ANALYSIS OF URBAN LANDSCAPE PATTERN AND ECO-ENVIRONMENT BENEFIT BASED ON HEAT ISLAND EFFECT – WITH BEIJING, CHINA AS AN EXAMPLE

LEI, L. J.¹ – WANG, W. C.²

¹*Jinzhong University, Jinzhong 030600, China*

²*Shanxi Urban and Rural Planning Design Institute Engineering Design Center, Taiyuan 030000, China*

**Corresponding author*

e-mail: Leilingjia@163.com; phone: +86-187-0344-7111

(Received 7th Jun 2019; accepted 10th Oct 2019)

Abstract. As urbanization picks up speed, great changes have taken place in the Urban Landscape Pattern (ULP), which in turn causes variation in urban climate. The Heat Island Effect (HIE), a prominent feature of the changing urban climate, poses a huge threat to our life and health. Starting with HIE and with the aid of geographic information system (GIS) and remote sensing (RS), this paper studies the remote sensing images of Beijing from 1995 to 2015, which were captured by Landsat Thematic Mapper (TM) and infrared technology. Specifically, the author analyzed the evolution laws of the ULP and the HIE in Beijing, discussed the relationship between the two factors, and disclosed the controlling effect of the ULP on the HIE. The results show that: the accelerated urbanization has fragmented the landscapes in Beijing dramatically; the HIE can be alleviated by increasing the greenery coverage, reducing the spacing between green lands, and enhancing their density. Finally, several suggestions were put forward to construct a secure and ecological ULP in Beijing from the angle of adjusting the green land landscape pattern. This research sheds new light on the relationship between the ULP and the HIE and lays a basis for the planning and construction of eco-cities.

Keywords: *heat island effect (HIE), urban landscape pattern (ULP), eco-environment benefit (EEB), Beijing, secure and ecological ULP*

Introduction

With the rapid growth of population and economy, the urbanization process is accelerating, and the cities are gradually expanding over surrounding areas. As a result, the changes in landscape pattern and land use, and the environmental pollution have caused ecological problems such as the soil property variation (e.g. unbalanced soil acid-base property and poor adsorption), urban heat island effect, etc. (Connors et al., 2013), which pose threats to people's health, and even influence the sustainable development of the cities. Therefore, analyzing the ULP and the evolution of the ecological environment is of great significance for constructing a secure and ecological ULP (Goward, 1981).

The city is a human-centered landscape ecosystem (Estoque et al., 2017). Urban ecosystems are composed of two ecosystems, or more precisely, it is dominated by the artificial ecosystem and supplemented by the natural ecosystem (Li et al., 2014). Land use is a main factor affecting the artificial ecosystem, so the research on the changes in land use is the focus of urban ecological security research (Yang et al., 2017). In the landscapes, the evolution of ecological processes such as biological migration, surface temperature, and local air flow, as well as the spatial distribution will all be influenced by the changes in landscape patterns. HIE is a phenomenon in which the urban temperature is significantly higher than the surrounding areas, it occurs as a result of the the process of urbanization and

is caused by the destruction of vegetation and water bodies, the increment of residential land construction, and the aggregation of population (Bao et al., 2016). HIE is one of the main consequences of the changes in ULP, it changes the urban climate and produces adverse effects on the health of residents and the ecological environment of the city (Chen et al., 2016). Xiao Rongbo adopted correlation analysis to study the actual surface temperature and related influencing factors of urban land in Beijing, and the results showed that ULP and land use situation are closely related to HIE (Chen et al., 2014). Cao Liping proposed through research that the human impact on the climate shows a trend from weak to strong with the progress of urbanization (Mohajerani et al., 2017). However, currently there are few researches on the correlation between ULP and HIE, and no unified conclusion has been formed yet.

Based on the above analysis, this paper carries out research on the HIE-based ULP and the EEB, and selects the data of Beijing city from 1995 to 2015 to analyze and study the evolution of ULP, the heat island spatial distribution and the causes of formation, as well as the heat island areas and green land patterns in Beijing. From the perspective of adjusting the green land landscape pattern, this paper proposes suggestions for constructing a secure and ecological ULP in Beijing, in the hopes of providing a reference for the planning and building of eco-cities.

Materials and methods

Data source of the evolution of ULP in Beijing and the research methods

This paper selected the GIS and RS data of Beijing from 1995 to 2015, and divided the landscapes within the Sixth Ring Road of Beijing into five categories: urban land, agricultural land, green land, water-area land and unused land (Xie et al., 2016). The study used the landscape index method and the gradient analysis to conduct quantitative analysis on the evolution of ULP in Beijing, and adopted the Fragstats landscape index calculation software to calculate the selected indices such as the SHDI (diversity index), the Contagion index, the MN-SHAPE (mean shape of the plaque) index, and the PD (Plaque Density) index, etc.

Shannon's diversity index (SHDI):

$$SHDI = \sum_{i=1}^m (P_i \times \ln P_i) \quad (\text{Eq.1})$$

Contagion index (Contagion):

$$Contagion = \left[1 + \sum_{i=1}^m \sum_{j=1}^n \frac{P_{ij} \ln(P_{ij})}{2 \ln(m)} \right] (100) \quad (\text{Eq.2})$$

Mean shape of the plaque (MN-SHAPE):

$$MN - SHAPE = \frac{\sum_{i=1}^m \sum_{j=1}^n \left(\frac{0.25 P_{ij}}{\sqrt{a_{ij}}} \right)}{N} \quad (\text{Eq.3})$$

Plaque density (PD):

$$PD = \frac{n_i}{A} \quad (\text{Eq.4})$$

where: P_i is the occurrence probability of the i-type plaque, m is the total number of plaque types, P_{ij} is the probability that two adjacent grid cells belong to types i and j, A is the total area of all landscapes, n_i is the total area of the i-type landscape elements.

Data source of HIE in Beijing and research methods

Although the data of surface temperature obtained by the field measurement method is accurate, it requires to set up a large number of meteorological stations in reasonable layout, which would consume huge financial resources and time (Chang et al., 2011), the development and application of thermal infrared remote sensing technology enable us to obtain the surface temperature of large areas, which has overcome the shortcomings of the traditional field measurement method. Therefore, this paper selected the Landsat TM/ETM+ images from 2000, 2005, 2010 and May 2015 to study the relationship between the built areas of Beijing and the heat island spatial distribution changes.

Generally, the temperature of the black body that radiates radiation energy equal to the observed object is called the brightness temperature, which is slightly less than the real temperature, and its relationship with the real temperature is $T = \varepsilon^{\frac{1}{4}} t$ (Huang et al., 2013). Using Equation 1, we can unify the range of surface brightness temperature to 0-1, meanwhile, the density segmentation method was applied to eliminate the time-phase differences in the images of the four seasons as much as possible (Zhang et al., 2013). Figure 3 shows the distribution of brightness temperature in Beijing in 2000, 2005, 2010 and 2015. According to historical statistics, the meteorological conditions of the dates selected in this paper are basically the same and comparable. According to the temperature, the brightness temperatures are divided into seven levels: very-high temperature (44-47 °C), high temperature (40-44 °C), sub-high temperature (36-40 °C), medium temperature (32-36 °C), sub-medium temperature (28-32 °C), low temperature (24-28 °C) and very-low temperature (20-24 °C). The seven levels are indicated by brown, red, orange, yellow, light green, green and blue.

$$N_i = \frac{T_i - T_{\min}}{T_{\max} - T_{\min}} \quad (\text{Eq.5})$$

Data source of urban heat island and urban green land pattern and research methods

Urban green land can increase the value of real estate, provide people with leisure and entertainment places, moreover, they have multiple important ecological functions such as reducing surface runoff, alleviating urban heat islands, cooling and humidifying (Cannistraro et al., 2017; Gehrt and Chelsvig, 2003; Jiao and Fang, 2018), as well as reducing ecological and environmental damages caused by urbanization. However, if we want to achieve the goal of improving the urban ecological environment through the urban green land system, we must not only ensure large areas of green land, but also scientifically plan the shape and spatial distribution of urban green land (Dai et al.,

2010; Dong et al., 2018). Therefore, this paper selected the urban images of Beijing taken by SPOT5 satellite in 2015, and adopted the gradient analysis and landscape index method (main landscape indices are calculated according to *Eqs. 1-4*) to analyze heat island areas in Beijing and the green land pattern on the main extension axes.

Table 1 shows the green landscape pattern of districts with different interference intensities.

Table 1. Greenland landscape pattern in districts with different interference intensities

Landscape index	Urban heat island area	Urban cold island area
Greenery coverage %	30.2	13.6
Average nearest neighbor distance (m)	41.62	56.45
Aggregation index	93.27	89.88
Average plaque area (h m ²)	0.86	0.53
Plaque density (/k m ²)	195	108

Results

Evolution of ULP in Beijing

Figure 1 shows the overall landscape dynamic changes of urban districts in Beijing from 1995 to 2015.

Figure 1. Dynamic changes of overall landscape in urban districts of Beijing

Figure 1 shows the dynamic changes of the overall landscape of urban districts in Beijing from 1995 to 2015, it can be seen from the figure that the density of plaques has shown a downward trend from 1995 to 2000, and a rapid upward trend after 2000. The landscape diversity index has shown a linear increase with the year, and for the MN-shape index and the Contagion index, both have presented a large downward trend at first, then hit the bottom in 2010 and 2005, respectively, after that, both rebounded, indicating that as the urbanization in Beijing has sped up, the degree of landscape fragmentation has intensified.

Figure 2 shows the proportion of urban land in Beijing in the four directions from 1995 to 2015. In terms of the distance from the city center, the south and west directions are negative, and the north and east directions are positive.

It can be seen from *Figure 2* that in the past 20 years, Beijing has shown a comprehensive and large-scale expansion of urban land from the city center to the surroundings in different directions, with a largest increase of about 50%, the expansion mainly concentrated in the plain area in the southeast, it is because the mountains in the west and north of Beijing have played a certain role in hindering the development of the city, so the development is relatively slow.

The rapid growth of Beijing's economy and population has led to an increase in urban residential construction land and related infrastructures such as the roads, and the conversion of suburban land into urban land has destroyed the original landscape pattern, which is the main reason for the evolution of ULP in Beijing.

Figure 2. Proportion of urban land in Beijing from 1995 to 2015

Spatial distribution and formation causes of urban heat islands in Beijing

Figure 3 shows the heat island brightness temperature distribution in Beijing, it can be seen from the figure that, the very-high temperature area (brown), the high temperature area (red) and the sub-high temperature area (orange) in Beijing have spread to the surroundings and increased year by year from 2000 to 2015. Wherein, the Shougang Plant Area, the Dashilan and the Yongdinghe River have been in high temperature areas for many years, while Yuyuantan Lake, Kunminghu Lake, Beihai, Shichahai and other water areas have been in the low temperature areas for many years. In the city center areas, there are vegetation and water body areas, as well as scattered low temperature areas, and the brightness temperature areas present a tendency to gradually increase from the center to the periphery. In addition, by 2015, the HIE in the downtown area within the Third Ring Road had been alleviated significantly, while the intensity of HIE around the Fourth Ring and the Fifth Ring roads had increased, this is because the newly-developed residence and technology parks are concentrated near the Fourth Ring and the Fifth Ring roads, while the green land construction had been strengthened within the Third Ring Road, so the isolation belt had separated the Third Ring Road from other high temperature areas.

Figure 3. Bright temperature distribution map of Beijing in 2000, 2005, 2010 and 2015

Figure 4 shows the comparison of the areas of urban districts in Beijing. It can be seen from the figure that since 2000, the area occupied by the urban heat island had decreased slightly, and the proportion of the low temperature area had gradually increased, indicating that the HIE had been alleviated.

Figure 4. Comparison of the areas of urban districts in Beijing

Analysis of the heat island area and green land pattern in Beijing

Figure 5 shows the area ratio of green land plaques of different area levels and in different directions.

Figure 5. Area ratio of green land plaques of different area levels and in different directions

Figure 6 shows the changes of greenery coverage in the east-west and north-south directions.

It can be seen from Figures 5 and 6 that the greenery coverage in all directions of the urban extension axes has no obvious correlation with the distance, and fluctuates between 10 and 30%. Overall, the north-south direction is slightly higher than the east-

west direction. In the east, west, south-north directions, peaks appeared at the positions of 4 km, 6 km, and 12 km, respectively, by analysis it is found that it is mainly due to the existence of park green land such as Yuyuantan Park, and the Olympic Park near these spots. In areas that have no park, the greenery coverage is below 15%, and the number of large plaque areas with a plaque area of more than 60% is less than 10%. These plaques are mainly concentrated in government units and urban parks, indicating that the distribution of large park green land determines the size of greenery coverage. It can be found from the data in *Table 1* that the anti-interference intensity of the landscape pattern increases with the increase of greenery coverage, plaque spacing and density, therefore, the artificial interferences can be eliminated by increasing the greenery coverage, reducing the spacing, and increasing the density.

Figure 6. Greenery coverage changes in two directions

Discussion

In order to alleviate the HIE in Beijing and construct a secure and ecological ULP in Beijing, this paper combines with the evolution of ULP, the HIE, and the green land pattern in Beijing to analyze the results, and proposes countermeasures and suggestions from the following three aspects:

Plan the development pattern scientifically

Change Beijing's current development pattern which is circle-shaped and single-centered; use evacuation and integration methods to alleviate the problem that the human activities often gather in the center of the city. To achieve the goal of multi-center development, relevant policies should be adopted to encourage and guide the migration of economy, population and industrial belt. In addition, the density of buildings is also one of the main factors of HIE. Therefore, in order to avoid the distribution of urban buildings from distributing in clusters and blocks, the spacing between buildings should be properly arranged and the density of the buildings should be strictly controlled.

Save energy, reduce emission, and develop ecological buildings

Previous research results (Oberndorfer et al., 2007) have confirmed that greenhouse gases from vehicle exhaust and industrial production, and heat emission caused by

human activities are important factors for the formation of HIE, therefore, we should make full use of renewable green resources such as wind energy and solar energy to reduce the use of gasoline and diesel, and meanwhile adopt new thermal insulation equipment, heating and ventilation equipment, and other energy-saving technologies to develop green buildings and reduce heat emissions caused by human activities.

Increase water body, greenery coverage, and improve the natural ecosystem

According to the research results of this paper, the green land and water body inside the city can effectively alleviate and reduce the HIE. Therefore, we can build heat island green belt inside the city, adjust the current green land pattern, and construct corridors between the central green land and other middle and small green land, so as to achieve the ideal status in which there are both scattered and concentrated green land, and at the same time, protect the suburb farmland and river surface from pollution and damage.

Conclusion

- The evolution of ULP in Beijing showed that the urbanization level of Beijing increased significantly between 1995 and 2015, mainly concentrated in the plain area in the southeast direction, due to the acceleration of urbanization and the changes in urban land use structure, the landscape pattern of Beijing had been fragmented more dramatically.
- The research results of Beijing's heat island spatial distribution and the cause of formation showed that, the very-high temperature area (brown), the high temperature area (red) and the sub-high temperature area (orange) in Beijing had spread to the surroundings and increased year by year from 2000 to 2015. Since 2015, the HIE within the Third Ring Road had alleviated significantly. In term of spatial distribution, we can see that in spots where the industry and population are gathered and the greenery coverage is low, the HIE is stronger.
- The analysis results of the heat island area and green land pattern in Beijing showed that the distribution of large park green land determines the size of greenery coverage, and the anti-interference intensity of landscape pattern increases with the increase of greenery coverage, plaque spacing and density.
- This paper proposed countermeasures and suggestions for constructing a secure and ecological ULP from three aspects: plan the development pattern scientifically; save energy, reduce emission, and develop ecological buildings; and increase water body, greenery coverage, and improve the natural ecosystem.
- The study of ULP and HIE requires to combine factors of various aspects to conduct case study and evaluation. This paper only discussed from the two aspects of urban land use and landscape pattern change, so it is not comprehensive enough, in future researches, we should also analyze other ecological process types and scales as well.

REFERENCES

- [1] Bao, T., Li, X. M., Zhang, J., Zhang, Y. J., Tian, S. Z. (2016): Assessing the distribution of urban green spaces and its anisotropic cooling distance on urban heat island pattern in Baotou, China. – ISPRS International Journal of Geo-Information 5(2): 12.

- [2] Cannistraro, G., Cannistraro, M., Trovato, G. (2017): Islands “Smart Energy” for eco-sustainable energy a case study “Favignana Island”. – *International Journal of Heat and Technology* 35(S1): S87-S95.
- [3] Chang, H., Li, F., Li, Z., Wang, R., Wang, Y. (2011): Urban landscape pattern design from the viewpoint of networks: a case study of Changzhou City in Southeast China. – *Ecological Complexity* 8(1): 51-59.
- [4] Chen, A., Yao, X. A., Sun, R., Chen, L. (2014): Effect of urban green patterns on surface urban cool islands and its seasonal variations. – *Urban Forestry & Urban Greening* 13(4): 646-654.
- [5] Chen, A., Zhao, X., Yao, L., Chen, L. (2016): Application of a new integrated landscape index to predict potential urban heat islands. – *Ecological Indicators* 69: 828-835.
- [6] Connors, J. P., Galletti, C. S., Chow, W. T. L. (2013): Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona. – *Landscape Ecology* 28(2): 271-283.
- [7] Dai, X., Guo, Z., Zhang, L., Wu, J. (2010): Spatio-temporal pattern of urban land cover evolution with urban renewal and expansion in Shanghai based on mixed-pixel classification for remote sensing imagery. – *International Journal of Remote Sensing* 31(23): 6095-6114.
- [8] Dong, J. H., Xu, M., Wan, S. M., Xie, F. H., Wu, Q. H. (2018): Stability analysis of accumulation body based on monitoring results of deep displacement. – *Instrumentation Measure Métrologie* 17(4): 563-572.
- [9] Estoque, R. C., Murayama, Y., Myint, S. W. (2017): Effects of landscape composition and pattern on land surface temperature: an urban heat island study in the megacities of Southeast Asia. – *Science of the Total Environment* 577: 349-359.
- [10] Gehrt, S. D. D., Chelsvig, J. E. E. (2003): Bat activity in an urban landscape: patterns at the landscape and microhabitat scale. – *Ecological Applications* 13(4): 939-950.
- [11] Goward, S. (1981): Thermal behavior of urban landscapes and the urban heat island. – *Physical Geography* 2(1): 19-33.
- [12] Huang, Y. X., Yin, X. Q., Ye, G. F., Lin, J. M., Huang, R., Wang, N., Wang, L., Sun, Y. (2013): Spatio-temporal variation of landscape heterogeneity under influence of human activities in Xiamen City of China in recent decade. – *Chinese Geographical Science* 23(2): 227-236.
- [13] Jiao, H., Fang, Y. C. (2018): Simulation and prediction of urban heat island effect of urban high-speed rail construction. – *International Journal of Heat and Technology* 36(4): 1438-1442.
- [14] Li, C. F., Shen, D., Dong, J. S., Yin, J. Y., Zhao, J. J., Xue, D. (2014): Monitoring of urban heat island in Shanghai, China, from 1981 to 2010 with satellite data. – *Arabian Journal of Geosciences* 7(10): 3961-3971.
- [15] Mohajerani, A., Bakaric, J., Jeffrey-Bailey, T. (2017): The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. – *Journal of Environmental Management* 197: 522-538.
- [16] Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., et al. (2007): Green roofs as urban ecosystems: ecological structures, functions, and services. – *Bioscience* 57(10), 823-833.
- [17] Xie, Y., Yu, M., Bai, Y., Xing, X. (2006): Ecological analysis of an emerging urban landscape pattern—Desakota: a case study in Suzhou, China. – *Landscape Ecology* 21(8): 1297-1309.
- [18] Yang, Q., Huang, X., Li, J. (2017): Assessing the relationship between surface urban heat islands and landscape patterns across climatic zones in China. – *Scientific Reports* 7(1): 9337.
- [19] Zhang, C., Wu, J., Grimm, N. B., Mchale, M., Buyantuyev, A. (2013): A hierarchical patch mosaic ecosystem model for urban landscapes: model development and evaluation. – *Ecological Modelling* 250(1753): 81-100.