

Observation and forecast on urban heat island effect based on Landsat data

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Abstract. This paper studies the urban heat island (UHI) effect of Jinan city with remote sensing image based on qualitative analysis. By inverting temperature from Landsat image of Jinan city at 2002, 2009 and 2015, Jinan city's UHI effect distribution and change tendency were analysed. And then, by using the Markov chain model, the UHI effect in 2021 and the steady state distribution in Jinan were predicted.

1. Introduction

The urban heat island(UHI) effect is the phenomenon that when the city develops to a certain scale, the temperature of urban places is significantly higher than that of suburbs, because of the change of city underlying surface, air pollution and the discharge of human-made exhaust heat^[1]. There are lots of scholars using the brightness temperature data or land surface temperature (LST) data of images (such as NOAA/AVHRR, Terra (Aqua)/MODIS, Aster, etc.) to study the spatial structure and seasonal variation of the UHI in Beijing, Nanjing, Changsha, Shenyang, etc. And they have made some achievements^{[2]-[4]}. However, most researches focused on monitoring, analysing and abstracting UHI effect, but few applied a certain model to forecast the future state and steady state of the UHI, which is also very important for macro decision-making and city environment improving. Therefore, we used the temperature inversed from the thermal infrared band of Landsat data, and used the statistic of October 2009 and October 2015 to compute transition matrix and the matrix of Initial state, and then forecasted the UHI of Jinan (36 ° 40 'N, 117 ° 00 'E) in 2021. Then, we applied the theory of Markov Chain to forecast the distribution of UHI in steady state.

2. Data Processing and LST Retrieval

In this study, we chose Landsat images at October 6, 2002, October 17, 2009 and October 15, 2015 to do LST Retrieval (the details of the temperature retrieval are shown in the Reference^[5], so we won't repeat the process in this article), before which we did radiometric calibration, atmospheric correction, geometric rectification, image mosaic and image cropping.



3. Results and Analysis

To show inversion results of the UHI better, we chose mean-standard deviation to classify the inversion results to six classifications^[6], which were extra high temperature region ($T_s \geq \mu + \text{std}$), high temperature region ($\mu + 0.5\text{std} \leq T_s < \mu + \text{std}$), sub high temperature region ($\mu \leq T_s < \mu + 0.5\text{std}$), medium temperature region ($\mu - 0.5\text{std} \leq T_s < \mu$), sub medium temperature region ($\mu - \text{std} \leq T_s < \mu - 0.5\text{std}$) and low temperature region ($T_s < \mu - \text{std}$). The classification maps are shown as fig.1.

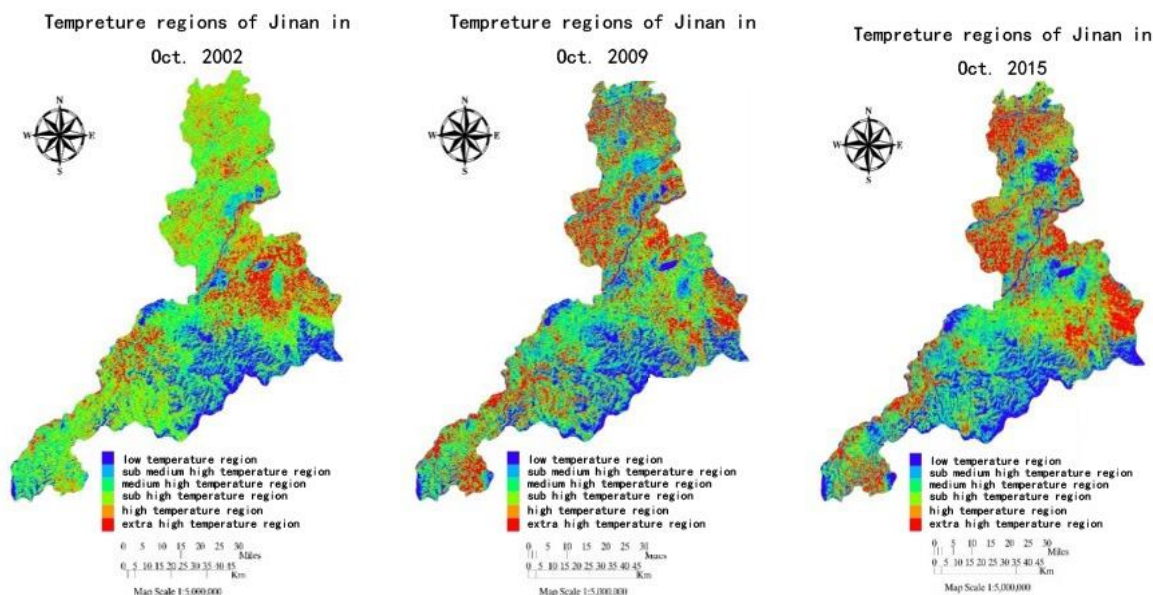


Fig.1 temperature regions of the UHI of Jinan in Aug

From the results of classification, we can figure that:

- (1) From 2002 to 2015, the UHI tended to move from the south to the north, with an increasing UHI in the north of Yellow river and a decreasing UHI in the south year by year.
- (2) The UHI tended to move to the eastern area (Licheng, Zhangqiu), where the UHI strengthening year by year.
- (3) Weak UHI appeared in medium and low temperature region such as streams, pools, lakes and southern coteau.

To further analyse the change of the UHI of Jinan in time series, we counted the area of each temperature region (details are shown in table.2). It shows that: since 2002, the area of middle region (medium temperature region, sub high temperature region) changed from 54.92% to 39.64%, and then to 37.02%, showing apparent decreasing trend; Left side region (low temperature region, sub medium temperature region) changed from 19.47% to 30.76%, and then to 31.99%, showing apparent increasing trend; Right side region (high temperature region, extra high temperature region) changed from 25.61% to 29.60%, and then to 30.99%, showing apparent increasing trend. In short, the UHI of Jinan (polarized into two opposite trend) showed apparent trend of Polarization.

4. The Trend Forecast of the UHI

The basic thought, K-step transition probability and stationary state of Markov Chain are shown in the reference^{[7],[8]}. In this study, Stationary Markov chain combined with the attributes of the UHI has numerous solutions, and it is not easy to get the proper solution by conventional methods. Therefore, we solved the Stationary Markov Chain by programming, and got satisfactory results after the gradual optimization and validation.

4.1. The performing of matrixes of state transition about each temperature region

According to the area of difference from October 2009 to October 2015, we could calculate the matrix of the transformations, as shown in table.1:

Table.1 Transition matrix of probability

K year	K+1 year					
	low temperature region	sub medium temperature region	medium temperature region	sub high temperature region	high temperature region	extra high temperature region
low temperature region	0.7003	0.2051	0.0599	0.0167	0.0087	0.0094
sub medium temperature region	0.2091	0.3894	0.2656	0.0904	0.0298	0.0158
medium temperature region	0.0701	0.2339	0.3588	0.2266	0.0801	0.0306
sub high temperature region	0.0237	0.0910	0.2395	0.3105	0.2150	0.1203
high temperature region	0.0121	0.0401	0.1378	0.2495	0.2846	0.2759
extra high temperature region	0.0071	0.0151	0.0455	0.1098	0.2245	0.5979

4.2. Analysis of the prediction result of Markov Chain

According to the Markov chain prediction model, we could get the prediction results of the UHI in 2021. And then by solving the nature of Stationary Markov chain, we obtained the temperature regions of Jinan city when the proportion of the forecast results tended to be stable. After testing, each predicted value was greater than 0, and the sum of each predicted value was 1, which meant the prediction results were reasonable.

We can get the percentages of all temperature regions in October 2009 and in October 2015, as well as the prediction results of the 2021 and the percentages of temperature regions of the steady state, as shown in table.2:

Table.2 Measured and predicted values of each temperature region (%)

	low temperature region	sub medium temperature region	medium temperature region	sub high temperature region	high temperature region	extra high temperature region
2009	13.60	17.16	20.36	19.28	11.81	17.79
2015	15.26	16.74	19.74	17.28	13.76	17.23
2021	16.27	16.65	19.26	16.93	13.71	17.19
steady state	18.53	17.11	18.82	16.19	13.03	16.32

(1) As is shown in the table 2, from the beginning of 2009, the trend of middle temperature region (including medium temperature region and sub high temperature region) is from 39.64% to 37.02% and to 36.19%, significantly decreasing year by year; The trend of left temperature region (including low temperature region and sub medium temperature region) is from 30.76% to 31.99% and to 32.92%, significantly increasing year by year; The trend of right temperature region (high temperature region and extra high temperature region) is from 29.60% to 30.99% and to 30.90 %, which has significantly increasing trend, too. To sum up, from 2009 to 2015 and then to the prediction of 2021, the UHI effect of Jinan has obvious phenomenon of polarization, which is consistent with the results of the analysis in chapter 3.

(2) From the predicted results of the stable state, the left temperature region continued to maintain a growth of 35.64%, and there was a growth of 2.72% compared with 2019; The medium temperature region and sub high temperature region continued to decrease, having a total reduction of 1.78%. It is noteworthy that, from the beginning of 2002, the strong heat island region (the right temperature region) in 2015 (30.99%) was the cut-off point, and by contract, there were different reductions for 2021 (30.90%) and the stable state (29.35%).

By analysis above, it is concluded that the strengthening trend of the UHI effect has somewhat eased after 2009. And the proportion of each temperature region tends to be stable. Which indicates that the Jinan municipal government's policies (Eastern Expansion, Western development, Southern regulation,

northern span and central relief) is effective. While maintaining the current artificial and natural disturbing condition, after several years of Jinan city, the strong heat island tends to be stable, which maintained at around 29.35%. However, although there is no worsening trend, the ratio of the extra high temperature region still reached 16.32%, and the heat island effect is still serious, too.

5. Conclusions

The main conclusions of this study are as follows:

- (1) According to the analysis of interannual variation, the UHI effect of Jinan has obvious moving trend from the south to the north, and the regional UHI effect becomes more and more serious in the areas of the north of the Yellow River from 2002 to 2015.
- (2) According to the analysis of the UHI of Jinan from 2002 to 2015, it is found that the UHI effect is not simply increasing year by year, but from the middle temperature region (medium temperature region and sub high temperature region) to two other temperature regions (low temperature region and sub medium temperature region, high temperature region and extra high temperature region). In other words, it is polarizing obviously.
- (3) As is shown in the spatial distribution, the UHI effect is closely related to the underlying surface, which shows that the urban land and the bare land are obvious high temperature areas. And water and green land are obvious low temperature regions, that is to say cooling effect is remarkable.
- (4) According to the prediction results, while maintaining the current artificial and natural disturbing condition, it shows that the UHI effect has polarized phenomenon in 2021, which keeps the characteristics of the UHI effect of Jinan in time series, and this shows that the Markov chain has a certain reliability for the research of the UHI. Through the steady-state prediction results, it can be found that the UHI effect worsening trend has significantly eased, but still at a high level. Therefore, the government departments should make more effective policies to strengthen law enforcement to ease the impact and the harm brought by the UHI.

Acknowledgments

This research was sponsored by the National Science-technology Support Plan Project of China (Grant Nos. 2015BAJ02B00) and the Special Foundation of the Chief of the Institute of the Remote Sensing and Digital Earth, Chinese Academy of Sciences (Grant Nos. Y6SJ2800CX)

References

- [1] PENG Shao-lin, ZHOU Kai, YE You-hual, SU Juan, et al. Research progress in urban heat island [J]. Ecology and Environment, 2005, 14(4): 574-279.
- [2] YAN Hao, DENG Lian-tang. Character Analysis Of Heat Island In Shanghai City Using Remote Sensing Parameters [J]. Journal of Tropical Meteorology, 2004, 20(5): 579-585.
- [3] Li Le, Xu Hanqiu. Urban Expansion and Thermal Environment Changes in Hangzhou City of East China [J]. Remote Sensing Technology and Application, 2014, 29(2): 264-272.
- [4] ZHANG Xinyi. RS and GIS-based research on Shanghai land use/cover change with respect to thermal Environmental effect [D], East China Normal University, 2006.
- [5] You Chengzeng, Yang Xinyuan Shu An, Peng Ling, Li Xiang. Analysis and estimation on Urban Heat Island Effect Based on Landsat Data [J]. Environmental Engineering, 2016, S1: 1145-1150+1158.
- [6] ZHANG Dianjiang, ZHOU Bin, LI Hongwe, WANG Xiao-tang, SI Min. Prediction of Urban Heat Island Expansion Based on Markov Chain Theory [J]. China Population, Resources and Environment, 2013, S2: 321-325.
- [7] Qian Mingping, Qian Min. THE DECOMPOSITION INTO A DETAILED BALANCE PART AND A CIRCULATION PART OF AN IRREVERSIBLE STATIONARY MARKOV CHAIN [J]. Science in China, Ser. A, 1979, S1: 69-79.
- [8] The Stationary Distribution of Markov Chains in Random Environments [J]. Chinese Journal of Applied Probability and Statistics, 2012, 04: 337-344.