EXPLORING SPATIAL HETEROGENEITY OF URBAN HEAT ISLAND THROUGH BUILT ENVIRONMENT MORPHOLOGY

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ABSTRACT

Urban heat island (UHI) is a phenomenon of urban thermal environment, a complex spatial dynamic process of physical environment and human activities. The morphology of built environment is central to the complexity because of heterogenous urban fabrics and density. Multiple regression models of UHI can only explain the relationship of land surface temperature to the area amount of land cover variables. The difference of local buildings' morphology definitely mean various air fluid dynamics, and it is a spatial heterogenous of UHI.

The research aims to investigate the variability in land surface temperature across different parts of an urban area, and to understand how this variation is influenced by the physical characteristics of the built environment. Measurements by landscape ecology theory is discussed as a quantitative description of built environment morphology, and applied to bivariate local spatial autocorrelation analysis to reveal the spatial heterogeneity of UHI.

The ASTER LST infrared satellite imagines of Taichung were collected for empirical study UHI of the study area Taichiung. Indicators of spatial association (LISA) analysis is conducted to identify areas with higher UHI intensity and land surface temperature (LST). Additionally, Kriging and Contour analyses are employed to locate areas with high UHI values and represent them using contour lines, revealing the spatial characteristics associated with high UHI values. Finally, these analytical results are used to define the boundaries of different urban heat island areas in the study region.

The findings of the research indicate that the heat island effect is not particularly significant in the outlying urban areas, which encompass the North, West, and South Tuen districts. These regions are predominantly characterized by low-rise buildings and a limited building coverage, mainly comprising structures with specific attributes falling within the range of ($0 \leq L < 3$ and $0 \leq GSI < 0.15$). Conversely, within the city center and the surrounding regions of the Central, Western, and Northern districts, the heat island effect is notably pronounced. In this area, there are also community plots where the heat island effect is scattered and substantial, marked by buildings of medium height and a texture that ranges from medium to high compactness ($3 \leq L < 7$ and $GSI \geq 0.25$). In most instances, it illustrates a relationship where high values of GSI, FSI, and L correlate with low OSR, corresponding to elevated UHII levels.

KEYWORDS _ *Urban Heat Island, spatial heterogeneity, Indicators of spatial association (LISA)*

INTRODUCTION

UHI is seen as an urban development area that is significantly warmer than its surrounding rural areas due to the built environment and the human activities occurred. The urban heat island intensity (UHII) can be quantified as "ΔT_(u-r)", which subtracts the temperature between urban and rural areas (Memon, Leung et al. 2009), and the urban hear island area shows a larger temperature difference at night than during the day and is most apparent when winds are weak (Roth, Oke, & Emery, 1989).

As urban heat island (UHI) is a complex spatial dynamic process of human activities occurred physical environment, the morphology of built environment plays an important role to the complexity because of heterogeneous urban fabrics and density. Multiple regression models have been one of main approaches in modelling the relationship of land surface temperature to the area amount of land cover variables. The difference of local buildings' morphology definitely mean various air fluid dynamics, and it is a spatial heterogeneous of UHI.

In recent years, some studied the relationship between the spatial pattern of UHI and factors of it, including LST (Land Surface Temperature) clusters analysis and the spatial transformation of vegetation to identify the direction of urban sprawl (Majumdar & Biswas, 2016), another one is analysing the relationship between LST clusters/hot spots and the compositions of the land surface resulting in the discovering the high differences of landscapes between clusters (G. Guo et al., 2015). Those studies are on the focus to reveal spatial heterogeneous of UHI phenomena by spatial patterns. However, there is few discussions about fabrics, so this study aims at clarifying the relationship between the fabric density measures and UHI spatial pattern.

RESEARCH DESIGN & METHODOLOGY

To analyse the relationship between urban heat island (UHI) and urban fabrics, multiple methodologies are utilized, see Figure1 for the research framework. Firstly, an UHI map is created to visualize the UHI spatial patterns. Then, local indicators of spatial association (LISA) analysis (Anselin, 1995) is conducted to identify areas with higher UHI intensity and land surface temperature (LST) compared to the surrounding regions, thereby pinpointing the distribution of heat island areas. Additionally, Kriging and Contour analyses are employed to locate areas with high UHI values and represent them using contour lines, revealing the spatial characteristics associated with high UHI values. Finally, these analytical results are used to define the boundaries of different urban heat island areas in the study region.

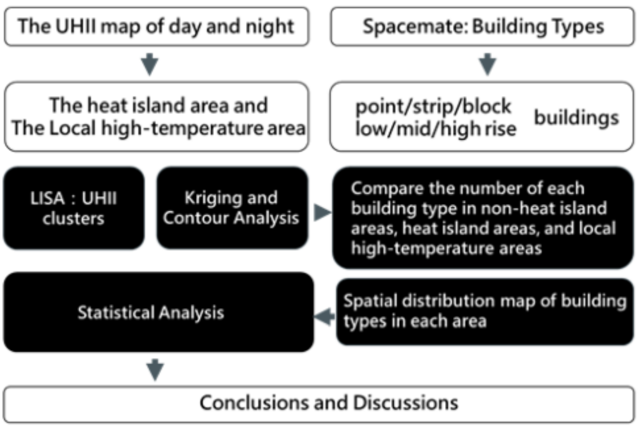

Figure 1: The design of research framework

On the other hand, Spacemate's multiple density indices (Haupt, Pont, and Moudon, 2005) are used to measure and classify built environment based on building types. Each building type is characterized by multiple density indices that capture the urban fabric properties if the local. Subsequently, the quantity and distribution of different building types in areas exhibiting distinct heat island characteristics are analysed to identify the types and abundance of buildings affected by varying degrees of heat island effects.

Furthermore, statistical analysis is employed to investigate the relationships between Spacemate's density indices and UHI variations. Firstly, the average values of each density index in areas with different heat island characteristics are compared to determine if the average density indices vary according to the intensity of heat island effects. Moreover, correlation analysis and scatter plots are used to examine the interactive trends between each density index and UHI.

URBAN HEAT ISLAND AREA (UHI) IDENTIFICATION

This study used the ASTER Kinetic Surface Temperature provided by NASA that ASTER surface temperature data for multiple time periods over a long duration, although it lacks multiple time periods data within a single day or month. However, it has the advantage of high spatial resolution of 90m and high algorithm accuracy, as well as the availability of imagery for both daytime and night time. especially it is widely used in many research studies (Gillespie et al., 1998; Ando et al., 2009; Hartz et al., 2006; Kato et al., 2008; Mavrogianni et al., 2009).

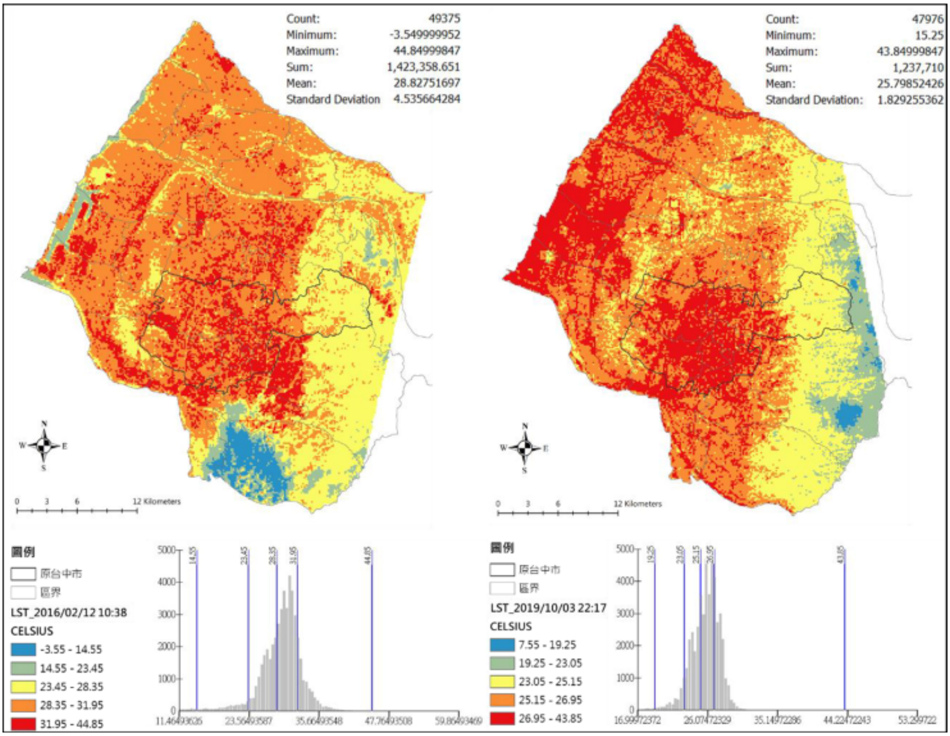

Figure 2: (a) The day time UHII map of Taichung, (b) The night time UHII map of Taichung.

The study area is Taichung City, Taiwan, 163 square kilometers, accounting for 7% of the area is plain, far away from the coast, and there are no highly developed towns around, so its UHI phenomenon is obvious.

The 150 m grid is the unit of analysis for urban form (Ye & Van Nes, 2014), so it is used to divide the buildings in Taichung City. Also, the area of the grid is regarded as the fabric area (Van Nes, Berghauser Pont, & Mashhoodi, 2012). We got 5,489 urban fabric grids, and each grid has Ground Floor Space Index(GSI), Floor Space Index(FSI), Open Space Ratio(OSR), Layer(L), and UHII data for its location.

MEASUREMENT OF URBAN FABRICS

The measurement of building density has traditionally been an integral tool in urban design and planning for prescriptive and descriptive purposes, and has been applied to the classification and interpretation of building types (Alexander, Reed, & Murphy, 1988; Diamond, 1976; Martin & March, 1972; Moudon, 1994, 1997). Haupt, Pont, and Moudon (2005) developed Spacemate: multiple parameters of density, which combines multiple density indicators, so the built form can be described correctly. In this study, the dots on the scatter plot represent an urban fabric grid (Figure 3).

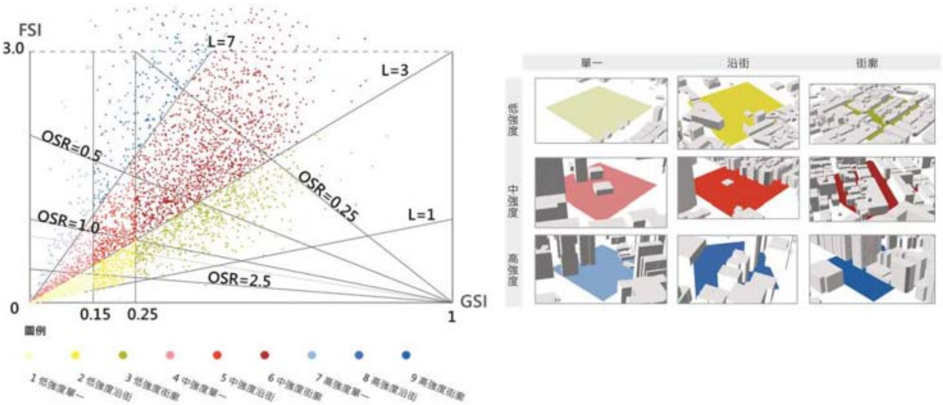

Figure. 3: Spacemate Plane and nine Building Types

RESULTS AND DISCUSSION

Generally speaking, the UHI effect in urban areas is more than that in highly developed rural areas where is higher than in low-developed rural areas, which is higher than rural areas. This fact is particularly obvious during day time. The temperature difference between the country and other regions is 2 to 3 degrees Celsius higher than at night. Besides, the average UHII in H-H areas during the day is 1.6 to 1.8 degrees Celsius higher than the average at night, which is the same result as in urban areas. Therefore, regardless of the entire area of Taichung City or the urban area, the UHI effect will have a greater impact during the day.

Regarding the fact of global influence, according to the analysis of LISA and Kriging and Contour, we know that the urban area of Taichung city is the main area of the UHII cluster. On the other hand, the fact that local effects can be seen during the day, the ports on the west coast, and the industrial areas in the urban area exhibit extreme UHI effects, but no places are suffering extreme UHI at night.

Finally, through the Spacemate plane, we see the interaction between the urban fabric and the UHI phenomenon, which shows that as the degree of UHII increases, GSI, FSI, and L increase, while OSR decreases. This applies to non-heat island areas mainly composed of low-rise point buildings, as well as heat islands and higher temperature areas mainly composed of mid-rise block buildings, whether day or night. They all follow this rule: from local high-temperature areas to heat island areas, and then to non-heat island areas, the urban fabric changes from highly developed and highly intensive to low development and less intensive.

Last but not least, we should remember that, except for the urban fabric, due to certain factors, every area has outliers. These make them appear higher or lower the UHI effect than other similar fabrics. This study comprehensively describes the urban fabric and its interaction with the UHI spatial pattern, thereby providing an opportunity to find the performance of the UHI effect based on the characteristics of these urban fabrics.

It is concluded the Spacemate analysis map highlights the interplay between building-texture characteristics and heat island intensity. In most instances, it illustrates a relationship where high values of GSI, FSI, and L correlate with low OSR, corresponding to elevated UHII levels.

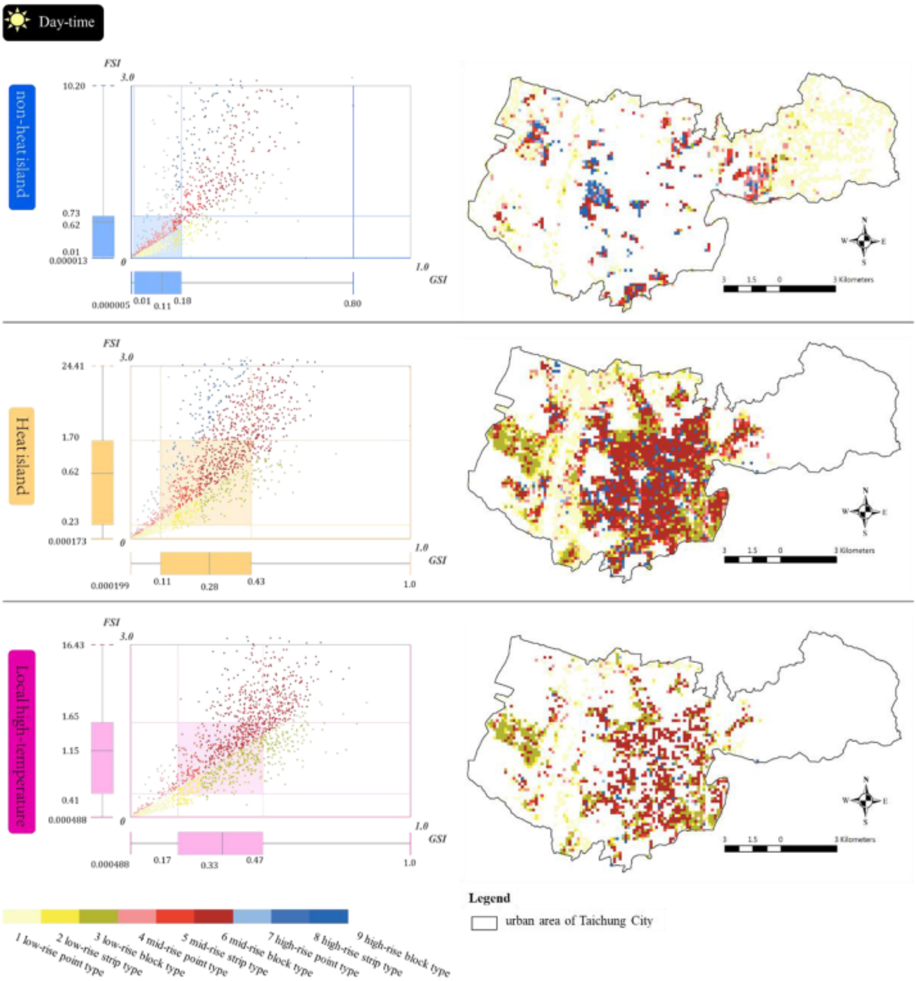

Figure 4: Spacemate Plane and the Building types map of non-heat island area, heat island area, and local high-temperature area during day time.

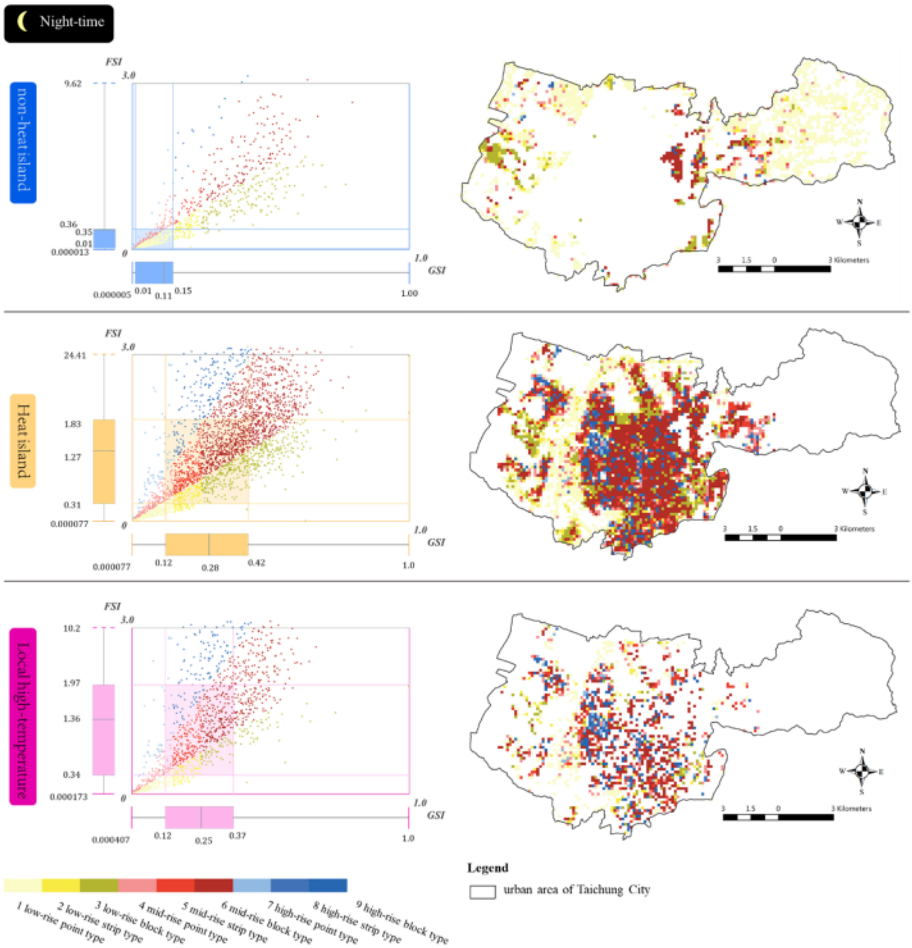

Figure 5: Spacemate Plane and the Building types map of non-heat island area, heat island area, and local high-temperature area during night time.

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