Spatial-temporal Variation of Vegetation Cover and Its Response to Sunshine in the Beijiang River Basin, South China

Zhanming LIU[1,2*], **Rong FU**[2]

1. School of Architecture and Planning, Foshan University, Foshan 528000, China; 2. School of Environment and Chemical Engineering, Foshan University, Foshan 528000, China

Abstract Based on MODIS NDVI data and sunshine hours data from 2000 to 2019, using mathematical statistical methods, the monthly variations in vegetation and sunshine hours in the Beijiang River basin were primarily analyzed, as well as the response relationship between the two. The results showed that: ① the annual average NDVI of the basin was 0.58. In terms of intra-annual distribution, the lowest value was recorded in February (0.41), and it gradually increased from February to September, reaching the highest value in September (0.72). Then, it gradually decreased from September to next February. The overall NDVI of the basin showed a fluctuating upward trend. From an intra-annual perspective, it increased rapidly in the second half of the year (July to December). Areas with low vegetation coverage were mainly distributed in the southern part of the basin and the valley plains in the central and northern parts. ② The average annual sunshine hours was 1 595.80 h, but there were significant variations between years, and the overall trend of annual sunshine hours was a decline. NDVI and sunshine hours were primarily positively correlated, with a stronger correlation from January to June.

Key words NDVI; Sunshine hours; Correlation analysis; Beijiang River basin

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Under the background of global warming, the relationship between climate change and terrestrial ecosystems has become a hot topic of concern for the international community[1–2]. As the mainstay of terrestrial ecosystems, vegetation serves as a key factor for material and energy exchange and information transmission across various spheres. It plays a significant role in ecological service functions such as climate regulation, soil and water conservation, and biodiversity conservation[3]. The Normalized Difference Vegetation Index (NDVI) can indicate the growth status of vegetation and has a significant linear relationship with vegetation coverage. Therefore, it is commonly used to study the response of vegetation cover change to ecological factors (such as climatic factors, land use, human activities, *etc.*)[4]. Currently, scholars have studied the characteristics of NDVI changes in different vegetation types and their correlation with climatic factors at global, national, and regional scales[5–6]. The results indicated that climate change has a significant impact on vegetation growth.

The Beijiang River basin (Fig. 1) serves as an important ecological barrier and water conservation area for the Pearl River Delta in southern China, as well as the Guangdong – Hong Kong – Macao Greater Bay Area. In the context of global warming, it is of great significance for regional ecological security construction by studying the spatiotemporal changes in vegetation coverage in the Beijiang River basin and its response to sunlight. It can also provide a basis for effectively mitigating and responding to climate anomalies. Based on previous research, studies on the correlation between NDVI and sunshine are rarely seen in specific research related to the Beijiang River basin. In this paper, based on MODIS NDVI data and sunshine data from 2000 to 2019, using mathematical statistical methods, the monthly variations in NDVI and sunshine hours in the Beijiang River basin were primarily analyzed, as well as the response relationship between the two. The research results had theoretical and practical significance for understanding the evolution of the ecosystem in this region and for ecological security construction.

1 Data and methods

1.1 Sunshine hours The sunshine hours data was sourced from 18 Chinese national benchmark meteorological stations (Fig. 1) distributed evenly across the Beijiang River basin, with the data provided by the China Meteorological Administration.

1.2 Source and processing methods of remote sensing data The remote sensing data came from the MODISQ1 data released by the National Aeronautics and Space Administration (NASA) (https://ladsweb.nascom.nasa.gov/), with a spatial resolution of 250 m and a temporal resolution of 16 d. The product dataset has undergone preprocessing such as geometric correction, radiometric correction, and atmospheric correction to ensure data quality. The data spanned from 2000 to 2019, with 23 images covering the Beijiang River basin each year. The specific processing procedure

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* Corresponding author.

was as follows:

① The downloaded MODIS image data underwent projection coordinate system conversion (unified to WGS84 coordinate projection), band operation, and format conversion using MRT software.

② Since the original data was presented as an image covering 16 d, in order to obtain monthly and annual data, it was necessary to synthesize the data. The synthesis method was the widely used Maximum Value Composites (MVC) method both domestically and internationally. This method can further eliminate the interference from clouds, atmosphere, solar elevation angle, *etc*[7]. ArcGIS10.2 software was utilized to perform maximum processing on the data, to acquire monthly and annual NDVI data. The formula was as follows:

$$MNDVI_i = Max\ (NDVI_1,\ NDVI_2) \quad (1)$$

where i is month ordinal, with a value range of 1 - 12; $MNDVI_i$ is NDVI value in the i^{th} month; $NDVI_1$ and $NDVI_2$ are NDVI values for the first and second halves of the i^{th} month. Similarly, the annual NDVI value can be obtained using this method.

③ The outliers were removed from the maximized and synthesized NDVI data. ArcGIS10.3 software was used to eliminate negative values, given that the NDVI value range was between -1 and 1, with NDVI < 0 indicating no vegetation coverage. Subsequently, the NDVI image of the study area was extracted based on the mask.

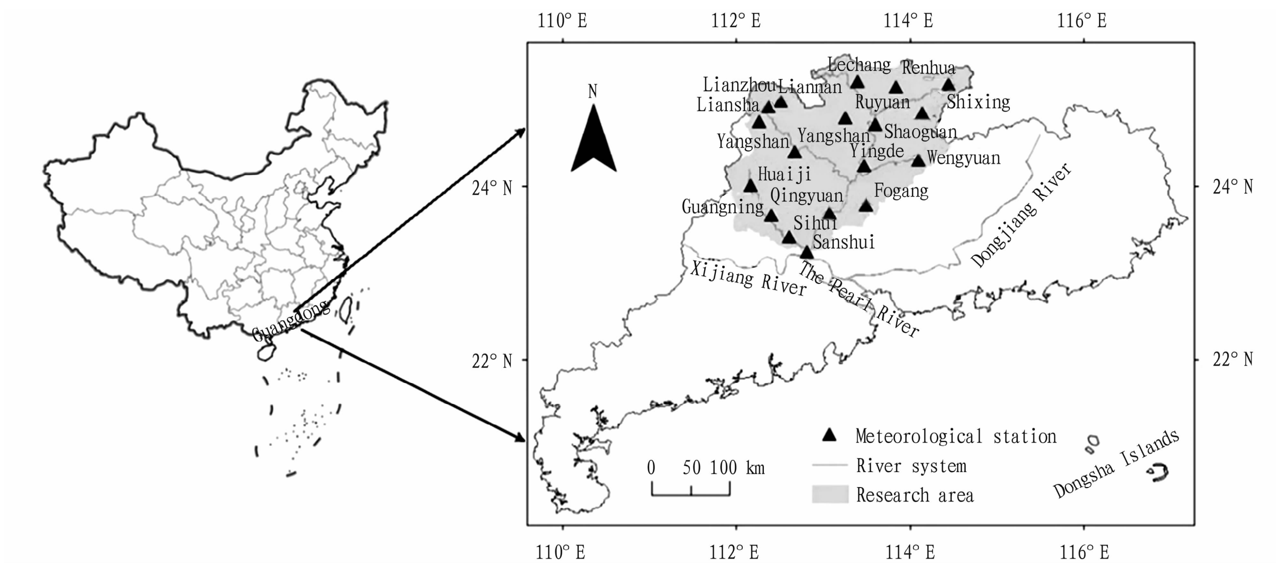


Fig. 1 Geographical location of the Beijiang River basin

1.3 Research methods The mathematical statistical methods employed in this study, such as the Mann - Kendall (abbreviated as M - K) trend test, linear trend analysis, and Pearson correlation coefficient method, are widely adopted and mature methods in this research field by numerous experts and scholars. The specific calculation formulas are not be elaborated further here.

2 Results and analysis

2.1 NDVI

2.1.1 Temporal variation. As shown in Table 1, the NDVI values for each month in the Beijiang River basin ranged from 0.41 to 0.72 between 2000 and 2019. Specifically, the NDVI values for January, February, March, and April fell within the range of 0.41 to 0.50, with February recording the lowest value at 0.41. The NDVI values for other months ranged from 0.58 to 0.72, with September recording the highest value at 0.72. From the perspective of changes within the year (Fig. 2), there was a gradual increase from February to September, followed by a gradual decrease from September to next February.

Table 1 Monthly and annual change statistics of NDVI from 2000 to 2019

Time	Mean	Linear trend//10 a^{-1}
January	0.49	0.071
February	0.41	0.024
March	0.43	0.002
April	0.49	-0.001
May	0.58	0.001
June	0.59	-0.009
July	0.65	0.063
August	0.67	0.036
September	0.72	0.032
October	0.69	0.039
November	0.63	0.032
December	0.61	0.068
Annual	0.58	0.022

Based on the trend of NDI changes in each month (Table 1), there was a slight decrease in April and June (0.001/10 a and 0.009/10 a, respectively); all other months showed an increase. Specifically, the increase was rapid from July to October and in December. For example, the increase rate from August to October ranged from 0.03/10 a to 0.04/10 a, while the increase rates in July and December were 0.063/10 a and 0.067/10 a, respectively.

On an annual scale (Table 1, Fig. 3), the NDVI showed a fluctuating upward trend (0.022/10 a) from 2000 to 2019, with the lowest value occurring in 2005 (0.51) and the highest value occurring in 2018 (0.64). The multi-year average value was 0.58.

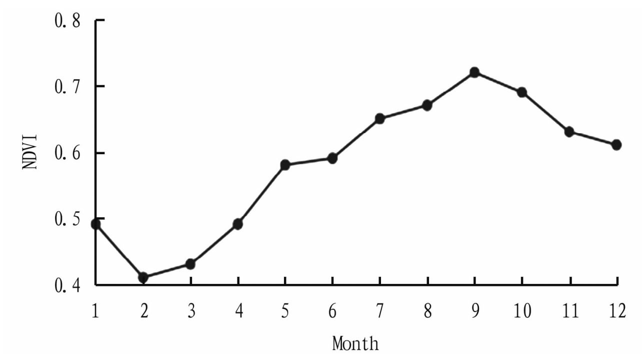


Fig. 2 Monthly NDVI in the Beijiang River basin

2.1.2 Spatial variation of monthly vegetation index. As shown in Fig. 4, the NDVI of the Beijiang River basin was overall relatively high from May to October, with minor differences in most areas. The areas with lower NDVI were mainly distributed in the southern part near the Pearl River Delta and the valley plains in the central and northern parts. The reason may be that these areas have a concentrated population (towns) and a high intensity of human activity intervention, resulting in severe damage to the original vegetation. From November to next April, regional differences were quite pronounced. Especially from January to March, concentrated and contiguous areas with low NDVI were widely distributed. This may be related to changes in factors such as illumination, temperature, and precipitation caused by changes in climatic conditions (seasonal transitions).

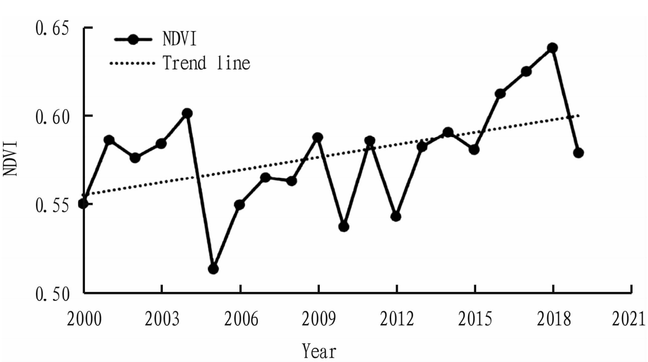


Fig. 3 Annual NDVI in the Beijiang River basin

2.2 Sunshine hours

2.2.1 Annual sunshine hours. The annual sunshine hours and its variations in the Beijiang River basin from 2000 to 2019 were presented in Table 2 and Fig. 5. Over the 20-year period, the average sunshine hours was 1 595.80 h. However, there were significant variations among different years. For instance, the sunshine hours exceeded 1 700 h in 2003, 2004, 2007, and 2009, with 2004 reaching the highest value of 1 844.85 h. In contrast, the sunshine hours was below 1 500 h in 2002, 2005, 2010, 2012, and 2015, with 2012 recording the lowest value of 1 382.59 h. For other years, the sunshine hours ranged from 1 500 to 1 700 h. In terms of the changing trend, there has been an overall downward trend over the past 20 years, with a trend rate of −4.71 h/a.

Table 2 Monthly and annual change statistics of sunshine hours from 2000 to 2019

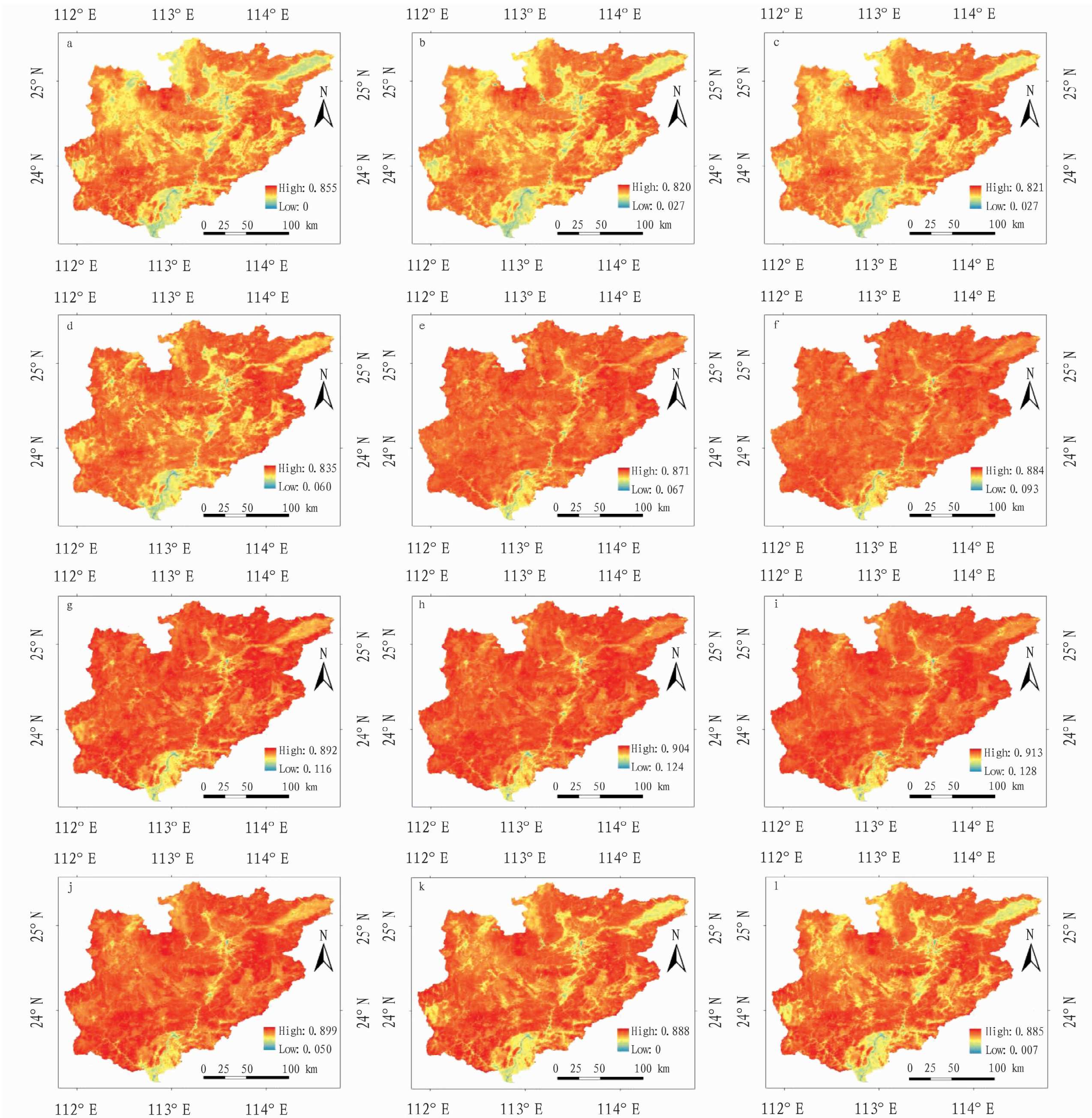
Time	Mean//h	M−K statistic
January	98.03	0.39
February	70.34	−0.03
March	65.01	−1.43
April	79.03	−0.09
May	112.27	−2.67*
June	143.28	0.84
July	196.42	0.21
August	196.41	0.46
September	176.73	−0.98
October	182.81	0.38
November	137.35	−2.29*
December	138.13	−0.71
Annual	1 595.80	−1.30

Note: * shows passing the 0.05 of confidence test.

2.2.2 Monthly sunshine hours. The monthly sunshine hours and its variation in the study area from 2000 to 2019 were presented in Table 2 and Fig. 6. From July to October, the sunshine hours ranged from 175 to 200 h, marking the high-value period of the year. Specifically, the sunshine hours in July and August both exceeded 196 h. From January to April, the sunshine hours ranged from 65 to 100 h, marking the low-value period of the year, with March having the lowest, at only 65.01 h. The sunshine hours in the remaining months ranged from 110 to 145 h. In terms of the trend of change, there was an upward trend in January, June to August, and October, while there was a downward trend in other months. Notably, the decline was significant in May and November (passing the 0.05 of confidence test).

2.3 Correlation analysis between NDVI and sunshine hours

To investigate the response relationship between NDVI and sunshine hours, SPSS software was used to conduct a correlation analysis between NDVI and sunshine hours during the same period. The results showed that their correlation coefficients from January to December were 0.573*, 0.526*, 0.436, 0.657*, 0.294, 0.587*, 0.220, 0.109, 0.107, −0.203, 0.081, and 0.019 respectively (* indicated passing the 0.05 of confidence test). Except for the negative correlation in October, all other correlations were positive; the correlation coefficients from January to June were generally higher than those from July to December, with significant correlations in January, February, April, and June (passing the 0.05 of confidence test).



Note: a. January; b. February; c. March; d. April; e. May; f. June; g. July; h. August; i. September; j. October; k. November; l. December.

Fig. 4 Spatial distribution of monthly NDVI in the Beijiang River basin

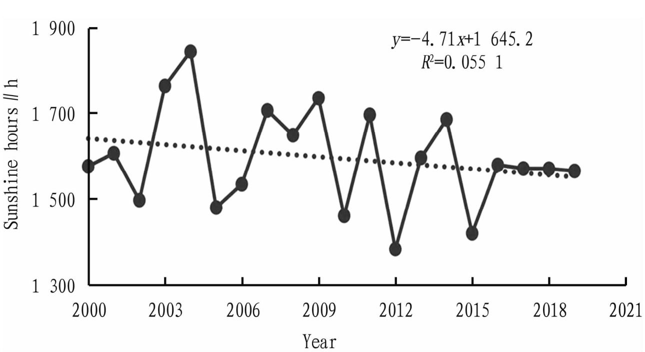


Fig. 5 Annual sunshine hours in the Beijiang River basin

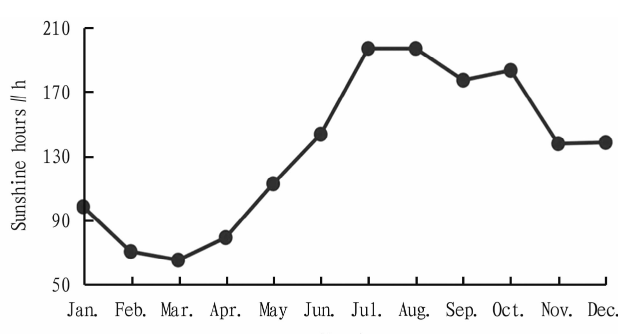


Fig. 6 Monthly sunshine hours in the Beijiang River basin

3 Conclusions

In this paper, based on MODIS NDVI and sunshine data from 2000 to 2019, using the mathematical statistical methods, the monthly variations in vegetation and sunshine hours in the Beijiang River basin were primarily analyzed, as well as the response relationship between the two. The results showed that:

(1) The annual average NDVI of the basin was 0.58. In terms of intra-annual distribution, it was the lowest in February (0.41), gradually increased from February to September, reached its highest in September (0.72), and then gradually decreased from September to next February. The overall NDVI of the basin showed a fluctuating upward trend (with a linear trend of 0.022/10 a). In terms of monthly trends, there was a slight decrease in April and June, followed by a rapid increase in July, August, September, October, and December. In terms of spatial distribution, the overall NDVI of the basin was relatively high from May to October, with minor differences in most areas. From November to next April, regional differences became more pronounced. Areas with lower NDVI were primarily distributed in the southern and central-northern river valley plains.

(2) The average annual sunshine hours was 1 595.80 h, but it varied greatly from year to year, with the highest value being 1 844.85 h (in 2004) and the lowest value being 1 382.59 h (in 2012). The annual sunshine hours generally showed a downward trend, with a trend rate of −4.2 h/a. Regarding the sunshine hours for each month, it ranged from 175 to 200 h from July to October; from 65 to 100 h from January to April; and from 110 to 145 h for the remaining months. The sunshine hours in most months showed a downward trend, with significant decreases in May and November (passing the 0.05 of confidence test). Correlation analysis indicated that there was a positive correlation between NDVI and sunshine hours, with a stronger correlation from January to June.

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4 Conclusions

In this paper, the ecological water demand research comprehensively considered factors such as the annual runoff variation characteristics of rivers, the minimum runoff under the drought limit of rivers, and the minimum monthly runoff measured over many years in terms of theory and method. These methods are representative and meet the requirements of protecting river ecosystems in practice. Therefore, the average values obtained through these methods have certain reference value for water resource utilization planning in the Dongting Lake basin.

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