Sensors & Transducers, Vol. 23, Special Issue, July 2013, pp. 122-126

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Dynamic Monitoring and Evaluation on Urban Heat Island Effects Using Remote Sensing Technology

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Received: 15 April 2013 /Accepted: 20 July 2013 /Published: 30 July 2013

Abstract: Land surface temperature (LST) of the Nanchong City in China was retrieved using Landsat TM/ETM+ images, which obtained on September 15, 1988, July 22, 2000, and September 20, 2007 respectively, and then be classified by Mean-standard Deviation method. The spatio-temporal evolution of UHI was analyzed including UHI distribution variation and transformation. Research result are the following: (1) The UHI area in the Nanchong city was continually increasing from 1988 to 2007, and the rate in the later period (from 2000 to 2007) was 1.8 times that in the previous period (from 1988 to 2000). The UHI expansion was synchronous with built-up area, and the expansion form was extending along and outwards the Jialing River. (2) The UHI-in area was far greater than the UHI-out area from 1988 to 2007. In the previous period, the UHI-into rate was 4.0 times that of UHI-out, and in the later period, the UHI-into rate was 2.2 times the UHI-out rate. Comparison of the previous and later period, the UHI-into rate or UHI-out rate was increasing, but the increased scope of UHI-into rate was more 22.42 hm^2/a than UHI-out rate. In short, the UHI in the Nanchong City was continuously strengthening from 1988 to 2007, and the rate in the latter period was higher than that in the previous period. *Copyright © 2013 IFSA.*

Keywords: Urban Heat Island Effects, Land Surface Temperature (LST), Dynamic Monitoring and Evaluation.

1. Introduction

Since the concept of Urban Heat Island (UHI) was proposed by Lake Howard in 1833, this problem has attracted wide attention of many scholars. Especially in recent years, with the development of urbanization, Urban Heat Island Effects has already become the typical characteristic of urban climate. It is seriously affecting urban people's quality of life.

At present, there are many methods of UHI research. Remote Sensing technology as the efficient surface observation mean has been applied widely to UHI research in several large cities. For instance, XU Han-Qiu *et al.* quantitatively evaluated the UHI of the Xiamen City in China using UHI Ratio Index (URI) [1]. Chen Yun-Hao *et al*. analyzed the spatial-temporal characteristics of urban thermal environment in the Shanghai City, China [2]. Jiang Zhang-Yan *et al.* studied the UHI of the Beijing City and discussed its relationship with land cover and vegetation index [3]. Wang Tian-Xing *et al.* analyzed the spatio-temporal evolution of UHI in the Fuzhou City from 1989 to 2004 in various aspects [4].

This article analyzed the spatio-temporal evolution of UHI in the Nanchong City of Sichuan Province in China using Landsat multi-temporal

Article number P_SI_414

TM/ETM+ data, in order to provide the basis for the local environment evaluation and city planning.

2. Research Region and Data Source

The Nanchong City lies in the northeast of Sichuan Basin, and locates in the middle reaches of the Jialing River (see Fig. 1). The topography is mainly hilly, and the altitude is from 26 to 480 meters. The research region is the urban area of the Nanchong city, which locates in the west of the Jialing River and the east of the Xi River, including the Shunqing District, the Jialing District and the Gaoping District. The Shunqing District and the Jialing District lies in the west of the Jialing River, and the Gaoping District lies in the east of the Jialing River. The Jialing River flows through the east side of the urban from north to south. The urban area is surrounded by the highway. The highway from Chengdu to Nanchong runs across the south of urban area.

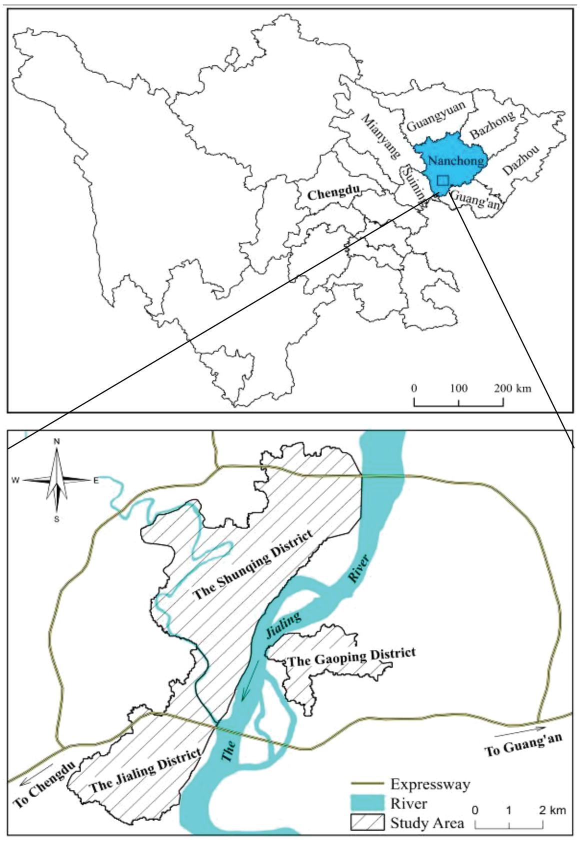

Fig. 1. General situation of research region.

This research used Landsat-5 TM data, which obtained on September 15, 1988 and September 20, 2007, and Landsat-7 ETM+ data obtained on July 22, 2000. The satellite channel number is 128/039. The projection of the images is UTM 48N, the ellipsoid and reduced plane of which is WGS84, the spatial resolution of image is 30 meters. The quality of images is good.

3. Retrieving Land Surface Temperature (LST)

3.1. Radiation Calibration

Radiation calibration is a process of converting the digital value (DN) of remote sensing data into spectral radiance value of sensor. For Landsat-5 TM data, the calculation model is formula (1), and for Landsat-7 ETM+ data, the model is formula (2) [5].

$$L_\lambda = \frac{L_{\max_\lambda} - L_{\min_\lambda}}{Q_{\max}} Q_\lambda + L_{\min_\lambda}, \quad (1)$$

$$L_\lambda = \frac{L_{\max_\lambda} - L_{\min_\lambda}}{Q_{\max} - Q_{\min}} (Q_\lambda - Q_{\min}) + L_{\min_\lambda}, \quad (2)$$

where L_λ is the spectral radiance by the sensor ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$), Q_λ is the digital number of analyzed pixel, Q_{max} is the maximum digital number (255), Q_{min} is the minimum digital number, $L_{\max_\lambda}$ and $L_{\min_\lambda}$ are the maximum and minimum spectral radiance.

3.2. Retrieving Brightness Temperature

Based on spectral radiation value of pixels on sensor, brightness temperature can be directly calculated by Planck's radiation function or an approximation formula (3) [6, 7].

$$T_{rad} = \frac{K_2}{\ln(1 + \frac{K_1}{L_\lambda})}, \quad (3)$$

where T_{rad} is the brightness temperature of pixels and its unit is K, K_1 and K_2 are the pre-launch calibration constants, as for ETM+ band 6, K_1 is 666.093 W. m^{-2}. $ster^{-1}$. μm^{-1}, and K_2 is 1282.708 K, as for TM band 6, K_1 is 60.766 mW. cm^{-2}. $ster^{-1}$. μm^{-1}, and K_2 is 1260.56 K [8].

3.3. Retrieving Land Surface Temperature (LST)

Retrieving land surface temperature (LST) is the key of Urban Heat Island Effect research. At present, there are four methods for retrieving land surface temperature using Landsat thermal infrared band, which are Radioactive Transfer Equation (RTE), Image-Based Method (IB), Mono-Window

Algorithm (MW) and Single Channel Method (SC) respectively. Comprehensively considering the advantages and disadvantages of above four methods, this research selected the algorithm of Image-Based Method to retrieve land surface temperature through brightness temperature.

LST can be calculated according to formula (4) [9]:

$$T_s = \frac{T_{rad}}{1 + (\lambda \cdot T_{rad} / \rho)\ln \varepsilon}, \quad (4)$$

where T_s is the LST and its unit is K, λ is the center wavelength (11.4 µm), $\rho = h \cdot c / \sigma$, where h is the Planck constant ($6.626 \times 10^{-34} J \cdot s$), c is the velocity of light ($2.998 \times 10^8 m/s$), σ is the Boltzmann constant ($1.38 \times 10^{-23} J/K$), ε is the surface emission coefficients, when NDVI<0.05, ε=0.973, when NDVI>0.7, ε=0.99, when 0.05≤NDVI≤0.7, ε=0.004P_V+0.986, where P_V is the vegetation proportion in pixel, $P_v = (NDVI - NDVI_s)/(NDVI_v - NDVI_s)$, $NDVI = (\rho_4 - \rho_3)/(\rho_4 + \rho_3)$, ρ_3 and ρ_4 are the surface reflectance acquired in the red and near-infrared band of Landsat TM/ETM+ respectively [10, 11]. $NDVI_v$ (0.7) and $NDVI_s$ (0.05) stand for the NDVI value of vegetation and bare land.

4. Analysis of Spatial-temporal Evolution of UHI

Mean-standard deviation method was used to divide land surface temperatures of the research region into five grades, which are high temperature area, secondary high temperature area, medium temperature area, secondary low temperature area and low temperature area [12]. The results in research region are displayed in Fig. 2, Fig. 3 and Fig. 4. High temperature area and secondary high temperature area is defined as the heat island area, others are called non-heat island area.

4.1. Analysis of UHI Distribution Variation

Fig. 2 showed that, in 1988, the UHI area in the Shunqing District showed strip distribution and mainly distributed in the Five-star Garden, the Wufengshan, the West Street, the Southeast Street and the Zhoujiaba, and the UHI patches were smaller, which in the Gaoping District was lest and distributed in the White Pagoda Park and the Gaoping Town.

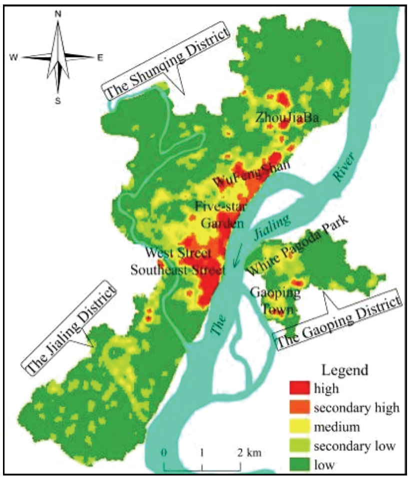

Fig. 2. Land surface temperature grades on September 15, 1988.

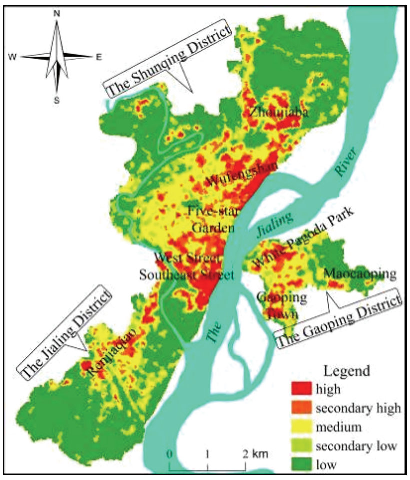

Fig. 3. Land surface temperature grades on July 22, 2000.

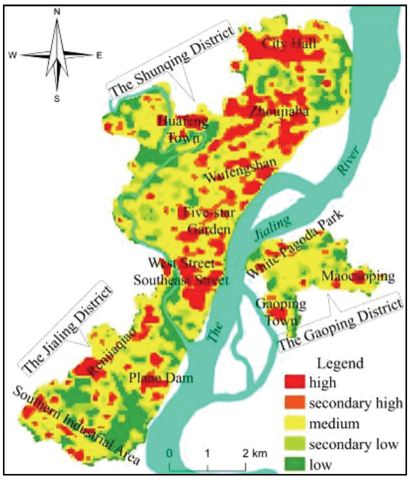

Fig. 4. Land surface temperature grades on September 20, 2007.

Fig. 3 showed that, in 2000, the UHI area in the Shunqing District was expanded except that in Five-star Garden was disappeared, that in the Renjiaqiao of the Jialing District appeared, and that in the White Pagoda Park and the Gaoping Town of Gaoping District was expanded. Fig. 4 showed that, in 2007, the UHI area in the City Hall and the Hua Feng Town was increased in the Shunqing District, the UHI area of the Zhou Jia Ba expanded, and the UHI area in the Wufengshan, the West and Southeast Street decreased. The UHI area in the Southern Industrial Area and the Plane Dam was increased in the Jialing District, and that in the Maocaoping was increased in the Gaoping District. From 1988 to 2007, the UHI expansion was synchronous with built-up area, and the expansion tendency form was extending along and outwards the Jialing River.

According to the statistics from three LST images (Fig. 2-4), the UHI area in 1988 was 291.06 hm^2, that in 2000 was 621.81 hm^2, and that in 2007 was 960.48 hm^2, accounting for 7.31 %, 15.61 % and 24.11 % of research region respectively. From 1988 to 2000, the UHI area increased by 330.75 hm^2, the increasing rate was 27.56 hm^2/a, and from 2000 to 2007, the UHI area increased by 338.67 hm^2, the rate was 48.38 hm^2/a. In short, from 1988 to 2007, UHI area was continually increasing, and the rate in later period (from 2000 to 2007) is 1.8 times that in previous period (from 1988 to 2000).

4.2. Analysis of UHI Area Transformation

Using GIS software of ArcGIS, temperature grades transformation image from 1988 to 2000, and from 2000 to 2007, were derived from temperature grades images in two phases respectively (Fig. 5 and Fig. 6). In the pictures, different color zones represent the transformation types of the different temperature grades.

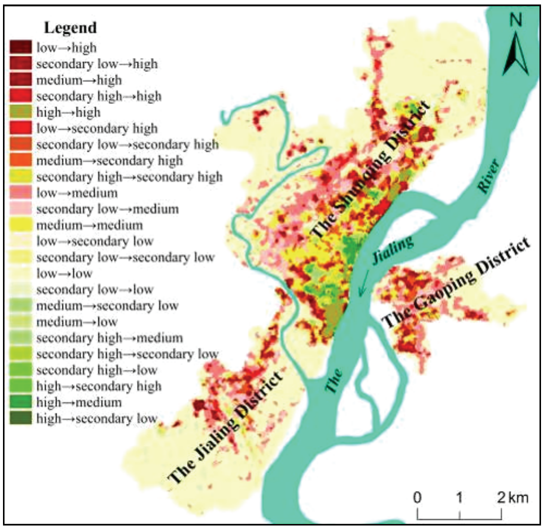

Fig. 5. Land surface temperature grade transformation from 1988 to 2000.

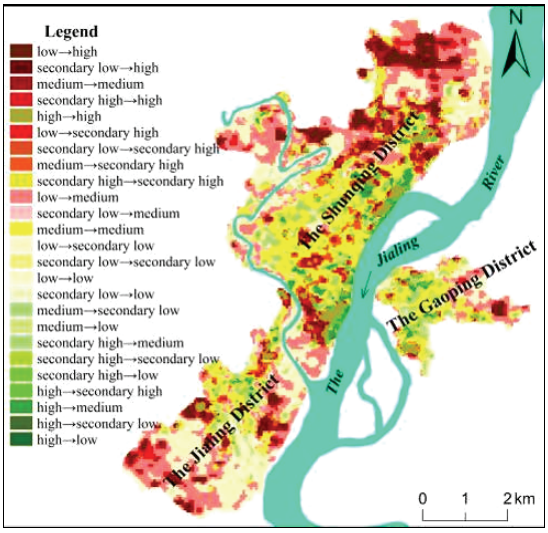

Fig. 6. Land surface temperature grade transformation from 2000 to 2007.

The statistics from Fig. 5 showed that, from 1988 to 2000, the UHI area without transformation was 206.19 hm^2.The area from non-UHI to UHI was 415.62 hm^2, and its rate was 34.64 hm^2/a.The area from UHI to non-UHI was 104.04 hm^2, and its rate was 8.67 hm^2/a.

The statistics from Fig. 6 showed that, from 2000 to 2007, the UHI area without transformation was 329.67 hm^2,the area from non-UHI to UHI was 630.81 hm^2, and its rate was 90.12 hm^2/a.The area from UHI to non-UHI was 292.14 hm^2, and its rate was 41.73 hm^2/a. Comparison of the previous period (from 1988 to 2000) and the later period (from 2000 to 2007), the UHI-into rate or UHI-out rate was increasing, but the increased scope of UHI-into rate was more 22.42 hm^2/a than UHI-out rate.

5. Conclusions

The UHI in the Nanchong City was dynamically monitored using multi-temporal remote sensing images. The main conclusions are the following:

(1) The UHI area in Nanchong city was continually increasing from 1988 to 2007, and the rate in later period (from 2000 to 2007) is 1.8 times that in previous period (from 1988 to 2000). The UHI expansion was synchronous with built-up area, and the expansion form was extending along and outwards the Jialing River.

(2) The UHI-in area was far greater than the UHI-out area from 1988 to 2007. In the previous period (from 1988 to 2000), the UHI-into rate was 4.0 times that of UHI-out. In the later period (from 2000 to 2007), the UHI-into rate was 2.2 times that of UHI-out. Comparison of the previous and the later period, the UHI-into rate or UHI-out rate was increasing, but the increased scope of UHI-into rate was more 22.42 hm^2/a than UHI-out rate.

In short, the UHI in Nanchong city was continuously strengthening from 1988 to 2007, and the later rate strengthened (from 2000 to 2007) was higher than the previous rate (from 1988 to 2000).

Acknowledgements

This research was supported by the open foundation of the Laboratory of Geo-special Information Technology, Ministry of Land and Resources, Chengdu University of Technology, China (NO.KLGSIT2013-10), and by the key project of Sichuan Environmental Protection Bureau (NO.2010HBY003) and the research project of Sichuan College of Architecture Technology (2011).

References

[1] Xu Hanqiu, Chen Benqing, An Image Processing Technique for the Study of Urban Heat Island Changes Using Different Seasonal Remote Sensing Data, *Remote Sensing Technology and Application*, Vol.18, Issue 3, 2003, pp.129-133.

[2]. Chen Yun-Hao, Gong A-Du, Li Jing, Study of Urban Thermal Environment Using Remote Sensing Data Based on Radiation Normalization, *Journal of China University of Mining & Technology*, Vol. 35, Issue 4, 2006, pp. 462-467.

[3]. Jiang Zhangyan, Chen Yunhao, Li Jing, Heat Island Effect of Beijing Based on Landsat TM data, *Geomatics and Information Science of Wuhan University*, Vol. 31, Issue 2, 2006, pp. 120-123.

[4]. Wang Tian-Xing, Chen Song-Lin, Yan Guang-Jian, Estimation of Land Surface Parameters and Spatio-temporal Characteristics of Urban Heat Island, *Scientia Geographica Sinica*, Vol. 29, Issue 5, 2009, pp. 697-702.

[5] Xu Hanqiu, Image-based Normalization Technique Used for Landsat TM / ETM+Imagery, *Geomatics and Information Science of Wuhan University*, Vol.32, Issue 1, 2007, pp.62-66.

[6]. G. M. Chander, Revised Landsat5 TM Radiometric Calibration Procedures and Post-calibration Dynamic Rannes, http://www.gsfc.nasa.nov

[7]. J. F. Mustard, M. A. Camey and A. Sen, The use of satellite data to quantify thermal effluent impacts, *Estuarine Coastal and Shelf Science*, Vol. 49, 1999, pp. 509-524.

[8]. Schneider K., Mauser W., Processing and accuracy of Landsat Thematic Mapper data for lake surface temperature measurement, *Int. J. Remote Sensing*, Vol. 17, 1996, pp. 2027–2041.

[9] Artis D. A., Carnahan W. H., Survey of emissivity variability in thermography of urban areas, *Remote Sensing of Environment*, Vol. 12, Issue 4, 1982, pp. 313-329.

[10]. Goward S. N., Markham B., Dye D. G., Dulaney W., Yang, J., Normalized difference vegetation index measurements from the advanced very high resolution radiometer, *Remote Sens. Environ*, Vol. 35, 1991, pp. 257–277.

[11]. Santos P., Negri A. J., A comparison of the normalized difference vegetation index and rainfall for the Amazon and Northeastern Brazil, *J. Appl. Meteorol*, Vol. 36, 1997, pp. 958–965.

[12]. Chen Songlin, Wang Tianxing, Comparison Analyses of Equal Interval Method and Mean-standard Deviation Method used to Delimitate Urban Heat Island, *Journal of Geo-Information Science*, Vol. 11, Issue 2, 2009, pp. 145-147.