Impacts of urbanization on surface urban heat island in Beijing, China

急速な都市化によって多くの環境問題を抱えこんだ北京。最新の観測データを用い、都市化の進行に伴うヒートアイランド現象の深刻さを解明する。

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Abstract

As the capital of China, Beijing has become a world city after decades of development. Urbanization in Beijing has brought not only many benefits for the residents but also kinds of environmental problems to the city. It is necessary and meaningful to have a comprehensive investigation of the urban situation in Beijing. In addition, with the development and wide application in urban studies, the remote sensing technology was put into use as a significant tool in this study which including DMSP-OLS and Landsat TM/ETM.

This study was made up with two aspects: the urbanization investigation and the urban heat island effect survey. For the first part, the investigation was carried out by the correlation analysis with the official statistics and the night time light series images from DMSP-OLS. Another important aspect of this study is the urban heat island effect survey, the Landsat TM/ETM data in 1995 and 2009 was processed to provide the vegetation coverage and land surface temperature distribution in the study region. By using the correlation analysis and regression analysis, the comprehensive understanding of the phenomenon of urban heat island in Beijing can be got and come to a conclusion.

Keywords urbanization, urban heat island, DMSP/OLS, Landsat, land surface temperature

1. Introduction

With the rapid development of economies, the sustained growth of the population, the fast urbanization and modernization, a number of the metropolis have emerged in the world. As China's capital city, the scale and process of urbanization in Beijing is remarkable, especially after the Chinese economic reform in recent decades. Moreover, high rate of urbanization also contributes to the change of the living environment such as global warming, urban heat island, air pollution, etc. One of the major implications of urbanization is increase of surface temperature and development of urban heat island. For this research, the analysis was focused on the processing of urbanization and the situation of urban heat island in Beijing.

As mentioned before, this study was made up with two aspects: the urbanization investigation and the urban heat island effect survey. For the urbanization part, the investigation was carried out by analyzing the official statistics and the DMSP-OLS, the official statistics provide the development of urbanization situation from two representative aspects: population and the economics; the night time light was applied to stand for the urbanization level and the urban land-use by necessary data processing and classification. Another important aspect of this study is the urban heat island effect survey, remote sensing

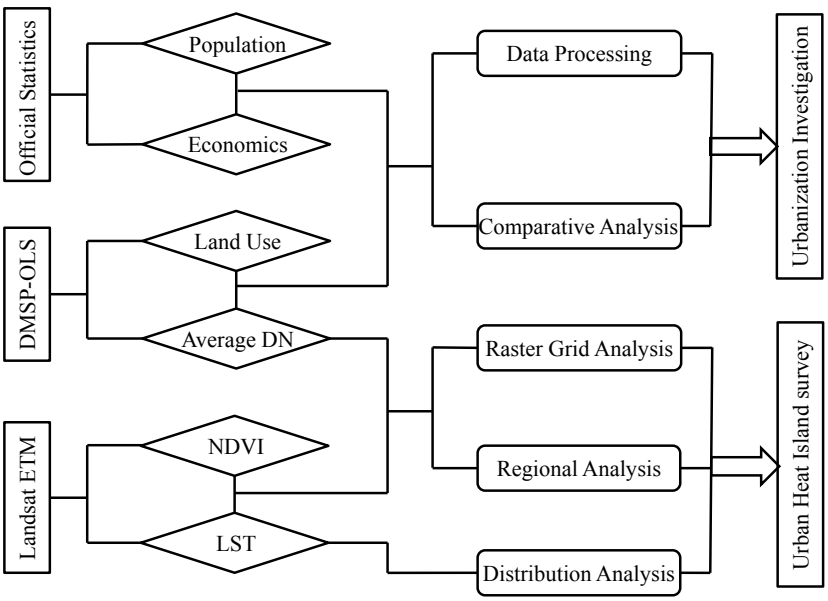

Fig. 1 Research Flow

data from Landsat TM/ETM image in 1995 and 2009 was applied to provide the situation of vegetation coverage and land surface temperature distribution in the study region. During the survey for the urban heat island, three different kinds of analysis methods were carried out to get comprehensive information from different scales which were: the raster grid analysis, the regional analysis and distribution analysis.

The objective of this research, the purpose of the investigation is to get a comprehensive understanding of what had happened to the city, propose suggestion and advice for more balanced and environmentally friendly development in the future.

2. Study area and research method

2.1 Study Area

In this research, the part of investigation of urbanization was proceed within the whole area under administration of Beijing; however, the part of urban heat island survey was proceed only within the urban area which was represented by the area within the 6th ring road to have a clear result in the downtown.

Synthetically, taken the statistical data collection and remote sensing data features into consideration, the study period in this research is from 1992 to 2012.

2.2 Research method

As the figure of research flow shows, the analysis was carried out step by step. The official statistics contain two aspects: population and economics; the night time light images from DMSP/OLS was applied to get the land use change information by classifying of the image and the urbanization level with average value of digital number; the Landsat imagery was used to get the land surface temperature (LST) and the normalized difference vegetation index (NDVI).

The analysis methods in this research include data processing, comparative analysis, raster grid analysis, regional analysis, and distribution analysis. The first two kinds of analysis methods were carried out for the investigation of urbanization in Beijing, while the remaining three methods were the important processes to get the urban heat island survey.

3. Investigation of the urbanization in Beijing

3.1 Introduction of DMSP/OLS

DMSP/OLS, whose full name is Defense Meteorological Satellite Program/Operational Line-scan System, the products from it were widely used in urban studies and energy or population research. One of the most frequently used data from DMSP/OLS is the version 4 of global night time light series, which provide annual global composited imagery from 1992 to 2012.

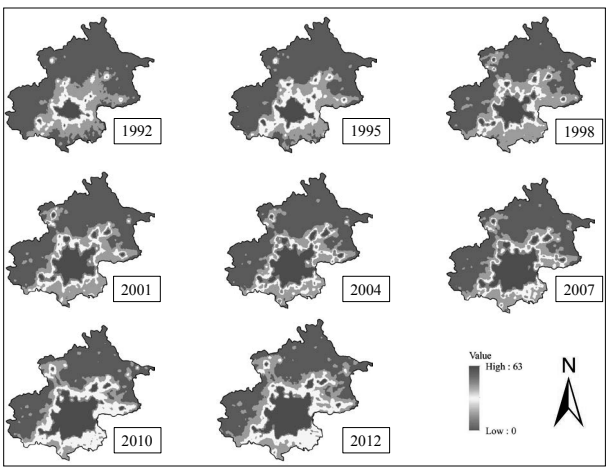

Fig. 2 Night Time Light Series Images from DMSP/OLS

3.2 Urbanization by average DN

The images from DMSP/OLS are composed of grid-based annual visible band digital number (DN) range from 0 to 63, which stand for the light intensity of the areas. The satellite-derived observations of stable anthropogenic light was used as an indication of varying degree of development, the average value of DN of all pixels within the scope was considered as an evaluation indicator of urbanization level of that year which the data was got. Figure 2 shows part of the result of the digital number in Beijing, in which the higher value of the digital number area was displayed into red and the color of blue stands for the area that hold a lower value of digital number. The change of average value of digital number was shown in the Figure 3 according to the statistical result.

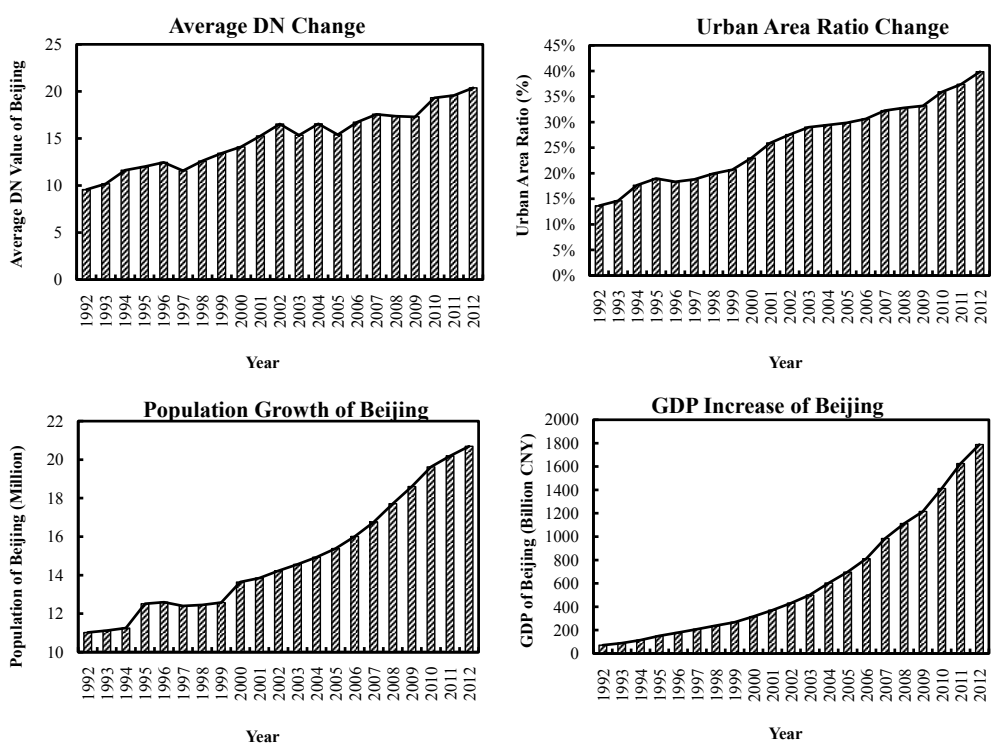

Fig. 3 Statistical Results

$$\text{Average DN}=\frac{\sum_{i=0}^{63} DN_i * N_i}{N_{Total}} \quad \cdots\cdots (1)$$

where Ni is the number of the pixels whose Digital Number value equals DNi; N_{Total} is the total number of pixels within the boundary of the study area.

3.3 Urban area extension from DMSP/OLS

ΩIt is well certified that the DMSP/OLS night time light images could be used to represent the spatial extent of human settlement of the study area, but the most important step of the land use analysis is to establish a correlation between the DN value and the different intensities of urban development, in this study, the area was divided into five types of land use classes using indices of urban compactness:

① 0≤DN<5 no-development area;
② 5≤DN<20 scattered development area;
③ 20≤DN<52 sub-urban development area;
④ 52≤DN<60 compact development area;
⑤ 60≤DN<63 central core area.

In addition, the part which DN value is greater than 20 was considered as the urban area, otherwise would be treated as the rural area. The statistics of the urban area ratio was shown in the Figure 3 which increased from 13.6% in 1992 to 39.9% after 20 years development.

3.4 Urbanization by statistics

As a matter of fact, a lot of indexes exist to describe the urbanization situation of a city, the most representative and intuitionistic among the all indicators are population and GDP. The statistics of the indicators are available from the home page of the National Bureau of Statistics of China.

Population is a clear expression of the whole process of urbanization. From 1992 to 2012, the population of Beijing increased from 11.0 million to 20.7 million, has increased 9.7 million by 1.88 times. Moreover, the economic development level to some extent can describes the standard of urbanization situation. The GDP of Beijing had an unbelievable

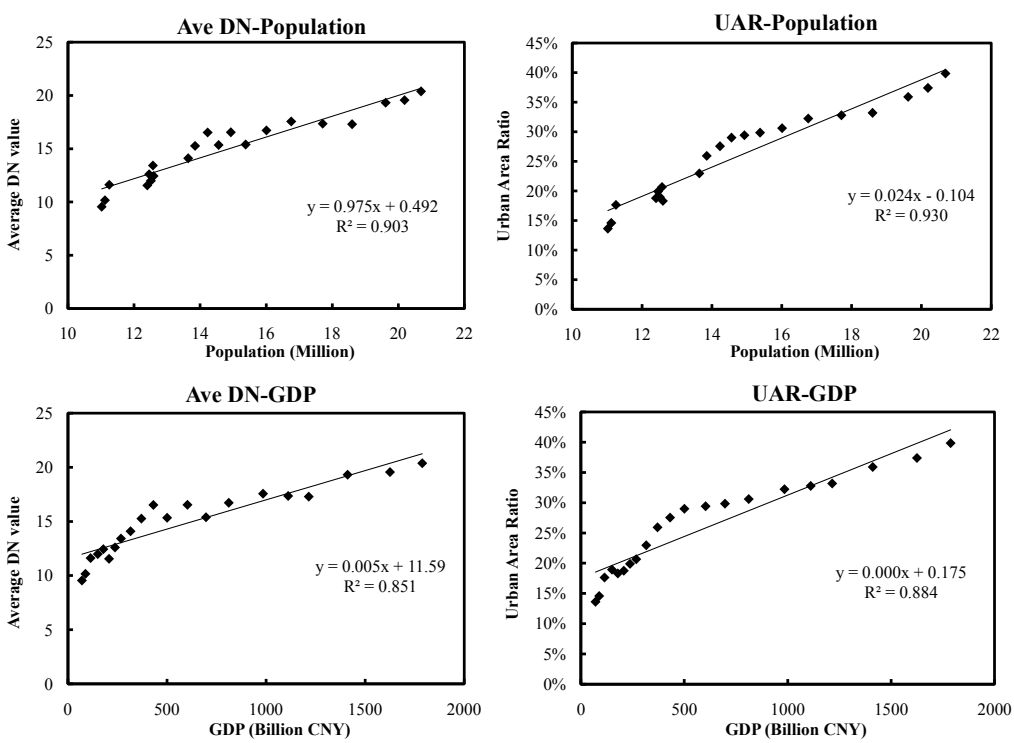

Fig. 4 Correlation Analysis of Urbanization

growth during the period by an increase of 25.21 times, from 70.91 billion CNY in 1992 but reached 1787.9 billion CNY at 2012.

Figure 4 shows the correlation analysis between the data from the remote sensing observing and the official statistics. With high value of correlation coefficient, the result proved a close relationship between the population, GDP and the urbanization condition provided by DMSP/OLS.

4. Urban heat island by Landsat

4.1 Introduction of the Landsat TM/ETM+

The Landsat Program is the longest running exercise in the collection of multispectral, digital data of the earth's surface from space. The images acquired by the instruments on the Landsat satellites, are unique resources for global change research and applications in agriculture, geology, forestry, regional planning, education and national security.

A Thematic Mapper (TM) is one of the earth observing sensors introduced in the Landsat 5. TM images consist of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Spatial resolution for Band 6 (thermal infrared) is acquired at 120 meter resolution. The TM Image has become useful tool to study global warming, climate change and urban heat island. Enhanced Thematic Mapper Plus (ETM+), which is known as a successor of TM, was carried by the satellite of Landsat 7. Table 1 shows the detailed information of the collected data in 1995 and 2009 from the Landsat program.

Table. 1 Information of the Collected Data

	1995	2009
Landsatscene ID	LT512303219952 59HAJ00	LE7123032200922 5SGS00
Station ID	HAJ	SGS
Space Craft ID	Landsat-5	Landsat-7
Sensor ID	TM	ETM+
Data Acquired	1995/09/16	2009/08/13
Scene Center Time	09:55:25	10:43:41

4.2 Derivation of NDVI

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigour of vegetation at the Low Temperature Zone Medium surface. It is a simple graphical indicator that can be used to assess whether the target being observed contains green vegetation or not, as a result, the NDVI can be considered as the index which can reflect the situation of the vegetation of the target. Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1, it can be calculated by the pixel value of band 3 and band 4 of the Landsat imagery from the equation below.

$$\mathrm{NDVI} = \frac{(\mathrm{Band4} - \mathrm{Band3})}{(\mathrm{Band4} + \mathrm{Band3})} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

4.3 Retrieval Land Surface Temperature

Land surface temperature (LST) is a key variable in climatological and environmental studies, related to surface energy balance and the integrated thermal state of the atmosphere within the planetary boundary layer. With satellite technology, another type of LST, satellite-based surface temperature is becoming available recent years. As to this study, band 6 of the Landsat imagery was used for deriving the surface temperature. The skin temperature of the surface is inferred from the thermal emission of the earth's surface and is generally average effective radiative temperature of various canopy and soil surfaces.

During the processing of the Landsat imagery, ArcGIS was put into use which played an important role to get the land surface temperature by using the tool of retrieve LST. In addition, with the data statistics and calculation, the average value of the LST can be get from different regions.

4.4 Result and analysis

To get the detailed information of the urban heat island effect in Beijing's urban area, two kinds of zonal statistic and analysis methods were used for further investigation, one is the raster grid analysis,

the other one is regional analysis.

The raster grid analysis is a kind of analysis tool which divide the target area into raster grid. In this research, within the Beijing 6th ring road, the area was divided into 3 Km grid, and among every grid, the average value of LST, NDVI and average DN was calculated as an average level of the 3 Km grid. Figure 5 shows the processing result of the raster grid analysis in 1995 and 2009. From the images of the export, we can get the general information of the distribution of the three parameters which displayed grid by grid. Figure 6 shows the correlation analy-

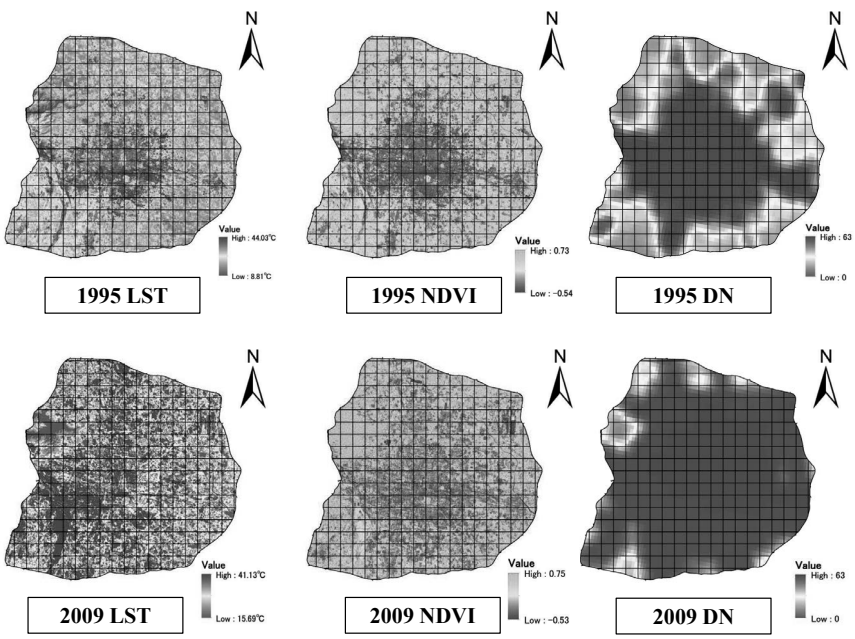

Fig. 5 Result of Raster Grid Analysis

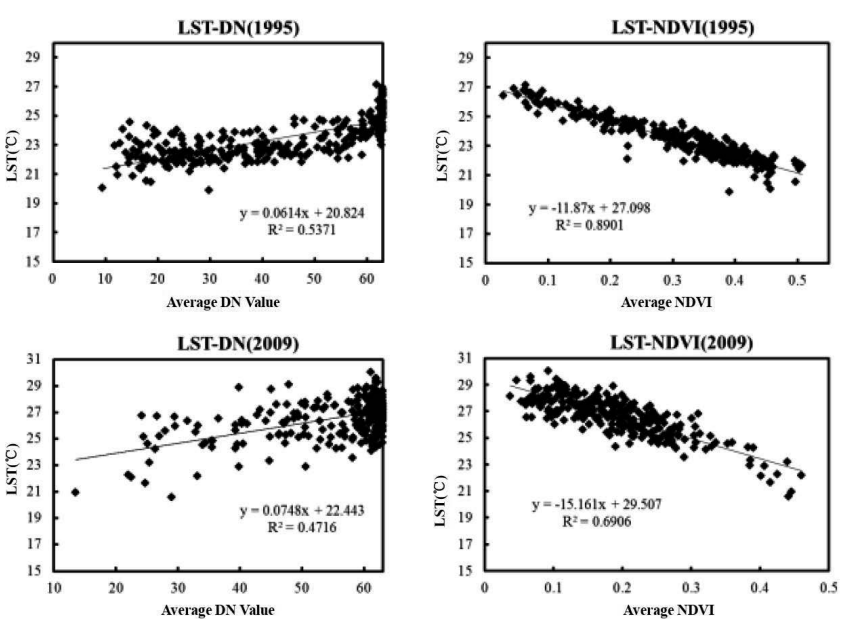

Fig. 6 Correlation Analysis of Raster Grid Analysis

sis result of the LST, NDVI and average DN which reflect the relationship between the temperature, vegetation and the average urbanization level.

The regional analysis was carried out from the ring roads scale with an obvious regional disparity. Carrying through the ring road grid analysis, we can find the distribution of the three parameters associated to the geographic distribution. Figure 7 shows the exported result of the regional analysis, in accordance with expectation, the results indicate an obvi-

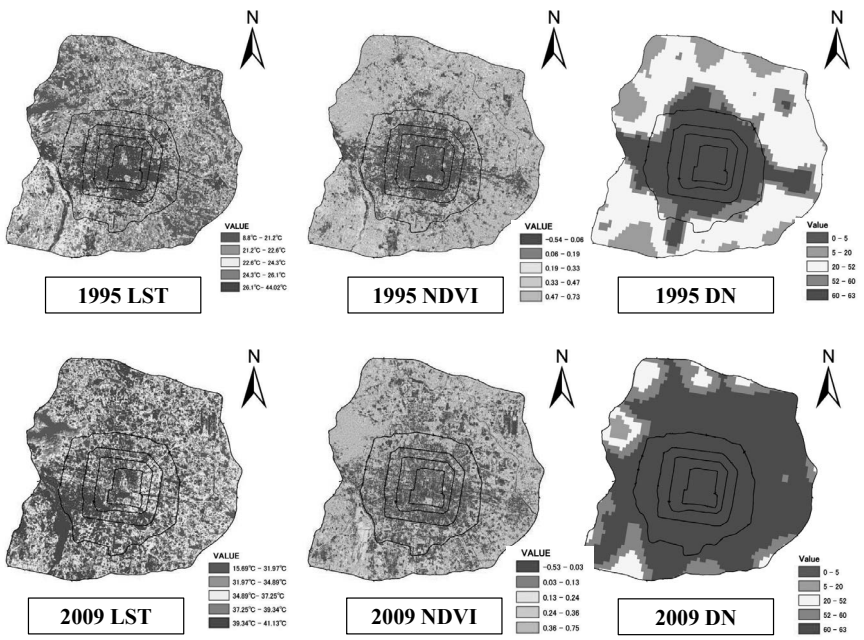

Fig. 7 Result of Regional Analysis

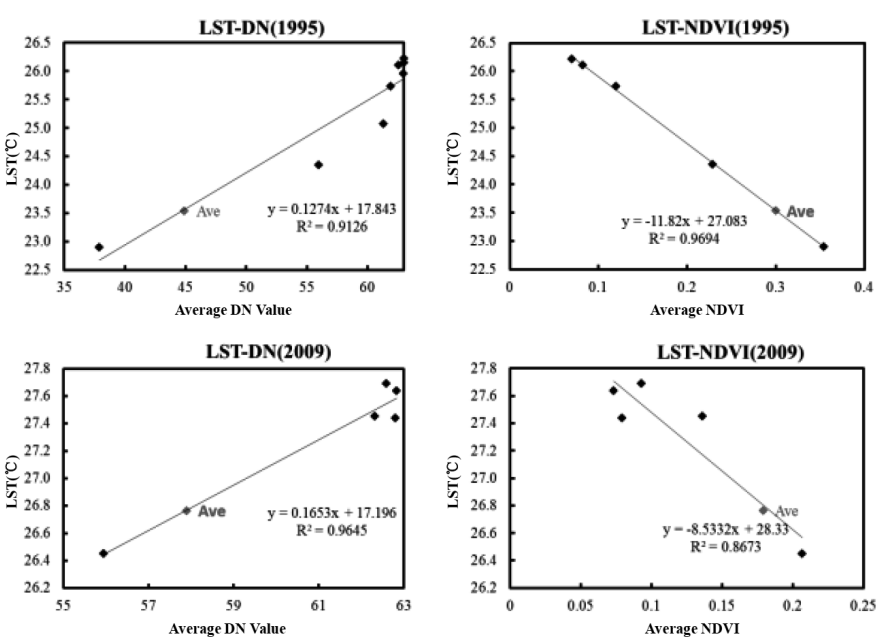

Fig. 8 Correlation Analysis of Regional Analysis

ous difference in different region, by using the zonal statistical tool, the average value of LST, NDVI and average DN was calculated and applied to correlation analysis between them, which was shown in Figure 8.

During the urban heat island study, the temperature distribution plays an important role during the research. By using the geostatistical and classification tool in ArcGIS, the isothermal diagram and zonal classification of the target area were output to draw the situation of the temperature distribution in the region. As the Figure 9 shows, by the application of an equal interval method, the area was divided into four different classes by different value of land surface temperature. The result of the classification in 1995 and 2009 was shown in Figure 10 and Figure 11. From the result, we can get a general understanding of the urban heat island phenomenon development and the situation change in the period. For the part of heat island zone and sub-heat island zone, the grid number had an increase during these years of development, the medium temperature zone and low temperature zone, to the contrary, the grid number had a reduction. In addition, the temperature difference between the heat island zone and the low temperature zone also had an increase from 4.7°C to 5.81°C.

5. Conclusion

The remote sensing data from the DMSP/OLS provided strong evidence that Beijing had gone through a markedly urbanization process during the study period by two aspects: the average level of the urbanization that represented by the average digital number and the urban area ratio that shows the urban land sprawl. In addition, the information from the statistics also proved the urbanization of Beijing by detailed figures. The result of the urbanization investigation shows the close relationship between the remote sensing observing and the official statistics

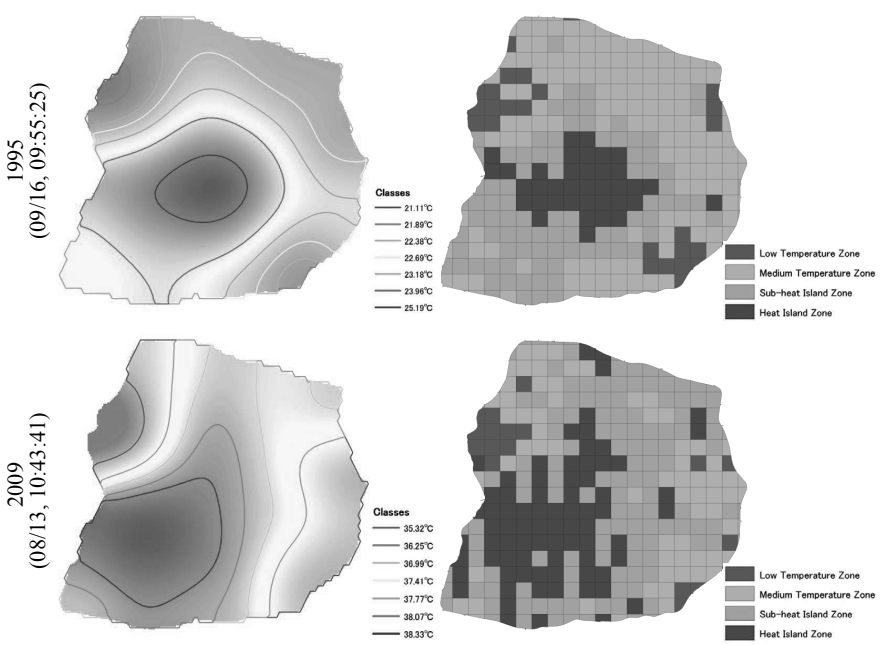

Fig. 9 Zonal classification of LST

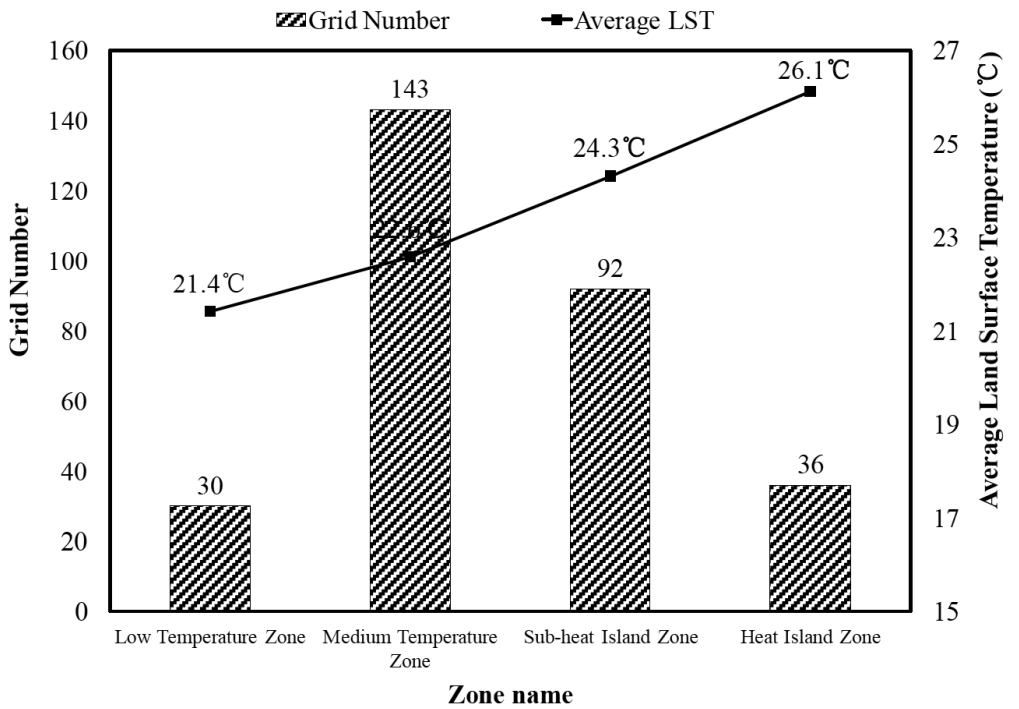

Fig. 10 Classification result in 1995

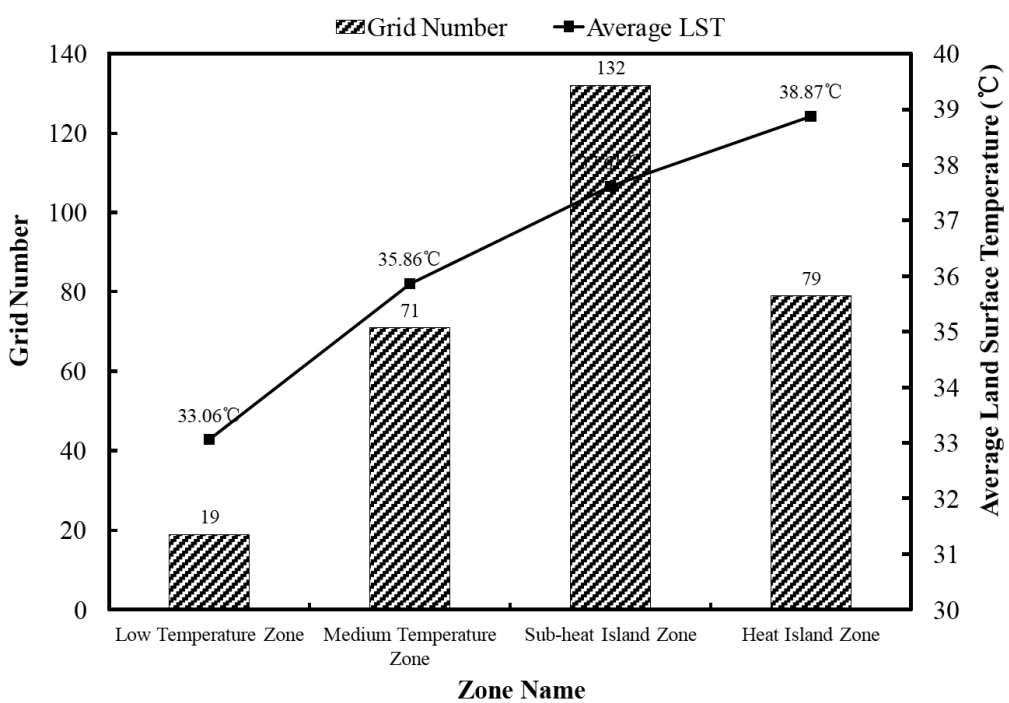

Fig. 11 Classification result in 2009

on population and economics.

The survey of urban heat island came to a conclusion that the phenomenon exist in the city with strong evidence. Moreover, by different methods, the correlation between the land surface temperature, the normalized difference vegetation index and average digital number were carried out which shown close relationship between the temperature distribution, the vegetation and the urbanization level of the region. What inspired us from the result is that the temperature distribution is closely related with the vegetation situation and the urbanization level. To get better thermal comfort in our homeland and to eliminate the heat island effect, the city should follow balanced development with more vegetation as possible.

Acknowledgements

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