QUANTITATIVE ANALYSIS OF LAND SURFACE TEMPERATURE-VEGETATION INDEXES RELATIONSHIP BASED ON REMOTE SENSING

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ABSTRACT:

Vegetation coverage has a significant influence on the land surface temperature (LST) distribution. In the field of urban heat islands (UHIs) based on remote sensing, vegetation indexes are widely used to estimate the LST-vegetation relationship. However, little evaluation work has been done on the comparison of the relationship between different vegetation indexes and LST. A Landsat Thematic Mapper image was corrected for atmospheric effects. Then, the LST was calculated by utilizing a mono-window algorithm. Next, five vegetation parameters were computed respectively: Normalized difference vegetation index (NDVI), Ratio Vegetation Index (RVI), Greenness Vegetation Index (GVI), Modified Soil-Adjusted Vegetation Index (MSAVI) and the vegetation fraction (f_g). Combined with the spatial distribution of LST in Beijing, comparison and analysis were conducted to investigate the relationship between LST and five vegetation parameters. Quantitative analysis of vegetation effect on UHI was also made. Results demonstrate that among the five parameters of vegetation, f_g has the strongest correlation with LST. The average urban LST is 6.41K and 10.06K higher than the suburban and outer suburban temperature, respectively. In the urban area, the low vegetation fraction is the important contributor of the high LST.

1. INTRODUCTION

Urban heat island (UHI) as an important character of urban climate change has a significant impact on the human settlements of city. In recent years, Urban Heat Environment has become the focus of many scholars' research at home and abroad. With the further research on UHI, people find that the land surface temperature (LST) and energy balance can be affected by vegetation which changes the exchange of energy and water between land surface and air. In order to investigate the driving mechanism of UHI more deeply, increasing emphases have been placed on the research of vegetation-LST relationship.

Recently, some investigations found the relationship between NDVI and vegetation abundance to be nonlinear (Asrar et al., 1984; Small, 2001; Jiang et al., 2006). And this nonlinearity suggests that NDVI may not be a competent indicator for quantitative analyses of vegetation (Small, 2001). At present, there are two main problems in vegetation-LST relationship and UHI research: (1) the reality of urban heat island intensity may not be acquired, because the brightness temperature that observed by remote sensor was often used to instead of LST directly in many studies; (2) NDVI as an indicator of vegetation abundance is the most widely used vegetation index in UHI researches which is based on remote sensing to estimate the relationship between vegetation and LST. But the nonlinearity of NDVI suggests that NDVI may not be a good indicator for quantitative analyses of vegetation to investigate the vegetation-LST relationship. So the relationship between the LST and NDVI should be further calibrated. And seeking a more suitable and robust vegetation abundance indicator to supersede NDVI in vegetation-LST relationship study should be placed more emphasis.

This paper has two objectives. The first is to analyze the relationship between five vegetation indicators and LST. Correlation analyses were made to evaluate the correlations between LST and these vegetation parameters. The second is that the vegetation parameter which describes the distribution of LST best will be used for quantitative analysis of urban heat island in Beijing.

2. STUDY AREA AND DATA

Beijing, the capital of the People's Republic of China, locating on the north-western margin of North China plain(39°28′N∼41°05′N ,115°25′E∼117°35′E) has been chosen as the area of study (Fig.1). With the location of middle-latitude, the study area's climate is typical characteristic of diversification: hot in summer and cold in winter. In the study area, the sharp spatial disparity of vegetation results in clear contrast of coverage conditions between urban and rural.

Coming through a rapid development, Beijing has been an international metropolitan. However, many environment problems, such as UHI and pollution, were brought about by the urbanization of the city. To understand the law of UHI development, the investigation of the relationship between vegetation indicators and LST is worth more consideration.
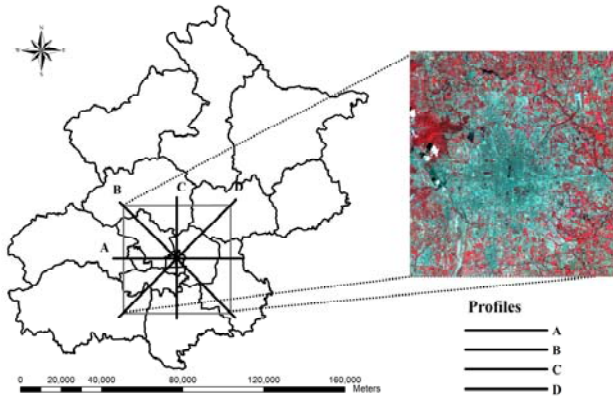

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Figure 1. Location of the study area

In this research, a Landsat Thematic Mapper image, acquired on 6 July 2004, which contains both urban and out urban areas, was processed to retrieve the LST and vegetation parameters. The data acquisition date has a highly clear atmospheric condition. Meanwhile, the traditional meteorological data observed at the time of Landsat/TM passing by the study area by the Beijing Meteorological Station was also collected.

3. METHODS

3.1 Image pre-processing

The TM image was resampled using the nearest neighbour algorithm with a pixel size of 30 by 30m for all bands. The RMSE of geometric rectification was limited to be less than 0.5 pixel.

According to formula (1) (Chander, 2003), the Top of Atmosphere (TOA) radiance was calculated. Then, the atmospheric simulation programs 6S was used to correct the atmospheric effect and compute reflectance of all band except for thermal band.

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \qquad (1)$$

where L_λ = TOA radiance
$G_{rescale}$ = gain value
Q_{cal} = digital number
$B_{rescale}$ = offset value

The brightness temperature of thermal band was computed by following formula (Chander, 2003):

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)} \qquad (2)$$

where T_B = brightness temperature
K_1 = 607.76W/m²•sr•μm
K_2 = 1260.56K

3.2 Retrieval of LST from TM imagery

Base on the thermal radiance transfer equation, the mono-window algorithm for retrieving LST from TM developed by Qin (Qin, 2001). The algorithm does not need simultaneous in situ atmospheric profile data which is usually unavailable, so it

is very useful when the situ atmospheric observation data cannot be acquired. However, using the algorithm there are three parameters were needed: emissivity, transmittance and effective mean atmospheric temperature. In this research, the following equations were used to retrieve the LST (Qin, 2001):

$$T_s = [a(1-C-D) + (b(1-C-D)+C+D)T_B - DT_a]/C \qquad (3)$$

$$C = \varepsilon\tau \qquad (4)$$

$$D = (1-\tau)[1+(1-\varepsilon)\tau] \qquad (5)$$

where T_s = land surface temperature
a = -67.355351
b = 0.458606
T_B = brightness temperature
T_a = mean atmospheric temperature
ε = land surface emissivity
τ = atmospheric transmissivity of TM thermal band

T_a can be represented by a simple relationship with near surface temperature T_0 (Qin, 2001). τ can be calculated from the atmospheric water vapour content w which can be acquired from the meteorological observation data. And ε can be estimated from NDVI (STATHOPOULOU, 2004). The relative equations are given following:

$$T_a = 16.0110 + 0.92621T_0 \qquad (6)$$

$$\tau = \begin{cases} 0.974290 - 0.08007w & (0.4 < w < 1.6) \\ 1.031412 - 0.11536w & (1.6 < w < 3.0) \end{cases} \qquad (7)$$

$$\varepsilon = \begin{cases} 0.990 & (NDVI < 0.2, NDVI > 0.5) \\ 0.004Pv + 0.986 & (0.2 \le NDVI \le 0.5) \end{cases} \qquad (8)$$

$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right]^2 \qquad (9)$$

where T_0 = near surface temperature
w = atmospheric precipitable water
$NDVI_{min}$ = 0.2
$NDVI_{max}$ = 0.5

The results of parameters sensitivity analysis demonstrate that the mono-window algorithm is insensitive to land surface emissivity, but it can be affected by the atmospheric transmissivity greatly. The average error of LST estimation could be decreased to 1.1K if the land surface emissivity and atmospheric transmissivity can be well calculated.

3.3 Vegetation abundance indicators

NDVI is the one of most widely used vegetation index, as biophysical descriptors of vegetation, for indicating the vegetation abundance. However, NDVI has not only the nonlinear relationship with other measures, such as leaf area index, but also the spatial scale dependencies. Therefore, in order to acquire a better indicator of vegetation to improve the estimation of the land surface temperature (LST)–vegetation

relationship, a further comparative investigation should be conducted.

Five vegetation abundance indicators, with wide application in the remote sensing of vegetation, are chosen to evaluate relationships between the LST and different indicators of vegetation abundance. Definitions of vegetation parameters are given in the Table 1.

Study	Definition
Rouse (1974)	$NDVI = (\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R)$
Pearson (1972)	$RVI = \rho_{NIR}/\rho_R$
Crist (1986)	$GVI = -0.2728\rho_{TM1} - 0.2174\rho_{TM2} - 0.5508\rho_{TM3}$ $+0.7221\rho_{TM4} + 0.0733\rho_{TM5} - 0.1648\rho_{TM7} - 0.7310$
Qi (1994)	$MSAVI = \rho_{NIR} + 0.5 - \sqrt{(\rho_{NIR} + 0.5)^2 - 2(\rho_{NIR} - \rho_R)}$
Gutman (1998)	$f_g = (NDVI - NDVI_s)/(NDVI_\infty - NDVI_s)$

Table 1. Definitions of Vegetation Parameters

Note: ρ_{NIR}, ρ_R,-the reflectance of near-infrared band and red band respectively; ρ_{TMi}-the reflectance of TM all band, except for TIR band; $NDVI_\infty$, $NDVI_S$-the NDVI for vegetation with infinite LAI and bare soil respectively

4. RESULTS AND DISCUSSION

Fig.2 shows the distribution of LST in Beijing, and the city's intense UHI effect can be identified clearly. The retrieval of LST ranges from 295.80 to 339.16K with a mean of 309.74K and standard deviation of 5.71k. It is evident from the map that there are four huge hot regions: Shijingshan District, the southeast region of the city (near the cross of Jingjintang Highway and Sihuan Road), the centre of the city and the large bare soil area (located in the south of the city). The forming reason of these hot regions is primarily because of sparse vegetation. Besides, the releases of urban anthropogenic heat and the shielding effect of dense buildings also contribute to the UHI.

There were also many smaller cold patches mainly caused by water and parks in the city. The development of the huge hot region was effectively blocked by water and vegetation, and meanwhile the fragmentation of urban surface temperature field was increased too. In this case, the more amount of vegetation cover the city has, the weaker the UHI effect is.

To examine the correlation between vegetation parameters and LST, four transects (profiles) were drawn to across the study area through the centre of the city, starting from the W-E profile and drawing a new transect every 45° (Fig.1). The LST and five vegetation parameters of each pixel crossed by profile was be extracted for a correlation analysis. Table 2 shows the statistical calculation of the correlation coefficients according to the category of vegetation parameter on four profiles.
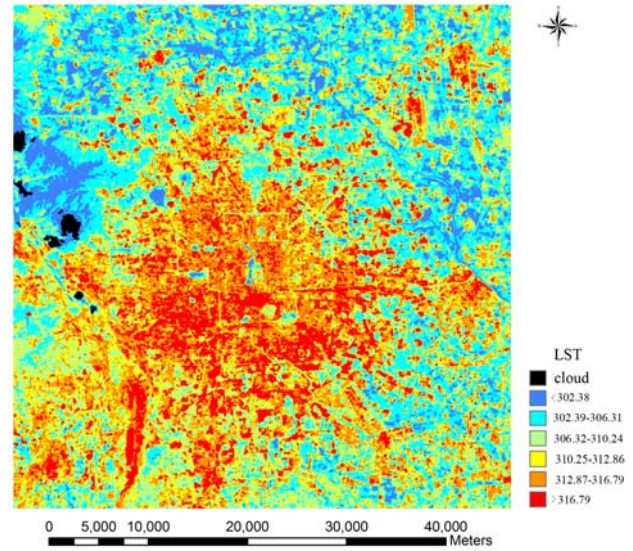

Figure 2. Geographical distribution of land surface temperature

Statistics	NDVI / LST	RVI / LST	GVI / LST	MSAVI / LST	f_g / LST
Mean	-0.764	-0.698	-0.730	-0.755	-0.780
Standard deviation	0.040	0.030	0.038	0.030	0.016
Variation coefficient (%)	5.20	4.24	5.24	3.94	2.05

Table 2. Descriptive statistics of correlation coefficients between LST and five parameters of vegetation

Since among the five vegetation parameters, f_g exhibits not only the highest mean values of correlation coefficient (-0.780), but also the least values of standard deviation (0.016) and the least values of variation coefficient (2.05%), it can be concluded that the correlation between f_g and LST is more strong and robust than other four vegetation abundance indicators. So it is possible to deeply investigate the law of spatial distribution of LST by a close analyze the relationship between LST and f_g.

It is obvious from the comparison of the distribute image of LST (Fig. 2) and f_g (Fig. 3) that the trend of LST is contrary to the trend of f_g. To further quantitatively analyze the LST-f_g relationship for well understanding the development of the urban thermal environment, three sample areas located in urban, suburban and outer suburban were chosen respectively. To be more representative, the location and area of the sample region have been given careful consideration.
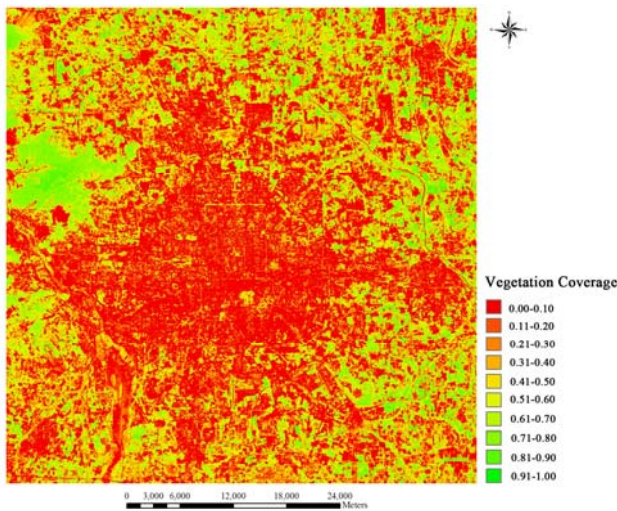
Figure 3. Geographical distribution of vegetation coverage (f_g)

The results demonstrate that the highest mean value of LST was found in the urban area (315.28K), followed by suburban (308.87K), and the lowest mean temperature of surface was given by outer suburban (305.22K). On the contrary, the urban area exhibited the least mean value of f_g (0.12), and the suburban (0.36) processed a lower f_g mean value than outer suburban (0.44). So it can be concluded that the higher the f_g a surface has, the lower the land surface temperature is. The strong correlation between LST and f_g promise a potential success for using linear regression models to predict surface temperatures if f_g values are known. The linear regression modelling result are as follow:

$$T_s = 315.699 - 17.235 f_g \qquad \left(R^2 = 0.606 \right) \qquad (10)$$

The results by F test showed that the regression equation is significant at 0.01level. When the vegetation cover rises by 0.1, the land surface temperature reduces 1.72K.

5. CONCLUSIONS

In this research, the mono-window algorithm for retrieving LST from Landsat TM was used to calculate the LST of Beijing. The LST spatial distribution shows that this city has a significant UHI effect. Five widespread vegetation parameters were computed to assess correlations between them and LST.

The results of comparison demonstrate that vegetation fraction (f_g) processes a more strong and robust negative correlation than the other four parameters. The usage of NDVI as an indicator of vegetation abundance to investigate the vegetation-LST relationship by studies based on remote sensing in the past was proved not suitable enough. The results from this study demonstrate that the average LST of urban is 6.41K and 10.06K higher than that of suburban and outer suburban respectively, in Beijing. Although many factors could contribute to the relief of UHI effect, vegetation abundance is the one of the most influential factors.

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