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Study on the Effect and Influencing Factors of Urban Green Space on Thermal Environment: A Case Study of Mianyang City Center

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Abstract: Due to the rapid expansion of urban development, green space is occupied, urban landscape and ecological environment are greatly damaged, and urban thermal environment problems are prominent and severe. Based on GIS and RS, this paper analyzes the evolution of thermal environment and green space in Mianyang city center from 2002 to 2021, analyzes the correlation between various elements of green space and land surface temperature, and further studies the influence and mechanism of urban green space on urban thermal environment. The following conclusions are drawn: 1) From 2002 to 2021, the area covered by urban green space generally shows a decreasing trend; The area of urban high temperature area is gradually increased, and the urban heat island effect is gradually strengthened. 2) The minimum temperature inside the green space patch was negatively correlated with its perimeter characteristics and area characteristics, and the correlation between the green space area and the urban thermal environment was slightly higher than the perimeter; 3) There was a significant negative correlation between the LSI (shape index) of green spatial patches and the minimum internal temperature; There is a significant positive correlation between the girth area ratio and the internal correlation. 4) There is an obvious negative correlation between surface temperature and vegetation coverage in the study area. The conclusion can provide a scientific basis for the urban planning of urban center to alleviate the thermal environment from the green space, so as to improve the urban thermal environment.

1. Introduction

Nowadays, most countries have experienced a stage of rapid development of urbanization. Urbanization is the change of urban internal structure such as population, economic structure, scientific industry and social space. It is also an inevitable product of economic and social development, scientific and technological progress, and a historical trend in the process of human development. China's urbanization has the characteristics of fast speed, large scale, high resource and energy consumption, and has intensified a series of ecological problems, among which the thermal environment problem is particularly prominent, and the most intuitive reflection is the urban heat island effect.[1]

The research on urban green space and thermal environment has been the focus of academic circles in recent years, and has accumulated abundant research results. In the study on the relationship between urban green space elements and urban thermal environment, Zhang Changshun[2] studied and analyzed the cooling function of urban green space from the perspective of green space types, green space structures and management measures. Yang Wei and Ma Tengyao[3] studied and analyzed the influence of the attributes of green patches on the internal temperature of green patches and the influence of green patches on the surrounding thermal environment. Chen Fangmin[4] analyzed the influence of heat island effect from the aspects of park patch characteristics, green landscape types and differences in surrounding land use structures.

However, most of the current research on urban thermal environment focuses on revealing the relationship between green space elements and thermal environment, focusing on the study of urban green space and parks, and lacking in-depth discussion on the impact of various elements on urban thermal environment from the perspective of green space as a whole. Based on GIS and RS, this paper analyzes the evolution of thermal environment and green space in Mianyang city center from 2002 to 2021, analyzes the correlation between various elements of green space and land surface temperature, and further studies the influence and mechanism of urban green space on urban thermal environment. The conclusion can provide a scientific basis for the urban planning of urban center to alleviate the thermal environment from the green space, so as to improve the urban thermal environment.

2. Study area and data source

The research area covers the downtown area of Mianyang, including Fucheng district, Anzhou District and part of Youxian District. Mianyang city is located in the northwest of Sichuan Basin, the middle and upper reaches of the Fujiang River, is one of the seven regional centers of Chengdu-Chongqing economic circle. The climate of the region belongs to the north subtropical mountainous humid monsoon climate area, hot in summer and cold in winter. Due to the rapid development of the city, the construction land in Mianyang has gradually increased, the city has expanded rapidly, the green space has been occupied, the urban landscape and the ecological environment have been greatly damaged, and the urban thermal environment problems are prominent and severe.

2.1 Data source and preprocessing

Landsat remote sensing images released by geospatial data cloud platform (http://www.gscloud.cn/) were used as data sources for analysis of urban thermal environment and green spatial pattern. The imaging dates were July 11, 2002, July 11, 2008, and July 31, 2021. (Detailed information is shown in Table 1) The data source has a long time span, imaging time is in the same month, and temperature error is small, which is conducive to carrying out research on spatial evolution characteristics and thermal environment. In the summer period, vegetation growth is vigorous, which can reflect the characteristics of green space well. Multi-spectral radiometric calibration and atmospheric correction were performed on the image data of 3 periods by ENVI, and the pre-processing data results were obtained by calibration and clipping.

Table 1: Landsat data source information table

Imaging date /Year - Month - Day	Satellites and sensors	Spatial resolution /m		Center latitude and longitude /	Strip number	Line number	Imaging time
		Thermal infrared band	Other bands				
July 11, 2002	Landsat 5 TM	30	30	104.9539E/31.7354N	129	38	03:08:34
July 11, 2008	Landsat 5 TM	30	30	104.9539E/31.7354N	129	38	03:19:56
July 31, 2021	Landsat 8OLI_TIRS	30 (TIRS)	30 (pancolour15)	104.9539E/31.7354N	129	38	03:08:34

3. Research method

3.1 Surface temperature inversion

The radiation transfer equation method is used to invert the surface temperature (LST). Its basic principle is to obtain the surface heat radiation intensity by subtracting the influence of atmospheric heat radiation from the total heat radiation of the sensor [5]. Firstly, the corresponding radiation luminance (Lλ) is calculated according to the pixel value (DN) in the thermal infrared band of Landsat data, and then the luminance temperature (Ts) is calculated. Finally, the luminance temperature is converted into the surface temperature according to the surface specific emissivity (ε). The formula is as follows:

$$T_s = K_2 / \ln[K_1 / B(T_S) + 1]$$

Where, ε is the surface specific emissivity; TS is the true surface temperature (unit: K); B(TS) is the blackbody radiation brightness; τis the transmittance of the atmosphere in the thermal infrared band. Known thermal infrared luminance values Lλ have been stored in thermal infrared luminance images of Landsat 8. Atmospheric upward luminance ↑, atmospheric downward luminance ↓, and atmospheric thermal infrared transmittance τ can be found on the website provided by NASA.

3.2 Surface temperature classification

Table 2: Classification of land surface temperature grades

	Temperature range /℃	Temperature zoning
Low temperature range	LST<Tmean - 2Tstd	Extremely low temperature region
	Tmean - 2Tstd≤LST<Tmean-Tstd	Cryogenic zone
	Tmean - Tstd≤LST<Tmean - 1/2Tstd	Lower temperature region
Medium temperature range	Tmean - 1/2Tstd≤LST<Tmean + 1/2Tstd	Mesothermal region
High temperature range	Tmean + 1/2Tstd≤LST<Tmean + Tstd	Higher temperature area
	Tmean + Tstd≤LST<Tmean + 2Tstd	High-temperature region
	LST≥Tmean + 2Tstd	Very high temperature area

In order to eliminate the influence of temperature differences in different periods, the extreme value standardization method was first adopted to normalize the surface temperature in different periods before the classification, and on this basis, the mean-standard deviation method was introduced for classification to obtain better spatial expression.[6-7] In this study, the land surface temperature is divided into 7 levels: extremely low temperature region, low temperature region, relatively low temperature region, medium temperature region, high temperature region, and extremely high temperature region. Among them, low temperature region and low temperature region constitute cold island region, and low temperature region and high temperature region constitute heat island region. The divisions are shown in the following table 2:

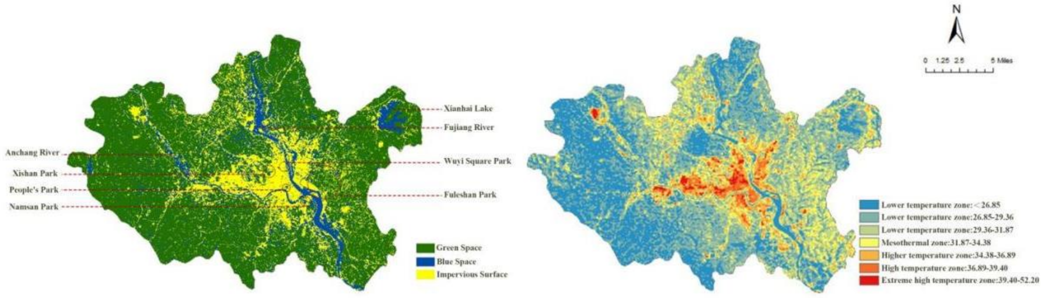
3.3 Green space classification interpretation

The essence of supervised classification is the method process of identifying other unknown pixels in remote sensing images by using pixels with clear categories,[8] and the method of confusion matrix analysis of ground realistic interest region is often used to implement classification accuracy test. The most important accuracy test indexes are overall classification accuracy and Kappa coefficient. The overall classification accuracy is the ratio between the number of correctly divided category pixels and the total number of pixels. The closer the value is to 100 percent, the higher the classification accuracy is. The Kappa coefficient represents the proportion of error reduction between classification and completely random classification, and the closer the value is to 1, the higher the classification accuracy. Support vector machine Classification (SVM) in Supervised Classification is used to interpret land use classification of data sources and extract green space, blue space and impervious space to analyze the relationship between various elements in each space. The accuracy of the classification results was evaluated according to Kappa coefficient. The overall Kappa coefficient of the data classification in 2002, 2008 and 2021 was 0.834, 0.812 and 0.924 respectively, which met the research standards and accuracy requirements, and the classification results could better reflect the land use status of the study area.

4. Results and analysis

4.1 Comparison of urban thermal environment and green space evolution

Based on the inversion of land surface temperature and the classification of urban land use in Mianyang city, it is found that: From the perspective of the overall urban thermal environment and land use, compared with the relevant data of land surface temperature and the changes of different types of land patches from 2002 to 2021(Fig. 1), there is a significant relationship between the green space patches and the corresponding average surface temperature. From 2002 to 2021, the patch area of green space in Mianyang city center gradually decreased, and the mean surface temperature of the city also increased. A large number of green Spaces have been converted to impervious water, and the development of urbanization has made large-scale construction land replace the former woodland, grassland and cultivated land.



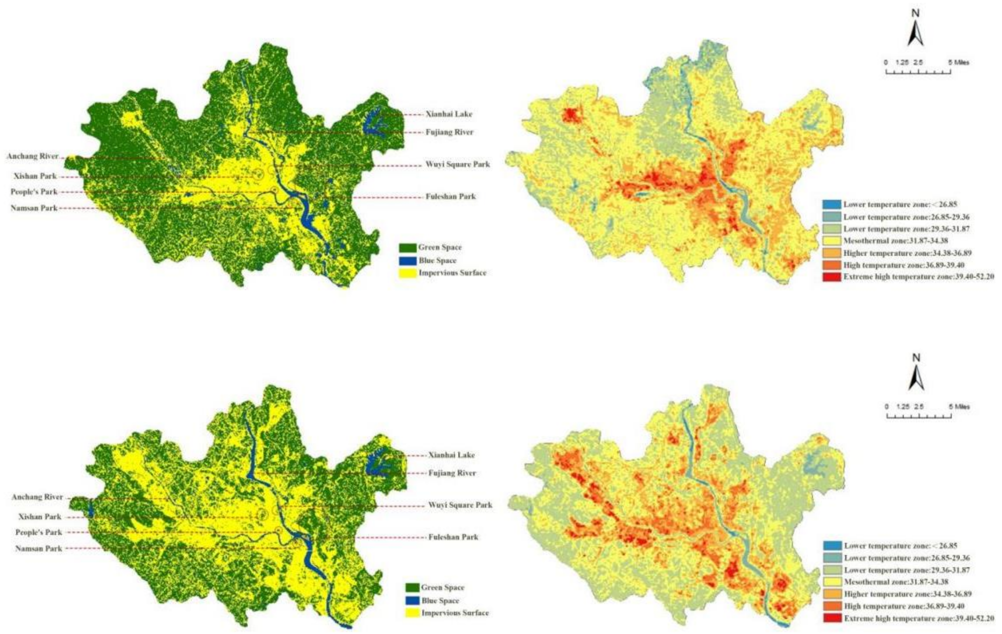


Figure 1: Comparison of green space and thermal environment pattern in Mianyang city center from 2008 to 2021

According to the temperature difference and the result of land use classification interpretation, the characteristics of land surface temperature change in Mianyang city were further studied, and the spatio-temporal evolution of thermal environment and green space in Mianyang city was compared and analyzed year by year, and the east-west thermal environment profile was analyzed based on the geometric center of the city. The profile analysis from the east to the west of the cultivated area, through the city center built-up area, has a typical research significance. In 2002 (Fig. 2), the high temperature area was mainly concentrated in Fucheng District, followed by some areas of Youxian District and Anzhou District. The low temperature area is mainly concentrated in blue Spaces such as Anchang River and Fujiang River, and contains parks mainly composed of green Spaces, such as People's Park and Fuleshan Park, among which the extremely low temperature area formed in the southwest and northeast areas of the city is particularly prominent, and the low temperature area also exists in the suburban forest land and cultivated land with high vegetation coverage. Between 2008 and 2021, the rapid construction of the urban center area, the high temperature area increased significantly, and the overall heat island increased significantly. From the analysis of thermal environment profile, different types of land use are an important cause of peak-valley interleaving, and green space is a typical low-temperature valley area (Fig. 3 and Fig 4). Urban green space occupies the vast majority of urban low temperature area.

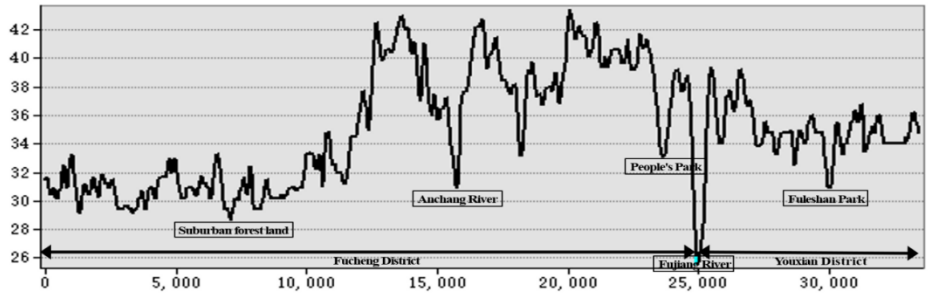


Figure 2: Analysis of east-west temperature profile in Mianyang City centerfrom 2008 to 2021

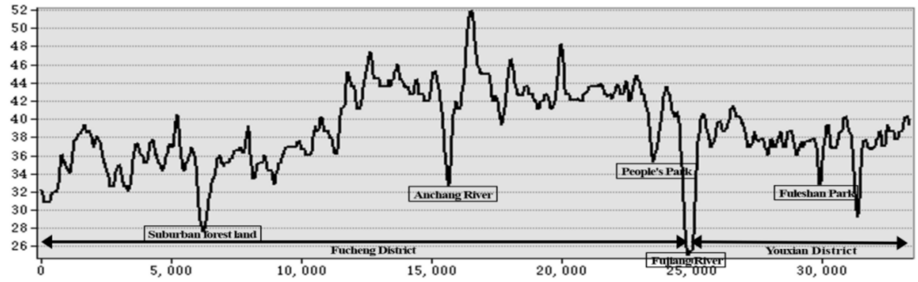


Figure 3: Analysis of east-west temperature profile in Mianyang City center in 2008

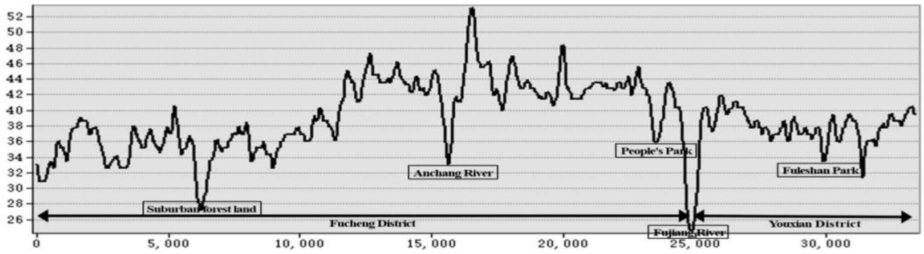


Figure 4: Analysis of east-west temperature profile in Mianyang City Center in 2021

4.2 The influence of urban green space on thermal environment

Through different land temperature data in 2002, 2008 and 2021, in-depth analysis of green space patches and thermal environment was carried out.This is shown in Table 3, In 2002, 2008 and 2021, the mean surface temperature in central urban area of Mianyang City was 39.95℃, 36.14℃ and 33.52℃ respectively, and the mean patch temperature in green space was 34.18℃, 35.17℃ and 42.69℃ respectively (variance was 1.98, 3.40 and 3.49, respectively). All were lower than the overall average temperature. It further reveals the cold island effect of green space in the city.

Table 3: Surface temperature of different land types

		Minimum temperature/℃	Max temperature/℃	Mean temperature/℃	St
2002	Blue space	24.77	48.9	36.835	2.28
	Green space	27.1	41.26	34.18	1.98
	Impervious surface	27.91	52.2	40.055	1.58
2008	Blue space	18.9	52.2	35.55	2.23
	Green space	23.63	46.71	35.17	3.40
	Impervious surface	24.57	56.69	40.63	2.62
2021	Blue space	26.24	55.23	40.735	2.37
	Green space	31.47	53.92	42.695	3.49
	Impervious surface	31.34	66.33	48.835	1.49

4.2.1 Effects of scale factors on thermal environment

Taking the data of 2021 as an example, correlation analysis was conducted between the green space patch area, perimeter index and the internal minimum temperature, and the results were shown in the following table 4. Correlation analysis showed that the minimum temperature inside the green space patch had a significant negative correlation with its perimeter characteristics ($P < 0.01$), and also had a significant negative correlation with its area characteristics ($P < 0.01$). The correlation index of the influence of the two factors on the thermal environment is similar, and the correlation with the area is slightly higher than the perimeter. The results show that the thermal environment improvement ability can be significantly improved by optimizing the circumference and area of blue-green space patches.

Table 4: Correlation between scale factors and internal temperature of green space

	Coefficient of correlation with internal temperature
Perimeter	-0.446(0.000***)
Area	-0.445(0.000***)

4.2.2 Influence of shape elements on thermal environment

The relationship between green space and average standard temperature is shown in Table 5: LSI (shape index) has a significant negative correlation with the minimum internal temperature ($P < 0.01$); There was a significant positive correlation between the area ratio of green space circumference and the internal correlation ($P < 0.01$). This shows that for shape elements (shape index LSI), the larger the minimum internal temperature of green space is, the more the shape deviates from square form, the lower the internal temperature will be. The cooling effect of a blue-green space patch with rich shapes and complex edges is stronger than that of a simple one with regular edges.

Table 5: Correlation between scale factors and internal temperature of green space

	Coefficient of correlation with internal temperature
LSI	-0.426(0.000***)
Perimeter area ratio	0.422(0.000***)

4.2.3 Effect of vegetation coverage on thermal environment

Within the research scope, the green space patches in the suburbs are large and cover a wide area. Therefore, in order to further explore the influence of vegetation coverage on thermal environment, the research area is divided into a grid with a side length of 30m×30m to meet the accuracy requirements of correlation analysis. The grid covers all the data information of surface temperature and vegetation coverage in the study area. The spatial resolution of the vegetation coverage image and the surface temperature image is 30m×30m, so each grid in the image corresponds to each original raster data. The ArcGIS10.2 software was used to calculate the average of grid data in the grid, and the grid classification images of vegetation coverage and land surface temperature were obtained. Correlation research was conducted on the data of vegetation coverage and land surface temperature in all grids. The regression analysis results between the vegetation cover and land surface temperature in 2002, 2008 and 2021 are shown in the figure 5 below. There is an obvious negative correlation between surface temperature and vegetation coverage in the study area. The higher the vegetation coverage is, the lower the surface temperature is. The coefficient of determination (R^2) of the regression equation is 0.48902, 0.45648 and 0.53312, respectively, and the regression equation fits well. At the significance level of 5%, the overall model passed the test, indicating that there is a strong correlation between the two. The slopes of the regression equations for 2002, 2008 and 2021 are -10.108, -9.310 and -12.144 respectively, and their absolute values range from 9.310 to 12.144. From these data, it can be concluded that the increase of vegetation coverage can effectively change the regional land surface temperature. Every 0.1 increase of vegetation coverage index in central urban area of Mianyang city can reduce the land surface temperature by 0.9~1.2°C.

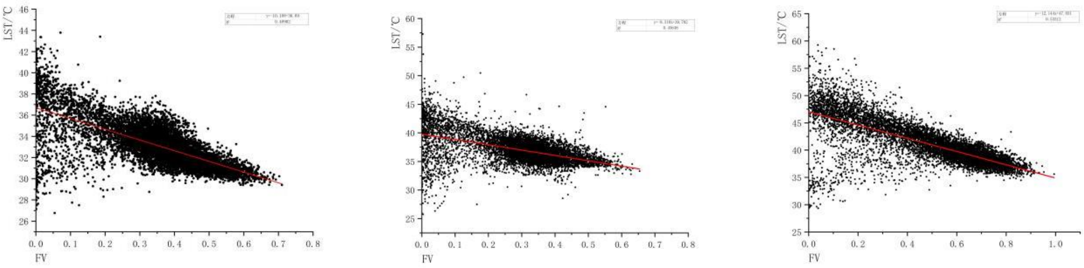


Figure 5: Regression analysis of land surface temperature and vegetation coverage

5. Conclusion and prospect

This study quantifies the effect of green space on the thermal environment and three aspects of the influencing factors, and analyzes the correlation between the scale elements, shape elements and vegetation coverage characteristics of green space and the thermal environment, which can play a role in alleviating the thermal environment for more reasonable planning and layout of green space, and improve the cooling capacity and efficiency more effectively. This study draws the following conclusions:

1) From 2002 to 2021, great changes have taken place in green space and surface temperature in Mianyang city center. Due to the continuous expansion of urban construction land in Mianyang city, the area covered by urban green space is generally decreasing. The area of urban high temperature area is gradually increasing, and the urban heat island effect is gradually strengthened.

2) The minimum temperature inside the green space patch was negatively correlated with its perimeter characteristics and area characteristics, and the correlation between the green space area and the urban thermal environment was slightly higher than the perimeter; Increasing the circumference and area index of green space patch can effectively improve the thermal environment.

3) There was a significant negative correlation between the LSI (shape index) of green spatial patches and the minimum internal temperature; There is a significant positive correlation between the girth area ratio and the internal correlation. For shape elements (shape index LSI), the larger the shape, the more the shape deviates from the square shape, and the lower the internal temperature, and the cooling effect of a green space patch with rich shapes and complex edges is stronger than that of a green space patch with simple shapes and regular edges.

4) There is an obvious negative correlation between surface temperature and vegetation coverage in the study area. When vegetation coverage in the study area increases by 10%, the average surface temperature can be reduced by 0.9℃~1.2℃.

Urban green space plays a certain role in the improvement of thermal environment, and its cooling effect is also a hot topic to be discussed in recent years. This paper analyzes the relationship between thermal environment and green space in terms of scale, shape and vegetation cover, and the research conclusions can provide suggestions for improving thermal environment, coping with climate challenges and promoting ecological civilization construction through green space planning. Due to the limitation of technology and data, the relevant conclusions obtained in this study have certain limitations. In the future, the law of the thermal environment and the characteristic elements of green space under the fine scale will continue to be discussed, so as to accurately and efficiently play the ecological cooling effect of green space and alleviate the urban heat island effect.

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