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The Investigation of Urbanization and Urban Heat Island in Beijing Based on Remote Sensing

Wei Chen [a], Yao Zhang [a], Weijun Gao [a]*, Dian Zhou [b]

[a]Faculty of Environmental Engineering, The University of Kitakyushu, Kitakyushu 808-0135, Japan
[b]School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an 710049, China

Abstract

As the capital of China, Beijing has become a world city after decades of development. It is necessary and meaningful to have a comprehensive investigation of the urban situation in Beijing. In addition, with the development and widely applied 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 times series images from DMSP-OLS. Another aspect is the urban heat island effect survey, the Landsat TM/ETM data in 1995 and 2009 were processed to provide the NDVI and LST 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.

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 are 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

* Corresponding author. Tel.: +81 093-695-3234; fax: +81-93-695-3335.
  E-mail address: gaoweijun@me.com

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 process 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, the remote sensing 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 of 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.

To the objective of this research, the purpose of the investigation is to get a comprehensive understanding of what had happened to the city, to get a systematic investigation of the development in Beijing in the past time, at the same time, propose suggestion and advice for more balanced and better living environment and better thermal comfort in the habitat.

2. Study area and research method

2.1. Study Area

In this research, the part of the investigation of urbanization was proceeded within the whole area under the administration of Beijing; however, the part of the urban heat island survey was proceeding only within the urban area which was represented by the area within the 6th ring road to have a clear result in the downtown which holds a higher population density and it is much more meaningful and important to investigate and analysis the situation in the central of the city.

Synthetically, taken the statistical data collection and remote sensing data features into consideration, the study period in this research is from1992 to 2012. In addition, due to the uncertainties and influencing factor of the Landsat products, in order to have an inspection of the spatial development of the city, two Landsat products from1995 and 2009 was selected for the analysis and comparison of the phenomenon of urban heat island.
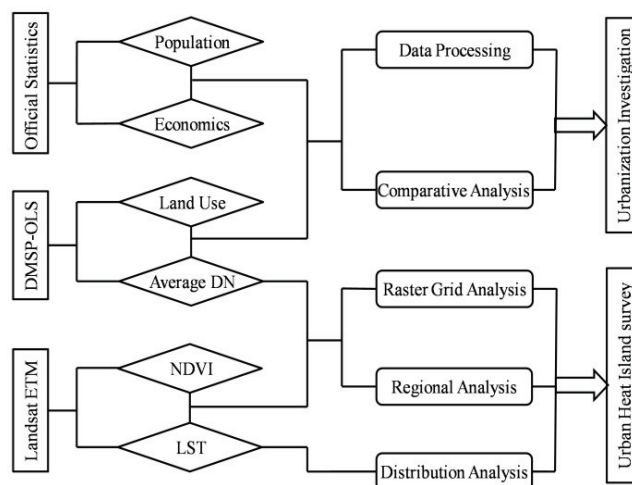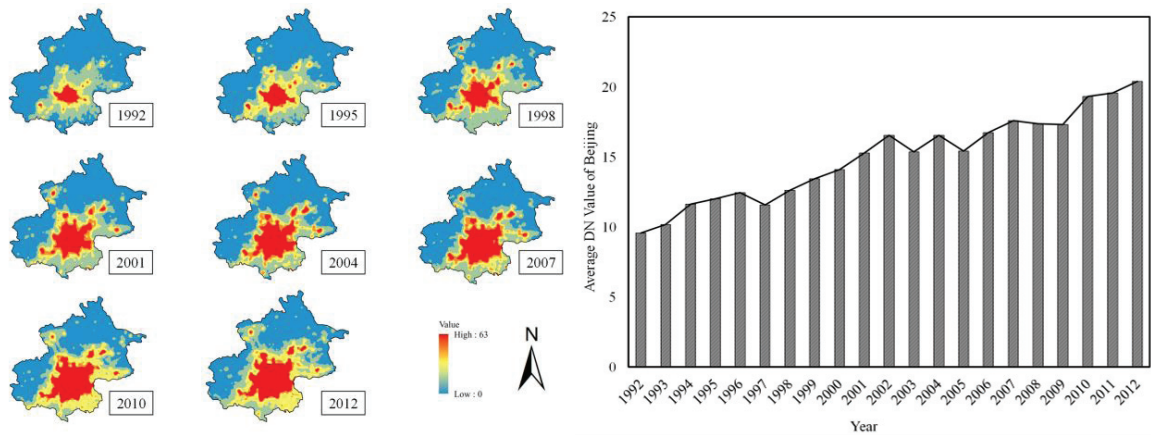

Fig.1. Research Flow

Fig.2. (a) Time Series Digital Number distribution from DMSP/OLS; (b) Average DN Value Change from 1992 to 2012.
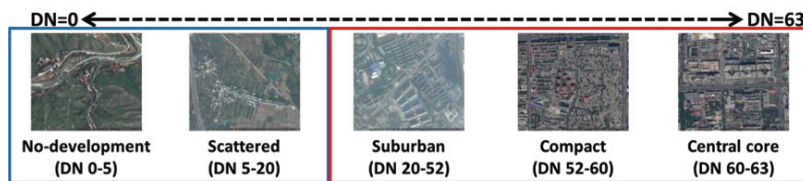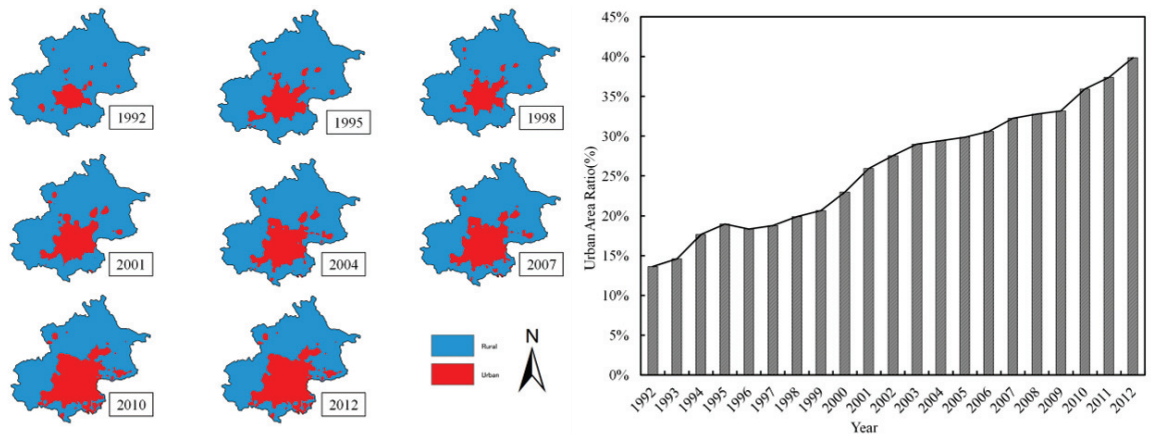

Fig.3. Partition method of the Urban Area

Fig.4. (a) Time Series Urban Area Partition from DMSP/OLS; (b) Urban Area Ratio Change 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 information 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 calculating the average value of digital number; the Landsat imagery was used to get the land surface temperature (LST) and the normalized difference vegetation index (NDVI).
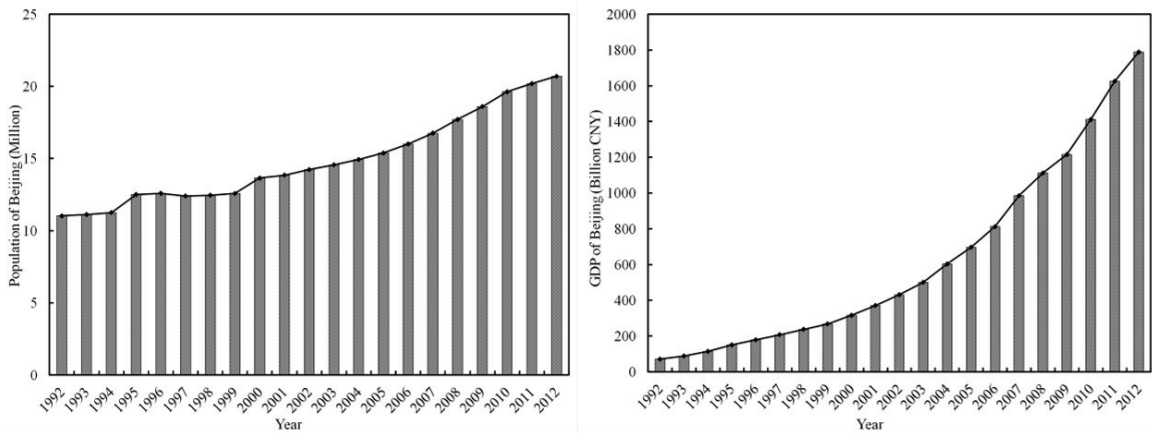
Fig.5. (a) Population growth in Beijing from 1992 to 2012; (b) GDP increase in Beijing from 1992 to 2012.

The analysis method in this research including data processing, comparative analysis, raster grid analysis, regional analysis, and distribution analysis. The first two kinds of analysis methods were carried out in the investigation of urbanization in Beijing, while the remaining three methods were the important processes to get the urban heat island survey. For the part of the analysis, the linear-regression analysis was carried out as the most important method to explore the relationship between the factors.

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 composite imagery from 1992 to 2012. The most notable advantage of DMSP/OLS nighttime light imagery is that the night light brightness have been utilized in several studies for quantitatively estimating and mapping socio-economic activities related to the urbanization processes at regional to global scales.

3.2. Urbanization by average DN

The images from DMSP/OLS are composed of grid-based annual visible band digital number (DN) ranges 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. For Beijing, all pixels spatially contained within the administrative boundary of the city have been collected by overlaying the administrative unit map onto DMSP/OLS images based upon a uniform geo-reference system. Figure 2 (a) shows part of the result of the digital number distribution in Beijing in several years, in which the higher value of the digital number area was displayed into red and the color blue stands for a lower value of digital number. The annual average value of digital number was shown in the Figure 3 according to the statistical result.

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

Where N_i is the number of the pixels whose Digital Number value equals DN_i; N_{Total} is the total number of pixels within the boundary of the study area. The result of the average Digital Number value in each year within the boundary of Beijing was shown in Figure 2 (b).
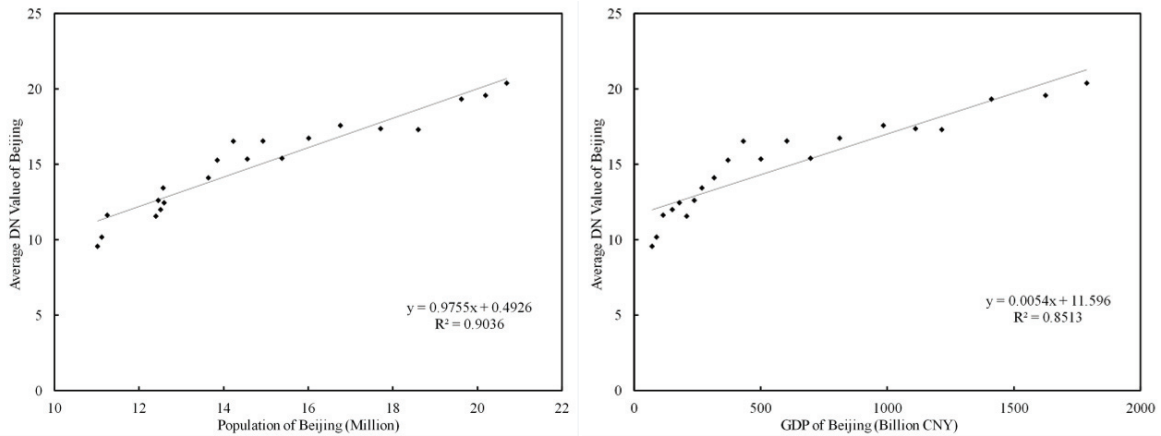
Fig. 6. (a) Correlation analysis between Ave DN and population; (b) Correlation analysis between Ave DN and GDP
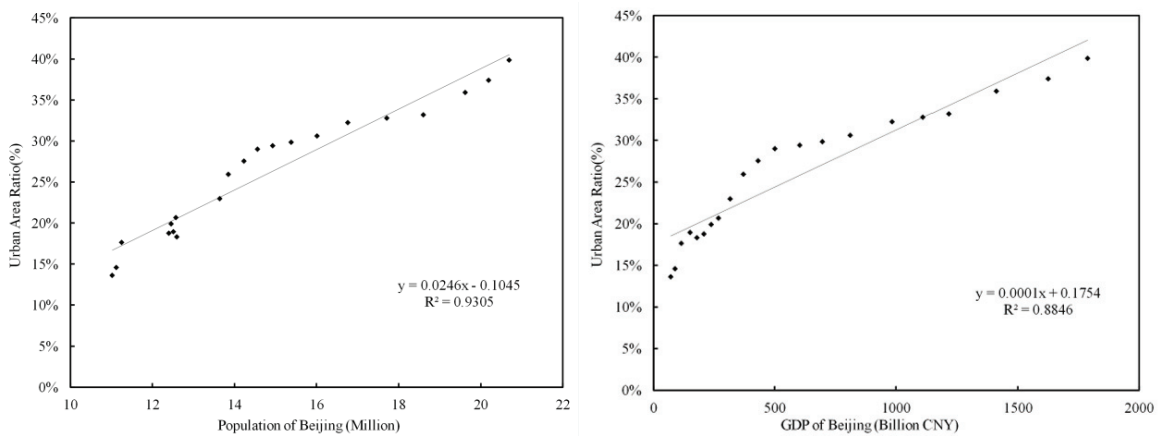

Fig. 7. (a)Correlation analysis between UAR and population; (b) Correlation analysis between UAR and GDP.

### 3.3. Urban area extension from DMSP/OLS

It 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, the classification method was shown in Figure 3:

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

In addition, by the classification of the different types, the part which DN value is greater than 20 was considered as the urban area, otherwise would be treated as the rural area. Then the urban area ratio was calculated in each year as a representative of the urbanization on land-use aspect. The statistic of the urban area ratio was shown in the Figure 4 which increased from 13.6% in 1992 to 39.9% after 20 years development.

Table.1. Information of the collected Landsat products

Items	1995	2009
Landsat scene ID	LT51230321995259HAJ00	LE71230322009225SGS00
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
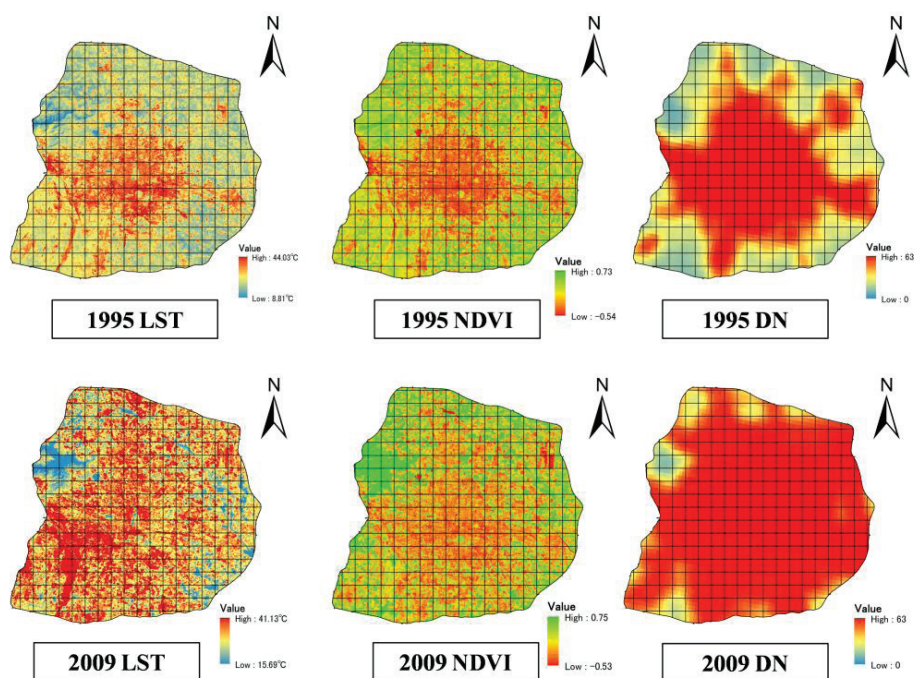
Fig.8. Raster Grid Analysis within 6th ring road in 1995and2009

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 in Beijing are available from the home page of the National Bureau of Statistics of China, after necessary calculation and data processing, the statistical result of the population and GDP were shown in Figure5..

Population urbanization 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 describe the standard of urbanization situation. The GDP of Beijing had an unbelievable growth during the period with an increase of 25.21 times, from 70.91 billion CNY in 1992 but reached 1787.9 billion CNY at 2012.
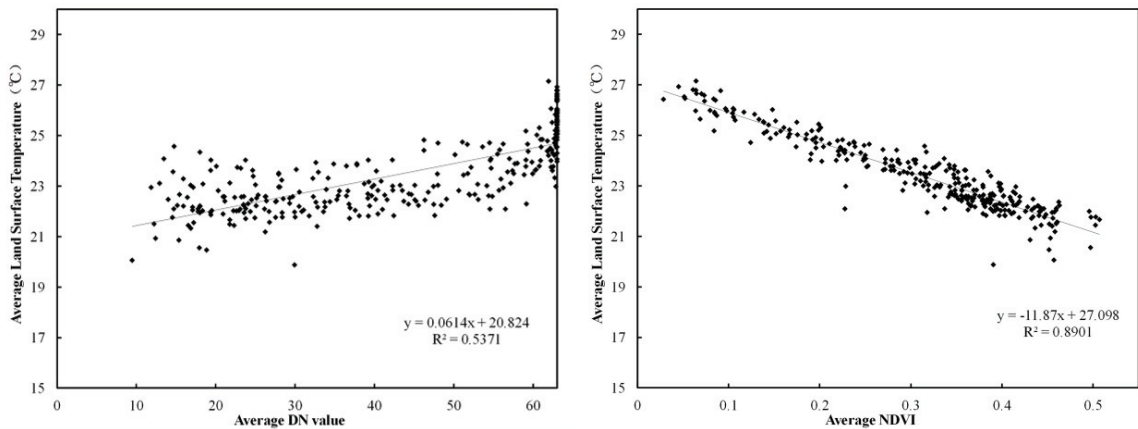
Fig. 9. (a) Correlation analysis between Ave DN and LST in 1995; (b) Correlation analysis between NDVI and LST in 1995
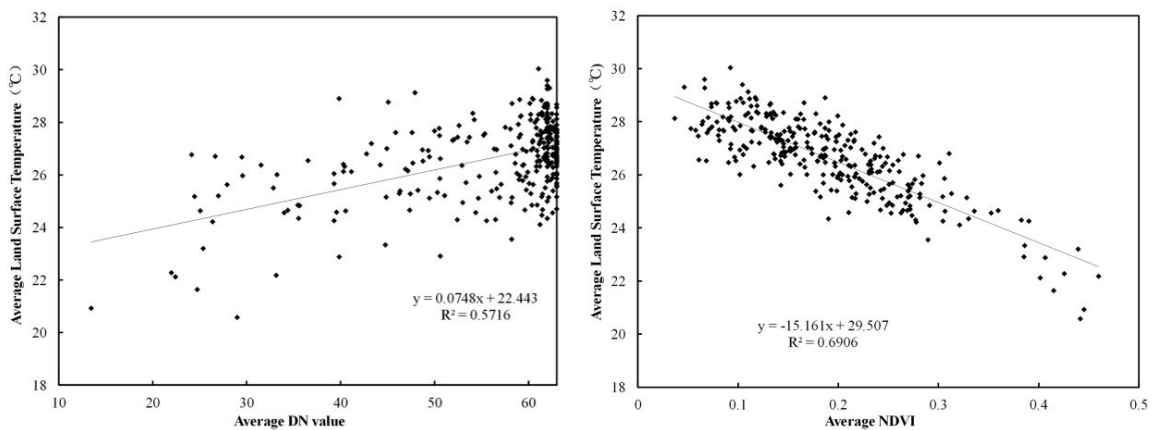

Fig. 10. (a) Correlation analysis between Ave DN and LST in 2009; (b) Correlation analysis between NDVI and LST in 2009

Figure 6 and Figure 7 shows the correlation analysis between the data that from the remote sensing observing and the official statistics. From the result, we can easily get that there are very closely related between the two kinds of indicators with high value of correlation coefficient, the result proved a closely positive relationship between the population, GDP and the urban condition that provided by DMSP/OLS. Both of the remote sensing observing products and official statistical could provide strong evidence that Beijing had gone through a remarkable urbanization with amazing scale and process.

4. Urban heat island investigation 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 that acquired by the instruments on the Landsat satellites are a unique resource 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 a useful tool to study global
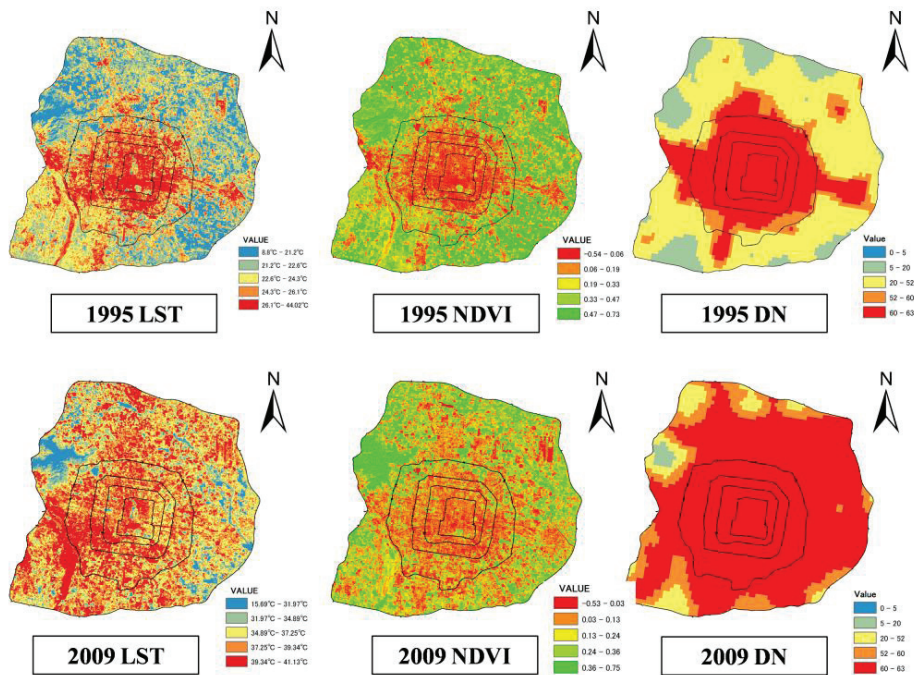
Fig. 11. Regional Analysis within 6th ring road in 1995and2009.

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.

4.2. Derivation of NDVI

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigor of vegetation on the 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.

$$\text{NDVI} = \frac{(\text{Band4} - \text{Band3})}{(\text{Band4} + \text{Band3})} \tag{2}$$

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 in recent years. As for 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 retrieving LST. In addition, with the data statistics and calculation, the average value of the LST can be got from different regions.
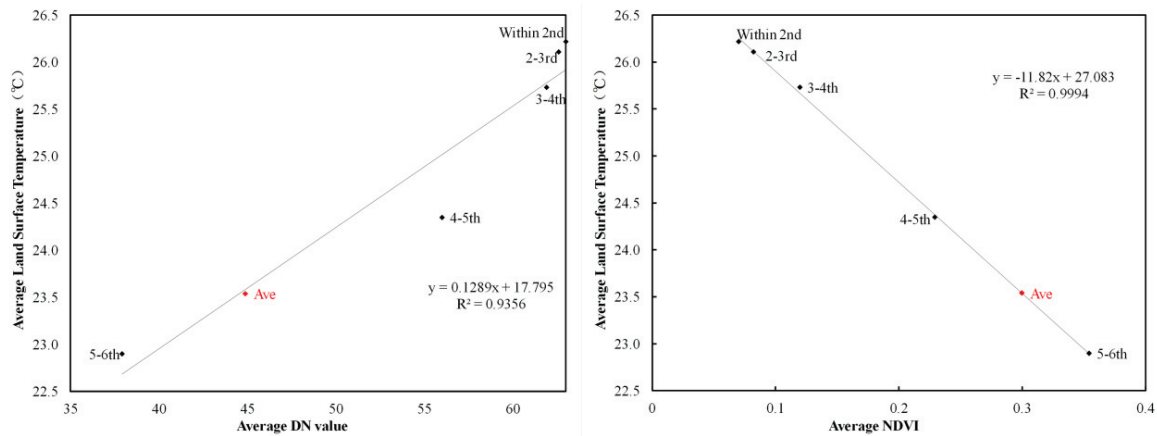
Fig. 12. (a) Correlation analysis between Ave DN and LST in 1995; (b) Correlation analysis between NDVI and LST in 1995.
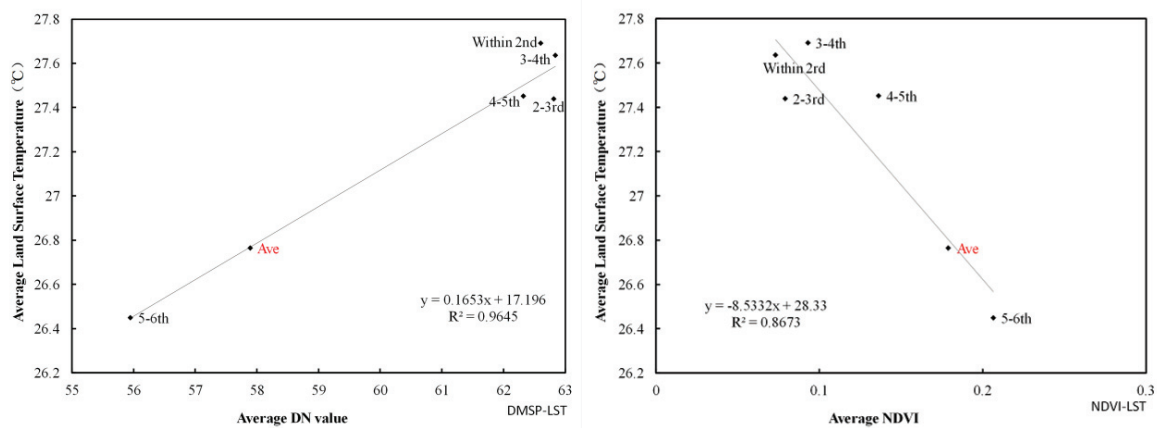

Fig. 13. (a) Correlation analysis between Ave DN and LST in 2009; (b) Correlation analysis between NDVI and LST in 2009

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 method was 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 8 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 on the distribution of the three parameters which displayed grid by grid. Figure 9 and Figure 10 shows the correlation analysis result of the LST, NDVI and the average DN in each year, which reflect the relationship between the temperature, vegetation and the average urbanization level.

The regional analysis, which was carried out by the ring roads scale with an obviously regional disparity. Carrying through the ring road grid analysis, we can find the distribution of the three parameters associated with the geographic distribution. Figure 11 shows the exported result of the regional analysis, in accordance with expectation, the results indicate an obvious difference in different region, by using the zonal statistical tool, the

average value of LST, NDVI and the average DN were calculated and applied to correlation analysis between them, Figure 12 and Figure 13 shows the relationship between the three indicators.

During the urban heat island study, the temperature distribution plays an important role during the research. By using the geo-statistical 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. Compared with the result of 1995, the high temperature region moved toward southwest after the development, the low temperature zone located in the boundary of the region, mainly located northwest and southeast of the area.

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 a close relationship between the remote sensing observing result and the official statistics 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 a 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 the balanced development with more vegetation as possible.

Acknowledgements

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