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Monitoring of Urban Heat Island Based on Community Scale: A Case Study of Guangzhou

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Abstract: *This paper is purposed to systematically explain the mechanism of community-scale urban heat island effect, thus providing a practical guidance on how to mitigate it in the urban community-scale thermal environment. Herein, a research is conducted into the surface urban heat island (SUHI) intensity on community scale in the five center urban districts of Guangzhou city. the urban heat island intensity on community scale (CUHII) of the five center urban districts is calculated to analyze the correlation between CUHII and six community factors, including plot ratio, building height, building density, the total number of community households and greening rate. The significant influencing factors for CUHII are building height, plot ratio and greening ratio. The areas with higher CUHII are located in the south of Baiyun District, the whole of Liwan District and the southwest of Haizhu District, but low in the north and the east. The CUHII in different stages of the construction concentrates on the second and third levels (4~8℃), showing an upward trend with the age of construction. There is also an increasing trend shown over time by the significance of correlation between the spatial anisotropy of CUHII and the following four factors, building height, plot ratio, the total number of households, and greening rate.*

Keywords: *Community heat island, Influencing factors, Spatial pattern, Geographic detector, Guangzhou city*

1. Introduction

Urbanization is an inevitable result from the development of human society, providing an essential path to achieving modernization for an individual country. According to WCR2020, the proportion of urban population worldwide has approached 56.0% as of 2020 [1]. According to China's seventh census bulletin, the urban population in China accounts for 63.89% of the national total in 2020 [2]. At present, the whole world is experiencing an unprecedented wave of urbanization [3,4]. In particular, the urban population in developing countries is growing at a much faster pace than in developed countries [5]. As urbanization proceeds continuously, the climate and environmental issues caused by urbanization have become increasingly prominent. Among them is the urban heat island (UHI). The UHI effect is a phenomenon that the temperature of urban air and surface is significantly higher than in the suburbs of the city. In addition to having a direct impact on local and regional climate, the UHI also exert effects on water resources, air quality, human health, biodiversity and ecosystem function, thus causing various ecological problems such as photochemical smog [6,7]. Due to global warming and urban heat island effect, the urban thermal environment has an increasingly significant impact on human health, which makes it the focus of public attention [8,9].

The present research of UHI is focused mainly on urban canopy heat island based on observations from meteorological stations or mobile devices and SUHI based on the inversion of remote sensing data [10,11]. For the evaluation of quantitative urban heat island, the most direct and traditional method is to analyze the evolution of UHI effect under different time scales through comparative analysis as well as mathematical and statistical methods. For example, by using the data collected from ground-based meteorological stations, some researchers analyzed the characteristics of UHI effect in different cities with annual, quarterly and diurnal variations [12,13,14]. Besides, Bejar and Camilloni [15], Lee and Balk [16], and Cao et al. [17] investigated the impact of different weather conditions, precipitation, atmospheric pollution and other factors on the UHI effect. In recent years, thermal infrared remote sensing has provided more statistical support for the quantitative evaluation of UHI effect research, such as GOES series, FY-2 / SVISSR, NOAA series, and land-sat series [18,19].

This paper is purposed to reveal how the interaction of multiple factors would impact on the urban

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heat island effect at different community scales (community urban heat island, CUHI) in Guangzhou City through the geographic probes based on remote sensing data, community profile data, land use data and other data. The results contribute to better understanding the mode of each factor and the combined heat island drivers, thus providing scientific reference for community development and urban heat risk mitigation.

2. Materials and Methods

2.1. Study Area

Guangzhou is located in the south central part of Guangdong Province. It covers an area of 7434.4 km^2, with a total population of 18.81 million (as of 2021). Guangzhou features a warm and humid climate all year round. The average annual temperature ranges from 20 to 22°C, reaching 27°C in July. It has abundant precipitation throughout the year, with the annual average reaching 1720mm. Guangzhou City consists of eleven municipal districts, including five central urban districts, namely, Yuexiu, Haizhu, Liwan, Tianhe, and Baiyun. Herein, the afore mentioned five central urban districts are taken as the study area. These five districts are the most densely populated urban areas in Guangzhou, accounting for 57.23% of the total population in the city [20] , as shown in Figure 1.

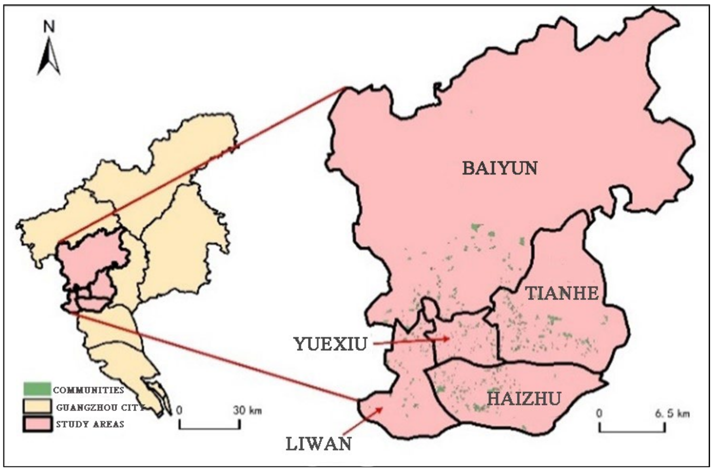

Figure 1: The location of the study area

2.2. Datasets

The datasets collected for the present study include the landsat-8 surface temperature product dataset, the land cover/use dataset, DEM data, the population, as well as the boundaries and buildings of all the community. The landsat-8 surface temperature product dataset is sourced from the United States Geological Survey (USGS, https://earthexplorer.usgs.gov/, accessed on 20 February 2020). The land cover/use dataset is obtained from the landsat-derived annual land cover product of China as produced by the school of remote sensing information engineering, Wuhan University (CLCD, http://doi.org/ 10.5281/zenodo.4417809). The overall level of data accuracy is 80%. The DEM data are sourced from the SETMDEM gathered by geospatial data cloud(https://www.gscloud.cn/). The spatial resolution of all the datasets as mentioned above is 30m*30m.

3. Methodology

3.1. Data Processing

After being geometrically and radiometrically corrected, the landsat-8 surface temperature product dataset can be directly used to calculate the real surface temperature with the assistance of ArcGIS software. The algorithm used to calculate the real surface temperature is presented as the following equation:

$$T = b1 * 0.00341802 - 124.15 \tag{1}$$

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Where b1 represents the digital number for C2L2 surface temperature products obtained from Landsat-8.

The land cover datasets and DEM data are used to choose the suburban zones for comparison of the five central urban districts. The main criteria of selection are as follows: 1) the difference in altitude between the suburbs and the suburban area does not exceed 100m; 2) the land use type is forest in all the suburban zones; and 3). the land use type has remained unchanged over the last 30 years. In total, 17 suburban zones are chosen for comparison (Figure 2).

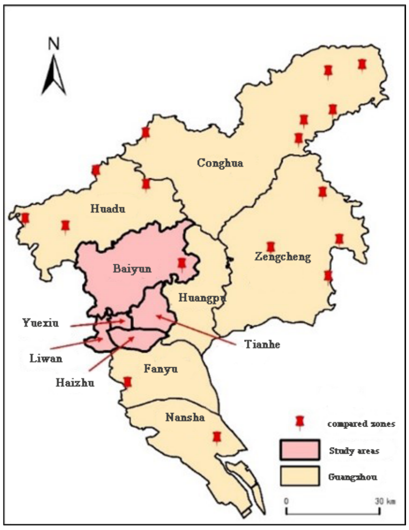

Figure 2: The distrubition of the 17 compared suburban zones

The projection of boundaries and building data of all the community is set as WGS-84. The names or ID numbers of the community are treated as a matching field to extract 1320 records of community. After the removal of missing or invalid community data, there are 632 pieces of complete community data on the five central urban districts considered useful.

3.2. Calculating CUHII

The average temperature and average greenery rate of the 632 communities and 17 suburban zones for comparison were extracted by using the raster extraction tool from Landsat-8 surface temperature dataset and land cover/use dataset. Then, the community urban heat island intensity(CUHII) was obtained by subtracting the average suburban surface temperature from the average community surface temperature.

$$CUHII = T_{urban} - T_{suburb} \tag{2}$$

3.3. Geo-Detector

Geographical detector is premised on the assumption that the spatial distribution of independent and dependent variables is supposed to be similar if an independent variable exerts a significant effect on a dependent variable. Through the divergence and factor detection, the driving factors of CUHII spatial pattern were explored to understand the heat island space under the influence of various factors from different administrative perspectives and the communities of different construction ages. The geographical detector q-statistic can be applied to assess the strength of driving forces for the spatial pattern of community heat islands.

$$q = 1 - SSW/SST$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2 \ , SST = N\sigma^2 \tag{3}$$

Where h represents the stratification of dependent or independent variable factors; N_h and N represent the number of cells in layer h and the whole area, respectively; σ_h^2 and σ^2 represent the variances of the dependent variables for layer h and the whole region, respectively; and SSW and SST represent the sum of within-squares (Within Sum of Squares) and the total sum of squares (Total Sum of Squares), respectively.

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The range of q value is [0,1]. Besides, the greater the value, the closer the correlation between the independent variable and the dependent variable. When the q value is 1, it indicates that the independent variable completely controls the spatial distribution of the dependent variable; when the q value is 0, it means that the independent variable factor is irrelevant to the dependent variable.

4. Results

4.1. Community heat island by district

CUHII is classified into four classes according to the equidistant method, with each class separated by 2°C. Figure 3 shows the heat island intensity box plot for each community. The CUHII within the five central urban districts concentrates in the second and third classes. More specifically, the CUHII is higher in Liwan District than in the other districts, followed by Haizhu District, Baiyun District and Yuexiu District. Tianhe District is the lowest in terms of heat island intensity.

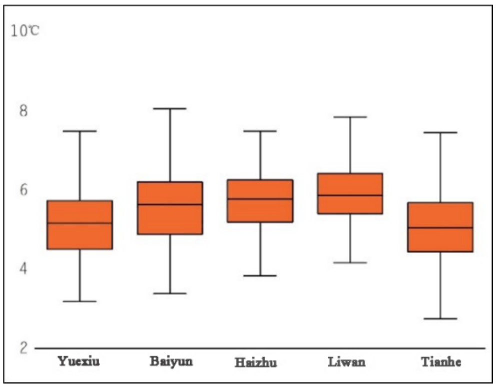

Figure 3: CUHII within the five central urban districts

The impact of each variable on the CUHII was calculated by using geo-Detector, the divergence and factor detection. Besides, the natural breakpoint method was used to divide the calculation results into 5 levels, with the values assigned in order from 1 to 5 (Table 1).

Table 1: q values of different factors within the five central urban districts

District	Building Height	Plot ratio	Building Density	total number of households	Greening Rate
Yuexiu	0.0704	0.0354	0.0213	0.0066	0.0369
Baiyun	0.0566	0.0124	0.0300	0.0119	0.1863
Haizhu	0.0949	0.0638	0.0302	0.0559	0.0435
Liwan	0.2118	0.1628	0.0613	0.0148	0.0588
Tianhe	0.0670	0.0643	0.0365	0.0118	0.0329
sum	0.1007	0.0436	0.0082	0.0127	0.0412

*The greater the value of q, the stronger correlation between the variable with CUHII.

The strength of interpretability of the six community factors on CUHII is assessed against building height, plot ratio, green ratio, the total number of households, and the building density within the whole study area. Building height shows the most significant correlation with CUHII. In these districts including Haizhu, Liwan and Tianhe, building height and plot ratio have a closer correlation with CUHII compared to the other three factors. The q value of building density in Liwan district is substantially higher compared to the other factors. This is mainly because this district is the oldest central urban district characterized by severe aging of buildings, high building density and a much lower greening rate relative to other districts(Figure 4).

To sum up, an analysis is conducted in this paper regarding the impact of six community factors on CUHII within the five central urban districts. It is discovered that building height has a much closer correlation with CUHII than the other variables, which can be accounted for by the greater energy consumption required for the operation and maintenance of high-rise buildings. Within each district, the correlation between six factors and CUHII various. Therefore, more factors are worth considering to build a better community heat environment.

4.2. Community heat island by the age of construction

The communities in these five central urban districts are divided into five time periods according to the era in which they were built: the 1970s, the 1980s, the 1990s, the 2000s and the 2110s. Considering the too small number of communities in the 1970s and the 1980s, the communities of the 1970s are classified into the communities of the 1980s.

Figure 4 shows the heat island intensity box plot for each community in different ages of the construction. The CUHII in different ages of the construction concentrates in the second and third levels(4~8°C), showing an upward trend with the age of construction.

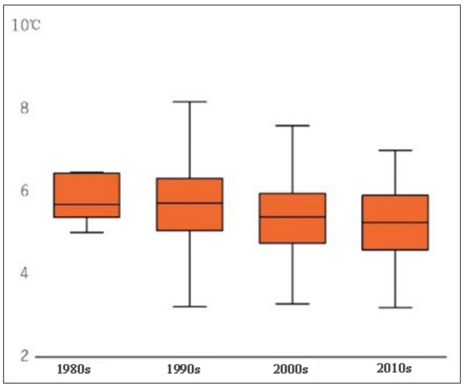

Figure 4: CUHII in different age of the construction.

For the communities in the 1980s, plot ratio has the most significant correlation with the CUHII compared to the other factors with a q value of 0.1328(table 2). While in the 1990s, building height was most significantly correlated with the CUHII. It appears that none of these factors have a close correlation with the CUHII in the 2000s, despite the fact that building height and plot ratio have a much more significant correlation with the CUHII than the others in the 2010s.

Table 2: q values of different factors of community in different age of the construction.

Year	Building Height	Plot ratio	Building Density	total number of households	Greening Rate
1980s	0.0160	0.1328	0.0295	0.3593	0.6319
1990s	0.1312	0.0075	0.0066	0.0234	0.0347
2000s	0.0752	0.0532	0.0218	0.0091	0.0421
2010s	0.1283	0.1384	0.015	0.0306	0.0599
sum	0.0160	0.1328	0.0295	0.3593	0.6319

* The greater the value of q, the stronger correlation between the variable with CUHII.

There is an increasing trend shown over time by the correlation between the spatial anisotropy of CUHII and the following four factors, building Height, plot ratio, the total number of households, greening rate, which is closely linked to the development of urban planning and design. In order to accommodate more people on a limited amount of land, the planners adopted the planning ideology of high-rise buildings in Hong Kong, where the geographical conditions are similar but construction development is far more mature. With the application of shear wall structure, the height community buildings increases constantly, as does the plot ratio of the community, so as to enhance economic efficiency.

5. Discussion

In the present study, the landsat-8 surface temperature product dataset is used to retrieve the real surface temperature of Guangzhou city. Then, by using the land cover/use dataset and DEM data, the community urban heat island intensity (CUHII) of each center urban district is calculated to analyze the correlation between CUHII and six community factors: plot ratio, building height, building density, the total number of community households, greening rate, and the changes in CUHII over time. With the assistance of geo-detector, building height, floor area ratio, and greenery ratio are identified as the significant influencing factors for the CUHII.

In response to the current situation that there are differences in the dominant factors for CUHII in

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different construction eras, it is necessary to take different measures. Due to the increase in plot ratio and the total number of households in the communities from 1980s to 2010s, the community heat island effect has become more evident. However, it is difficult to change these two factors in a short period of time. For the greening of such communities, Liu [21] proposed that the temperature of the community can be significantly reduced by increasing the greening rate as appropriate. The effective solutions to reducing the community heat island and create an agreeable thermal environment include the construction of vertical greening and rooftop gardens, the green space planning mode of "group green space + residential green space", the reasonable configuration of outdoor landscape vegetation and the enhancement of urban ventilation. In the future practice of urban planning and design, it is necessary to properly restrict the high-rise buildings above 80m, and impose control on the lower limit of building height in communities with a greater plot ratio than 2. In addition, there are some important factors for the further studies on the CUHII, such as building orientation and layout, visible sky factor, building material and thermal performance, and indoor landscape vegetation.

6. Conclusions

For different administrative regions, the strength of correlation between these five factors and the spatial pattern of CUHII is as follows: building height is the most significant, followed by plot ratio, greening ratio, the total number of households, building density, and CUHII is mainly concentrated in 4-8℃. CUHII is the highest in Liwan district and lowest in Tianhe district. For the whole study area, CUHII shows an "L-shaped" spatial pattern of being high in the south and the west, but low in the north and the east. The major impact factors in CUHII vary by community, which requires urban planners to consider the local conditions for building an agreeable community heat environment.

In different building ages, CUHII increases over time. Besides, the newer the communities, the less evident the heat island effect. The correlation between spatial anisotropy of CUHII and the following four factors, which are building height, plot ratio, the total number of households, greening rate, shows an increasing trend from the 1990s to the 2010s. For the communities built in the last century, it is worth paying attention to the reasonable layout of outdoor landscape vegetation. Differently, for the communities built in the new century, it is essential to focus on controlling the height of community buildings, not only by limiting the height of excessive buildings, but also by restricting the building height with a limit of 18-meter and a plot ratio greater than 2.

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