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Spatiotemporal Variation of NDVI in Anhui Province from 2001 to 2019 and Its Response to Climatic Factors

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Abstract: This paper intends to clarify that the spatial and temporal evolutionary patterns of regional vegetation and their relationship with climate form a premise of ecological conservation and environmental governance, and play an important role in maintaining regional ecosystem balance and promoting sustainable development. Based on measured data collected from NDVI remote sensing products and meteorological stations, NDVI variation in Anhui Province from 2001 to 2019 was determined through trend analysis and measurement methods involving coefficient of variation and Hurst index; in addition, the response to climatic factors was also explored. It was concluded that, firstly, in terms of spatiotemporal analysis, the interannual variation of NDVI in Anhui Province showed an increasing trend with a rate of 0.024/10 a, while the monthly variation showed a weak bimodal pattern, with the highest value in August and the lowest value in January. Furthermore, NDVI in Anhui Province showed significant spatial heterogeneity, with high values concentrated in mountainous regions in southern Anhui and Dabie Mountain region, and low values concentrated in the hilly areas of Jianghuai and areas along the Yangtze River. At the same time, the overall spatial variation of NDVI showed an increasing trend, and the areas with extremely significant and significant improvement in vegetation coverage accounted for 54.69% of the total area of Anhui Province. Secondly, in terms of the analysis on variation characteristics, the variation of NDVI in Anhui Province was generally stable, with an average CV coefficient of variation of 0.089, which, however, was quite different in different regions; meanwhile, the future trend of NDVI variation in the study areas was mostly in a random manner. Thirdly, the response of NDVI in Anhui Province to climatic factors showed significant spatial heterogeneity. NDVI was found to be positively correlated with precipitation and negatively correlated with temperature; in general, the impact of precipitation on NDVI was greater than that of temperature. In the 19 years studied, NDVI in Anhui Province showed an increasing trend; and climate, topography and human activities led to heterogeneous spatial distribution of vegetation. Therefore, in the future, the evolutionary trend of vegetation will be relatively random, and NDVI will be more greatly affected by temperature, than by precipitation.

Keywords: NDVI; trend analysis; coefficient of variation; Hurst index; climatic response

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1. Introduction

The unreasonable exploitation and utilization of resources by human beings and the drastic change of climate have aggravated global ecological and environmental problems [1]. As pointed out in the report of the 19th National Congress of the Communist Party of China, "we must establish and practice the concept that lucid waters and lush mountains are invaluable assets", which indicates the great importance attached by the state to ecological environmental protection. Ecological environment is the basic condition of human development and also the starting point of social development. Vegetation, as an important element in maintaining the balance of terrestrial ecosystems, can serve as an "indicator" in the fields of water and soil conservation, land cover change, and environmental conservation [2,3]. The long-term monitoring of vegetation can help to achieve an understanding of the development of the regional ecological environment, and prepare related policies, so as to promote the sustainable development of human society.

Normalized difference vegetation index (NDVI), expressed as the ratio of the difference between the near-infrared band, the red band, to their sum, in remote-sensing images, can better reflect the growth status of vegetation, with its high sensitivity to vegetation; therefore, it is generally taken as an effective evaluation index for the monitoring of regional ecosystems [4]. Meanwhile, with a good correlation with vegetation coverage, it is also used in the monitoring of dynamic changes of vegetation coverage [5]. The analysis of spatiotemporal variation of vegetation and its correlation with climatic factors have become hot topics in research on ecological environment change [6,7]. In recent years, many scholars have studied the spatiotemporal variation of regional NDVI from different spatial and temporal scales. The current research areas include different topographic and geomorphic units (Qilian Mountain [8], Loess Plateau [9]), and different river basins (Yangtze River Basin [10], Yellow River Basin [11]), as well as administrative scales (national [12], provincial administrative units [13]). In terms of time scale, there are studies within 10 a [14], but there are more studies with a longer time series [15,16]. In terms of the response of NDVI to climatic factors, many scholars have studied it by means of correlation analysis [17], partial correlation analysis [18] and complex correlation analysis [7]. Previous studies showed that in climatic factors, temperature and precipitation had the most significant contribution rate to the variation of NDVI [19], and the difference in vegetation types also led to different degrees of response to climatic factors [20,21]. Anhui Province, located in the transition zone between subtropical and warm temperate zones, features complex landforms such as plains, hills and mountains [22]. In recent years, with the implementation of the Yangtze River Delta integration policy, Anhui Province has enjoyed a sustainable development of its economy, and the impact of its economic activities on the regional ecological environment has deepened [23]. However, only a few studies based on Anhui Province have been conducted, with different durations [22,23]; there have not been enough studies conducted on the sustainability and future trend of vegetation development in Anhui Province. Furthermore, the existing studies mainly consider the impact of the variation of single factors on regional NDVI [24], and few studies have been conducted on the explanation of NDVI variation rules based on multiple factors. Therefore, it is necessary to carry out long-term monitoring and systematic research on vegetation growth in Anhui Province, and discuss the response mechanism of NDVI from the perspectives of climate, human activities, and topography, thus, providing reference for the related studies on regional vegetation, in a similar environment.

In view of the above factors, Anhui Province was taken as the study area for this paper, and the spatiotemporal variation of NDVI was analyzed by trend analysis, CV and Hurst index, in combination with time series data of NDVI from 2001 to 2019, and its future trend was predicted. In addition, a per-pixel partial correlation analysis was performed on the correlation between temperature/precipitation and NDVI, to explore the response relationship between vegetation and climate elements, thus, providing scientific and objective reference for the management and protection of vegetation in Anhui Province.

2. Materials and Methods

2.1. Study Area

Anhui Province is located in the middle and lower reaches of the Yangtze River (29°41′–34°38′N, 114°54′–119°27′E). The terrain is high in the west and low in the east, and high in the south and low in the north; the whole province is divided into five natural zones from north to south by Chaohu Lake, Yangtze River and Huaihe River: namely, Huaibei Plain, Jianghuai hilly area, Western Anhui mountainous area, area along the Yangtze River, and Southern Anhui mountainous area (Figure 1). Anhui is located in the East Asian monsoon region, which leads to various climates and changeable weather; the unique climatic conditions and topographic features have promoted the development of forestry and agriculture. In Anhui Province, there is mainly broadleaved deciduous forest, evergreen needle leaved forest, and evergreen broadleaved forest [25]. Since the 1990s, several key projects have been implemented in Anhui Province, including the protection forest along the Yangtze River and Huaihe River, Returning Farmland to Forest, and World Bank Forestry Project [26]. By 2020, the forest area in Anhui Province had reached 62.62 million mu, with the forest coverage of 30.22% [27].

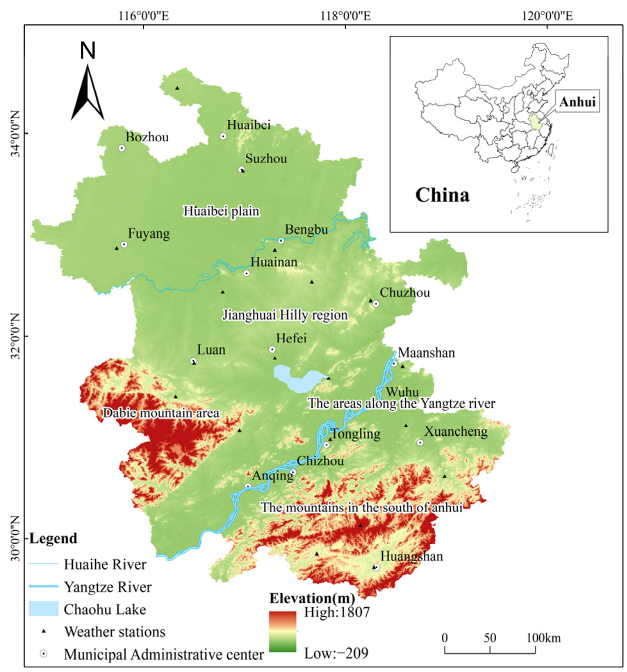


Figure 1. Geographical location and altitude of study area. The whole province is divided into five natural zones from north to south by Chaohu Lake, Yangtze River and Huaihe River: namely, Huaibei Plain, Jianghuai hilly area, Western Anhui mountainous area, area along the Yangtze River, and Southern Anhui mountainous area. The national meteorological stations and municipal administrative centers are shown in the figure.

2.2. Data Preparation

The data adopted in this paper included the NDVI remote sensing data, temperature and precipitation data, and basic geographic data. NDVI remote sensing data were the data synthesized by Terra-MODIS13Q1 from January 2001 to December 2019, with a time resolution of 16 d and spatial resolution of 250 m. The data were collected from the National Aeronautics and Space Administration (NASA) (https://labsweb.modaps.eosdis.nasa.gov/, accessed on 9 February 2022). The meteorological data are daily temperature data (daily average temperature) and daily precipitation data (from 8 p.m. to 8 p.m. the next day) collected from 20 meteorological stations in

Anhui Province from 2001 to 2019, and they were obtained from the China Meteorological Data Network (http://data.cma.cn, accessed on 20 February 2022); while basic geographic data were digital elevation data (DEM), administrative division data, and water system data, in which DEM data were obtained from the geospatial data cloud platform (http://www.gscloud.cn, accessed on 2 March 2022), and the administrative division data and water system data were obtained from the National Geomatic Center of China (http://www.ngcc.cn/ngcc/, accessed on 2 March 2022).

Firstly, MRT developed by NASA (MODIS Reprojection Tools) and bat command were used for batch reprojection, format conversion and image stitching of MODIS-NDVI data collected from 2001 to 2019; ArcGIS software was used to clip, to obtain the monthly NDVI data by max value composite, and at the same time, the annual average NDVI was calculated by the method of mean value based on the monthly NDVI data. Secondly, the data of 20 meteorological stations were used to calculate the average annual temperature value of each meteorological station by means of mean method and the annual cumulative precipitation value of each meteorological station by summation, and through Kriging interpolation and clipping, the meteorological raster data with the same pixel size and projection as NDVI data were finally obtained.

2.3. Research Methods

2.3.1. NDVI Trend Analysis

In order to study the spatial distribution characteristics of NDVI in Anhui Province from 2001 to 2019, univariate linear regression was adopted in this paper, which was used to simulate the variation of a single pixel over time, thus, reflecting the whole spatial variation characteristics. It can be calculated as follows:

$$\text{slope} = \frac{n \times \sum_{i=1}^{n} i \times \text{NDVI}_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} \text{NDVI}_i}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \quad (1)$$

where, i is the year; n is the number of years of study, namely, 19 years; NDVI_i is the value of NDVI in the year i within the duration. Slope is the slope of the regression equation, and slope > 0 represents that NDVI increases over time; and slope < 0 represents that NDVI decreases over time.

2.3.2. Coefficient of Variation

Vegetation growth would be affected by natural and human factors. The coefficient of variation is the ratio of standard deviation to mean value, which is generally used to reflect the variation of vegetation in the study area. It can be calculated as follows:

$$\text{CV} = \frac{\text{SD}_{\text{NDVI}}}{\overline{\text{NDVI}}} \quad (2)$$

where, SD_{NDVI} is the standard deviation of the average NDVI within the duration of study; $\overline{\text{NDVI}}$ is the average NDVI within the duration of study; the greater CV indicates greater annual variation of NDVI, and the smaller CV indicates more stable annual variation of NDVI. In order to analyze the variation degree of NDVI in Anhui Province in these 19 years more directly, in accordance with the actual situation in Anhui Province and with reference to existing studies [28], the coefficient of variation was divided into four levels in this paper, namely, very stable (CV ≤ 0.04), stable (0.04 < CV ≤ 0.08), slight variation (0.08 < CV ≤ 0.12), and severe variation (CV > 0.12).

2.3.3. Hurst Index

Hurst index can be used to predict the evolution trend of time series, and it is an effective method to detect the long-term dependence of time series [29]; its basic principle, based on rescaled range (R/S) analysis method, has been widely used in research fields such as ecology, hydrology, and meteorology [30].

Hurst index can reflect the future development trend of regional NDVI. H = 0.5 indicates that the future development trend of NDVI is uncertain and random; 0.5 < H < 1 indicates that the future variation trend of NDVI is the same as in the past, with sustainability, the higher the H means the greater the sustainability; and 0 < H < 0.5 indicates that the future variation trend of NDVI is contrary to that in the past, with anti-sustainability, the smaller the H means the greater the anti-sustainability. The Hurst index equation can be seen in the relevant literature [20].

2.3.4. Partial Correlation Analysis

Partial correlation analysis can remove the impact of other variables, and analyze the correlation between two variables only. In this paper, the partial correlation between vegetation, and the precipitation and temperature, was analyzed through calculating the partial correlation coefficient. The partial correlation coefficient can be calculated as follows:

$$R_{xy\cdot z} = \frac{R_{xy} - R_{xz} \cdot R_{yz}}{\sqrt{(1 - R_{xz}^2)(1 - R_{yz}^2)}} \quad (3)$$

where, $R_{xy\cdot z}$ is the partial correlation coefficient between x and y when z is fixed; R_{xy}, R_{yz}, and R_{xz} are the correlation coefficients between x and y, y and z, x and z; x is NDVI, y is temperature, and z is precipitation.

3. Results

3.1. Monthly Time-Based Variation of NDVI in Anhui Province

3.1.1. Monthly Variation of NDVI

The average NDVI was determined based on monthly average MODIS-NDVI data from 2001 to 2019 (Figure 2). The planting of bi-seasonal crops in Anhui Province led to a weak bimodal pattern of NDVI in a year, with the highest peak in August (about 0.747), the second highest peak in April (about 0.616), and the minimum value in January (about 0.389). As shown in Figure 2, the intra-year variation of NDVI in Anhui showed two trends of increasing first, and then decreasing. Specifically, it showed an increasing trend from January to April due to growth of winter wheat and rape, and the germination of mountain trees in spring. In May, it showed a decreasing trend due to the harvest of winter wheat in northern Anhui Province, and as a result, NDVI decreased. From June to August, NDVI increased again, reaching a peak in August, as the high temperature and sufficient rainfall in summer promoted the growth of vegetation, the most flourishing plant period; however, due to the harvest of partial winter wheat in early June, NDVI was lower than in July and August; while in mid-to-late June, due to the planting of new crops, NDVI in June was slightly higher than in May. From September to December, it showed a decreasing trend again due to the gradual maturing of crops in September, the falling of leaves of most crops, and the reduced vegetation coverage, reaching its lowest level in January of the following year.

3.1.2. Annual Variation of NDVI

Figure 3 shows the interannual variation of NDVI in Anhui Province from 2001 to 2019. As shown in the Figure, the trend of NDVI changes in Anhui Province from 2001 to 2019 can be roughly divided into two stages: NDVI in Anhui Province from 2001 to 2014 showed an increasing trend, with the growth rate of 0.042/10 a; and NDVI in Anhui Province from 2014 to 2019 showed a decreasing trend, with a rate of 0.052/10 a. The main reason may be related to the occurrence of the increase in the number of geological disasters such as landslides and avalanches [31]. NDVI in Anhui Province changed between 0.5 and 0.58, with the long-time average annual value of 0.55; the maximum value (about 0.576) appeared in 2014, and the minimum value (about 0.505) in 2001. The above results showed that the vegetation coverage in Anhui Province was gradually improved in the

19 years, reflecting the strict implementation of ecological protection policies in Anhui Province.

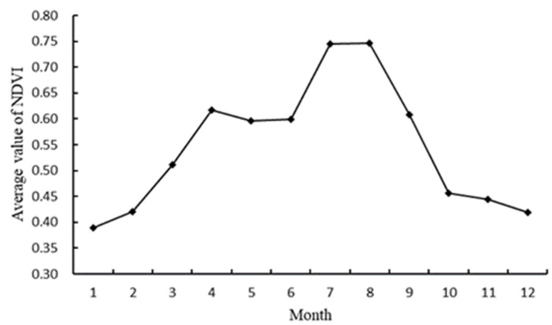


Figure 2. Monthly variation of NDVI in Anhui Province from 2001 to 2019.

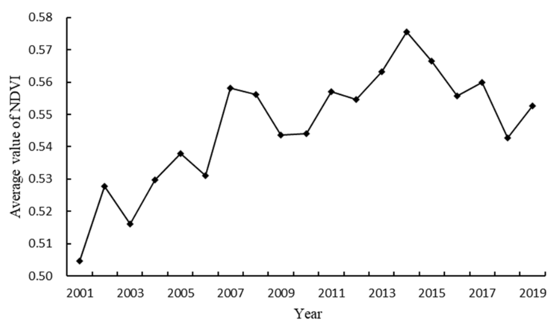


Figure 3. Annual variation of NDVI in Anhui Province from 2001 to 2019.

3.2. Annual Variation of NDVI in Anhui Province

Figure 4 shows the interannual spatial distribution of NDVI in Anhui Province from 2001 to 2019. As shown in the figure, the overall distribution of NDVI in Anhui Province had a significant spatial difference, with an increasing trend from north to south. In terms of the spatial distribution, NDVI was higher in Dabie Mountain area and Southern Anhui mountainous area due to the larger areas of woodland with more evergreen plants, less human activities, and excellent hydrothermal conditions suitable for vegetation growth. The planting of seasonal crops such as rape and paddy, the growing of evergreen and deciduous broad leaved mixed forest in Jianghuai hilly area, and the rapid urban expansion and frequent human activities in the area along the Yangtze River greatly affected their NDVI values; therefore, NDVI in these two areas was lower than in other areas. The planting of long-growth cycle crops such as winter wheat and corn in Huaibei Plain caused NDVI in this area to reach a medium level in Anhui.

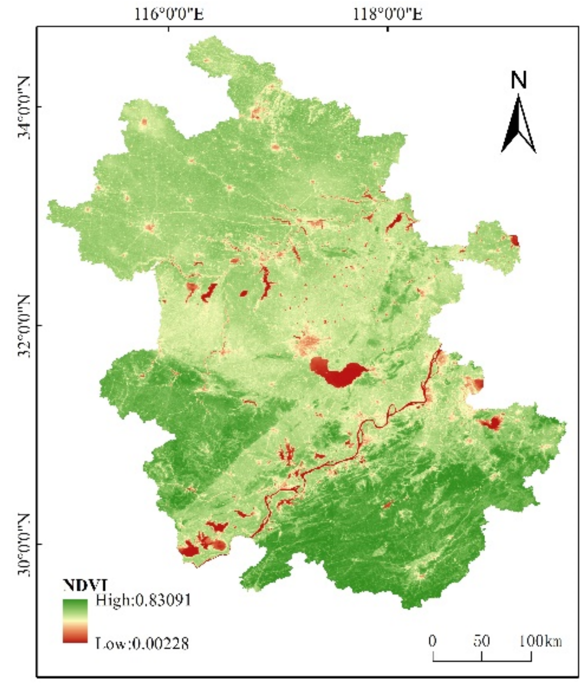


Figure 4. Interannual spatial distribution of NDVI in Anhui Province from 2001 to 2019. NDVI values ranged from 0.00228 to 0.83091.

In this paper, the quantitative study was conducted on spatial variation trend of NDVI in Anhui Province; the area of each grade of vegetation was obtained by trend analysis method, and the variation trend of NDVI was divided into six grades according to the significance test results (confidence level of 0.01 and 0.05) (Table 1 and Figure 5). According to the slope of the regression equation, the area with slope > 0 accounted for 81.57% of the total study area, and the overall vegetation coverage in Anhui Province was gradually improved. The areas with extremely significant and significant improvement accounted for 54.69% of the total area, in which the areas with extremely significant improvement (43.32%) were mainly concentrated in the northeast of Huaibei Plain, east of Jianghuai hilly area, Dabie Mountain area and Southern Anhui mountainous area with evergreen broad-leaved forest. The areas with significant improvement (11.37%) were mainly concentrated around the areas with extremely significant improvement; the areas without significant improvement (26.88%) were mainly concentrated in the northwest of Huaibei Plain, and Jianghuai hilly area. The areas with significant and insignificant degradation accounted for 14.13% of the total area, most of which were located on both sides of the Yangtze River in Anhui Province and the southwest of Huaibei Plain. The areas with extremely significant degradation accounted for 4.29%, which were mainly located in the central area of each city, some areas along the Yangtze River, and surrounding areas of urban and settlement places, with serious vegetation degradation due to the impact of urban development and human activities.

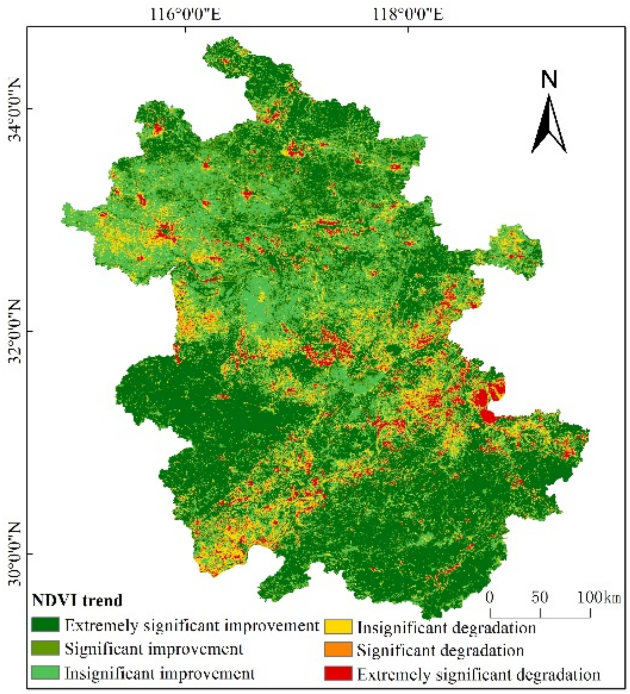


Figure 5. Spatial distribution of variation trend of NDVI in Anhui Province from 2001 to 2019. According to the change trend and significance test results of NDVI, the change trend was divided into 6 grades: extremely significant improvement, significant improvement, insignificant improvement, insignificant degradation, significant degradation, and extremely significant degradation.

Table 1. Significant statistical results of variation trend of NDVI in Anhui Province.

Degree	Grading Criteria	Area (km²)	Area (km²)
Extremely significant improvement	slope > 0, $p < 0.01$	60,686.13	43.32
Significant improvement	slope > 0, $0.01 \leq p < 0.05$	15,928.88	11.37
Insignificant improvement	slope > 0, $p \geq 0.05$	37,661.50	26.88
Insignificant degradation	slope < 0, $p \geq 0.05$	16,911.06	12.07
Significant degradation	slope < 0, $0.01 \leq p < 0.05$	2886.38	2.06
Extremely significant degradation	slope < 0, $p < 0.01$	6015.25	4.29

3.3. Stability of NDVI in Anhui Province

As shown in Figure 6, CV of NDVI in Anhui Province from 2001 to 2019 was 0.008–3.140, with the average value of 0.089; CV in most regions was less than 0.08, indicating that the variation of vegetation coverage in Anhui Province was relatively stable, and the overall vegetation stability in Anhui Province increased from north to south. In Dabie Mountain area and Southern Anhui mountainous area in the evergreen broad-leaved forest zone, the high forest coverage and vegetation coverage base made the variation of surface vegetation cover relatively stable; in Huaibei Plain and Jianghuai hilly area mainly covered by crops, the vegetation coverage fluctuated slightly due to agricultural production and human activities; in areas along the rivers and around the lakes, vegetation coverage generally maintained stable or unchanged, but the calculated CV in these areas was unusually high, with a greater degree of variation, which was associated with the low vegetation coverage or zero value. Based on these results, it could not be concluded that there was a great variation of vegetation coverage in areas along the rivers and around the lakes; in addition, the fluctuation in urban areas was relatively high, and the rapid urban development had a great impact on vegetation distribution, thus, leading to the greater fluctuation of the vegetation coverage.

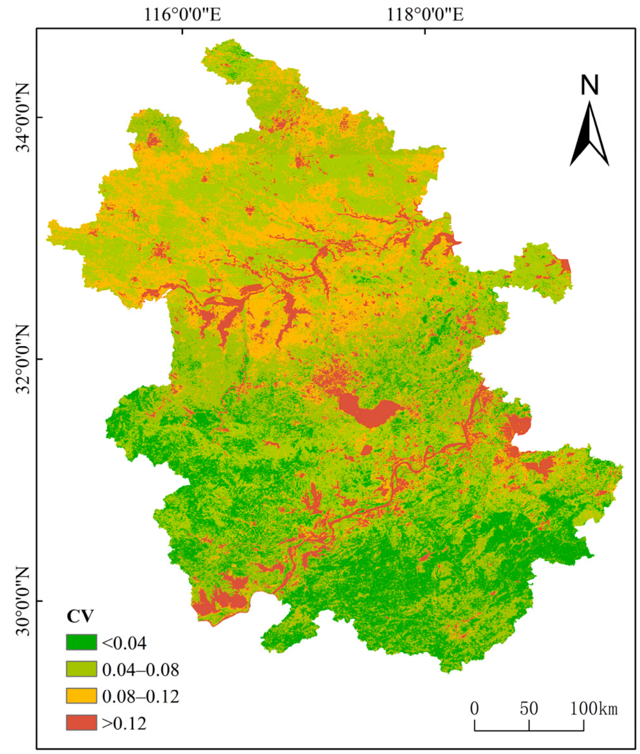


Figure 6. Spatial distribution of CV of NDVI in Anhui Province. It shows the stability degree of NDVI in Anhui Province: the smaller the CV value, the more stable the vegetation change.

3.4. Future Variation Trend of NDVI in Anhui Province

Based on the Hurst index calculated by pixel with the time series data of NDVI in Anhui Province from 2001 to 2019 (Figure 7a), it was divided into three types with ArcGIS: $H < 0.4$, $0.4 \leq H < 0.6$, and $H \geq 0.6$. Table 2 shows the meaning of each type. Hurst index in Anhui Province was 0.11–1, with an average value of 0.51. The area of random variation accounted for 67.62%, and the area with strong sustainability of NDVI variation (17.45%) was larger than the area with strong anti-c (14.93%). It can be seen from the figure that the areas with strong sustainability were mainly concentrated in Jianghuai hilly area and area along the Yangtze River, while those with strong anti-sustainability were mainly concentrated in the northern Huaibei Plain, Dabie Mountain area and Southern Anhui mountainous area. The results indicated that the future variation trend of NDVI in Anhui Province had strong randomness, with slightly stronger homodromous development than reverse development.

Based on the variation trend of NDVI and Hurst analysis results, the future variation trend of NDVI in Anhui Province was further analyzed (Figure 7b and Table 3). Spatially, the variation of NDVI in Anhui Province was generally random variation. The areas of continuous improvement accounted for 11.90% of the total area, which were mainly distributed in Jianghuai hilly area and north of Suzhou City. The areas with continuous degradation accounted for 5.55%, which were mainly distributed in the centers of various cities, the area along the Yangtze River and the center of Hefei. The areas turned from improvement to degradation accounted for 13.34%, which were mainly distributed in Bozhou City and Huaibei City in the north of Huaibei Plain, the south of Dabie Mountain area and Southern Anhui mountainous area. The areas turned from degradation to improvement accounted for 1.59%, which were mainly distributed in the north of Liu'an

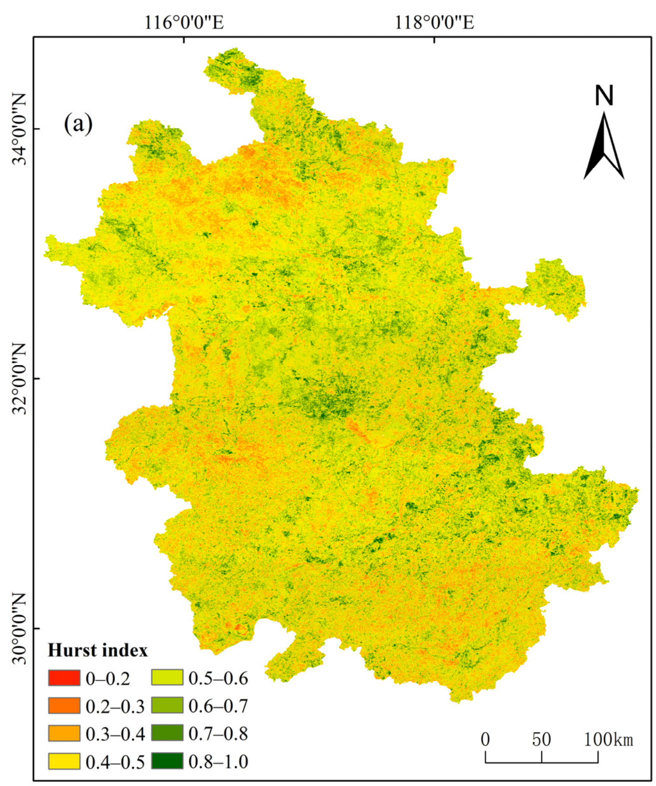
City, and parts of Wuhu City and Ma'anshan City. In terms of the future development trend of NDVI in Hefei, there will be a trend of improvement and degradation, which will be more obvious than in other cities due to the following reasons: in Hefei, a provincial capital, the dense population and the frequent and intense human activities will greatly affect the vegetation; meanwhile, the construction of ecological environment, the monitoring and restoring of vegetation growth in some areas in Hefei would result in both improvement and degradation under the intervention of human activities.

Table 2. Statistics of Hurst index of NDVI in Anhui Province.

Hurst Index	Meaning	Percentage (%)
H < 0.4	Strong anti-sustainability	14.93
0.4 ≤ H < 0.6	Random	67.62
H ≥ 0.6	Strong sustainability	17.45

Table 3. Statistics of sustainability prediction results of NDVI variation trend in Anhui Province.

Variation Trend	Sustainability	Trend Prediction	Percentage (%)
slope > 0	H ≥ 0.6	Continuous improvement	11.90
slope < 0	H < 0.4	From degradation to improvement	1.59
slope > 0	H < 0.4	From improvement to degradation	13.34
slope < 0	H ≥ 0.6	Continuous degradation	5.55
slope > 0	0.4 ≤ H < 0.6	Random	56.32
slope < 0	0.4 ≤ H < 0.6	Random	11.30



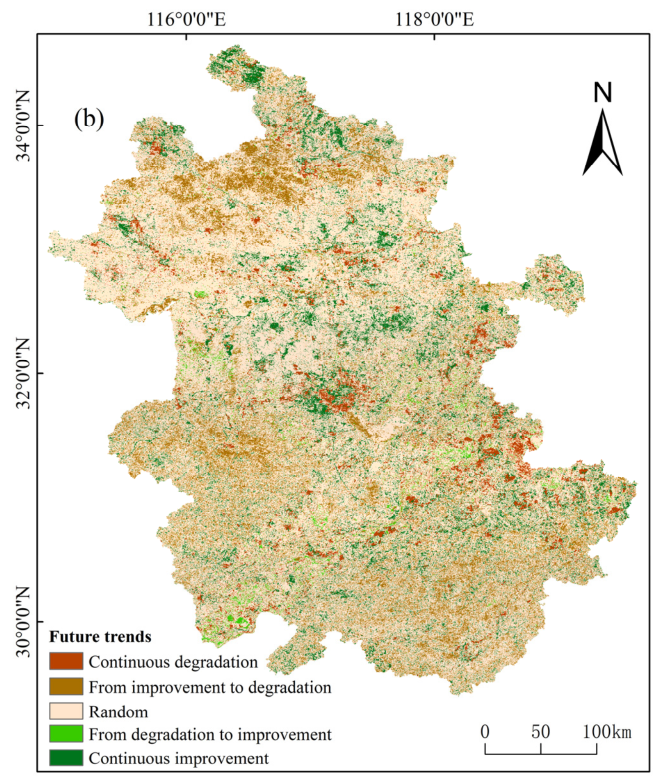
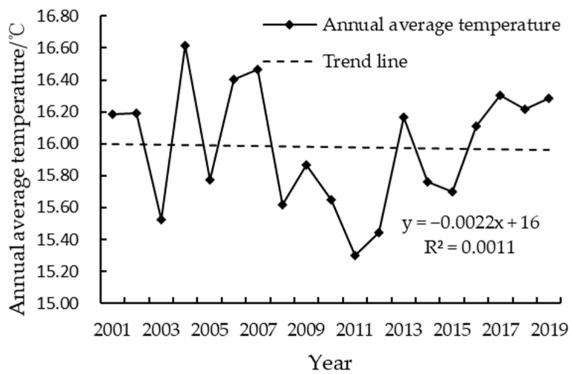


Figure 7. Spatial distribution and variation trend prediction of Hurst index in Anhui Province from 2001 to 2019: (**a**) spatial distribution of Hurst index, its value ranged from 0.11 to 1; (**b**) variation trend prediction of Hurst index, and according to the change trend and persistence of NDVI, the future change trend of NDVI was divided into 5 grades: continuous degradation, from improvement to degradation, random, from degradation to improvement, and continuous improvement.

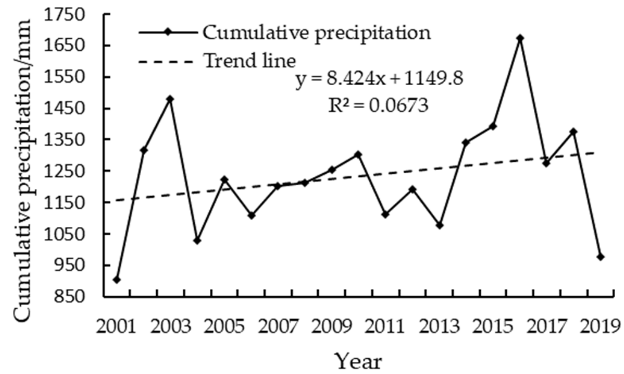
3.5. Response of NDVI in Anhui Province to Climatic Factors

3.5.1. Interannual Variation Characteristics of Climate Factors

Figure 8 shows the variation trends of average temperature and cumulative precipitation in Anhui Province from 2001 to 2019. As shown in the figure, the average temperature fluctuated slightly in Anhui Province over the 19 years, roughly showing a V-shape, with the maximum value in 2004 (16.61 °C) and the minimum value in 2011 (15.30 °C), and the annual average temperature of about 15.98 °C. The average temperature in 2001–2002, and 2006–2007 basically remained stable. In general, the annual average temperature showed a slight decreasing trend at a rate of 0.022 °C/10 a. In these 19 years, the accumulative precipitation in Anhui Province fluctuated greatly. The annual precipitation had two peaks, in 2003 (1480 mm) and 2016 (1675 mm), and two low values, in 2001 (903 mm) and 2019 (976 mm); the average annual precipitation was around 1234 mm; and the precipitation in 2007–2008 basically maintained unchanged. In general, the average annual precipitation showed an increasing trend with a rate of 84.24 mm/10 a.



(**a**)



(**b**)

Figure 8. Annual average temperature (**a**), and cumulative precipitation (**b**), in Anhui Province from 2001 to 2019.

3.5.2. Response of NDVI in Anhui Province to Climatic Factors

Climate change will affect vegetation growth, thus, changing the vegetation coverage. Research on the relationship between climate factors and vegetation coverage has become a major direction of regional sustainable development and ecological environment protection. In this paper, the quantitative study was conducted on the relationship between climate factors and NDVI, and the partial correlation coefficient between NDVI and the annual cumulative precipitation and annual average temperature from 2001 to 2019 was calculated in a pixel-by-pixel manner. It was divided into six grades by significance test using t statistic: extremely significant positive correlation, significant positive correlation, insignificant positive correlation, insignificant negative correlation, significant negative correlation and extremely significant negative correlation.

Figure 9a,b show the partial correlation coefficient between NDVI in Anhui Province and average annual temperature and spatial distribution of significance level. Partial correlation between NDVI and average annual temperature in Anhui Province from 2001 to 2019 was between −0.873 and 0.914. The statistical results showed that the areas with NDVI that positively and negatively correlated with average annual temperature accounted for 36.97% and 63.03% of the total area, respectively. The positively correlated areas were mainly distributed in Southern Anhui mountainous area, Dabie Mountain area, area along the Yangtze River, and parts of Hefei City and Chuzhou City; while the negatively correlated areas were mainly distributed in Huaibei Plain and Jianghuai hilly area, which were heavily planted with crops, and the rise of temperature would accelerate evaporation and lead to drought. The proportion passing 0.01 and 0.05 level of significance test was 5.47% and 12.68%, respectively, and the areas of extremely significant positive correlation (4.1%) and significant positive correlation (6.11%) were mainly distributed in Southern Anhui mountainous area, as sufficient precipitation and temperature increase could promote vegetation growth.

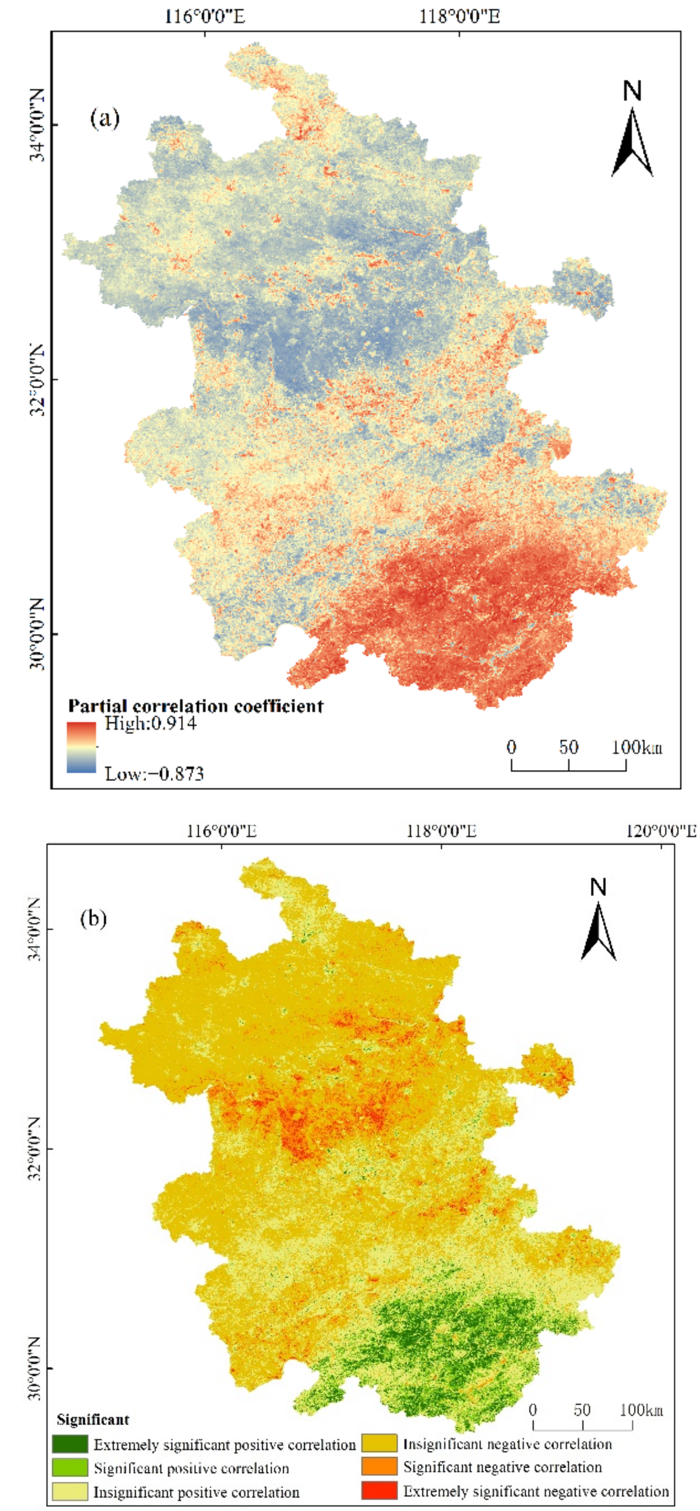
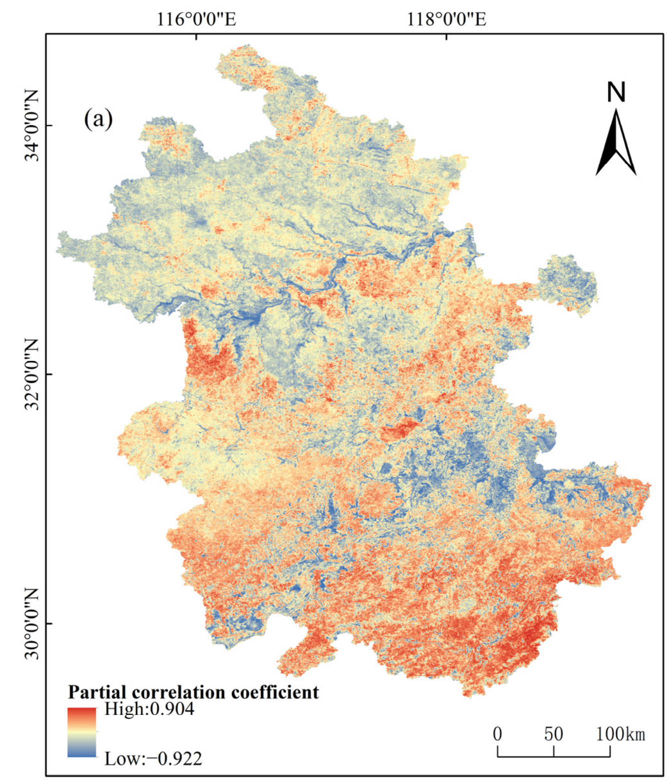


Figure 9. Partial correlation coefficient between NDVI and temperature and distribution of significance level: (**a**) partial correlation coefficient between NDVI and temperature, its value ranged from −0.873 to 0.914; (**b**) distribution of significance level, divided into 6 grades by significance test using t statistic: extremely significant positive correlation, significant positive correlation, insignificant positive correlation, insignificant negative correlation, significant negative correlation, and extremely significant negative correlation.

Figure 10a,b show the partial correlation coefficient between NDVI in Anhui Province and annual precipitation and spatial distribution of significance level. The partial correlation coefficient between NDVI and annual precipitation was between −0.922 and 0.904, showing a large spatial difference. The statistical results showed that the areas with NDVI that positively and negatively correlated with precipitation accounted for 52.61% and 47.39% of the total area, respectively. The positively correlated areas were mainly distributed in Southern Anhui mountainous area, Jianghuai hilly area, and most parts of Liu'an City, Chuzhou City and Anqing City; due to the coverage of forests and grassland, precipitation had a greater impact on NDVI variation. The negatively correlated areas were mainly distributed in the area along the Yangtze River and Huaibei Plain, with flourishing vegetation on both sides and sufficient water supply; therefore, the increase in precipitation inhibited the growth of vegetation in these areas. The proportion passing 0.01 and 0.05 level of significance test was 1.92% and 5.94%, respectively, and the areas of extremely significant positive correlation (0.87%) and significant positive correlation (3.6%) were mainly distributed in the Southern Anhui mountainous area. In general, the spatial distribution of the response of NDVI in Anhui Province to climatic factors showed significant heterogeneity, and NDVI was more affected by precipitation than temperature.



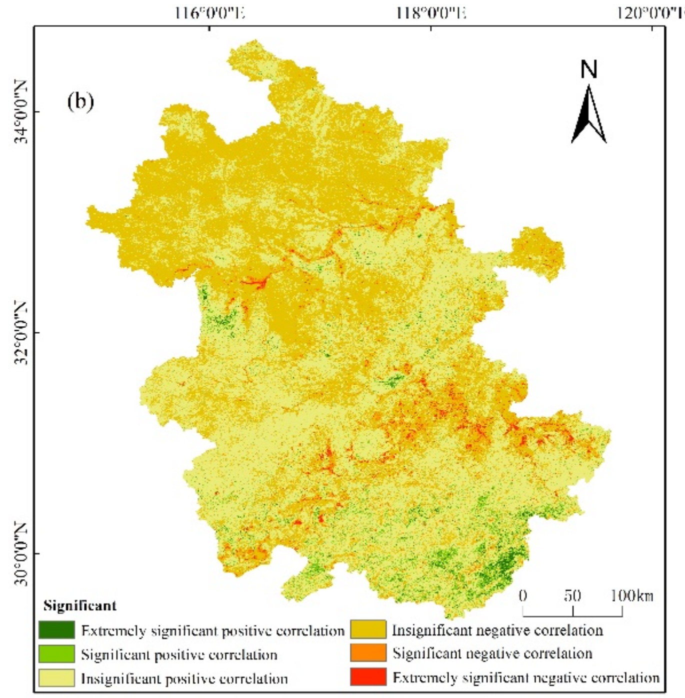


Figure 10. Partial correlation coefficient between NDVI and precipitation and distribution of significance level: (**a**) partial correlation coefficient between NDVI and precipitation, its value ranged from −0.873 to 0.914; (**b**) distribution of significance level, divided into 6 grades by significance test using t statistic: extremely significant positive correlation, significant positive correlation, insignificant positive correlation, insignificant negative correlation, significant negative correlation, and extremely significant negative correlation.

4. Discussion

In this paper, NDVI variation in Anhui Province from 2001 to 2019 was determined through trend analysis and measurement methods involving coefficient of variation and Hurst index based on the measured data collected from NDVI remote sensing products and meteorological stations; in addition, the response to climatic factors was also explored.

4.1. NDVI Time Variation

The vegetation cover in Anhui Province probably showed an improving trend from 2001 to 2019, which may be related to the implementation of reforestation, ecological environment construction, and the construction of high-standard farmland in Anhui Province [32,33]. However, NDVI in Anhui Province showed a decreasing trend from 2014 to 2019, and the trends of temperature and precipitation in the same period were not quite the same as those of NDVI, indicating that the factors affecting NDVI changes are more diverse. Geological disasters have been frequent in Anhui Province since 2014, with 126, 616, and 726 geological disasters occurring in 2014, 2015, and 2016, respectively, [31], further indicating that geological hazards may have an impact on the changes of NDVI.

4.2. Spatial Variation of NDVI

The areas with high NDVI values in Anhui Province are mainly located in the more forested southern Anhui and Dabie mountains, followed by the Huaibei Plain area, where crops are mainly grown, and finally the riverine area, which has convenient transportation and frequent human activities, leading to a greater impact on vegetation, which is consistent with the existing research results [25]. Among the future trends of NDVI changes, Hefei, as the provincial capital city, shows a more obvious trend of improvement and degradation in the region, indicating that large cities will negatively affect vegetation during the development process but conversely, will pay attention to environmental protection, and, thus, it can provide a reference for vegetation protection in the development process of similar cities [34]. In this paper, based on the analysis results of NDVI trends in Anhui Province and the prediction of future evolutionary trends, we focus on the areas where NDVI may be degraded, and where artificial intervention can improve vegetation, so as to provide a reference for the balance and sustainable development of the ecosystem in Anhui Province.

4.3. Response of NDVI to Climate Factors

In terms of the response of NDVI to climate factors, the degree of NDVI response to climate factors varies among crop growing areas, mountainous areas, and riverine areas, etc. Temperature and precipitation are the main influencing factors for NDVI changes [19], but there are many factors that affect NDVI changes such as human activities [35], altitude [24], and different vegetation types [20]. In this paper, the classical Kriging interpolation method was used for spatial interpolation when using measured temperature and precipitation data from meteorological stations [9,36]. There are many current interpolation methods such as inverse distance weighting (IDW) and DEM-based multiple linear regression (MLR) [37], etc., and different interpolation methods may have an impact on the study results [38]. The next step would be to use different interpolation methods to compare and select the optimal interpolation results, for different study areas.

This paper only analyzed the influence of climate on vegetation, but there are many factors affecting vegetation changes, including human activities, topography, and natural disasters, etc. Therefore, analysis of other causes of NDVI changes is further work needed in this research area. Due to differences in resolution and quality of different NDVI data, the change results of NDVI will be different. In the future, different NDVI data will be used for mutual verification to obtain more accurate results.

5. Conclusions

The trend of NDVI changes in Anhui Province from 2001 to 2019 can be roughly divided into two stages. NDVI in Anhui Province from 2001 to 2014 showed an increasing trend, with the growth rate of 0.042/10 a, and NDVI in Anhui Province from 2014 to 2019 showed a decreasing trend, with a rate of 0.052/10 a. NDVI in Anhui Province fluctuated between 0.5 and 0.58, with the long-time average annual value of 0.55. The vegetation coverage in Anhui Province gradually improved over the 19 years. The monthly average variation of NDVI showed a weak bimodal pattern. In May, the winter wheat was harvested, reducing the vegetation coverage; in August, the vegetation was the most luxuriant; in September, crops gradually became mature and started defoliating, reducing the vegetation coverage.

The distribution of NDVI in Anhui Province showed significant regional differences, with a trend of high in the south and low in the north. The average annual NDVI in Southern Anhui mountainous area and Dabie Mountain area was relatively high, followed by Huaibei Plain cultivated with seasonal crops; and NDVI was lowest in Jianghuai hilly area and area along the Yangtze River with frequent human activities. The areas with extremely significant and significant improvement of NDVI in Anhui Province accounted for 54.69%, and they were mainly concentrated in the northeast of Huaibei Plain, east of Jianghuai hilly area, Dabie Mountain area and Southern Anhui mountainous area within the evergreen broad-leaved forest zone. The areas with insignificant improvement accounted for 26.88%; the areas with significant and insignificant degradation accounted for 14.13%; and the areas with extremely significant degradation accounted for 4.29%. NDVI in Anhui Province generally showed an increasing trend, and a diversified development trend as affected by climate and human factors.

The overall vegetation coverage in Anhui Province from 2001 to 2019 was stable, with an average CV of 0.089. The variation was stable in Dabie Mountain area and Southern Anhui mountainous area due to the high vegetation coverage base; in Huaibei Plain and Jianghuai hilly area, the vegetation coverage fluctuated slightly due to agricultural production; but the vegetation coverage in urban areas fluctuated greatly due to urban development. In Anhui Province, the future development trend of NDVI was predicted to be high in randomness, accounting for 67.62%. The areas of homodromous development was predicted to be greater than those of reverse development. The future development of NDVI in Hefei City would be subject to greater polarization than other cities, which may be caused by the impact of frequent human activities and, conversely, the construction of ecological environment.

The variation of NDVI in Anhui Province was correlated with climatic factors, and in general, NDVI was positively and negatively correlated with annual precipitation and average annual temperature, respectively. The areas with positive and negative correlations between NDVI and average annual temperature accounted for 36.97% and 63.03% of the total area, respectively; and those with positive and negative correlations between NDVI and precipitation accounted for 52.61% and 47.39%, respectively. NDVI showed obvious spatial heterogeneity in the response to climatic factors, and the impact of temperature on NDVI was greater than that of precipitation.

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