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The Spatiotemporal Characteristics and Influencing Factors of Urban Heat Island Effect in Beijing——Taking Chaoyang District and Tongzhou District as Examples

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Abstract: *Urban Heat Island (UHI) refers to the phenomenon where the atmospheric and surface temperatures in the central area of a city are higher than those in the surrounding suburban or rural areas. The urban heat island effect can affect urban energy consumption and the health and comfort of residents, while also having adverse effects on urban ecosystems. With the acceleration of urbanization, urban heat island effect has gradually become a widely concerned ecological environment issue. This study used ArcGIS, ENVI and other software to process and analyze Landsat remote sensing images. The thermal field variation index was used to study the spatiotemporal changes of urban heat island effect in Chaoyang District and Tongzhou District of Beijing. The influencing factors of urban heat island effect were analyzed from the perspectives of land use classification, average surface temperature, and epidemic situation. The research results show that: (1) On June 14, 2019, August 3, 2020, June 19, 2021, and July 19, 2023, the urban heat island effect in Chaoyang District, Beijing was slightly higher than that in Tongzhou District; (2) Among the selected research dates, the urban heat island effect in Chaoyang District and Tongzhou District of Beijing was the weakest on August 3, 2020; (3) The land use types that affect the urban heat island in Chaoyang District and Tongzhou District of Beijing are mainly impermeable surfaces and cultivated land; (4) The changes in urban heat island effect are closely related to the average surface temperature. When the average surface temperature increases, the areas of non heat island and weak heat island areas decrease, while the areas of other heat island areas increase. When the average surface temperature decreases, the areas of non heat island and weak heat island areas increase, while the areas of other heat island areas decrease.*

Keywords: *Beijing city, thermal field variation index, urban heat island effect, spatiotemporal characteristics, influencing factor*

1. Introduction

In 2012, China clearly placed ecological environment at the top of its “Five-in-One” strategy. In 2017, China proposed to accelerate the reform of the ecological civilization system and build a beautiful China. As China’s urbanization process accelerates and economic development shifts from fast to good, ecological civilization construction has gradually become a key issue in my country’s development. Urban Heat Island (UHI) refers to a climate phenomenon in which the temperature in urban areas is higher than that in surrounding suburbs. As early as 1833, British scholar Lake Howard first recorded this phenomenon through meteorological monitoring and proposed that it was closely related to urbanization [1]. In 1958, Manley formally proposed the concept of “urban heat island” [2], using it as a significant feature of studying the impact of human activities on the natural environment during the urbanization process. Since then, the urban heat island effect has gradually become the focus of attention of multiple disciplines such as urban climatology, ecology, and geography. In recent years, with the development of remote sensing technology and the widespread application of high-precision data, the study of urban heat island effect has gradually expanded from early local observations to large-scale and multi-dimensional analysis. The research focus has gradually shifted from descriptive analysis to mechanism exploration, including in-depth exploration of the formation process, spatiotemporal distribution patterns and influencing factors of the urban heat island effect. Existing studies have shown that the urban heat island effect is affected by a combination of factors, including land cover type, population density, energy consumption, climate conditions, etc. [3]. Vegetation cover is considered to be the main regulatory factor for the intensity of the daytime heat island, while the intensity of the nighttime heat island is more affected by building density and anthropogenic heat emissions [4]. Remote sensing technology has become an important tool for analyzing the urban heat island effect due to its advantages such as large area, low cost and strong timeliness. Peng et al. calculated the surface heat island intensity of 419 major cities around the world based on MODIS surface temperature products and found that vegetation cover is a key factor affecting the daytime heat island effect [5]. Zhou et al. analyzed the heat island intensity of 32 cities in China and proposed that the daytime heat island is related to vegetation activity and climate, while the nighttime heat island is more affected by human heat emissions and building intensity [6]. The coarse-grained model developed by Manoli et al. introduced parameters such as population density and background climate into the study of urban heat islands, revealing the decisive role of differences in evapotranspiration and convection efficiency between urban and rural areas in the intensity of urban heat islands [7].

Research on the urban heat island effect is not limited to its causes and distribution patterns, but also focuses on proposing feasible mitigation measures. In the 1980s, German scholar Kress first proposed the concept of urban ventilation corridors [8] and applied it to the urban planning of Stuttgart. Since then, the "Wind Road" project in Tokyo, Japan has significantly reduced the urban heat island effect by optimizing building layout and introducing sea breeze [10].

Domestic scholars have also explored mitigation strategies from many aspects: Xie Miaomiao et al. pointed out that increasing urban green space and water coverage can effectively reduce surface temperature, and suggested promoting roof greening and vertical greening [11]. By scientifically designing ventilation corridors and optimizing building layout, air mobility can be enhanced and the intensity of urban heat islands can be reduced [9]. Based on multi-temporal data from 2019 to 2023, this study deeply explores the spatiotemporal characteristics and driving mechanisms of the urban heat island effect in Chaoyang District and Tongzhou District of Beijing from multiple perspectives such as land use type, surface temperature and the impact of the epidemic, providing a scientific basis for improving the urban heat island research system and optimizing regional urban planning[12].

2. Overview of the research area and data processing

2.1 Overview of the research area

Chaoyang District is located in the central southern part of Beijing, at latitude 39 ° 49 'to 40 ° 5' north and longitude 116 ° 21 'to 116 ° 38' east. The area is 470.8 square kilometers. The terrain within the jurisdiction is flat, with a gentle slope from northwest to southeast. The average elevation is 34 meters, with the highest point reaching 46 meters and the lowest point reaching 20 meters. The outline is north-south long, with a maximum length of about 28 kilometers; It is narrow from east to west, with a maximum width of about 17 kilometers. There are rivers such as Wenyu River, Qinghe River, Bahe River, Liangma River, Xiaotaihou River, Liangshui River, and Beixiaohe River within the territory. According to the "Beijing Urban Master Plan (2016-2035)" [13], Chaoyang District belongs to the central urban area of Beijing. Its functional positioning is to strengthen international communication functions in the eastern and northern regions, and to build it into an internationally first-class business center, international science and technology cultural and sports exchange area, and a carrier for various international communities; The southern region will transform traditional industrial areas into areas that integrate cultural creativity and technological innovation for development.

Tongzhou District is located in the southeast of Beijing, at the northern end of the Grand Canal. The geographical coordinates are 39 ° 36 '~40 ° 02' north latitude, 116 ° 32 '~116 ° 56' north latitude, 36.5 kilometers wide from east to west, 48 kilometers long from north to south, and an area of 905.95 square kilometers. Adjacent to the Central Business District (CBD) of Beijing, it is 13 kilometers west of the International Trade Center, 16 kilometers north of the Capital International Airport, and 100 kilometers east of Tanggu Port. It is known as the "One Beijing, Two Guards, and Three Tongzhou". The entire region is located in the alluvial plain of Yongding River and Chaobai River, with a flat terrain and an average elevation of 20 meters. There are 13 rivers distributed with a total length of 245.3 kilometers, including the North Canal, Chaobai River, Liangshui River, and Fenggangjian River. The climate belongs to the warm zone continental semi humid monsoon climate zone.

2.2 Data acquisition and preprocessing

The data in this article was downloaded from the official website of the United States Geological

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Survey(https://earthexplorer.usgs.gov/)This study selected Landsat 8/9 data from 2019 to 2023. As Landsat 9 and Landsat 8 have similar parameters, Landsat 8 related parameters are taken as an example, as shown in Table 1.

Table 1. Landsat 8 related parameters

	Bands	Wavelength (micrometers)	Resolution (meters)
Land Imager OLI	Band1 - Coastal aerosol	0.43-0.45	30
	Band2 - Blue	0.45-0.51	30
	Band3 - Green	0.53-0.59	30
	Band4 - Red	0.64-0.67	30
	Band5 - Near Infrared (NIR)	0.85-0.88	30
	Band6 - Shortwave Infrared (SWIR) 1	1.57-1.65	30
	Band7 - Shortwave Infrared (SWIR) 2	2.11-2.29	30
	Band8 - Panchromatic	0.50-0.68	15
	Band9 - Cirrus	1.36-1.38	30
TIRS	Band10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
	Band11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

2.3 Statistical analysis of zoning area of heat island intensity

Vectorize the grid data of the thermal field variation index distribution in Chaoyang District and Tongzhou District, and classify the thermal field variation index. Taking the vectorization result of the thermal field variation index classification in Chaoyang District on June 14, 2019 as an example, as shown in Figure 1.

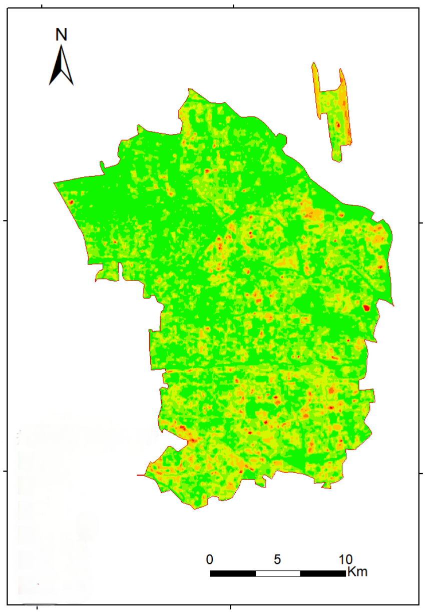

Figure 1. Classification results of thermal field variation index in Chaoyang District on June 14, 2019

3. Influencing factors and mitigation measures of urban heat island effect

3.1 Land use classification

Download the China Land Cover Dataset (CLCD) provided by the School of Remote Sensing at Wuhan University for the years 2019 and 2021. The classification of land types is shown in Table 2.

On June 14, 2019, the land types overlapping with the strong and extremely strong heat island effect areas in Tongzhou District include impervious surfaces, cultivated land, and a very small part of grassland and water. Among them, the impervious surface area is 12685300m2, accounting for 58%; the cultivated land area is 9184670m2, accounting for 42%; there is also a very small amount of grassland, with an area of 6092m2 and a very small amount of water, with an area of 1800m2.

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On June 19, 2021, the land types overlapping with the strong and extremely strong heat island effect areas in Chaoyang District include impervious surfaces and cultivated land. Among them, the impervious surface area is 1665520m2, accounting for 69%; the cultivated land area is 755272m2, accounting for 31%.

On June 19, 2021, the land types overlapping with the strong and extremely strong heat island effect areas in Tongzhou District include impervious surfaces, cultivated land, and a very small part of grassland and water. Among them, the impervious surface area is 6892400m2, accounting for 46%; the cultivated land area is 8031840m2, accounting for 54%; and there is a very small amount of grassland, with an area of 1228m2.

Table 2. Land classification table

Type	Color Segment
Cropland	250,227,156
Forest	68,111,51
Shrub	51,160,44
Grassland	171,211,123
Water	30,105,180
Sonw/Ice	166,206,227
Barren	207,189,163
Impervious	226,66,144
Wetland	40,155,232

The comprehensive analysis of land use classification results shows that impervious surface and cultivated land are important factors affecting the urban heat island effect in Chaoyang District and Tongzhou District of Beijing. Among them, the impact of impervious surface is the greatest, while the impact of cultivated land is relatively small.

This is because in places where the coverage rate of impervious surface and cultivated land in the city is high, the coverage rate of vegetation and water bodies is low, and the heat will be more in the form of sensible heat exchange, which leads to temperature rise and the formation of urban heat island; while areas covered by vegetation and water bodies have higher transpiration, and the heat is more in the form of latent heat exchange, which reduces the temperature [14].

3.2 Average surface temperature

On June 14, 2019, the minimum temperature was 29.19℃; the maximum temperature was 60.72℃; the average temperature was 43.61℃; and the standard deviation was 3.62℃. On August 3, 2020, the minimum temperature was 31.25℃, which was 2.06℃ higher than in 2019; the maximum temperature was 63.83℃, which was 3.11℃ higher than in 2019; the average temperature was 41.95℃, which was 1.66℃ lower than in 2019; the standard deviation was 3.48, which was 0.14 lower than in 2019. On June 19, 2021, the minimum temperature was 28.72℃, which was 2.53℃ lower than in 2020; the maximum temperature was 64.79℃, which was 0.96℃; the average temperature is 45.18℃, which is 3.23℃ higher than that in 2020; the standard deviation is 3.42, which is 0.06 higher than that in 2020. The minimum temperature on July 19, 2023 was 25.94℃, which was 2.78℃ lower than that in 2021; the maximum temperature was 60.84℃, which was 3.95℃ lower than that in 2021; the average temperature was 43.21℃, which was 1.97℃ lower than that in 2021; the standard deviation was 3.17, which was 0.25 lower than that in 2021. As shown in Figure 2.

Combining the changes in the area of various levels of heat island areas in Chaoyang District in summer and the changes in the area of various levels of heat island areas in Tongzhou District in summer, it can be found that these data are basically consistent with the changes in the intensity levels of heat islands in the study area.

In 2019, the average summer temperature was 43.61℃, and the areas of non-low temperature areas and low temperature areas in the city were relatively balanced; with the outbreak of the epidemic, Beijing took measures to close the city, and the average summer temperature in 2020 dropped to 41.95℃, resulting in a significant increase in the area of no heat island areas and weak heat island areas in the study area, and the area of other heat island areas expanded; in 2021, the average temperature rose to 45.18℃, and the area of no heat island areas and weak heat island areas decreased this year, while the area of other heat island areas increased significantly. This change is consistent with the increase in traffic and industrial activities during the first unblocking during the epidemic, which

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caused the urban heat island effect to rebound; by 2023, the average temperature rose to 43.21℃. As the epidemic policy was gradually relaxed, people resumed their normal production and life half a year later, and the average summer temperature gradually returned to the situation before the outbreak in 2019.

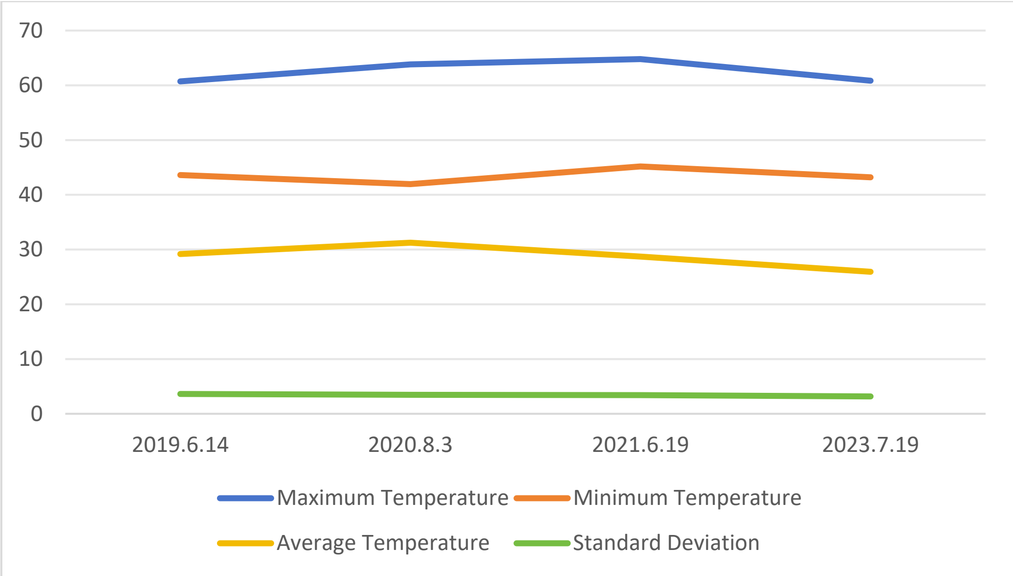

Figure 2. Surface temperature statistics of Chaoyang District and Tongzhou District, Beijing from 2019 to 2023

From the relationship between the average temperature data of the study area from 2019 to 2023 and the changes in the intensity and area of each level of heat island, it can be seen that the change in the urban heat island effect is closely related to the average surface temperature. When the average surface temperature rises, the area of the non-heat island area and the weak heat island area decreases, and the area of the other heat island areas increases; when the average surface temperature drops, the area of the non-heat island area and the weak heat island area increases, and the area of the other heat island areas decreases.

3.3 Phase and epidemic

From a temporal perspective, phase and epidemic are extremely critical factors affecting the urban heat island effect in Chaoyang District and Tongzhou District of Beijing. From the epidemic announcement issued by the Wuhan Municipal Health Commission and the notice on the full lifting of the blockade issued by the National Health Commission, it can be known that the duration of the epidemic is roughly from December 12, 2019 to December 16, 2022. Combined with the data of urban heat island areas and surface temperature data of various levels from 2019 to 2023, the conclusions obtained are basically consistent with the changes in the epidemic situation: On June 14, 2019, the new crown pneumonia epidemic had not yet appeared, various activities in the city were normal, the average temperature was 43.61℃, and the areas of non-low temperature areas and low temperature areas in the city were relatively balanced; on August 3, 2020, compared with the midsummer surface temperature in June and July, Beijing took measures to close the city with the outbreak of the epidemic. The average temperature in the study area dropped to 41.95℃, resulting in a significant increase in the area of no heat island areas and weak heat island areas in the study area, and the area of other heat island areas expanded; on June 19, 2021, the average temperature rose to 45.18℃. The area of no heat island areas and weak heat island areas decreased this year, and the area of other heat island areas increased significantly. This change is consistent with the increase in transportation and industrial activities during the first unblocking during the epidemic, which caused the urban heat island effect to rebound; on July 19, 2023, the average temperature rose to 43.21℃. As the epidemic policy was gradually relaxed, people resumed their normal production and life half a year later, and the average summer temperature gradually returned to the situation before the epidemic in 2019. Taking the Capital International Airport in the northeast of Chaoyang District as an example, on August 3, 2020, the heat island effect was significantly reduced, and the intensity of the heat island effect on other dates was higher than that date.

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3.4 Measures to mitigate the urban heat island effect

The study found that during the epidemic, people followed a series of protective measures such as home isolation, reduced outdoor activities, and reduced the urban heat island effect. Therefore, improving traffic planning and management is an effective measure to alleviate the urban heat island effect. Beijing has a large population. Continuously developing public transportation, improving bus routes and facilities, encouraging residents to choose public transportation more, and reducing the use of motor vehicles can effectively reduce the large amount of heat caused by traffic congestion and vehicle emissions. This study optimizes road design, improves road capacity, and reduces the heat generated by vehicles due to congestion. At the same time, by accelerating the promotion of new energy vehicles, gradually reducing the number of traditional fuel vehicles, and reducing exhaust emissions and heat generation.

Optimizing urban planning is also a key measure to alleviate the urban heat island effect. This study aims to avoid excessive concentration of commercial and residential areas by arranging the layout of urban functional zones in a reasonable manner, thus creating high heat source areas. For example, when planning a new urban area, scientifically design ventilation corridors, fully consider the coordination of functional areas, and prevent local overheating.

Strengthening the construction of green infrastructure can also effectively reduce the urban heat island effect. This study found that the two types of land use that affect the urban heat island effect in Chaoyang District and Tongzhou District of Beijing are impervious surfaces and cultivated land. Therefore, increasing the coverage rate of vegetation and water bodies and reducing the proportion of impervious surfaces and cultivated land are the construction directions for alleviating the urban heat island effect. This study aims to increase urban forest coverage through large-scale afforestation activities. Trees can effectively block solar radiation, and their transpiration process will consume a lot of heat, bringing significant cooling effects. Actively promote rooftop greening and vertical greening, and use the three-dimensional space of buildings to increase green coverage, which will not only not occupy additional land resources, but also play a cooling effect. Ecological wetlands can also be built to use water evaporation and the ecological role of plants to regulate the surrounding climate.

4. Conclusion

Using the thermal field variability index method, the temporal and spatial distribution of the urban heat island effect in Chaoyang District and Tongzhou District of Beijing from 2019 to 2023 in summer was analyzed, and the following results were obtained: (1) During the study period, the urban heat island effect in Chaoyang District of Beijing was slightly higher than that in Tongzhou District; (2) On August 3, 2020 and June 19, 2021, the intensity of the urban heat island effect in Chaoyang District and Tongzhou District of Beijing was lower than that on June 14, 2019 and July 19, 2023.

In terms of influencing factors, through the analysis of land use products, it was found that: (1) The main land types affecting the urban heat island effect in Chaoyang District and Tongzhou District of Beijing from 2019 to 2023 in summer were impervious surfaces and cultivated land, among which the impact of impervious surfaces on the heat island effect was greater than that of cultivated land; (2) The change of the urban heat island effect was closely related to the average surface temperature. When the average surface temperature rises, the area of non-heat island areas and weak heat island areas decreases, while the area of other heat island areas increases; when the average surface temperature drops, the area of non-heat island areas and weak heat island areas increases, while the area of other heat island areas decreases. (3) During the full outbreak of the epidemic, the intensity of the urban heat island effect in Chaoyang District and Tongzhou District of Beijing was lower than before and after the epidemic. (4) The intensity of the urban heat island effect varies in different phases.

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