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Research on surface temperature inversion and spatio-temporal distribution characteristics based on Landsat data

Shuang Wu [1], Chao Zhang [2][3],[*], Zhen Yang [4], Yanni Rong [1], Yuxia Wang [1]

[1] School of Land Resources and Surveying, Shandong Agriculture and Engineering University, Jinan.250000, P.R. China

[2] School of Civil Engineering, Shandong Jiaotong University, Jinan.250000, P.R. China

[3] College of Geography and Environment, Shandong Normal University, Jinan. 250000, P.R. China

[4] Shandong Lu Bang Geographic Information Engineering Limited Company, Jinan.250000, P.R. China

*Corresponding author e-mail:naonao81@126.com

Abstract: With the rapid development of urban scale and the rapid expansion of urban population, the urban heat island effect caused by the rapid increase of urban anthropogenic heat emissions has gradually become an important factor that seriously affects urban living environment and residents' health. This study uses the Landsat TM5 and Landsat 8OLI_TIRS remote sensing data from 2000, 2006, 2013 and 2018 to calculate the surface temperature of the main urban area of Jinan, and the spatial distribution characteristics and thermal environment of the heat island in the main urban area of Jinan. Quantitative research on the relationship with natural vegetation, provide some data support for alleviating the urban heat island phenomenon in Jinan, promote ecological environment construction, and make scientific and rational planning for the future urban development of Jinan City.

Key words: Urban heat island effect Surface temperature inversion Temporal and spatial distribution characteristics.

1. Introduction

As the core content of economic, political and cultural development, the city has made positive contributions to the rapid development of society. The acceleration of the urbanization process has had a tremendous impact on the city's environment and climate. As one of the many urban environmental problems, the urban heat island effect has attracted more and more attention from all walks of life. Urban heat island phenomenon leads to the decline of urban air quality, urban climate comfort is worse, urban ecological environment quality is reduced, causing great troubles for urban residents' lives. The study of urban heat island effect has become an important issue in urban climate, regional climate and urban environment research. . Based on multi-source remote sensing data, this paper quantitatively studies the spatial distribution characteristics of the heat island in Jinan City and the relationship between thermal environment and natural vegetation, in order to study the root cause of the urban heat island effect in the

main urban area of Jinan, in order to alleviate Jinan City. The problem of urban heat islands will contribute to the construction of Jinan urban ecological environment, and provide data basis for the urban construction planning work of Jinan North Cross and old and new kinetic energy conversion.

2. Data source and research area overview

2.1. Data source
The image data of the study area selected in this study has less cloud amount and better quality, which satisfies the research conditions. In addition, Jinan City administrative division vector data, atmospheric profile parameters, and some meteorological data were collected.

Table 1. Description of remote sensing data sources

Data type	Projection system	Path	Row	Imaging time
LandsatTM5	WGS84	122	35	2000/5/1 2:23:57
LandsatTM5	WGS84	122	35	2006/5/2 2:40:27
Landsat8OLI_TIRS	WGS84	122	35	2013/5/21 2:50:33
Landsat8OLI_TIRS	WGS84	122	35	2018/5/3 2:47:17

2.2. Overview of the study area
Jinan City is located at the junction of the low mountain hills of Luzhong and the northwest of the alluvial plains of northwest. The north is near the Yellow River and the south is hilly and mountainous. The terrain is high in the south and low in the north. Jinan City is located in the middle latitude area, with an annual average temperature of 13.8 ° C, a frost-free period of 178 days, a maximum temperature of 42.5 ° C, and a minimum temperature of minus 19.7 ° C. In 2000, the urban population of Jinan City was 2,998,800. In 2018, the urban population was 3,625,700, an increase of 17.26%.

3. Research content and technical route

3.1. Research content
(1) Through the four-phase image data of Jinan City, the radiation temperature equation algorithm (atmospheric correction method) is used to perform surface temperature inversion, and the results of inversion are compared to analyze the spatial distribution and variation characteristics of urban heat islands in Jinan.

   (2) Remote sensing supervision and classification of the main land types in Jinan City, and the classification results are compared with the inversion results of Jinan city surface temperature to obtain the relationship between the land type and the thermal environment.

   (3) By comparing the surface temperature inversion in Jinan and the distribution of main land types on the ground, summarizing the spatial distribution and variation characteristics of heat islands in Jinan, and catering to the north span of Jinan and the new and old kinetic energy conversion strategy, the future city of Jinan Development to make planning recommendations.

3.2. Technical route
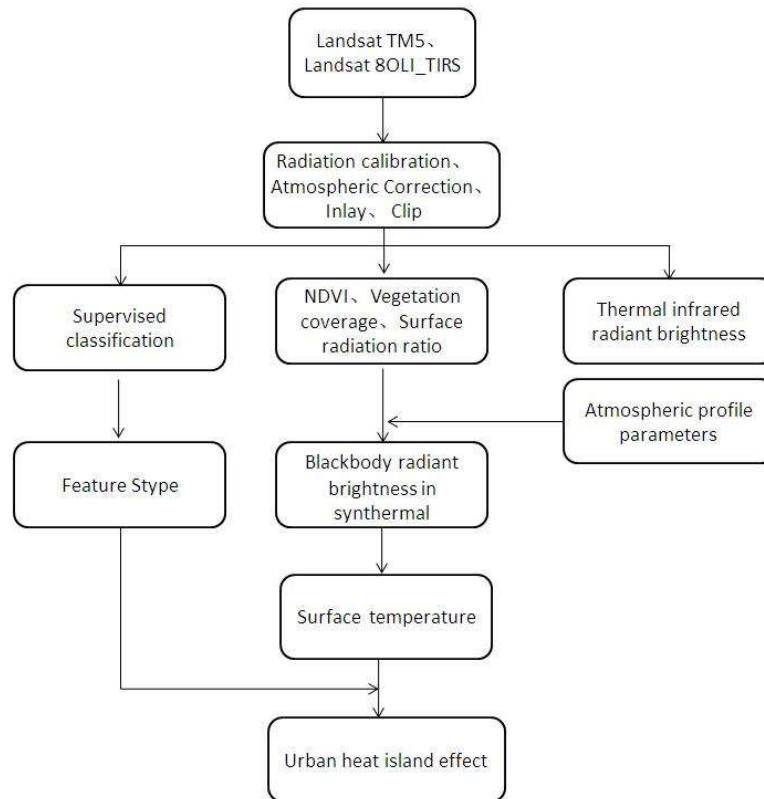The specific technical route is shown in Figure 1:

Figure 1. Technical roadmap

4. Data acquisition and research methods

4.1. Remote sensing data preprocessing
Pre-processing four-stage image data, radiometric calibration, atmospheric correction, mosaic and cropping, etc., to obtain basic image data of the study area.

4.2. Atmospheric correction
The surface temperature inversion of the atmospheric correction method is a process of calculating the thermal radiation intensity near the surface and converting it to the surface temperature by calculating the influence of the atmosphere on the surface radiation. The atmospheric correction expression is:

$$L_\lambda = [\varepsilon B(\mathrm{TS}) + (1 - \varepsilon)L\!\downarrow]\tau + L\!\uparrow \tag{1}$$

ε is the surface specific emissivity, $B(\mathrm{TS})$ is the black body thermal radiance, and τ is the atmospheric transmittance in the thermal infrared band.

4.3. Calculating the surface emissivity

The vegetation coverage Pv is calculated by the NDVI model. The formula for calculating Pv is:

$$（ (b1\,gt\,0.7)*1+(b1\,lt\,0.05)*0+(b1\,ge\,0.05\,and\,b1\,le\,0.7)*((b1-0.05)/(0.7-0.05)) ） \quad (2)$$

The formula for calculating the surface emissivity is:

$$\varepsilon = 0.004P_v + 0.986 \quad (3)$$

P_V is the vegetation coverage.

4.4. Calculate the black body radiance at the same temperature

The radiance B (TS) formula is:

$$B(TS) = [L_\lambda - L\uparrow - \tau(1-\varepsilon)L\downarrow]/\tau\varepsilon \quad (4)$$

ε is the surface specific emissivity, B(TS) is the black body thermal radiance, τ is the atmospheric transmittance in the thermal infrared band, and Lλ is the thermal radiation band brightness.

The inversion temperature TS is obtained using the Planck function formula:

$$TS = K2/Ln(K1/B(TS)+1) \quad (5)$$

For TM5 remote sensing images, K1 is 607.76 W/(m2*μm*sr) and K2 is 1260.56K, which is a constant.

K1 and K2 of TIRS Band10 are obtained from the *_MTL.txt metadata file. For the inversion of surface temperature, the focus is on the determination of atmospheric profile parameters. This study used the NASA official website to obtain the atmospheric profile parameters of the study area. Enter the shadowing time, the center latitude and longitude, and other corresponding parameters to obtain the atmospheric profile information as shown in Table 1 below:

Table 2. Atmospheric Profile Parameter Table

Years	Thermal infrared transmittanceτ	Upward radiance L↑	Downward radiance L↓
2000	0.89	0.83W/(m^2*sr*μm)	1.43W/(m^2*sr*μm)
2006	0.83	1.18W/(m^2*sr*μm)	1.97W/(m^2*sr*μm)
2013	0.83	1.36W/(m^2*sr*μm)	2.33W/(m^2*sr*μm)
2018	0.95	0.36W/(m^2*sr*μm)	0.65W/(m^2*sr*μm)

4.5. Surface temperature inversion

According to the above temperature inversion model, receive the surface temperature image of the four-stage image and Jinan City surface temperature classification map.The surface temperature data is divided into five levels with an interval of 1 standard deviation. The area results of the classification criteria and the surface temperature by grade are shown in Tables 3 and 4:

Table 3. Temperature division level table

Grade	Formula
Low temperature	$T < T_M - std$
Secondary low temperature	$T_M - std \leq T < T_M - 0.5*std$
Medium temperature	$T_M - 0.5*std \leq T < T_M + 0.5*std$
Secondary temperature	$T_M + 0.5*std \leq T < T_M + std$
high temperature	$T > T_M + std$

T is the surface temperature of the inversion, TM is the average surface temperature of the inversion, and std is the standard deviation of the temperature.
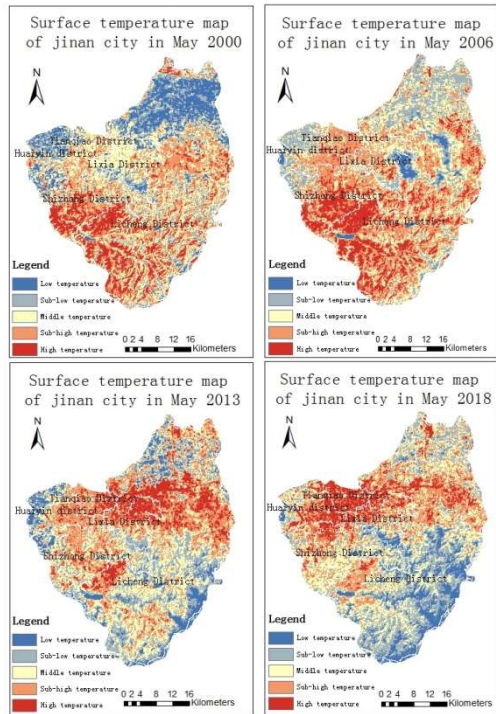

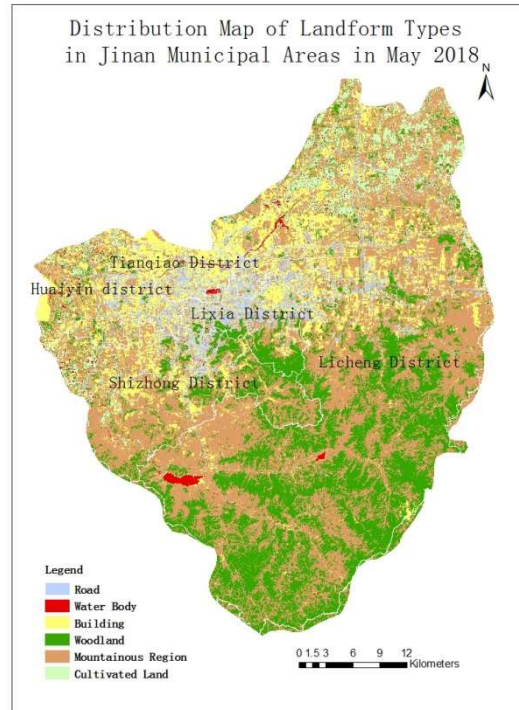**Figure 2.** Jinan City surface temperature classification map

Figure 3. Jinan distribution map of land types

Table 4. Geothermal area of the study area - scale table

Grade	May 2000		May 2006		May 2013		May 2018	
	area /km^2	proportion /%	area /km^2	proportion /%	area /km^2	proportion /%	area /km^2	proportion /%
Low temperature	232.04	12.35％	46.42	2.47％	153.56	8.18％	200.19	10.66 ％
Secondary low temperature	347.58	18.50％	331.12	17.63％	405.99	21.61 ％	469.08	24.97 ％
Medium temperature	537.58	28.62％	494.43	26.32％	517.04	27.53％	535.40	28.50％
Secondary temperature	520.63	27.72％	692.61	36.87％	545.31	29.03％	451.87	24.06％
high temperature	240.5	12.80％	313.75	16.7％	256.45	13.65％	221.81	11.81％

It can be seen from Figure 2 that the high temperature areas in Jinan in 2000 and 2006 were mainly concentrated in the southern mountainous areas and the densely populated areas in the main urban areas. The northern part of the main urban area is developing slowly, and the population and buildings are scarce, mainly cultivated farmland, and the temperature is low; compared with 2013 and In 2018, the high temperature is mainly concentrated in urban areas and some mountainous areas. The temperature in the radiation range of the main city has increased significantly and spread along the north-south direction, and the overall temperature is closer to the urban center. From 2000 to 2006, the area of high temperature area and sub-high temperature area increased significantly. The proportion of high temperature area increased from 12.80% to 16.7%, and the sub-high temperature area increased from 27.72% to 36.87%. The increase rate was obvious, and the proportion of low temperature area decreased by 12.35%. To 2.47%, the area of the sub-low temperature and medium temperature regions has also decreased; compared with 2013-2018, the area of secondary high temperature, high temperature zone

and low temperature zone has decreased, and the medium temperature zone and the sub-low temperature zone have increased, and the increase and decrease are not too small. obvious.

4.6. Relationship between feature types and thermal environment
Based on the remote sensing image of May 2018 in Jinan City, the main likelihood types of Jinan City were supervised and classified by ENVI software, which were divided into six categories: forest land, cultivated land, mountainous land, buildings, water bodies and roads. The results of the classification of feature types are shown in Figure 3below:

Comparing the classification results (Fig. 3) with the surface temperature inversion results (Fig. 2), it can be seen that the temperature in the main urban area of Jinan is significantly higher than that in the surrounding suburbs and mountainous areas. The trend of spreading from the center to the surrounding area is mainly due to the research area. A large area is surrounded by mountains, and the city is low-lying and forms a basin. The buildings in the urban area are densely distributed, the road traffic network is densely covered, the green vegetation is less, and the winds around the hills and mountains are blocked. The heat is not easily lost outside, and the heat is circulated in the city to form a heat island effect. The study area is seriously lacking in water resources. Although it has famous tourist attractions such as "Baotu Spring" and "Daming Lake", most of them are groundwater resources. The water body absorbs less heat and is difficult to dissipate heat, so the city forms hot weather.

5. Conclusion
According to the surface temperature inversion results of the fourth-phase remote sensing data of Jinan City, there is a significant heat island effect phenomenon in the main urban area of Jinan City. The temperature in the urban center (around the city) is generally higher than that in the suburbs, and the high temperature area is propelled along the east-west direction. With the increase of new residential buildings and population, the temperature in the main urban area has increased significantly. Especially in the high-tech zones at the east and west of Jinan, the temperature near the CBD business circle has increased significantly. As time progresses, the high temperature zone has a tendency to spread from the city center to the surrounding suburbs.

Especially in the vicinity of the high-tech zone in the east of the Lixia District and the West Railway Station in Jinan, with the rapid development in recent years, the temperature has shown an obvious upward trend. Based on all aspects of investigation and understanding, the following suggestions are proposed for the mitigation of the urban heat island effect in Jinan: (1) Increase the investment in infrastructure construction such as urban and surrounding public land, road traffic, urban green space, etc., and make overall plans. (2) Control industrial and artificial emissions, reasonably organize large industrial enterprises to move away from urban areas, and move outwards; rationally plan urban roads, reduce emissions from motor vehicles; reduce the release of artificial heat, and vigorously promote green travel. (3) Seizing the opportunities of the new and old kinetic energy conversion pilots and implementing the Yellow River North Cross-Strategy will not only ease the huge urban traffic pressure in Jinan, but also drive the development of surrounding cities and create a new pattern in the Yellow River era.

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