_T = \frac{L_\lambda - L_u - \tau(1-\varepsilon)L_d}{\tau\varepsilon} \quad \text{(Yuan \& Bauer, 2007)} \quad (2)$$

Where; L_T is the radiance of blackbody.

L_λ is spectral radiance at sensor's aperture in W /(m^2.sr.µm).

L_u is the radiation brightness upward from atmosphere 1.68 W /(m^2.sr.µm).

L_d is the radiation brightness downward from atmosphere 1.74 W /(m^2.sr.µm).

τ is the atmospheric transmission, estimated as 0.77.

ε is the emissivity of the surface, specific to the target type. ε was computed by using the following equation.

$$\varepsilon = \varepsilon_{veg}P_v + \varepsilon_{soil}(1 - P_v) \quad \text{(Li et al., 2004)} \quad (3)$$

Where; ε_{soil} and ε_{veg} are the emissivity of soil, estimated as 0.97 and the emissivity of vegetation, estimated as 0.99 respectively.

P_v is the vegetative proportion, computed by using the following equation.

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4)$$

Where; $NDVI_{max}$ and $NDVI_{min}$ was 0.5 and 0.2 respectively.

NDVI was calculated from pixel values of the Landsat-5 TM as:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (5)$$

Where; ρ is band reflectivity. Reflectivity was calculated as:

$$\rho P = \frac{\pi \times L_\lambda \times d^2}{ESUN_\lambda \times \cos\theta_s} \quad \text{(Chander \& Markham, 2003)} \quad (6)$$

Where; ρP is unitless planetary reflectance.

$ESUN_\lambda$ is solar exoatmospheric irradiances.

θ_s is solar zenith angle in degrees.

d is the earth-sun distance in astronomical units and calculated by using the following equation (United Nations Educational, Scientific and Cultural Organization, 2006).

$$d = 1-0.01674 \cos(0.9856(JD-4)) \quad (7)$$

Where; JD is day of year (Julian Day).

Lastly, the radiance was converted to surface temperature using the following equation.

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_T}+1)} \quad \text{(Yuan \& Bauer, 2007)} \quad (8)$$

Where; T_B is the temperature in Kelvin (K).

K_1 is the pre-launch calibration constant 1 in W /(m^2.sr.µm).

K_2 is the pre-launch calibration constant 2 in W /(m^2.sr.µm).

For Landsat-5 TM, K_1 and K_2 was 607.76 and 1260.56 respectively.

5. RESULT

Figure 3 (A) illustrates the estimated LST from various land use types in January 1990, December 1999, November 2006, December 2008, January 2009 and February 2009 and the average and standard deviation (SD) value of LST are shown in Table 1 and Figure 4 (A). It was found that the estimated LST in the area with less forest and none forest such as urban, bare soil, cropland especially burnt area were higher than the area with dense forest. LST of dense urban and dense forest were 29.5-33.2 ^{O}C and 17.5-23.3 ^{O}C respectively.

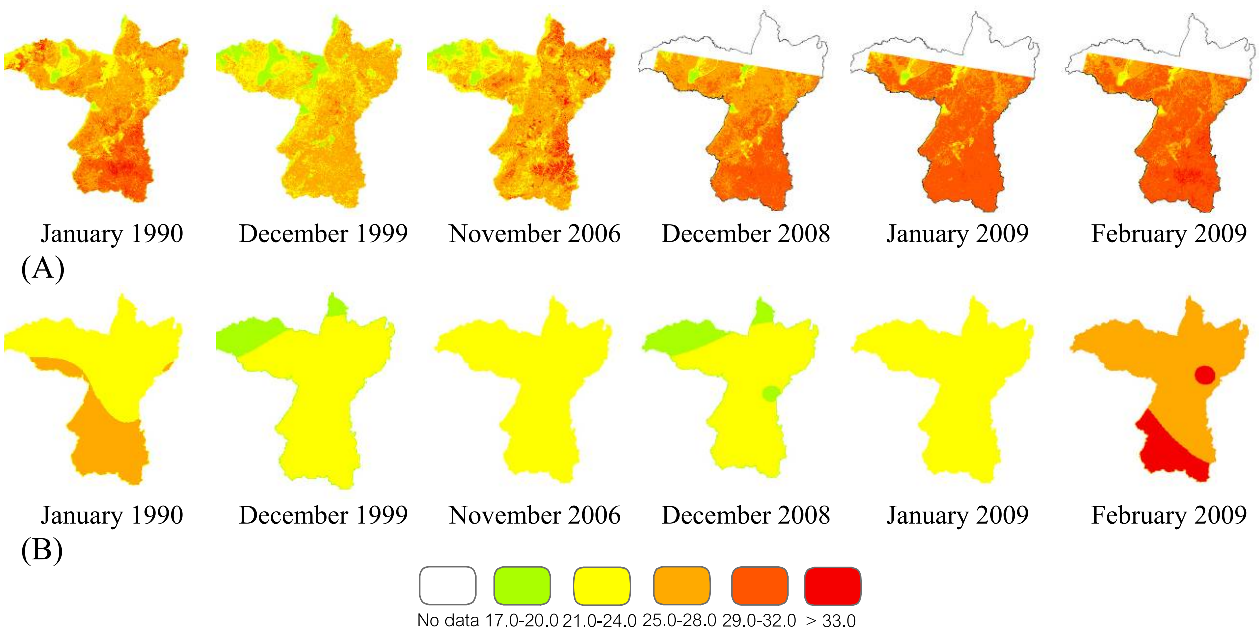


Figure 3 (A) Estimated LST in 1990-2009. (B) The interpolated atmospheric temperature in 1990-2009.

Table 1 Average and standard deviation value of estimated LST.

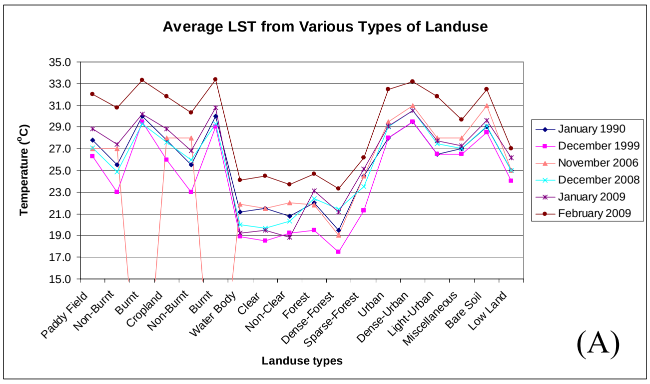
Land use Type	Average estimated LST (^oC) and SD value											
	Jan 1990		Dec1999		Nov 2006		Dec 2008		Jan 2009		Feb 2009	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Paddy Field	27.8	3.2	26.3	4.6	27.0	3.9	27.1	3.1	28.8	1.9	32.0	1.8
-Non-Burnt	25.5	1.3	23.0	1.6	27.0	3.9	24.9	0.7	27.4	0.6	30.8	0.6
-Burnt	30.0	1.6	29.5	1.9	-	-	29.3	0.9	30.2	0.8	33.3	1.1
Cropland	27.8	3.2	26.0	4.2	28.0	2.2	27.6	2.3	28.8	2.8	31.8	2.2
-Non-Burnt	25.5	1.3	23.0	2.2	28.0	2.2	26.0	0.4	26.8	1.3	30.3	1.3
-Burnt	30.0	1.6	29.0	2.2	-	-	29.3	0.9	30.8	1.5	33.4	0.9
Water Body	21.2	0.5	18.9	0.5	21.8	0.4	20.0	0.4	19.2	0.5	24.1	0.5
-Clear	21.5	0.7	18.5	0.7	21.5	0.7	19.7	1.5	19.5	0.9	24.5	0.8
-Non-Clear	20.8	2.6	19.2	2.6	22.0	1.6	20.3	1.4	18.8	2.2	23.7	1.1
Forest	22.0	3.5	19.5	3.0	21.8	3.9	22.4	1.5	23.1	2.7	24.7	2.1
-Dense-Forest	19.5	1.3	17.5	1.4	19.0	1.6	21.4	0.4	21.2	0.7	23.3	0.5
-Sparse-Forest	24.5	1.9	21.3	0.9	24.5	3.6	23.5	1.6	25.1	0.6	26.2	0.9
Urban	28.0	2.1	28.0	2.1	29.5	2.1	29.0	2.2	29.1	2.0	32.5	0.9
-Dense-Urban	29.5	1.9	29.5	2.4	31.0	2.2	30.5	1.2	30.5	0.7	33.2	1.6
-Light-Urban	26.5	1.3	26.5	1.3	28.0	2.7	27.5	1.1	27.7	0.6	31.8	0.3
Miscellaneous	27.0	2.8	26.5	3.2	28.0	4.2	27.0	2.9	27.3	3.3	29.7	3.9
-Bare Soil	29.0	1.0	28.5	1.3	31.0	1.6	29.1	0.7	29.6	0.6	32.5	0.8
-Low Land	25.0	1.3	24.0	1.6	25.0	2.2	25.0	1.6	26.2	0.8	27.0	1.1

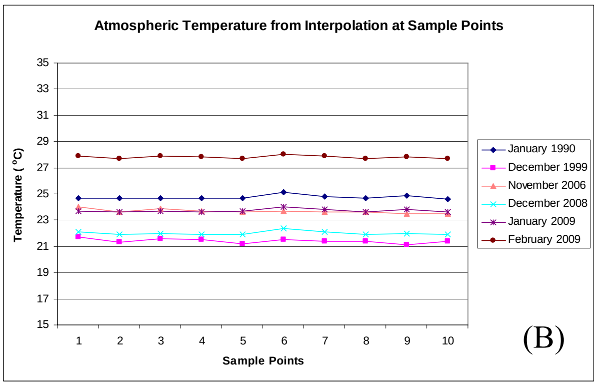
Figure 3 (B) and Figure 4 (B) illustrate the atmospheric temperature from interpolation using inverse distance weighted (IDW) method at sample points in January 1990, December 1999, November 2006, December 2008, January 2009 and February 2009. It was found that atmospheric temperature in December 1999 was lower than the temperature in other months especially in February 2009. When the estimated LST was compared to the atmospheric temperature, it showed that the estimated LST was conformed to atmospheric temperature since both of them were low in December and higher in January and February.

Table 2 and Figure 4 (C) illustrate the comparison of the measured LST in field and the average estimated LST, calculated from Bi-Linear method at sample points. Sample point 1-6 were measured in the morning closely to the time which images were acquired, therefore, the curve of estimated LST and measured LST in Figured 4 (C) are closely together. In the afternoon, the temperature is usually higher than in the morning, hence, the LST measured during 12.00-15.30 hrs (sample point 7-8) was much higher than estimated LST. Then they were not much different again after 15.30 hrs (sample point 9-10).

Table 2 Comparison of average estimated LST and measured LST.

Sample Points	Land use type	Average LST from Bi-Linear Method (^oC)						Measured LST in Field		
		Jan 8, 1990	Dec 27, 1999	Nov 4, 2006	Dec 23, 2008	Jan 12, 2009	Feb 13, 2009	Dec 20, 2008	Jan 10, 2009	Feb 13, 2009
1	re-cultivated sugarcane plantation	26.8	24.8	32.9	26.6	27.7	30.2	26.5	25.5	32.5
2		27.9	23.5	30.0	25.4	27.2	29.4	25.0	26.5	31.0
3	eucalyptus plantation	28.4	24.6	33.5	26.7	27.8	31.2	27.0	26.0	32.5
4	burnt paddy field	27.5	26.8	31.2	25.7	27.6	30.7	28.0	25.5	32.0
5		28.3	25.1	32.6	24.6	27.4	32.2	26.5	28.0	31.0
6	harvested paddy	28.6	24.9	28.5	23.1	27.6	31.3	22.0	27.0	33.0
7		27.6	23.9	29.2	24.9	26.3	30.5	29.0	30.5	33.4
8	harvested sugarcane plantation	27.1	24.0	31.7	25.9	27.3	30.8	29.0	30.0	32.5
9		26.4	22.8	30.7	24.0	24.5	26.9	29.0	26.0	28.0
10	bare soil	29.8	25.3	31.5	24.6	27.0	32.1	26.0	27.0	29.0





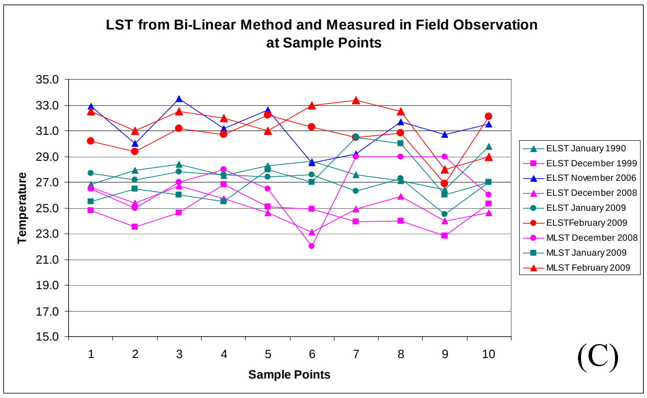


Figure 4

(A) Average estimated LST from various types of land use.

(B) Atmospheric temperature from interpolation at sample points.

(C) Average estimated LST (ELST) from Bi-Linear Method at sample points and Measured LST (MST)

6. CONCLUSION AND RECOMMENDATION

The result of this study showed the possibility to use band 3, 4 and 6 of Landsat-5 data for LST estimation. Since it showed clearly the difference temperature of urban area especially dense urban area (community and commercial area) where average temperature was approximately 29.5-33.2 ^{O}C, and suburban area especially dense forest where average temperature was approximately 17.5-23.3 ^{O}C. It seemed to demonstrate that UHI phenomenon took place in Khon Kaen province. The reliability assessment of estimated LST was planned to carry out by measuring LST in the field at 5 and 10 centimeters depth and will process at the same date of Landsat-5 TM acquiring.

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