Changes of vegetation coverage in Beijing in the background of urbanization based on the data from 2000 to 2019

Linyi Zhao¹, Fan Tianming Wang², Fan Dong¹,* and Caixuan Xiao³

¹ College of Government, Beijing Normal University, Beijing, 100875, China
² College of Life Sciences, Beijing Normal University, Beijing, 100875, China
³ The High School of Guiyang Attached to Beijing Normal University, Guiyang, Guizhou, 550081, China

*Corresponding author’s e-mail: 04021@bnu.edu.cn

Abstract. With the rapid development of urbanization, high-intensity human activities in Beijing profoundly impact the changes of ecological environment, especially on vegetation coverage. Vegetation can provide a variety of ecological services for the city. Based on the data of NDVI (Normalized vegetation Index) from 2000 to 2019, the study analysed the spatio-temporal changes of vegetation variation and land use pattern in Beijing by GIS analysis. The proportion of the significantly increased pixels of NDVI occupied 76.71% while that of the significantly decreased pixels only occupied 4.99% of the total. The significant positive trends of NDVI were concentrated in the urban core functional areas within the Fifth Ring Road and in the northern and western mountainous areas. The significant negative trends of NDVI were concentrated from the 5th Ring Road to the outside areas of the 6th Ring Road. And the gradual change of land use type is a prominent feature in significantly positive trend area. The reflection of the vegetation coverage and land use change on a large time scale in Beijing has a certain reference value for future land pattern planning and urban policy revision.

1. Introduction

The process of transformation from a traditional agricultural society to a modern urban society is called urbanization, which can produce the following main phenomena in this natural historical process: the concentration of population to the city, the increase of urban area, the expansion of urban scale is accompanied by the improvement of the level of modernization. However, in rapidly urbanized areas, the regional allocation, type and structure of vegetation cover will be changed due to the strong interference of human activities, which will have a far-reaching impact on the function of regional ecosystem [1]. The rapid development of urbanization will produce related eco-environmental problems in cities, such as urban heat island effect, reduction of natural vegetation area, increase of artificial green land area, a decrease of biodiversity, change of soil properties and pollution, etc. [2]. These changes have changed the ecological pattern of urban areas and affected urban and peri-urban vegetation and climate change. As a large developing country with a huge population, China has ushered in urbanization with the reform and opening up. At present, the process of urbanization in China is characterized by high speed, significant regional differences and obvious urban-rural dual structure [4]. Beijing is one of the fastest and most typical areas of urbanization in China. The period from 2000 to 2019 is an important stage for Beijing to carry out the 10th five-year Plan, the 11th five-
year Plan, the 12th five-year Plan and the 13th five-year Plan. It is also a period of rapid population growth and rapid economic development in Beijing. According to the Beijing Statistical Yearbook, the resident population in Beijing increased from 1107.5 million to 21.536 million from 2000 to 2019, an increase of 94.46 per cent. GDP increased from 246.05 billion yuan to 2.13308 trillion yuan, an increase of 766.93%, while the land area carrying population and economic and social development has not increased. Under the background of rapid urban development, the contradiction between supply and demand of land resources has become increasingly acute, resulting in a large-scale land use phenomenon characterized by the rapid expansion of urban land and the sharp decline of cultivated land [5].

Vegetation is an important part of terrestrial ecosystem, which plays an important role in improving local climate, reducing greenhouse effect, preventing soil erosion and so on. Urban vegetation is of great significance to improve the urban ecological environment. It can not only provide a good living environment for urban residents, but also improve the naturalness of urban landscape and promote the harmonious symbiosis between urban residents and nature. Therefore, urban vegetation can be used as an important index to reflect the status of urban ecological environment [6,7]. In the measurement of vegetation status, Normalized Vegetation Index (NDVI) has been widely used in many research aspects, such as global and regional environmental change, vegetation dynamic change monitoring, net primary vegetation productivity and so on [8]. At present, the global application data source of NDVI is mainly from a comprehensive project initiated by NASA’s Moderate Resolution Imaging Spectrometer (MODIS) in Earth Science Enterprise (ESE), which is an important equipment to observe the biological and physical processes of the earth. On the land side, the data obtained by MODIS have been widely used in the study of earth vegetation information distribution and plant health status [9]. Although there are still some deficiencies in the research based on MODIS-NDVI index [10], NDVI still has good applicability in areas where vegetation cover is not high (< 60%) and woodland is not dense.

Based on the MODIS NDVI time series from 2000 to 2019, this paper analyses the spatio-temporal evolution characteristics of vegetation cover and land use pattern in Beijing from 2000 to 2019 at pixel scale. The results can provide theoretical support for the study of spatio-temporal evolution characteristics of regional vegetation cover under the background of urbanization.

2. Data Sources and Research Methods

2.1. Data Sources and Initial Processing

The NDVI data comes from the MODIS MOD13Q1 (V6 version) data set provided by the Land Process Distributed Data Centre (LP DAAC) of National Aeronautics and Space Administration (NASA). The NDVI data is a 16d composite product with a 250m spatial resolution. The time series is from February 2000 to December 2019. The downloaded NDVI data are resampled, mosaic and projected by MRT4.1 software, and the vegetation data of each growing season are made into a time series stack. The time resolution of the processed data is 16d and the spatial resolution is 250m. The projection coordinate used in this study is GCS_WGS_1984.

2.2. Variable Slope Method

In order to study the spatial distribution characteristics of vegetation cover change in Beijing from 2000 to 2019, the change slope method is used to describe the change trend of NDVI. The change slope method is widely used to study the long-term changes of vegetation cover, biomass, NPP and crop yield. The calculation method of slope b is as follows:

\[ b = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - (\sum_{i=1}^{n} i)(\sum_{i=1}^{n} NDVI_i)}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \]

In the formula, i is the serial number of the year and n is the length of time. NDVI is a 20-year time series based on pixels, using the average growth season, that is, the NDVI mean of 13 images from
April to October each year. Slope $b$ can reflect the direction of vegetation cover change: if $b > 0$, vegetation cover shows an increasing trend; if $b < 0$, vegetation cover shows a decreasing trend; if $b = 0$, it shows that vegetation cover has no change trend. T-test is used to test the significance of the slope, and the significance level is set to 0.05.

2.3. Land Use Classification (Unsupervised Classification)

Due to the good continuity and moderate resolution of MODIS NDVI data, the unsupervised classification based on MODIS data can be used for land use classification. Unsupervised classification is based on the Iterative Self-organizing Data Analysis Technique (ISODATA) to calculate the class mean of uniform distribution in the data space, and then the minimum distance technique is used to iteratively aggregate the remaining pixels. The mean is recalculated in each iteration, and the pixels are reclassified according to the new mean. The stack of NDVI growing season in 2000 and 2019 is introduced into ENVI software, the convergence threshold is set to 0.99, and the initial classification number is set to 15. Refer to Google Earth high-definition images for human-computer interactive interpretation to determine the type of land use. Refer to the land use type classification standard of the Resources and Environment Science data Centre of the Chinese Academy of Sciences. Combined with the actual situation in Beijing, the land use types are classified into five categories, which are as follows: 1. Cultivated land. 2. Grass. 3. Forest. 4. Waters. 5. Built area.

3. Results and Analysis

3.1. Spatio-temporal Variation of Vegetation Cover

From 2000 to 2019, the average value of NDVI growth season in the whole city showed a significant increasing trend, and the average value of NDVI growth season basically changed between 0.5 and 0.6 (Fig. 1a). The pixel statistical results showed (Fig. 2): at the significance level of 0.05, the average NDVI of 76.71% pixels was significantly increased, while that of 4.99% pixels was significantly decreased. Furthermore, the interannual variation dynamics of vegetation in the area with significant change of NDVI (hereinafter referred to as “significant change area”) (Fig. 1b), NDVI significantly increased area (hereinafter referred to as "significant increase area"), the average value of NDVI growth season showed a significant increasing trend ($P < 0.001$), NDVI significantly decreased area (hereinafter referred to as "significant decrease area"), the average value of NDVI growth season showed a significant downward trend ($P < 0.001$). The NDVI values showed good continuity.

![Figure 1. Trend analysis of the average value of NDVI growth season from 2000 to 2019 (a: Beijing area; b: significant change area)](image)

From a spatial point of view, the vegetation cover change shows obvious spatial differentiation (figure 2) the significant change area has the following distribution characteristics: 1) there is an obvious increasing trend in the northern and western mountainous areas, and the NDVI generally shows a significant increasing trend within the Fifth Ring Expressway; 2) the outer side of the Fifth Ring
Expressway to the Sixth Ring Expressway is shaped into a ring that significantly reduces the composition of pixels. The significant reduction of NDVI zoning is closely related to the development of urban traffic roads. The Fifth Ring Expressway was completed in 2003 and the Sixth Ring Expressway was completed in 2009. It is the main new traffic road during the study period. Compared with the areas where the change of NDVI is not significant, the significant increase area obviously shifts to the outer part of the sixth ring, and the significant decrease area shifts to the Fifth Ring Expressway-the Sixth Ring Expressway area. The two new loops, the Fifth Ring Expressway and the Sixth Ring Expressway, have changed the accessibility of regional traffic. The area sandwiched by the Fifth Ring Expressway and the Sixth Ring Expressway has also become the most urbanized area in Beijing in recent years, and intense human activities have disturbed the vegetation.

The significant increase in NDVI in the northern and western mountainous areas can be attributed to a series of ecological projects in Beijing in recent years. Taking Mentougou as an example, the vegetation degradation caused by residential expansion, quarrying and mining in the past has been changed by ecological restoration projects and natural processes, and the vegetation cover has been improved. In addition, the vegetation within the Fifth Ring Expressway significantly increases the zoning, which is basically consistent with the construction area of the first green isolation belt. There is a significant increase in vegetation in the southeast periphery of the plain area, which can be related to the construction areas of 3-North Shelter Forest Program, sowing and sand cover projects and plain sand control projects.

![Figure 2. Trend analysis of the mean NDVI of growing season from 2000 to 2019 in Beijing.](image)

3.2. Spatio-temporal change of land use pattern
Through the unsupervised classification of ENVI 5.1 software, the land use types of Beijing in 2000 and 2019 were obtained (Fig. 3), and the classification results were tested. Two hundred points are randomly generated within the boundary of Beijing to test the ground accuracy, and the Kappa coefficient of the confusion matrix is 0.775, and the overall classification accuracy is 0.855, which shows that the classification results are highly consistent with the actual land use types and have a good fit to the real situation.

The calculation of Beijing land use transfer probability matrix (Table 1.) from 2000 to 2019 shows that: (1) the net change of built-up area is positive, and the types of outflow and inflow are mainly cultivated land; (2) the net change of woodland is positive, and the inflow type is mainly grassland; (3) the net change of cultivated land is negative, and the inflow type is mainly built-up area, and the outflow type is mainly built-up area and grassland. Generally speaking, there are mainly two paths in the transformation of land use types in Beijing during the past 20 years, one is the mutual
The transformation between built areas and cultivated land, and the other is the change from "cultivated land to grassland and woodland".

**Table 1. Land use transfer matrix of Beijing (%)**

|        | 2000  | 2019  | Reduction |
|--------|-------|-------|-----------|
| Water  | 0.09  | 0.22  | 0.31      |
| Built-up area | 0.06 | 10.43 | 15.18    |
| Cultivated land | 0.02 | 8.20  | 36.68    |
| Grass   | 0.00  | 0.33  | 8.36      |
| Forest  | 0.00  | 0.09  | 38.81    |
| Σ       | 0.17  | 19.27 | 100.00   |
| Increment | 0.08 | 8.84  | 5.47     |
| Net change | -0.14 | 4.08  | -5.14    |

**Figure 3. Land use and cover of Beijing in 2000(a) and 2019(b)**

The land use transfer matrix of the areas with significant increase and decrease of NDVI from 2000 to 2019 is shown in Table 2 and Table 3. The diagonal of the transfer matrix is the proportion of land use...
types that have not changed. There is no land use type change in 75.19% of the significantly increased areas, and the highest proportion is woodland (47.40%), followed by cultivated land (17.17%), built areas (7.95%) and grassland (2.68%). The largest new increment is woodland (9.55%), and the largest reduction is cultivated land (11.66%), both of which are about 10%. In terms of net change, forest land increased by 8.35%, cultivated land and built-up areas decreased by 5.67% and 3.13% respectively, and grassland increased slightly. It can be seen that about 3/4 of the areas with increased vegetation come from the gradual changes of land use types, mainly forest land, cultivated land and established areas, while the other 1/4 are mainly caused by the transformation from cultivated land to grassland, grassland to woodland. From the perspective of spatial distribution (figure 4a), in the gradual change type, the woodland is distributed in the northern, western and northeastern mountain areas, the cultivated land is distributed in the plain area far away from the main urban area, and the built area is mainly concentrated within the Sixth Ring Expressway. In the transformation type, the transformation from cultivated land to grassland has no obvious law, and the transformation from grassland to woodland is scattered in the mountainous area.

Table 2. Land use transfer matrix for areas with significant increase in NDVI (%)

|        | Water | Built-up area | Cultivated land | Grass | Forest | Σ Reduction |
|--------|-------|---------------|----------------|-------|--------|-------------|
| **2000**<br>Water | 0.00  | 0.00          | 0.00           | 0.00  | 0.00   | 0.01        |
| Built-up area | 0.00  | 7.95          | 4.90           | 0.16  | 0.07   | 13.07       |
| Cultivated land | 0.00  | 1.98          | 17.17          | 6.08  | 3.60   | 28.83       |
| Grass | 0.00  | 0.00          | 0.94           | 2.68  | 5.88   | 9.50        |
| Forest | 0.00  | 0.00          | 0.15           | 1.04  | 47.40  | 48.59       |
| Σ     | 0.00  | 9.94          | 23.16          | 9.96  | 56.95  | 100.00      |
| Increment | 0.00 | 1.99          | 5.99           | 7.28  | 9.55   | 24.81       |
| Net change | -0.01 | -3.13         | -5.67          | 0.46  | 8.35   |             |

In 37.45% of the areas with significant reduction of NDVI, there is no change in land use types, mainly in built-up areas (19.29%) and cultivated land (18.10%). The new increment mainly comes from the built-up area (55.43%), and the decrease mainly comes from the cultivated land (49.74%), both of which are about 1/2. From the perspective of net change, the main performance is that the built-up area increased by 55.25%, while the cultivated land and grassland decreased by 42.88% and 8.02%, respectively. It can be seen that about 1/3 of the vegetation reduction areas come from the gradual changes of land use types, mainly cultivated land and built-up areas, and another 2/3 are mainly attributed to the transformation from cultivated land to built-up areas. From the perspective of spatial distribution (figure 4b), in the gradual type, cultivated land and built-up area are scattered in the plain area, which seems to be irregular; in the transformation type, the transformation of cultivated land to built-up area is mainly concentrated between the Fifth Ring Expressway and the Sixth Ring Expressway and outside the south Sixth Ring Expressway (especially inside Daxing District), which has obvious characteristics of urban expansion.

Table 3. Land use transfer matrix for areas with significant decrease in NDVI (%)

|        | Water | Built-up area | Cultivated land | Grass | Forest | Σ Reduction |
|--------|-------|---------------|----------------|-------|--------|-------------|
| **2000**<br>Water | 0.00  | 0.00          | 0.00           | 0.00  | 0.00   | 0.00        |
| Built-up area | 0.02  | 19.29         | 0.17           | 0.00  | 0.00   | 19.48       |
| Cultivated land | 0.01  | 49.73         | 18.10          | 0.00  | 0.00   | 67.84       |
Grass   0.00  4.37  3.88  0.00  0.00  8.25  8.25
Forest  0.00  1.34  2.81  0.23  0.05  4.43  4.37
Σ       0.02  74.73 24.96  0.23  0.05 100.00 62.55
Increment 0.02  55.43  6.86  0.23  0.00  62.55
Net change 0.02  55.25  -42.88  -8.02 -4.37

Figure 4. Land use change in significantly positive trend area (a) and significantly negative trend area (b)

4. Conclusion
Through the study of the changes of vegetation cover in Beijing area from 2000 to 2019, the main conclusions are as follows:
(1) The vegetation coverage in Beijing changed significantly and spatially from 2000 to 2019. The significant increase area of NDVI is concentrated in the urban core functional area within the Fifth Ring Expressway and the northern and western mountainous areas, while the significant decrease area is concentrated in the outer side of the Fifth Ring Expressway to the Sixth Ring Expressway.

(2) Through the analysis of the land use structure in Beijing from 2000 to 2019, it can be seen that the reduced land is mainly cultivated land, while the increased land is mainly built-up area and woodland. The gradual change of land use types in the region where NDVI significantly increases is a prominent feature; NDVI significantly reduces the built-up area and the net change of cultivated land is relatively large, and has the characteristics of an increase in built-up areas and a decrease in cultivated land.

References
[1] Liang, Y.Q., Zeng, H., Li, J. (2012) Influence of land use change on vegetation cover dynamics in Dapeng Peninsula of Shenzhen, Guangdong Province of South China. Chinese Journal of Applied Ecology, 01: 199-205.
[2] Zhou, L. (2006) Landscape Pattern Change and Its Impact on Urban Heat Island in Beijing Urbanization. Beijing Forest University.
[3] Hu, A.H. (2004) The general law of urbanization in the world and our country's practice. Inquiry into Economic Issues, 09: 115-118.
[4] Jie, L.J., Zhou, S.H., Yan, X.P. (2010) A Review of the Recent Researches on China's Urbanization and Global Environmental Change. Progress in Geography, 08: 952-960.
[5] Zhao, Y., Zhao, L.F., Kong, X.W. (2011) Research on Land Resources Constraints in the Overall Development of Beijing's Urban and Rural Development. Probe, 01: 89-93.
[6] Liu, Q.P., Yang, Y.C., Tian, H.Z., Gu, L., Zang, B. (2014) Spatial-temporal Difference of Vegetation Changes in Built-up Areas in China during the Period of Rapid Urbanization. Journal of Natural Resources, 02: 223-226.
[7] Liu, J.L., Guo, H.D., Zhang, L., Lu, L.L. (2014) Impact of Urbanization on Vegetation Phenology Research in Beijing-Tianjin-Tangshan Region. Remote Sensing Technology and Application, 02: 286-292.
[8] Li, H.Y., Xie, Y.W., Ma, M.G. (2009) Reconstruction of Temporal NDVI Dataset: Evaluation and Case Study. Remote Sensing Technology and Application, 05: 596-602.
[9] Huang, J.J., Wan, Y.C., Liu, L.M. (2003) The Character and Application of MODIS. Geospatial Information, 04: 20-23+28.
[10] Wang, Z.X., Liu, C. (2003) From AVHRR-NDVI to MODIS-EVI: Advances in vegetation index research. Acta Ecologica Sinica, 05: 979-987.
[11] Sun, X.P., Wang, T.M., Wu, J.G., Ge, J.P. (2012) Change trend of vegetation cover in Beijing metropolitan region before and after the 2008 Olympics. Chinese Journal of Applied Ecology, 11: 3133-3140.