

DETECTING AND ANALYZING URBAN HEAT ISLAND PATTERNS IN BEIJING, CHINA

Rongbo Xiao, Zhiyun Ouyang*, Xiaoke Wang, Weifeng Li

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

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ABSTRACT:

The study reports a research aiming to detect the spatial pattern of urban heat island (UHI) phenomena in Beijing, China, and to determine the relationship between the UHI pattern and a set of landscape and demographical variables. The study area has been one of the fastest growing metropolises in China during the past two decades. Land surface radiance temperature (SRT) values were extracted from a Landsat TM image by 2001. Built-up area and road system were got from 1:10,000 scale topographic maps. A NDVI index map was extracted from the same image. Multiple correlation and regression analyses were used to examine the relationship between UHI pattern and land use/cover parameters (i.e. NDVI, built-up density and road density) and demographical variables (i.e. population density, non-agricultural population density and family households density) at the township level. It is found that dry river bed area across city was hottest, but multiple heat islands emerged over several satellite cities within the metropolis. The statistical analysis indicates that the UHI intensities had a negative relationship with NDVI, but positively correlated with built-up ratio, non-agricultural population density and road density. Interestingly, the stepwise regression analysis indicates that population density did not show any meaningful statistical relationship with the UHI intensity.

1. INTRODUCTION

Surface temperature is one of the most important factors impacting on urban surface environment (Voogt, 2003). With the development of world-wide urbanization, urban heat island effects are more and more distinct in many major cities due to the artificial heating emission, simultaneous removal of natural land cover and introduction of urban materials (Oke, T.R. 1982). However, several studies have shown that different factors have diverse influences on the intensity of UHIs in different cities. Most of these studies focused on developed countries. Much less study is known about the characteristics of urban heat island in developing countries. The main objective of this paper is detecting the spatial pattern of UHI phenomena in Beijing, China, and determining the relationship between the UHI pattern and a set of landscape and demographical variables.

2. STUDY AREA AND METHODOLOGY

2.1 Study Area and data description

Beijing is the capital and one of largest cities situated in north of China (39°56'N, 116°20'E). It has an area of 16808 sq km and a population of about 13 000 000. Beijing's road system can be briefly as a network, with ringroads and radial as its arteries. The road around the Forbidden City is named the first ring, and the ringroads beyond are the second, third fourth and fifth ringroads in order of the radial distance from the center of the city. In order to detect the UHI intensified area, our study area focused in the sixth ring road nearby region. It has 3270.5 sq km and a population of 10.02 million with an average population density of 12.44 person/km² (Beijing Municipal Bureau of Statistics, 2004). It has 14 counties involving 183 townships. The heat island effect in Beijing was evident from 1961 to 2000, and the mean daily temperature in the city was

4.6°C higher than that in the suburb, and the heat island effect was reinforced from 1978 to 2000 (Song, 2003).

Regarding the database, we have taken the different sources of data: topography, Beijing census of 2000 and Landsat 5 TM scene on August 31, 2001 whose weather condition was very good: no cloud cover, slight dust in the atmosphere. The building area and road system were got from 1:10,000 scale topographic maps.

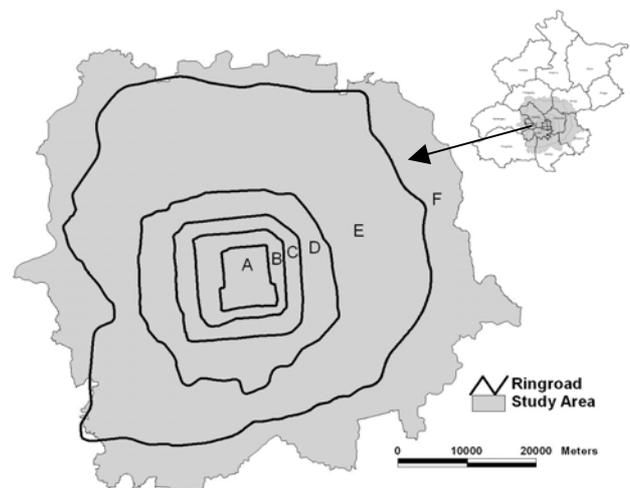


Figure 1 Location of the study area A within second ringroad, B between second and third ringroad, C between third and fourth ringroad, D between fourth and fifth ringroad, E between fifth and sixth ringroad, F outer of sixth ringroad.

* Corresponding author. zyouyang@mail.rcees.ac.cn

2.2 Data processing

2.2.1 Geometric correction: Geometric image correction was performed using corresponding ground control points in the GIS layer. The nearest-neighbour method of resampling was employed, resulting in a root mean square value of less than 1 pixel. The geometrically corrected image was used as “master” for the geometric correction of all other data sets.

2.2.2 Calculation of SRT and NDVI: Surface radiance temperature (SRT) was derived from the corrected TM TIR band (10.4–12.5 μm). The following equation was used to convert the digital numbers into absolute radiation luminance (Li, 1998)

$$R_{TM6} = (R_{max} - R_{min}) / 255 * DN + R_{min} \quad (1)$$

Where, R_{TM6} is the spectral radiation luminance, $R_{max}=1.869$ ($mW*cm^{-2}*sr$), $R_{min}=0.1534$ ($mW*cm^{-2}*sr$);

The radiance luminance per unit spectral range:

$$R_b = R_{TM6} / b, \quad (2)$$

where b is effective spectral range (sensor’s response $\geq 50\%$), $b=1.239\mu m$. R_b was converted into effective at-satellite temperatures T by:

$$T = K_1 / \ln(K_2 / R_b + 1) \quad (3)$$

where K_1 , K_2 are calibration constants. For Landsat 5 TM the constants $K_1 = 60,776 mW*cm^{-2}*sr^{-1}*\mu m^{-1}$ and $K_2 = 1260.56$. Temperatures were converted from degree Kelvin into degree Celsius for simpler handling.

Normalized Vegetation Index (NDVI) is one of vegetation indices which depicts the amount and nature of vegetation cover. It was retrained for each pixel in the composite product according to the following equation:

$$NDVI = \frac{ir - r}{ir + r} \quad (4)$$

Where, ir is the pixel value in the infrared band and r is the pixel value in the red band.

On the base of Beijing 2000 Population Census and Beijing township boundary, using zonal attributes in ERDAS Imagine, each township was calculated the mean temperature, mean land use/cover ratio and mean NDVI. The results were stored in a data base which was the basis for all statistical and spatial visualizations.

2.3 Relation between UHI density and influential factors

In order to assess the extent of the relationships between the UHI density and other various factors, multiple correlation and regression analyses were used, whose dependent variable was SRT, the independent variables tended to land use/cover parameters (i.e. NDVI, built-up density and road density) and demographical variables (i.e. population density, non-agricultural population density and family households density). The stepwise variable selection was employed during the regression in order to determine which variable to include in the multivariate regression. The applied implementation of this procedure can be found in the SPSS 9 computer statistics software. Predictors were entered or removed from the model

depending on the significance of the F value of 0.05 and 0.1, respectively.

3. RESULTS AND DISCUSSION

3.1 UHI spatial pattern in Beijing

In the whole study area, SRT ranged from 9.28 to 33.92°C with a mean of 20.71°C and standard deviation of 2.21. Figure 2 was produced based on the classification scheme of standard deviation, in which class 1 data values are less than one standard deviation below the mean, class 2 values fall between the mean and one standard deviation below the mean, and so on (Smith, 1986; Weng, 2004). The shape of the UHI pattern was almost concentric and the temperature values increase from outskirts towards the inner urban areas (Figure 2). In the center of Beijing within second ringroad, the mean SRT was highest (23.28°C), but it was only 19.72°C in the exurb area outer of sixth ringroad. Both the maximum (33.82°C) and minimum (9.28°C) SRTs were occurred in the same region from fifth to sixth ringroad. It was easy to identify UHIs from figure 2. The most evident UHI didn’t occur in the part of CBD, which was not just like in most of other cities. It was distributed in the west-southern part of the city which was dry Yongding river bed, the largest bared land, and much architectural garbage was piled up over there. There were also some UHIs in the south area from second to fourth ringroad. In the contrast, there were some vegetated urban parks which were cooler than their surrounding built environment in the center of city. This phenomenon was called “park cool island effect” by some scholars (Spronken-smith, 1998).

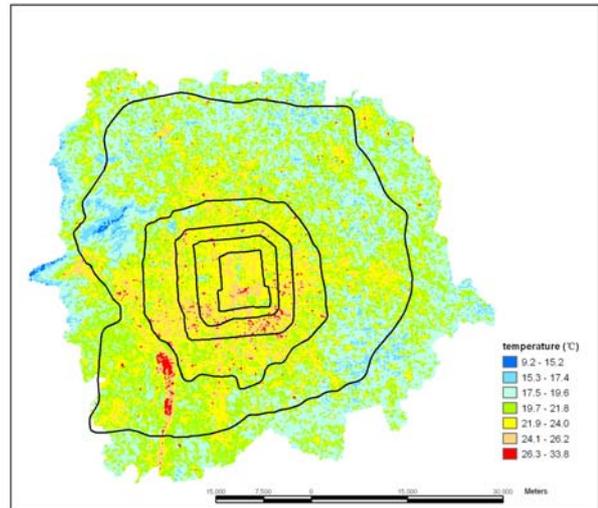


Figure 2 Radiance temperature of study area

3.2 Spatial characteristics of landscape & demographical parameters

There were many influential factors for controlling urban heat island, such as surface cover characteristics, urban morphology, human activity, and meteorologic condition, et al. But it’s very difficult to consider all factors. In view of data obtainable and aims of research, this study investigated here: NDVI, road density, built-up ratio, population density, non-agricultural population density, and family density.

The spatial distribution of the built-up ratio over the study area had a concentric shape decreasing from central urban areas to the outwards. The highest built-up ratio values were concentrated in the middle parts of the city within forth ringroad and most of them were more than 30.0%. The maximum value was higher than 67.0% in Chaoyangmen township. Out of fifth ringroad, the built-up ratio values were below 15.0% in most of townships. The minimum value was only 1.3% in Dongxinfang township.

Because the area within second ringroad was historical centre of Beijing, the road density over there ranged from 2.5%~4.5%. The high values were located in the area from second to forth ringroad, and most of them were above 4.5%.

The NDVI factor pattern was very complicated because of the significant variability of land use/cover. It ranged from -0.5882 to 0.6020 with a mean value of -0.0875, and standard deviation of 0.1513. The areas of high vegetation around the city had a correspondingly high NDVI value. The urban areas, on the other hand, had a relatively low NDVI value, as do water surfaces.

The total population density had the similar spatial pattern of built-up ratio distribution. The highest population density was 39874 person per km² in Chunshu township, and the lowest was only 196 person per km² in Laozhuangxiang township.

3.3 Statistical model equations

Table1 shows that the Person's correlation coefficients between SRT and other influential factors at township level. The significance of each correlation coefficient was determined using a 2-tailed Student's t-test and all was significant at the 0.01 level. Among all influential factors, only NDVI tended to negatively correlate with SRT and its correlation coefficient was highest (0.943), followed by built-up ratio (0.784), population density (0.685), non-agricultural population density (0.660), family density (0.653), road density (0.567). NDVI was correlated negatively with all other factors. Apart from SRT, the correlation coefficients dropped sharply for built-up ratio (-0.779), and population density (-0.760), and non-agricultural population density (-0.746), and family density (-0.732). The least correlation was found with road density. The coefficients correlated with road density were all small.

Table 1 Coefficient Correlations of radiance temperature and other parameters

	SRT	NDVI	RD	BT	FD	PD	NAPD
SRT	1.000						
NDVI	-0.943	1.000					
RD	0.567	-0.659	1.000				
BR	0.784	-0.779	0.402	1.000			
FD	0.653	-0.732	0.386	0.718	1.000		
PD	0.685	-0.760	0.500	0.820	0.872	1.000	
NAPD	0.660	-0.746	0.444	0.777	0.960	0.951	1.000

RD: road density, BR: built-up ratio, FD: family density, PD: population density, NAPD: non-agricultural population density.

For the study area as a whole, the model equation had four parameters. As it could be seen the NDVI predictor was the most important one among all of factors but built-up ratio and non-agricultural population density played also significant role. This model indicated a very strong linear connection between SRT and a set of landscape and demographical variables. The absolute value of the multiple correlation coefficients (r)

between the mean radiance temperature and the studied parameters was 0.955, and it was significant at 0.001 level. This meant that these four parameters were able to explain 91.2% of the above mentioned relationship. Interestingly, the stepwise regression analysis indicated that population density did not show any meaningful statistical relationship with the UHI intensity. The perhaps reason for this was that non-agricultural population could emit more artificial heat than agricultural population. So it played more prominent role than population density.

Table 2 Values of the stepwise correlation of radiance temperature and other factors by township level and their significance levels in Beijing

Parameter entered	r	r ²	Sign. Level
NDVI	0.943	0.890	0.000
NDVI, BR	0.947	0.896	0.000
NDVI, BR, NAPD	0.954	0.909	0.000
NDVI, BR, NAPD, RD	0.955	0.912	0.000

4. CONCLUSIONS

In this study we have estimated the spatial distribution of surface radiance temperature and analyzed the influential factors by combining thermal infrared remote sensing data with GIS in Beijing. The spatial distribution of UHIs had almost concentric shapes and the temperature values decreased from the central urban areas towards the outskirts. The most evident UHI was occurred in the dry Yongding river bed. The stepwise correlation analysis indicated that the UHI intensities had a negative relationship with NDVI, but positively correlated with built-up ratio, non-agricultural population density and road density. These four factors played important roles in the increment of the urban temperature. On the other hand, the stepwise regression analysis indicates that population density did not show any meaningful statistical relationship with the UHI intensity.

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