Spatial and temporal variation Trend Analysis of vegetation cover in Urban agglomeration of Pearl River Delta from 2000 to 2015

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Abstract: Based on MODIS NDVI remote sensing data, the methods of regression analysis, CV stability analysis, Hurst exponent analysis are used to invert the spatio-temporal variation trend of vegetation cover in the Pearl River Delta region from 2000 to 2015. On this basis, the future change trend of vegetation cover was predicted. The results indicate that (1) the vegetation coverage in the Pearl River Delta was on a rising trend in general from 2000 to 2015 (0.029/10 years). (2) The vegetation change in the Pearl River Delta region was mainly significantly improved (39.73%), and significantly degraded and slightly degraded areas accounted for only 13.22%, which were staggered with significantly improved regions. (3) Degree of vegetation cover fluctuation in cities and surrounding areas has significant spatial consistency with degraded areas of vegetation cover, which indicates that there is a certain correlation between the change of vegetation cover around the city and human activities. (4) Combined with the analysis of future and past trends, the condition that vegetation cover firstly degrades and then improves will occur. While vegetation degradation may occur in non-urban concentrated areas without good ecological planning. The research results will be helpful to understand the trend and spatial distribution of vegetation in the Pearl River Delta region.

1. Introduction

With the development of urban agglomeration economy and the awakening of human awareness of ecological protection, giving consideration to green development while urban development has become the main issue of economic and social sustainability[1]. As the main indicator of vegetation status at this stage, NDVI (Normalized Difference Vegetation Index) has some advantages in scale, aging and characterizing vegetation characteristics and other aspects [2].
The Outline of the Environmental Protection Plan for the Pearl River Delta indicated that a stable ecological security pattern should be formed in the Pearl River Delta region, a virtuous cycle of ecological environment should be realized, and an ecological city cluster should be built. By the NDVI sequential research, Liu Haichao[3] found that the vegetation coverage of The Pearl River Delta increased slowly during the study period. Further research is needed to predict whether the vegetation cover will continue to grow after 2010 and what kind of development trend it will have in a longer time scale in the future. At present, most of the existing studies focus on the NDVI mean time sequence analysis in the Pearl River Delta region. Its main defect is that it cannot describe the dynamic characteristics of the spatial and temporal pattern of vegetation cover in detail, and there is a lack of prediction on the future trend of vegetation cover. Therefore, based on MODIS NDVI sequential remote sensing data, the methods of regression analysis, CV stability analysis, Hurst exponent analysis are used in this paper to invert the spatio-temporal variation trend of vegetation cover in the Pearl River Delta region from 2000 to 2015 and to analyze its stability. On this basis, the future change trend of vegetation cover was predicted.

2. Study area
The Pearl River Delta (PRD) region is located in the Pearl River downstream, in the southern part of Guangzhou Province in China, adjacent to Hong Kong and Macao. Its scope of latitude and longitude are 111°59.7′E to 115°29.3′E and 21°17.6′N to 23°55.9′N (Figure 1). The PRD region covers an area of 5.47×10⁴ km², which has a tropical oceanic monsoon climate with abundant rainfall. The average annual temperature is 21.4℃~22.4℃. The PRD, one of the regions with the largest population density and highest urbanization rate, is an important economic center region in China.

3. Research Methods

3.1. Data Sources and Preprocessing
Remote sensing image data use MOD13A1-NDVI sequential products as the source data, which were obtained from the DATA website of NASA, with spatial and temporal resolution 500m×500m and 16 days respectively. To avoid the interference of special factors, and accurately reflect the vegetation cover, the season with relatively vigorous vegetation growth (April-October) was selected as the study period. Image preprocessing firstly uses MRT tools and codes to project and crop NDVI time series data, and then, the Maximum Value Composite was adopted to eliminate the interference of cloud and atmosphere on the image DN value [4].

3.2. Annual Change Trend of Vegetation Coverage
Taking the pixels as units, the method of unitary linear recursive analysis was used to simulate the variation trend of NDVI raster data in 16 years. The calculation formula is as follows,
In the formula, \( n \) is the total number of years; \( i \) is the year; \( M_i \) is the maximum of NDVI in the year of \( i \). \( \theta \) is the regression trend slope of NDVI series.

3.3. Stability of Vegetation Coverage

Coefficient of variation (CV) is a method used to quantify the degree of data dispersion. The larger the value is, the more discrete the pixel NDVI distribution is in the research period. The calculation method is as follows,

\[
CV = \frac{\sigma}{\overline{NDVI}} \quad (2)
\]

In the formula, \( \sigma \) is standard deviation. The calculation formula is \( \frac{\sqrt{\sum_{i=1}^{n}(M_i - \overline{NDVI})^2}}{n} \), \( \overline{NDVI} \) is the 16-year average value of each pixel NDVI in the research area.

3.4. Evolution Trend Prediction of Vegetation Coverage

Hurst index often used to study the sustainability of quantitative study of time series [5]. In this study, Hurst index is used to study the persistent character of NDVI time series in The Pearl River Delta. The basic calculation principle is as follows,

The existing \( \{NDVI(t)\} \) represents the NDVI time series, among them, \( t = 1, 2, 3, \ldots \); For any positive integer \( \tau \geq 1 \),

the mean sequence is defined as,

\[
\overline{NDVI}_\tau = \frac{1}{\tau} \sum_{t=1}^{\tau} NDVI(t) \quad (\tau = 1, 2, 3, \ldots, n) \quad (3)
\]

Cumulative deviation sequence is,

\[
X(t, \tau) = \sum_{i=1}^{\tau} (NDVI(t) - \overline{NDVI}_\tau) \quad (4)
\]

Differential sequence is,

\[
R(t, \tau) = \max(X(t, \tau)) - \min(X(t, \tau)) \quad (1 \leq t \leq \tau; \ \tau = 1, 2, 3, \ldots, n) \quad (5)
\]

Standard deviation sequence is,

\[
S_\tau = \left[ \frac{1}{\tau} \sum_{t=1}^{\tau} (NDVI(t) - \overline{NDVI}_\tau)^2 \right]^{rac{1}{2}} \quad (6)
\]

Introduce the dimensionless ratio \( R/S \), if there is \( H \) making \( R(t)/S(t) \propto t^H \) true, it shows that Hurst phenomenon exists in time series \( \{NDVI(t)\} \) \( (t = 1, 2, 3, \ldots, n) \). The value of \( H \) is the Hurst Index, the range of values is,

1) When \( 0 < H < 0.5 \), it shows that the NDVI time series is anti-persistent, that is, the future vegetation change is negatively correlated with the past vegetation change trend.

2) When \( H = 0.5 \), NDVI time series is an independent random sequence and has no correlation with the trend of vegetation change in the past.

3) When \( 0.5 < H < 1 \), future NDVI time series has long-term correlation, and the process is persistent.

4. Results and Analysis

4.1. Interannual Variation Characteristics

The vegetation coverage in the Pearl River Delta was on a rising trend in general from 2000 to 2015 (0.029/10 years). The lowest value of NDVI appeared in 2000 (0.6597), and the highest value appeared in 2015 (0.7175), with an average value of 0.679. There are obvious fluctuations in the growth process of 16 years (Figure 2). It can be divided into three stages, that is, slow growth period (2000-2003), fluctuating growth period (2004-2014), and rapid growth period (2014-2015), with the average growth rate of 0.53%, 0.26% and 4.12% respectively.
4.2. **NDVI spatial pattern**
Using NDVI time series data, the 16-year average value of NDVI was calculated on the pixel scale (Table 1). The analysis showed that the area with NDVI less than 0.2 in the whole region accounted for 4.70%. The area with NDVI value between 0.2–0.4 and 0.4–0.6 accounted for 33.04%, with moderate vegetation coverage, covering the central urban agglomeration of the Pearl River Delta; The area with NDVI value between 0.6–0.8 accounted for 60.81%. The area with NDVI value between 0.8–1 was the minimum, accounting for 1.45%, distributed sporadically throughout the region. It can be seen that with the increase of altitude, the mean value of NDVI in the study area first increased and then decreased.

Table 1. Spatial distribution of 16-year NDVI mean in the Pearl River Delta

| Area ratio (%) | Area/km² | -19–50m | 50–150m | 150–300m | 300–450m | 450–700m | 700–1523m | Subtotal |
|----------------|----------|---------|---------|----------|----------|----------|----------|----------|
| 4.70%          | 2665     | 30.5    | 1.25    | 0        | 0        | 0        | 2696.75  |
| 13.14%         | 7350.25  | 189     | 7.25    | 1.5      | 1        | 0        | 7549     |
| 19.89%         | 10346.25 | 956     | 74.5    | 29.25    | 16.75    | 1.75     | 11424.5  |
| 60.81%         | 8815     | 11322.75| 7289.5  | 4373     | 2363     | 761.75   | 34925    |
| 1.45%          | 0.25     | 42.25   | 298     | 367.5    | 124      | 2.5      | 834.5    |

4.3. **Spatial variation characteristics of NDVI**

4.3.1. **Analysis of NDVI spatial variation trend.**
From 2000 to 2015, the average annual variation trend of NDVI region in The Pearl River Delta region was significantly different. (Figure 3, Figure 4) NDVI degradation in Zhongshan and Pearl River was more obvious. NDVI basically remained unchanged in the following areas, southern coastal tidal flats, Zhaoqing, Huizhou and the mountainous and hilly area of Jiangmen. And the areas that had obvious improvement were mainly Guangzhou and Shenzhen.

Figure 3. Spatial distribution of vegetation coverage at significance level in the Pearl River Delta from 2005 to 2015.
4.3.2. Spatial fluctuation characteristics of NDVI.

The CV values of NDVI time series in the study area were 0.063~0.850 (Figure 5, Figure 6). The areas of low fluctuation change and low fluctuation change in the region were $2.76 \times 10^4 \text{km}^2$ and $1.41 \times 10^4 \text{km}^2$, accounting for 50.28% and 25.78%; The area of moderate fluctuation variation was $0.858 \times 10^4 \text{km}^2$, accounting for about 15.65%; The area of relatively high fluctuation change and high fluctuation change were $0.454 \times 10^4 \text{km}^2$ in total, accounting for about 8.29%.
4.4. The Characteristics of the Future Evolution Trend of NDVI

4.4.1. NDVI Spatial Sustainability.

According to the statistical results (Figure 7), the regional area of \(0 < H < 0.5\) was \(3.75 \times 10^4\) km\(^2\), accounting for about 66.32%, and the regional vegetation cover in this interval shows the characteristics of anti-continuity, that is, the trend of future vegetation cover was contrary to that of the past 16 years; The regional area of \(0.5 < H < 1\) was \(1.905 \times 10^4\) km\(^2\), accounting for about 33.68%, and the regional vegetation cover in this interval shows the characteristics of continuity, that is, the trend of future vegetation cover was similar to that of the past 16 years.

4.4.2. Future Development Trend of NDVI.

After reclassifying R/S calculation results, superposition coupling analysis was carried out to it and variation characteristics of NDVI time series. The following results were obtained (Figure 8). In the future, vegetation cover anti-continuous improvement regional area accounted for more than a half (55.36%), and continuous improvement area accounted for 25.4%, and continuous degradation area accounted for 8.27%. Although the proportion of continuous degradation was relatively small, the regional vegetation cover has an overall trend of degradation. From the perspective of spatial distribution, the anti-sustainable improvement area was mainly distributed in the area with good vegetation coverage. Due to urban development economic structure change and other factors, the regions of continuous degradation and anti-continuous degradation were distributed in the area with rapid development in recent years. Both of them were basically areas of significant degradation.

![Figure 7. Normal distribution plot of the Hurst index in the Pearl River Delta.](image-url)
5. Conclusion and Discussion

1) The vegetation coverage in the Pearl River Delta was on a rising trend in general in the 16 years (0.029/10 years). The vegetation coverage of the eastern, northern and western parts of the Pearl River Delta was relatively good, and the tidal flat along the South China Sea is the worst, and urban development has a significant impact on vegetation cover.

2) The stability of vegetation cover in The Pearl River Delta showed the condition of "Low fluctuation is more, high fluctuation is less, locality is obvious". The medium and high fluctuation of vegetation cover and the degraded area of vegetation cover in the Pearl River Delta have significant spatial consistency.

3) The vegetation in the Pearl River Delta is dominated by anti-sustainability. Based on the analysis of the change trend of the past 16 years and the future change trend, with the exception of a small number of urban areas such as Dongguan, the ecological development around the urban agglomeration will be gradually paid attention to with the development of cities, and the vegetation coverage will be degraded first and then improved. In areas other than urban concentration, such as Zhaoqing and Jiangmen, vegetation degradation may occur if there is no good ecological planning.

There is indeed a certain correlation between human factors and vegetation coverage change. Both ecological improvement and degradation exist in the surrounding areas of urban agglomerations. In the ecological status evaluation study. Zhang Jie et al [6] found that the improved ecological status of the Pearl River Delta region is mainly distributed in areas with high vegetation coverage or high altitude on the edge of urban agglomerations. In order to build a stable ecological security pattern and promote the benign development of regional ecological environment, it is necessary to pay attention to the anti-sustainable improvement of most areas around non-urban agglomeration in the future, only by reasonably planning the relationship between economic development and ecological development, and implementing the concept of green development, can we build a stable ecological security pattern.

References

[1] Wang, X. (2016). Study on vegetation change and its response to climate in the source area of The River from 1982 to 2013. Lanzhou, Master's thesis of Lanzhou University.

[2] Chen, X.Q. Heng, Wang. (2009). Spatial and temporal changes of vegetation zone and vegetation coverage in Inner Mongolia from 1982 to 2003. Acta Geographica Sinica, 64(1):84-94. temperature and rainfall variations. Journal of Geophysical Research Atmospheres, 115(D14): D14101.

[3] Liu, H.C. (2015). The research on the vegetation coverage dynamic change of Guangdong Province based on RS and GIS[D]. Guangzhou, South China Agricultural University.
[4] Stow, D. Petersen, A. Hope, A. (2007). Greenness trends of Arctic tundra vegetation in the 1990s: comparison of two NDVI data sets from NOAA AVHRR systems. International Journal of Remote Sensing, 28(21):4807－4822.

[5] Li, S.S. Yan, J.P. Wan, J. (2012). The spatial－temporal changes of vegetation restoration on loess plateau in Shaanxi-Gansu-Ningxia region. Acta Geographica Sinica, 67(7):960－970.

[6] Zhang, J. Yang, Y.Q. (2019). Remote sensing evaluation on the change of ecological status of Pearl River Delta urban agglomeration. Journal of Northwest Forestry University, 34(1):184-191.