Analysis of Mechanism for Formation of Urban Thermal Environment

——A Case of Shanghai

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***Abstract*- The transformation of natural landscapes into highly human-dominated environments is placing increased pressure on local and global ecosystems. One direct result of this transformation, so called "Urban heat island (UHI) phenomenon", is regarded as one of the most pervasive environmental problems nowadays. There is increasing evidence that the existence of UHI may bring a lot of troubles to the urban environment, further influence the sustainable development of urban and force urban planners to focus on the broad research on UHI.**

This paper based on TM image, choosing Shanghai as study area, analyzes the impact factors of urban thermal environment and attempts to explain the mechanism of urban thermal environment by a few but effective factors. For the sake of the accuracy and accordance with actuality, Principal Components Analysis is applied after spatial autocorrelation of the factors is eliminated. The results show that urban construction, industry distribution, land surface characters and landscape diversity become the most important factors to the formation and mechanism of urban thermal environment of Shanghai. This result can undoubtedly provide an excellent platform from which we can launch other investigations to better our environment. Meanwhile, the understanding of mechanism of urban thermal environment and more, taking measures to lessen the intensity of urban thermal environment are of great significance to improve life-quality of humankind and further maintain the sustainable development of urban.

***Keywords:* urban thermal environment; mechanism; Shanghai**

Ⅰ. INTRODUCTION

The urban heat island (UHI) is a well-known feature of urban thermal environment. Heat islands form as cities replace natural vegetation with pavement for roads, buildings, and other structures necessary to accommodate growing populations [1]. These impervious surfaces absorb – rather than reflect – the sun's heat, causing surface temperatures and overall ambient temperatures to rise. This phenomenon also forces the development of meteorological events (increased precipitation), boosts energy demands, poses threats to public health, and potentially contributes to global warming. UHI phenomenon has close linkage with wide-range socio-economic activities. So it is necessary for each party such as the central government, local governments, business and residents to take various measures [2].

Researchers have long been devoted to the studies of mechanism of UHI [3][4][5][6]. Physical land cover, human activities and environmental conditions combine to decide the main driving force behind urban thermal environment. Previous researches studied its mechanism either by contrastive analysis of temporal temperature between urban and suburb or routine regression analysis to simulate the relation between urban thermal environment and its impact factors [7]. However, partly due to the complex interaction of the magnitude of impact factors and partly to the particularity of distinct areas, our understanding of mechanism of urban thermal environment still remains incomplete [8].

Through the science of remote sensing, data on the state and condition of the land surface can be collected. Thermal infrared (TIR) sensors can obtain quantitative information on the amount of heat that is expressed by different surfaces across the landscape. These TIR data are critical for deriving land surface temperatures (LST) across the urban landscape and ultimately, for determining the magnitude of UHI over an urban area [2].

A case study is presented to characterize aspects of mechanism of urban thermal environment in Shanghai. As one of the most developed cities in China, Shanghai is undergoing great changes and suffering negative impacts of UHI as other metropolis in world. The purpose of this paper is to investigate the contributors to UHI in Shanghai and attempt to explain the causes and mechanism of the formation of UHI within Shanghai by use of remote sensed data.

Ⅱ. STUDY AREA AND METHODOLOGY

Shanghai, an important economic center and transport center on the east coast of China, is becoming an international modem metropolis. The rapid development brings on a series of environmental problems and UHI phenomenon can be obviously detected in Shanghai. This study focused on the city proper of Shanghai, i.e. within the Out Ring Road of Shanghai. (Fig.1)

Ⅲ. DATA AND METHODOLOGY

A. Computation of Surface Radiant Temperature

The data used in this study were Landsat Thematic Mapper (TM) image, dated on 14 June 2000 referred as a Level 1G product, which was rectified to a Shanghai local coordinate system. Nearest-neighbor algorithm was used for resampling

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with a pixel size of 60m by 60m for thermal infrared band (band 6) and 30m by 30m for other bands. Surface radiant temperatures were then derived from geometrically corrected TM thermal infrared data (band 6) according to the function and calibration constants offered by NASA [9].

B. Chosen of Impact Factors to UHI

As mentioned above, the mechanism of UHI is the result of complicatedly combined action of social, economic and ecological factors. However, some of the impact factors are difficult to remedy, while some are within our easy control. Considering the availability of data and actual circumstances, we classified the possible impact factors into three principal categories and altogether nine sub- categories (Tab.1).

It should be noted that all these data are resampled to raster format with pixel size of 500m×500m so as to reduce high spatial correlation among the factors.

C. Methodology

Principal Component Analysis (PCA) was applied in this study to eliminate the interaction among impact factors. PCA involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components (PC). The first PC accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. And we consider the remaining impact factors to UHI can both discover or to reduce the dimensionality of all the impact factors and meanwhile identify new meaningful underlying factors. The calculation of PCA in this study is performed in Arc/Info.

Ⅳ. Results And Analysis

A. Calculation of PCA

All the nine impact factors were taken for input variables and the result was shown in Tab. 2. The first four PCs reached 87.359% of the total information and were regarded to be the effective and few factors to explain the mechanism of UHI.

Tab. 3 gave out the detailed intrinsic components of the 4 PCs. Building Density and Plot Ratio contributed most while NDVI and Vegetation Fraction reduced the impact of the 1st PC; the 2nd PC mainly referred to Industry Density while the rest factors contributed little or even reduced the impact; as for the 3rd PC, Impervious Surface, NDVI, SHDI and Vegetation Fraction became the main contributors to UHI while Building Density and Plot Ratio which had positive influences in the 1st PC showed negative influences here in the 3rd PC; SHDI becomes the dominating factor in 4th PC.

As a conclusion, we considered that the 4 PCs represent urban construction (mainly owes to urban building and centralization of population), industry distribution, land surface characters and landscape diversity respectively. And in general, particularly to this study area, the mechanism of UHI comes down to the above 4 factors ranked by influencing intensity.

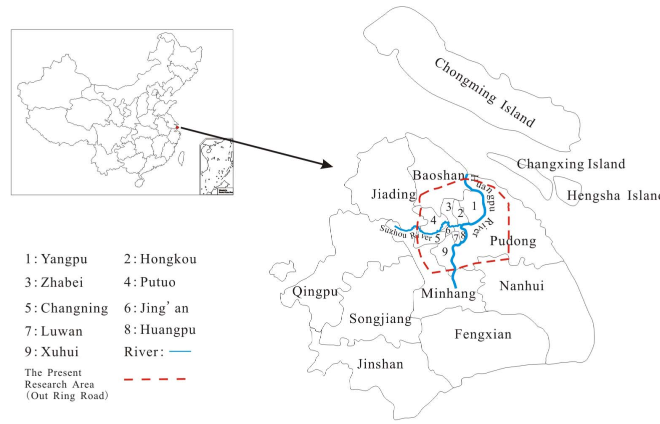

Figure 1. Shanghai city at the estuary of Yangtze River. Note our study area is within a specific road: Out Ring Road.

B. Spatial Distribution of 4 PCs

To get further understanding of the mechanism of UHI, detailed spatial distribution graphs of 4 PCs were drawn through the whole study area (Fig. 2).

For the PC of urban construction, high values were mainly detected in the core area west of HuangPu River. While the east part showed a gradually decreasing tendency from centre to fringe except for some regions along HuangPu River where low values were detected. This distributing phenomena obviously accords with that of UHI. The 2nd PC was highly influenced by industry, hence, the distribution of it related to that of industries within study area. Likewise, it was regarded as heat source of urban thermal environment and reinforced the impact on UHI. The 3rd PC characterized land cover/ land use of the study area. High values were found where parks, green spaces (open spaces) were in core area and farmlands were at fringes. Rivers and water bodies showed low values here due to the obvious effect of reducing the intensity of UHI. The 4th PC stood for the landscape diversity and was codetermined by mass factors of economy, society and ecology. Generally, high values were detected along the fringes of urban. As land cover/ land use of HuangPu River distinctly differed from its ambience, high values could also

TABLE 1: Impact Factors to UHI

Principal categories	Sub-categories	Explanation of impact factors
character of urban surface	Building Density	Ratio of bottom surface and total building area
	Plot Ratio	Ratio of building area and total area
	Impervious Surface	Ratio of both high and low albedo within one pixel
intensity of human activities	Population Density	Population per unit area
	Road Density	Length of roads per unit area
	Industry Density	Land use of industry per unit area
ecological environment	NDVI	The abundance of vegetation
	Vegetation Fraction	Ratio of vegetation with in one pixel
	SHDI	Diversity of land use

TABLE 2: Eigenvalues of Each PC and Its Proportion

Principal Component	Eigenvalues	Proportion (%)	Cumulative Proportion (%)
1	1109.464	45.539	45.539
2	612.265	25.131	70.671
3	232.455	9.541	80.212
4	174.122	7.147	87.359
5	102.209	4.195	91.554
6	88.987	3.653	95.207
7	59.222	2.431	97.638
8	54.840	2.251	99.889
9	2.707	0.111	100.00

be detected along the river. It was concluded that landscape diversity may improve the quality of urban thermal environment.

C. Modeling

Given the above 4 PCs as a basis, a integrated model for urban thermal environment of Shanghai city was established.

$$Y = 0.4554\times Y_1 + 0.2513\times Y_2 + 0.0954\times Y_3 + 0.0715\times Y_4$$

Where Y referred to the composite factor of urban thermal environment, $Y_1 \ldots Y_4$ represented 4 PCs as discussed above, i.e. urban construction, industry distribution, land surface character and landscape diversity. This model passed both *F*-test and *T*-test.

Fig. 3 shows the spatial distribution of composite factor of UHI in Shanghai. High values appeared in the relatively developed areas, for instance, core area and the west part of study area. While low values were commonly found at fringes and where parks and green spaces (open spaces) were located within urban.

To checkout the accordance of this model and UHI, correlation analysis was then performed between LST and calculated composite factor, compared with that of the original 9 impact factors. The correlation coefficients resulted to be 0.8504 for Impervious Surface, 0.3388 for Industry Distribution, 0.6907 for Building Density, 0.4990 for Plot Ratio, -0.4206 for NDVI, 0.4753 for Population Density, 0.4743 for Road Density, 0.4422 for SHDI, -0.6272 for Vegetation Fraction and 0.8250 for Composite Factor.

TABLE 3: Eigenvalues of Each PC

Impact Factors	1st PC	2nd PC	3rd PC	4th PC
impervious surface	0.3567	0.0873	0.5296	-0.2140
industry density	0.0617	0.9215	0.0922	-0.1953
building density	0.4143	0.0438	-0.0673	-0.0894
plot ratio	0.4221	-0.1719	-0.0450	-0.2172
NDVI	-0.2944	-0.0909	0.5623	-0.2066
population density	0.3620	-0.2605	0.0784	-0.3070
road density	0.2814	-0.1180	0.1990	-0.0395
SHDI	0.2547	0.0461	0.4017	0.8334
vegetation fraction	-0.3966	-0.1398	0.4257	-0.1671

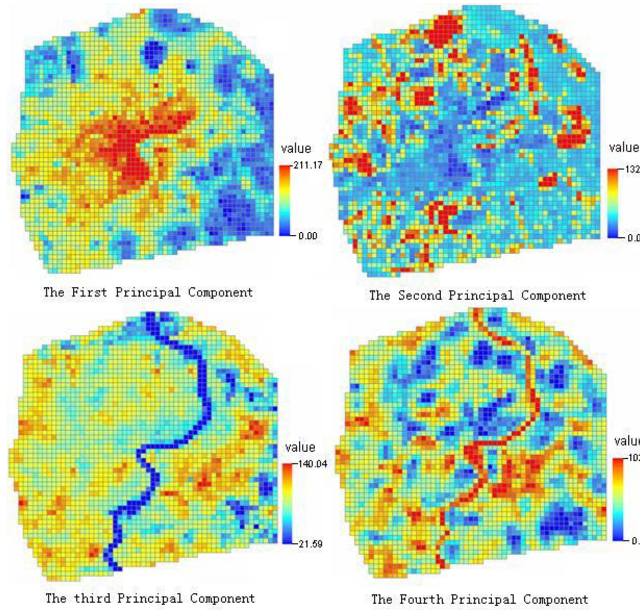

Figure 2. Spatial distribution of the first four PCs

It was clear that except for impervious surface, other factors do not show high relation to urban LST. Correlation coefficient of composite factor and LST reached 0.8250 and was far higher than other individual factors except for impervious surface. Moreover, high correlation which was detected between impervious and LST was due to the significant influence of land surface characters when deriving LST. As urban thermal environment is influenced by various factors as natural climate and human activities, this integrated model may reflect the mechanism of urban thermal environment and the process of its formation in an all-around level for Shanghai city.

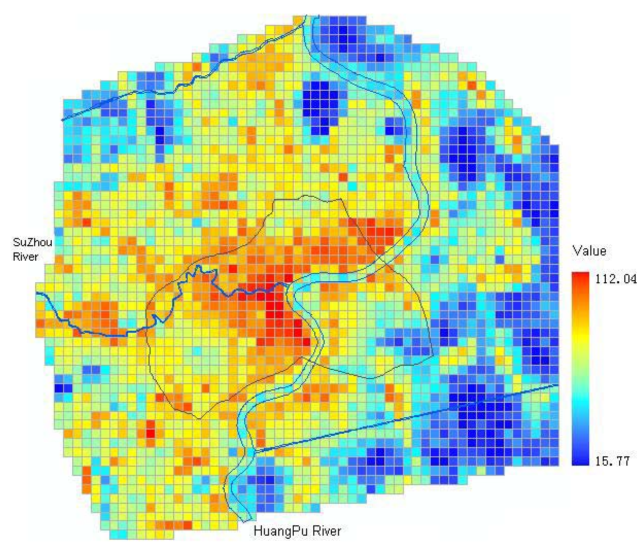

Figure 3. Spatial distribution of composite factor in Shanghai

V. CONCLUTION

Urban entironment provides unique opportunities to test the complex interactions between human and ecological environment. Although impacts of urban development often seem local, they cause environmental changes at larger scales. Shanghai, as other metropolis in the world, confronts the environmental problem known as UHI. A better understanding of the mechanism of urban thermal environment should improve our knowledge of impacts of urbanization as well as our ability to specify the causes for this phenomenon and further rebuilt a more sustainable environment for humans.

The findings of our study indicate that: (1) the application of PCA reduces the mass data and centralizes the spatial information to a few but effective factors which can easily and clearly explain mechanism of UHI; (2) there are fourprincipal factors, urban construction, industry distribution, land surface characters and landscape diversity, combined affecting the formation of urban thermal environment in Shanghai. And they distribute differently in spatial, which may set a more exact and correct goal to the construction of urban ecological environment and provide some basis in urban planning; (3) the composite factor calculated by the integrated model highly related with LST, which makes out that it can well reflect the mechanism of urban thermal environment. Hence, for urban planners, more importance may be attached to those areas with high values to lessen the intensity of UHI; (4) as urban thermal environment is a complex system itself, there might be still some factors should be taken into consideration. Further study may be carried on.

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