A study on urban growth, vegetation space variation and thermal environmental changes of Beijing city based on TM imagery data

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Abstract:- With the adoption of opening up and reform policy, growth of Beijing city has accelerated and exerted a dramatic influence on its thermal environment. Urban growth, vegetation space variation and their influence on the thermal environment of Beijing city were analyzed based on the 3 scenes of Landsat5 TM data acquired on September 26th 1987, August 28th 1994 and August 31st 2001 separately. Radiometric normalization between the three images from different dates was made firstly, followed by information extraction of urban growth and vegetation changes. The generalized single channel algorithm proposed by Jiménez-Muñoz J C, et al. in 2003 was applied to retrieve land surface temperature (LST) and thermal environmental changes were examined based on the normalized LST. The result shows urban growth area coincides with the thermal intensified area and a good similarity exists between vegetation increasing area and thermal relieved area or no change area. The characteristics of urban growth and thermal intensified area changes were similar, both spreading from the center of Beijing city to its outside in accordance with the ring road system.

Key words:- urbanization, vegetation space, thermal environment, change, TM, Beijing

1 Introduction

With the development of the research on global environment changes, more and more importance was attached to land use and land cover (LULC) and their impact on global environment, especially the climate. Urbanization, the conversion of other types of land to uses associated with growth of populations and economy, is a main type of land use and land cover change in human history. Land surfaces previously covered by vegetation and soil are now covered by urban buildings, roads and other impervious surfaces. Urban surfaces generally have a higher solar radiation absorption and a greater thermal capacity and conductivity. The thermal property differences, in conjunction with waste heat released from urban transportation, population, houses and industry contribute to the changes of urban environment. Urban heat island (UHI) is a key feature of urban environmental changes.

In China, the process of urbanization has accelerated since 1980s, and exerted serious influences on its environment. Beijing city, the capital and one of the largest cities in China also has this kind of problem. Furthermore, rampant urban growth, lack of appropriate land use planning and the measures for sustainable development has been creating severe environmental consequences. Therefore, there is an urgent need to assess the environmental impact of the rapid urbanization.

Remote sensing technology, capable of large-scale, short-cycle earth observation, has an evident advantage in urban research. Landsat 5 TM data has 6 multi-spectral bands (bands 1-5 and 7), and one thermal infrared band (band 6), with a spatial resolution of 30 meters and 120 meters respectively. Because of higher spatial resolution and long-term data storage, Landsat 5 TM data was widely used in urban expansion research. Guang-jin Tian et al. studied the dynamic landscape patterns of Beijing using TM images of 1988 and 2000[1]. Chun-yang He et al. simulated the city development of Beijing from 1975-1997[2]. However, most studies have been focused on city expansion characteristics and drivers. Studies on land use change and its environmental influences of Beijing were scarcely reported. The main goal of this paper was to evaluate urban growth and vegetation variation patterns in Beijing city and to analyze their influence on its thermal environment based on RS and GIS technology.

2 Methodology

2.1 Study area and data description
Beijing, capital of China, covers an area of 16808 km². With a population of about 13,000,000, Beijing is also one of the largest cities in the world. Beijing's road system can be briefly viewed as a network, with ring roads and radial as its arteries. The road around the Forbidden City is named the first-ring road, and the ring roads outside are the second, third, fourth and fifth ring roads in order of the radial distance from the center of the city.

Three Landsat 5 TM images used in this paper were acquired on September 26th 1987, August 28th 1994 and August 31st 2001 separately. The images were in the same season and with good quality. Each Landsat image was registered to common projection (Albers Conical Equal Area) based on large scale digital map. The resultant root-mean-squared error was less than 0.5 pixel.

2.2 Radiometric normalization of multi-temporal images

Radiometric normalization of multi-temporal satellite images is often necessary for land cover change detection. Previously, ground reference data or pseudo-invariant features (PIFs) were used in the radiometric rectification of multi-temporal images. But ground reference data are costly and difficult to acquire for most satellite remotely sensed images and the selection of PIFs is generally subjective. In addition, these methods were mainly used on radiometric normalization of two images. Conservation of radiometric resolution in the case of radiometric normalization between more than two images was also a problem. Yong Du et al. proposed a new procedure for radiometric normalization between multi-temporal images based on principal component analysis (PCA)[3]. In Yong’s approach, selection of PIFs can be done statistically. The satellite images are normalized radiometrically to a common scale tied to the reference radiometric levels, so this procedure ensures the conservation of radiometric resolution for the multi-temporal images involved. In this paper, this method was used to do the radiometric normalization of the three Landsat 5 TM images. Considering the need of built up area extraction (see details in section 2.3), we only chose band3, band4, and band5 to do the radiometric normalization.

2.3 Urban expansion detection and analysis

Conventionally land cover information was extracted from remote sensing images using two methods: manual interpretation and computer-assisted classification. Manual interpretation is tedious, time-consuming and the interpreted results are highly subjective to the image analyst. By comparison, supervised classification is much faster and requires far less human intervention. But, automatic classification of satellite images for urban areas is a difficult task to achieve at a high accuracy level due to the diverse range of covers. And the results automatically classified from satellite data, to some extent, are still subject to the characteristics of the selected training samples. Therefore, conventional methods of parametric classification tend to be slow as a result of the need to select quality training samples. Considerable efforts are being done to simplify the process of automatically extracting land covers, such as using indices. A new and simple method was proposed by Y. ZHA et al. for the rapid and accurate mapping of built-up areas (including barren land) based on the combinational use of normalized difference built-up index (NDBI) and normalized difference vegetation index (NDVI)[4]. The mapping procedure is accomplished through arithmetic manipulations and recoding of NDBI and NDVI images. This method was applied to extract built-up area in this paper. Then image differencing techniques were used to obtain built-up area change map. Results are as follows (Fig.1). Black lines indicate the ring roads of Beijing.
In order to analyze urban area changes quantitatively, a statistical table was made (Table 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>The total area of built-up and barren land (KM²)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>241.4</td>
<td>26.9</td>
</tr>
<tr>
<td>1994</td>
<td>338.2</td>
<td>37.8</td>
</tr>
<tr>
<td>2001</td>
<td>487.9</td>
<td>54.5</td>
</tr>
</tbody>
</table>

Table 1 shows that in 1987 the total area of built-up and barren land in the study area was only 241.4 KM², accounting for 26.9% of the study area. However, in 1994 and 2001, the total area of built-up and barren land were 338.2 KM² and 487.9 KM², with the percentage of 37.8% and 54.5% respectively. From this table, it is clear that there has been a considerable increase in built-up area during the two periods. From 1987-1994, the total area of built-up and barren land increased from 241.4 KM² to 338.2 KM², about 96.8 KM² and 10.9% of the study area. And from 1994-2001, it increased from 338.2 KM² to 487.9 KM², about 148.7 KM² and 16.7% of the study area. Obviously, the built-up area increased more drastically in the second period than that of the first period.

Fig.1 shows the areal extent and spatial occurrence of the urban area change. The red indicates the built-up increase area. The blue indicates the built-up decrease area, which means the land use and land cover change from built-up and barren land to other types (vegetation, water, etc). From Fig.1, we can see that, from 1987-1994, urban expansion mainly occurred within the fourth-ring road and from 1994-2001 urban expansion mainly occurred outside the fourth-ring road. Beijing city developed from its center to its outside, like the water waves. This development pattern is in accordance with its ring road system.

2.4 Vegetation space variation analysis

The reflectance graph of green vegetation has some evident features, with a valley in the red band and a high peak in the near infrared band. Based on these features, various vegetation indices were developed to characterize vegetation canopies, of which normalized difference vegetation index (NDVI) was mostly used. However soil background conditions exert considerable influence on partial canopy spectra and NDVI. For this, Huete presented a soil-adjusted vegetation index (SAVI) to address this problem [5]. SAVI was expressed as followed.

\[ SAVI = \frac{NIR - red}{NIR + red + L} \times (1 + L) \]  

L is the adjustment factor. L varied with vegetation density; however, a single adjustment factor (L=0.5) was shown to reduce soil noise considerably throughout the range in vegetation densities.
NDVI was found to be more suitable for moderate vegetation density area [6]. For cities with relatively low vegetation density, SAVI was more suitable [7]. Therefore SAVI was used to extract vegetation information for the three years, then image differencing techniques were applied to obtain vegetation change map (Fig.2).

Comparing urban expansion map with the vegetation change map, we can find that urban expansion area was almost within vegetation decrease area and built-up decrease area was in the vegetation increase area. It should be noted that some of the white region in Fig.1 (no change area) corresponded to vegetation decrease area or vegetation increase area in Fig.2. Possible reason is that NDVI and SAVI were used to express vegetation information in Fig.1 and Fig.2 respectively, and SAVI was more effective for urban vegetation study.

2.5 Analysis on thermal environmental changes

From stated above, with the fast development of Beijing city, the land use and land cover have undergone a dramatic change. These changes would inevitably exert impact on its environment. In the following, firstly land surface temperature (LST) of Beijing city was retrieved with the generalized single channel algorithm, then analysis on its thermal environmental changes was made.

2.5.1 Land surface temperature retrieval with the generalized single channel algorithm

The much higher resolution (120m) Landsat5 TM thermal infrared data were seldom used to retrieve land surface temperature because it has only one thermal channel. The fact of possessing only one thermal channel is a severe limitation in order to obtain LST, it does not allow to apply a split-window method. However, the proposal of a generalized single-channel algorithm (Jiménez- and Sobrino,2003) [8] makes it practical to use Landsat5 TM data to retrieve land surface temperature. This algorithm only uses the total atmospheric water vapour content and the emissivity data. The main advantage of this algorithm compared with the other single-channel methods is that in-situ radiosoundings or effective mean atmospheric temperature values are not needed. It was used in this paper to retrieve land surface temperature. The total atmospheric water vapor content was obtained using the meteorological observation data. Emissivity data was got from the Qin's method [9]. Because the TM data were acquired in different year and under different weather conditions, the calculated temperature can not be compared directly and must be normalized. Normalization was done according to the following formula.

\[ T = \frac{t - t_{\text{min}}}{t_{\text{max}} - t_{\text{min}}} \]

Where \( t \) represents the temperature before normalization, \( t_{\text{max}} \) and \( t_{\text{min}} \) represent the maximum and minimum temperature before normalization, \( T \) represents the normalization result. \( T \) belongs to 0～1 after normalization and 0 and 1 represent the minimum and maximum temperature respectively. By doing so we can compare the \( T \) values between different years. Similarly thermal change map was obtained using the image differencing techniques (Fig.3).

From Fig.3, it can be seen that within the second ring road, it is mainly the no change area, because land surface temperature there was highest in both periods. The thermal relatively intensified areas during the two periods are both like rings, of which the second period lies outside of the first period. It should be noted that in 1987-1994, there were large thermal relatively relieved area in the outskirts. Reason for this phenomenon is that the first image was acquired on September 26th, and the others were acquired in August and in September the crop was harvested in the outskirts.

2.6 Study on relationship between urban expansion, vegetation space variation and thermal environmental changes

The interactions of urban surfaces with the atmosphere are governed by surface heat fluxes, the distribution of which is drastically modified by urbanization. Urbanization has changed city environment greatly, owing to the replacement of vegetation by asphalt and concrete and increase in population and anthropogenic heat. Comparing Fig.1, Fig.2 and Fig.3, we can find that urban expansion area corresponded well to thermal relatively intensified area and vegetation increase area corresponded to thermal relatively relieved area and no change area. Urban expansion area and thermal relatively intensified area changed similarly, both from the city center to its outside, in accordance with the ring road system of Beijing. From stated above, urban expansion and vegetation space variation impacted thermal environment evidently. In order to analyze quantitatively, the percentage of thermal condition changes in urban expansion area and vegetation increase area was given in Table 2 using GIS spatial analysis techniques.
### 3 Remarks and Conclusions

In this study, three Landsat5 TM images acquired on September 26th 1987, August 28th 1994, and August 31st 2001 separately were used to detect urban expansion, vegetation variation and their impact on thermal environment of Beijing. Bands 3-5 of TM data were normalized radiometrically with a radiometric normalization procedure based on principal component analysis (PCA). Built-up area and vegetation space information were extracted and their changes were analyzed. From 1987-1994, built-up area increased from 241.4 KM² to 338.2 KM², with the increment of about 96.8 KM² and 10.9 % of the study area. And from 1994-2001, it increased from 338.2 KM² to 487.9 KM², about 148.7 KM² and 16.7 % of the study area. Urban expansion area was almost within vegetation decrease area and built-up decrease area was in the vegetation increase area. Land surface temperature retrieved from the generalized single-channel algorithm in the three years was normalized in favor of comparison. Results revealed a notable increase in built-up area and thermal relatively intensified area during both periods. Change pattern of thermal relatively intensified area was much similar to that of the built-up area, both affected by the ring road system of Beijing. Urban expansion area corresponded well to thermal relatively intensified area and vegetation increase area corresponded to thermal relatively relieved area and no change area. Quantitative analysis based on GIS spatial analysis techniques shows urban expansion and vegetation space variation impacted thermal environment evidently. In order to improve urban thermal environment, urban growth should be designed reasonably and city greening should be improved. Although urban thermal environment was seriously affected by urban expansion and vegetation space variation, other factors still exist. Studies on other factors affecting thermal environment of Beijing will be done in the future.

Acknowledgement: This research is supported by China Remote Sensing Satellite Ground Station, Chinese Academy of Sciences innovation project (062103) and the National Natural Science Foundation of China (60272032).

### References:


### Table 2. the percentage of thermal condition changes

<table>
<thead>
<tr>
<th></th>
<th>Percentage of thermal relatively intensified area (%)</th>
<th>Percentage of thermal relatively no change area (%)</th>
<th>Percentage of thermal relatively relieved area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987–1994</td>
<td>urban expansion area</td>
<td>44.3</td>
<td>54.0</td>
</tr>
<tr>
<td></td>
<td>vegetation increase area</td>
<td>4.7</td>
<td>36.2</td>
</tr>
<tr>
<td>1994–2001</td>
<td>urban expansion area</td>
<td>54.6</td>
<td>42.1</td>
</tr>
<tr>
<td></td>
<td>vegetation increase area</td>
<td>13.2</td>
<td>71.1</td>
</tr>
</tbody>
</table>
