



PREDICTION AND ANALYSIS OF URBAN HEAT ISLAND EFFECT IN DANGSHAN BY REMOTE SENSING

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Abstract- Vegetation index (NDVI) was extracted from bi-temporal multispectral images based on the data obtained from Landsat ETM⁺ on 14th, September, 2000 , Landsat ETM⁺ on 9th, September, 2004 , Landsat ETM⁺ on 15th, May, 2008 and Landsat-8 on 21st, May 2013 for Dangshan County in Anhui Province. Analysis and data extraction was carried out using the ENVI 5.0 software. Normalized values of thermal radiation brightness temperature and surface brightness temperature were inverted from the bi-temporal thermal infrared band images using the mono-window algorithm. Urban heat island effect in Dangshan County was divided into strong green island zone, green island zone, normal zone, heat island zone and strong heat island zone according based on arithmetic progression. Using regression analysis, quantitative relationship between NDVI and the heat island effect was determined. Results showed an acceleration in urbanization of Dangshan County over the years resulted in a gradual increase in the heat island effect from 2000 to 2013. In addition, area of the heat island and strong heat island increased was observed to increase rapidly, while the area of the green island and strong green island reduced by 46%. Also, using the Markov model, urban heat island effect in Dangshan County was predicted over the next 40 years. This model was feasible in predicting the urban heat island effect with small errors. Finally, it was determine that heat island effect was in negative correlation to the vegetation index (NDVI), and increasing green land appropriately would have a positive effect in alleviating the urban heat island effect.

Index terms: Urban heat island effect, remote sensing, Markov prediction, Landsat 8, Dangshan.

I. INTRODUCTION

With the increasing rate of urbanization over the recent years, urban heat island effect, where the temperatures are significantly higher in comparison to the surrounding rural areas has become increasingly common phenomenon [1-3]. Socio-economic development, air quality, public health and living environment are affected to the higher temperatures [1-3]. As a result, research on urban heat island effect has gained momentum and has received considerable attention [1-3]. Traditional methods of research rely on analysis of observed temperature data provided by the ground weather stations; However, solely based on this data it is difficult to understand spatial distribution for the urban heat island [1-5].

Alternatively, remote sensing technology can be used to map the spatial temperature distribution for an urban environment. This method allows for fast, accurate, real-time, efficient, and short cycle monitoring of the urban heat island effect. Due to the unique advantages of this method, it has become the primary method in the study of the urban heat island effect [6-8]. The combined use of thermal infrared image and remote sensing technology is popular among researchers worldwide conducting research on the urban remote sensing particularly focused on the study of heat island effect. In 1972, Rao [9] first demonstrated the use of satellite remote sensing images to study the urban heat island effect. Carnahan and Larson [10] used the Landsat TM thermal infrared band images to study surface temperature characteristics for Indianapolis. Tran et al. [11] used Modis and TM data to analyze thermal field images for Tokyo, Beijing, Shanghai, Seoul, Pyongyang, Bangkok, Manila and Ho Chi Minh. Zhou et al. [12] analyzed the distribution regularity of the urban thermal field in Shanghai using remote sensing and geographic information systems (GIS). Zhao [13] monitored and analyzed heat island effect for Kunming, China using the remote sensing images. Qin et al. [14] proposed a novel single window algorithm for surface temperature used images from TM6 to invert surface temperature.

Over the recent years, research efforts in China have focused on urban heat island effect for large cities such as Beijing, Xi'an, Chongqing, Suzhou, Changsha, Zhengzhou, Hefei, Dongying, and Xuzhou [15-23]. In these cases, prefecture-level and above was selected as the study area for the cities. It is important to note that very few reports in literature focus on the heat island effect of the entire County. Moreover, a majority of the data used in these studies were based on Landsat

TM / ETM⁺ images. Landsat 8 satellite was launched in February 2013, and little to no research has focused on combining Landsat ETM⁺ with Landsat 8 data to study urban heat island effect. In the case of previous studies, normalized difference vegetation index (NDVI) was extracted from bi-temporal multispectral images for Dangshan, China using the software package ENVI5.0 (*Exelis Visual Information Solutions*). Normalized values for thermal radiation brightness temperature and surface brightness temperature were inverted from bi-temporal thermal infrared band images using a mono-window algorithm method. According to the arithmetic progression, urban heat island effect in Dangshan County can be divided into five categories: strong green island zone, green island zone, normal zone, heat island zone and strong heat island zone. Based on this classification, urban heat island effect in Dangshan County was predicted for the next 40 years using the Markov model. Quantitative relationship between the NDVI and the heat island effect was determined using regression analysis. Results from this study enable positive impact to the urban environment, while simultaneously acting as a reference to allow improvement to the ecological environment of Dangshan County. Moreover, the data allows for improvement in living conditions in the County and can be used as a guide for other counties in the northern region of Anhui Province.

II. SUMMARY OF THE STUDY AREA AND DATA PROCESSING

A. Summary of the study area

Dangshan County is located at latitude 34°16'~34°39', longitude 116°29'~116°38', at the junction of Anhui, Jiangsu, Shandong and Henan provinces. The term elevation above sea level is a flat, central slightly higher, north and south slightly low. It has in its jurisdiction, 13 towns and two parks, with a total area of 1193 square kilometers. Several rivers flow through the County including the Yellow River, Grand River, Fuxin River, Limin River, Ba QingRiver, DongHong River and Wenjia River. Area under study in this article includes the built-up area and parts of the surrounding suburbs in Dangshan County, with a total area for 198 square kilometers.

B. Data sources and processing

Remote sensing images captured on September 14, 2000, September 9, 2004, May 15, 2008 using Landsat ETM⁺ and on May 21, 2013 using Landsat 8 are the data sources. Track number is 122-36, images cloudiness is 0%. Atmospheric correction and calibration processing were

separately applied to the images obtained in 2000, 2004, 2008 and 2013, including multi-spectral and thermal infrared band images in ENVI5.0. Image map projection to UTM for the images obtained in 2000, 2004, 2008, with number zone as 50, coordinate system were changed to WGS-84 with the image rotated clockwise by 10.24 degrees. Next, images for 2000, 2004, 2008 were geometrically registered based on the 2013 image. Following this, 20 control points were selected. RMS Error between the four was controlled to less than 0.2 pixels. Finally, the four images were cropped to center the built up area of Dangshan County. The final image size was 550 pixels by 400 pixels with a spatial resolution of 30 m. Figure 1 shows the final cropped and centered images.

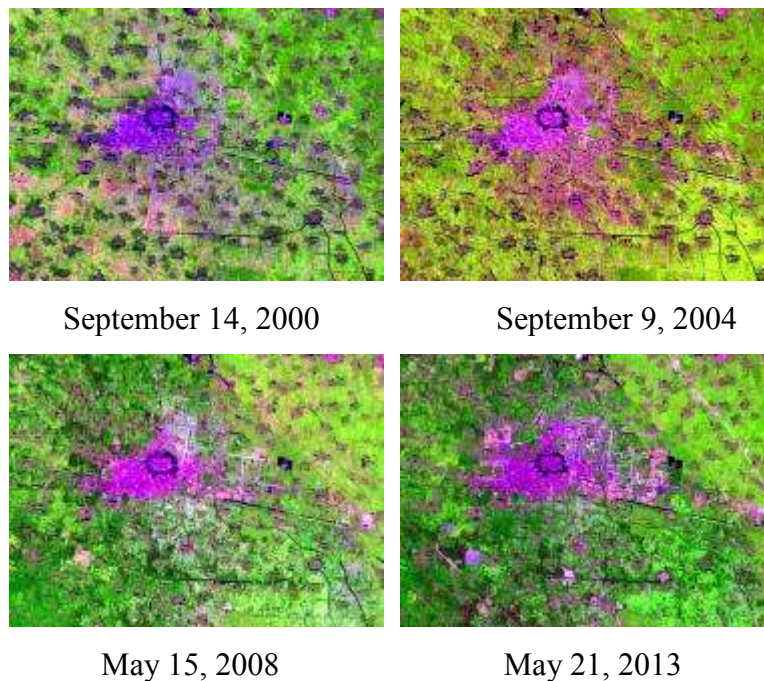


Figure 1. Bi-temporal images of the study area

C. Brightness temperature inversion

Previous research reported in literature related to the study of urban heat island effect used thermal infrared remote sensing images as the data source. In these cases, brightness temperature and surface temperature were inverted from the bi-temporal thermal infrared band images using the mono-window algorithm and single channel algorithm. Brightness temperature was calculated based on calibration parameters of the satellite sensor and the Planck equation. The parameters available include comprehensive reflection of the surface temperature, atmospheric temperature, atmospheric transmittance and surface emissivity. Based on these parameters, surface temperature can be calculated from brightness temperature after atmospheric correction and

emissivity calculation. The calculated results and the actual surface temperature are the same. This is because, inversion process of surface temperature can be largely influenced by many factors, such as atmosphere and surface emissivity. Calculation of the relevant parameters is not trivial and the accuracy cannot be guaranteed. Although, magnitude of surface temperature and brightness temperature were not equal, correlation between the two parameters was high. Moreover, brightness temperature contains more relevant information related to the atmosphere than the surface temperature. As a result, spatial distribution of the brightness temperature fits spatial distribution of the surface temperature and can be effectively used to reflect the heat island effect [19-20]. In this paper, only brightness temperature was inverted as it follows a similar trend of the real surface temperature. Inversion for brightness temperature is carried out according to eq.(1), which is provided by the Landsat official website. Gray value data numbers (DN) for band 6 of the Landsat ETM⁺ (band 10 or 11 for Landsat 8) image correspond to a brightness value of L. Then, according to the eq.(2) illustrates the inversion of corresponding brightness temperature from thermal radiation brightness value [19,25,27].

$$L = G_{\text{ain}} \cdot \text{DN} + B_{\text{ias}} \quad (1)$$

$$T_B = K_2 / \ln(1 + K_1/L) \quad (2)$$

Where, L is thermal radiation brightness ($\text{W}/(\text{m}^2 \cdot \text{sr} \cdot \mu\text{m})$), DN is the pixel gray value, G_{ain} is the gain value, B_{ias} is the offset value, T_B is brightness temperature (K), K_1 is brightness inversion constant ($\text{W} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \mu\text{m}^{-1}$), K_2 is brightness inversion constant (K). Thermal infrared band parameters of the Landsat ETM⁺ and Landsat 8 from the Landsat official website and metadata files of Landsat 8 are listed in table 1.

Table 1: Thermal infrared band parameters for Landsat ETM⁺ and Landsat 8

Parameters	Landsat ETM ⁺	Landsat 8	
		Band 10	Band 11
G_{ain}	0.037	3.3420E-04	3.3420E-04
B_{ias}	3.200	0.1	0.1
K_1	666.09	774.89	480.89
K_2	1282.71	1321.08	1201.14

Brightness temperature histogram for Dangshan County in 2000, 2004, 2008 and 2013 was

obtained using eq. (1) and eq.(2). The thermal infrared band images in 2000, 2004 and 2008 were the sixth band of the Landsat ETM⁺, while the thermal infrared band image for 2013 was the tenth band of the Landsat 8, shown in fig. 2. It can be seen from fig. 2 that the high temperature zone of the brightness temperature in Dangshan was mainly concentrated on the built-up area and low temperature zone was mainly seen in the suburbs. Brightness temperature in built-up areas was significantly higher than the surrounding suburbs. As a result, urban heat island effect seen here was significant.

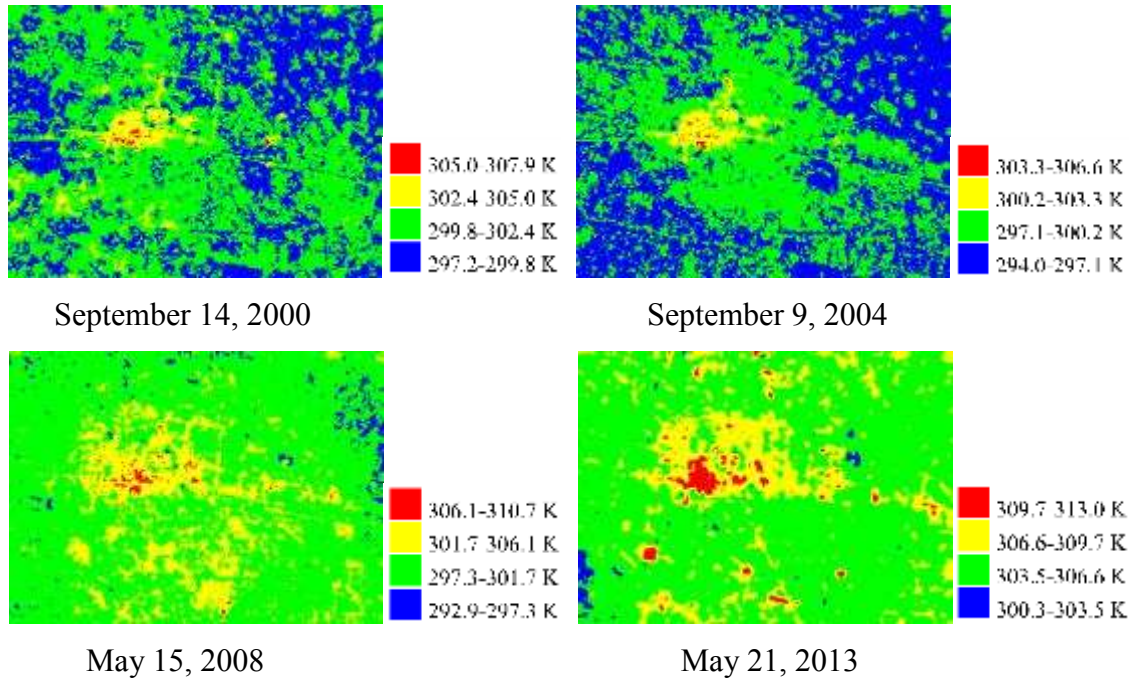


Figure 2. Brightness temperature histogram for Dangshan County

D. Normalization process for brightness temperature.

The conclusions of this would not be valid, if the urban heat island effect is directly contrasted based on data obtained using inversion brightness temperature as the four images obtained at different times. Brightness temperature normalized between 0 and 1 to eliminate the impact of the imaging time and make the heat island effect more comparable. Brightness temperature was normalization is given by [24]:

$$N = \frac{T_i - T_{\min}}{T_{\max} - T_{\min}} \quad (3)$$

Where, N is the i-th pixel normalization value of the brightness temperature for the thermal infrared band image, T_i is brightness temperature of the i-th pixel, $T_{\min}$ is minimum value of the

brightness temperature and $T_{\max}$ is maximum brightness temperature. According to the value of N , the heat island effect can be divide subdivide into five distinct zones [24]: strong heat island zone (0.8~1.0), heat island zone (0.6~ 0.8), normal zone (0.4~ 0.6), green island zone (0.2~ 0.4) and strong green island zone (0~0.2). From eq. (3), brightness temperature normalization was carried out for the 6th band of Landsat ETM⁺ and 10th band of Landsat 8. According to the value of N , heat island effect level histogram of Dangshan County was obtained and results are shown in fig. 3.

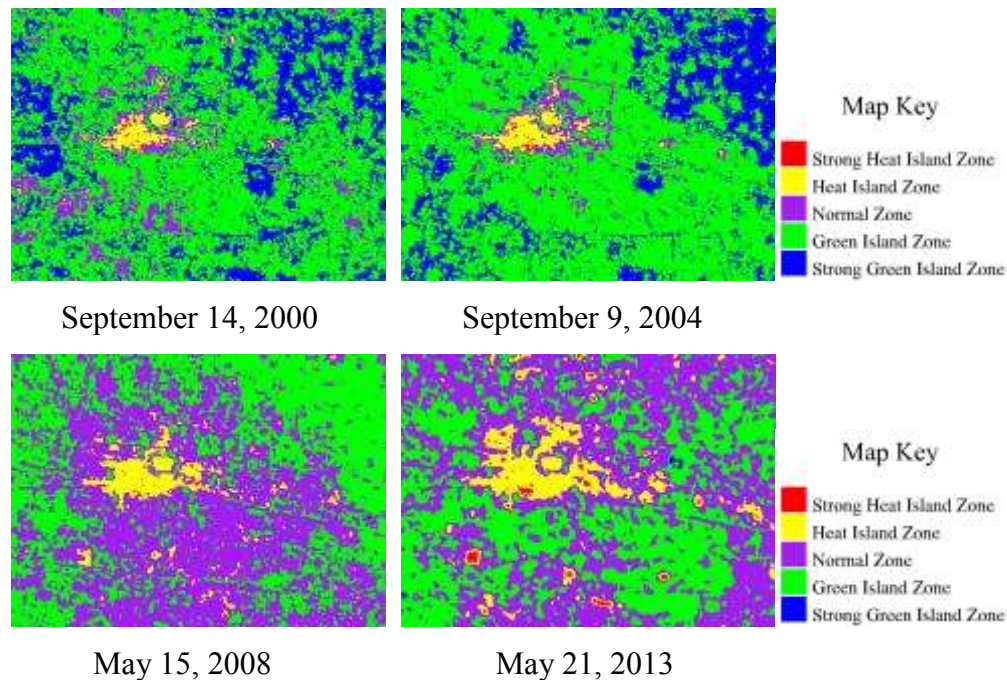


Figure 3. Heat island effect level histogram for Dangshan County

III. ANALYSIS OF URBAN HEAT ISLAND EFFECT IN DANGSHAN COUNTY

A. Spatial characteristics analysis of the heat island effect

Fig. 2 and Fig. 3 show spatial distribution of urban heat island. With acceleration of urbanization, the urban heat island phenomenon can be clearly seen in Dangshan County. Temperature of the Dangshan County in 2000, 2004, 2008 and 2013 was significantly higher than the surrounding suburbs. An expansion trend of the heat island was clearly strengthened, primarily in the northeast, southeast and northwest direction. The heat island zone was observed to be mainly distributed in the main urban zone and surrounding towns. All high-temperature zones appeared in residential areas, this indicates the performance characteristics of the urban heat island. The green island zone and strong green island zone were observed in regions with high vegetation

cover or over a water body. Normal zone was observed in in peri-urban region, covered by vegetation and low residential population density regions. The strong heat island zone was located in Dongcheng district, Xicheng district and surrounding towns, which were surrounded by the heat island zone.

B. Temporal characteristics analysis of the heat island effect

Based on the value of N , normalized brightness temperature for the 6th band of Landsat ETM⁺ and the 10th band of Landsat 8 were divided into five levels. Output from image classification of the density segmentation results were used to determine areas for the different heat island classification zones. Results are shown in table 2. From fig. 3 and table 2 it can be seen that in the year 2000, area of strong heat island zone and heat island zone in Dangshan were 0.1km² and 3.51km² respectively. This accounted for 0.05% and 1.78% of the total area. Area of the strong green island zone and green island zone were 45.6 km² and 127.12 km², which accounted for 23.03% and 64.2% of the total area. In 2004, area of strong heat island zone and heat island zone were 0.15 km² and 3.88 km², accounting for 0.08% and 1.96% of the total area. Whereas, area of strong green island zone and green island zone were 42.93 km² and 141.34 km², which accounted for 21.68% and 71.38% of the total area. In 2008, area of strong heat island zone and heat island zone were 0.17 km² and 9.27 km², accounting for 0.09% and 4.68% of the total area. Whereas, area of strong green island zone and green island zone were 0.21 km² and 86.97 km², which accounted for 0.11% and 43.93% of the total area. In 2013, area of strong heat island zone and heat island zone were 0.99 km² and 15.6 km², accounting for 0.5% and 7.88% of the total area. Whereas, area of strong green island zone and green island zone were 0.3 km² and 81.78 km², which accounted for 0.15% and 41.30% of the total area. With acceleration in urbanization in Dangshan County from 2000 to 2013, the urban heat island effect has become more prominent and obvious. Area of the heat island zone and the strong heat island zone were found to have increased. A huger reduction in area of up to 46% was seen for areas of the green island zone and strong green island zones.

Table 2: Area changes in heat island effect level zones in 2000~2013 for Dangshan County

Grade	Area km ²				Ratio %			
	2000	2004	2008	2013	2000	2004	2008	2013
strong heat island zone	0.10	0.15	0.17	0.99	0.05	0.08	0.09	0.50

heat island zone	3.51	3.88	9.27	15.60	1.78	1.96	4.68	7.88
normal zone	21.67	9.70	101.38	99.33	10.94	4.90	51.20	50.17
green island zone	127.12	141.34	86.97	81.78	64.20	71.38	43.93	41.30
strong green island zone	45.60	42.93	0.21	0.30	23.03	21.68	0.11	0.15

C. Quantitative analysis of heat island effect and vegetation index

Normalized difference vegetation index (NDVI) is an indicator used to reflect status of the vegetation growth. It is also an important parameter to reflect vegetation coverage. The value for NDVI ranges between -1 and 1. A larger value for NDVI indicates larger for vegetation coverage. NDVI extraction function in ENVI software was used to extract NDVI from the four-phase multi-spectral images of 2000, 2004, 2008 and 2013. Results are shown in fig. 4. It can be seen from fig. 4 that the built-up area in Dangshan County is dark, indicating that NDVI value is small, and vegetation coverage is low. Alternatively, for the suburbs NDVI value was large indicating that vegetation coverage is comparatively higher. Simultaneously, brightness temperature and NDVI of the four phase image was sampled at random using regression analysis and results are shown in fig. 5.

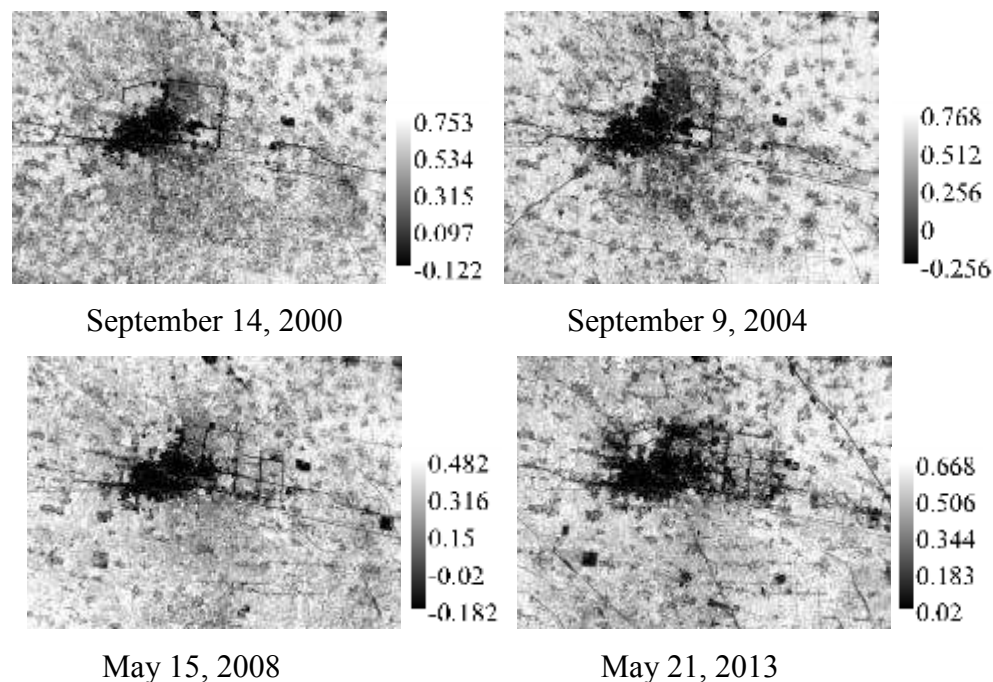


Figure 4. NDVI histogram for Dangshan County

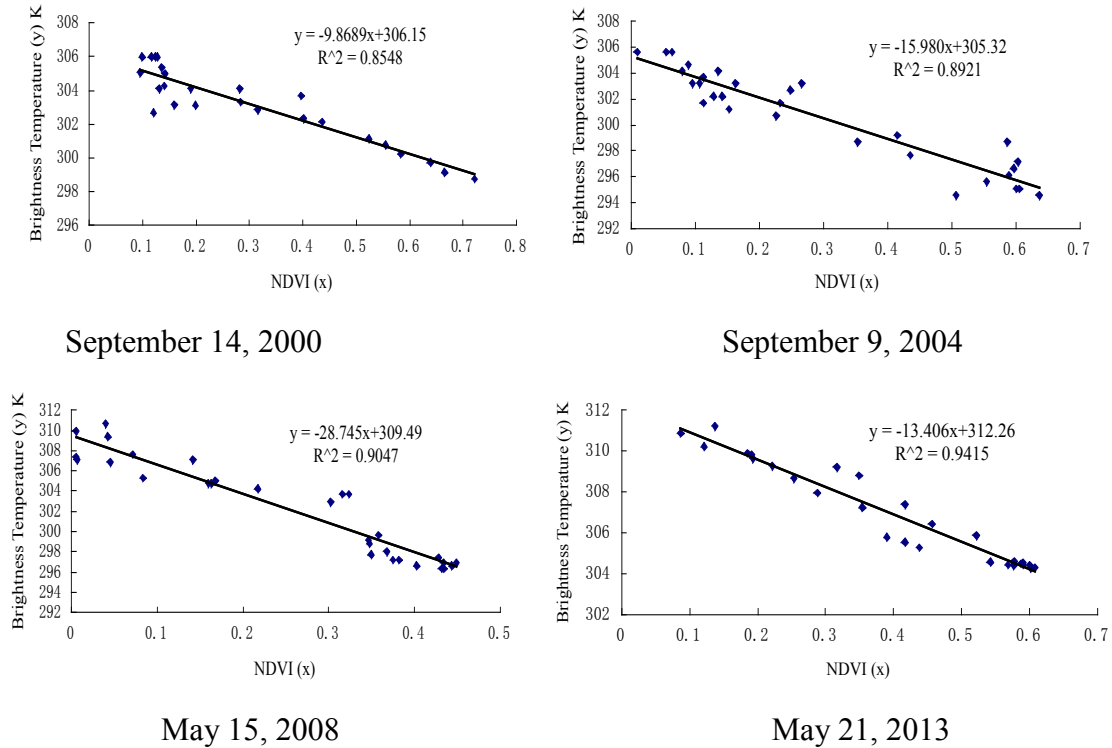


Figure 5. Correlation of the brightness temperature and NDVI for Dangshan County

Fig. 5 is not a true representation of the relationship between surface temperature and vegetation index. However, it reflects an approximately relationship between vegetation index and heat island effect. It can be seen from fig. 5 that vegetation index was negatively correlated with heat island intensity. An increase of the vegetation index was correlated to a decrease in brightness temperature, and a gradual weakening of the heat island effect was also seen. In 2000, for a 0.1 increase in vegetation index of the Dangshan County, the brightness temperature decreased by 0.99 K. In 2004, for a 0.1 increase in vegetation index, the brightness temperature decreased by 1.60 K. In 2008, for a 0.1 increase in vegetation index, the brightness temperature decreased by 2.87 K. Whereas, in 2013, for a 0.1 increase in vegetation index, the brightness temperature decreased by 1.34 K. This implies that the vegetation positively influenced in the suppression of the urban heat island effect.

IV. PREDICTION OF HEAT ISLAND EFFECT BASED ON MARKOV MODEL

Markov model is a random and time-series prediction model, which is based on probability

[26,28], and can be expressed as:

$$S^{(k+1)} = S^{(k)}P = S^{(0)}P^{(k+1)} \quad (4)$$

Where, $S^{(k)}$ is the state quantity of the prediction object at time $t=k$, P is the transition probability matrix, $S^{(k+1)}$ is the state quantity of the prediction object at time $t=k+1$ (generally refers to the prediction results). This model has been widely used in geosciences, especially in the land-use change and urban expansion, but has been rarely used in the heat island effect analysis. After normalizing brightness temperature for the 6th band of Landsat ETM⁺ and 10th band of Landsat 8 and taking into account density segmentation value for values of N , image classification output for the density segmentation results were obtained. Change monitoring function in ENVI 5.0 software was used to analyze the transfer matrix and transition probability matrix of the two-phase heat island effect level zone areas in 2000 and 2013. Results are shown in table 3 and table 4. Based on the data for the urban heat island effect in Dangshan County in 2000 (table 3), Matlab 7.0 was used to simulate the Markov formula for a step size $n=13$; $k=1, 2, 3$ and 4. Value for $S(0) = [0.11 \quad 3.51 \quad 21.67 \quad 127.12 \quad 45.6]$ and using the data from table 4, heat island effect of Dangshan County was predicted for the years 2013, 2026, 2039, 2052 and prediction results are shown in table 5.

Table 3: Transformation area of the heat island effect in Dangshan during 2000-2013 (km²)

2000	2013				
	Strong heat island zone	Heat island zone	Normal zone	Green island zone	Strong green island zone
strong heat island zone	0.02	0.08	0.01	0.00	0
heat island zone	0.18	2.86	0.33	0.14	0
normal zone	0.24	4.88	10.53	6.0	0.02
green island zone	0.49	6.83	66.71	52.94	0.15
strong green island zone	0.07	0.95	21.75	22.70	0.13

Table 4: Area transition probability matrix of the heat island effect in Dangshan during 2000-2013

2000	2013				
	Strong heat island zone	Heat island zone	Normal zone	Green island zone	Strong green island zone
strong heat island zone	0.182	0.727	0.091	0.000	0.000
heat island zone	0.051	0.815	0.094	0.040	0.000
normal zone	0.011	0.225	0.486	0.277	0.001
green island zone	0.004	0.054	0.525	0.416	0.001
strong green island zone	0.002	0.021	0.477	0.498	0.003

Table 5: Area prediction of the heat island effect in Dangshan during 2013-2052 km²

Heat island effect level	2013	2026	2039	2052
strong heat island zone	1.04	2.41	3.76	4.8
heat island zone	15.64	40.28	58.85	72.02
normal zone	99.36	92.9	81.94	73.78
green island zone	81.73	62.29	53.35	47.32
strong green island zone	0.29	0.18	0.16	0.14

It can be seen from table 5, for years ranging from 2013 to 2052, the strong heat island zone area and the heat island zone area in Dangshan County would increase every year, the strong heat island zone area of Dangshan County in 2026, 2039 and 2052 is 2.41 km², 3.76 km² and 4.8 km² respectively, the heat island zone area in 2026, 2039 and 2052 is 40.28 km², 58.85 km² and 72.02 km² respectively. Due to this it is important to take effective measures to reduce the urban heat island effect, and improve the local living environment. Area of the normal zone, green island zone and strong green island zone is predicted to decrease every year, the normal zone area of Dangshan County in 2026, 2039 and 2052 is 92.9 km², 81.94 km² and 73.78 km² respectively, the green island area in 2026, 2039 and 2052 is 62.29 km², 53.35 km² and 47.32 km² respectively, the strong green island area in 2026, 2039 and 2052 is 0.18 km², 0.16 km² and 0.14 km² respectively.

To verify the applicability of the Markov model to the study of urban heat island effect, data of the urban heat island effect in Dangshan County for the year 2000 was set as the initial state,

namely: $S(0) = [0.11 \quad 3.51 \quad 21.67 \quad 127.12 \quad 45.6]$. Heat island effect was predicted for the year 2013 and results are shown in table 6.

Table 6: Heat island effect area comparison of the monitoring and prediction in Dangshan in 2013 km²

2013	Strong heat island zone	Heat island zone	Normal zone	Ggreen island zone	Strong green island zone
monitoring value	0.99	15.6	99.33	81.78	0.3
prediction value	1.04	15.64	99.36	81.73	0.29
D-value	-0.05	-0.04	-0.03	0.05	0.01

It can be seen from table 6, that the Markov model can be used to predict the urban heat island effect for Dangshan County for the year 2013. D-value for the predicted results and remote sensing dynamic monitoring results were small with a maximum difference of 0.05 km², both highly consistent. As a result, it can be concluded that the Markov model can be considered to be feasible to predict urban heat island effect.

V. CONCLUSIONS

Brightness temperature for built-up area in Dangshan County was found to be significantly higher in comparison to the surrounding suburbs. As a result, it can be concluded that a significant urban heat island effect exists for Dangshan County. Due to the acceleration in urbanization of Dangshan County from 2000 to 2013, the urban heat island effect had become obvious, with the area of the heat island zone and strong heat island zone having expanded rapidly. The heat island zone was observed to be mainly distributed in the main urban zone and surrounding towns. All high-temperature zones appeared in residential areas, this indicates the performance characteristics of the urban heat island. The strong heat island zone was located in Dongcheng district, Xicheng district and surrounding towns, which were surrounded by the heat island zone. From 2000 to 2013, the green island zone and strong green island zone saw a 46% reduction in area, the green island zone and strong green island zone were observed in regions with high vegetation cover or over a water body. For a 0.1 increase in vegetation index of the

Dangshan County in 2000, 2004, 2008 and 2013, the brightness temperature decreased by 0.99 K, 1.60 K, 2.87 K and 1.34 K respectively. Based on the observed results, it was determined that vegetation index was negatively correlated with the heat island intensity. Increase in vegetation index resulted in a decrease in brightness temperature and a gradual weakening of the heat island effect.

The Markov model could be considered to be feasible to predict urban heat island effect, the Markov model was used to accurately predict urban heat island effect with low error and results were found close to the actual monitored value. The urban heat island effect in Dangshan County was predicted over the next 40 years by the Markov model, the prediction results show that the area of the normal zone, green island zone and strong green island zone in Dangshan County from 2013 to 2052 would decrease every year. Area of strong heat island zone and heat island zone will increase every year. As a result, it has become increasingly important to take effective measures to reduce the urban heat island effect.

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