Spatial-Temporal Change in Vegetation Cover and Climate Factor Drivers of Variation in the Haihe River Basin 2003-2016

Jingwen Li1,2, Zhipeng Su+, Jianwu Jiang1,2, Wenda Chen2, Na Yu2, Xu Li2, Jiali Xie1 and Jingshan Wei2

1Guangxi Key Laboratory of Spatial Information and Geomatics, Guilin University of Technology, Guilin 541004, China
2Guilin University of Technology, Guilin 541004, China

Abstract. In order to study the correlation between the annual dynamic change characteristics of vegetation and climatic factors in Haihe River Basin in recent 14 years. The MODIS / NDVI data from 2003 to 2016 were used to extract the vegetation coverage of the Haihe River Basin. The one-dimensional linear regression was used to analyze the trend of temporal changes of vegetation in the Haihe River Basin, and the trend analysis and correlation analysis of vegetation climate change were performed by combining the data of precipitation and temperature meteorological data from 2003-2016 in the Haihe River Basin. The study shows that the overall vegetation cover in the Haihe River basin is relatively high, and the cover type is mainly high, and the NDVI increases significantly at the rate of 0.021/10a; the spatial vegetation change trend in the Haihe River basin is mainly improvement, accounting for 94% of the basin area; climatic factor correlation analysis shows that precipitation is the main factor influencing the change of NDVI in the Haihe River basin.

1. Introduction
The Haihe river basin plays a very important role in the national economic pattern [1-3]. However, with the rapid economic development, the ecological environment of the Haihe River Basin has been seriously damaged [4-6]. Vegetation has a role in the ecosystem to regulate the climate, maintain soil and water, and purify the air [7, 8]. Therefore, the rapid and accurate expression of vegetation growth and trend evolution in river and sea basins is of reference value for ecological studies. The Normal Difference Vegetation Index (NDVI) can accurately reflect the status of vegetation cover [9, 10]. It is widely used in research areas such as land cover classification, monitoring of vegetation dynamics, and the relationship between vegetation change and climate [11]. In view of the change in the coverage of the Haihe River Basin, Lai et al. used the meteorological data of 33 stations in the Huaihe River Basin from 1961 to 2005 to analyze the change of the Huaihe River Basin and its relationship with climate factors [12]; Anyamba et al. analyzed the correlation between vegetation and precipitation in the Sahara region and found that NDVI showed a downward trend from 1982 to 1993, while NDVI showed an upward trend from 1994 to 2003 [13]. Ichii et al. analyzed the relationship between vegetation and meteorological factors on a global scale [14]. In this paper, the temporal and spatial variation characteristics of vegetation cover in haihe River Basin from 2003 to 2016 were analyzed by using MODIS product data and meteorological data. The relationship between climatic...
factors and vegetation cover was also discussed. It provides a reference for the restoration and improvement of the ecological environment in Haihe River basin.

2. Data and method

2.1. Overview of the study area
The Haihe River Basin is located in the northern part of the North China Plain, between 35°-43°N and 112°-120°E, covering a total area of 319,000km² and sloping from northwest to southeast, with mountainous and plain terrain.

2.2. Data sources and preprocessing
MODIS product data were obtained from the NASA Data Center with a spatial resolution of 1 km and a time series of 2003-2016. The interannual variation of regional coverage was analyzed by using the maximum synthesis method. The meteorological data were obtained from the China Meteorological Science Data Sharing Service (CMSDS), spanning the period 2003-2016 with a time resolution of 24 h. Rainfall and temperature data were pre-processed separately.

2.3. Methods

2.3.1. Trend analysis method. This method performs linear regression analysis on the time series images of NDVI values in the study area, and the slope of the annual mean NDVI is fitted on a pixel-by-pixel basis using the least-squares method to reflect the temporal and spatial evolution pattern of the vegetation cover. The equation for the one-dimensional linear regression analysis is as follows:

$$ S = \frac{\sum_{i=1}^{n} i \times NDVI_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} NDVI_i}{n \times \sum_{i=1}^{n} i^2 - \left( \sum_{i=1}^{n} n \right)} $$

In equation (1), S is the trend of change, i.e., the interannual trend of NDVI from 2003-2016, n is the time series, the time period of this study is 14, the value of n is 14, and NDVI_i is the NDVI value of year i. The value of NDVI is the value of the vegetation index. When S>0 indicates that the vegetation index tends to increase and S<0 indicates that the vegetation index tends to decrease.

2.3.2. Correlation analysis method. The method is to study the relationship between vegetation coverage and climatic factors. Using the grid calculator in ArcGIS, the correlation coefficient of NDVI with temperature and rainfall was calculated, and the correlation between NDVI value of vegetation and climate factors was analyzed. In this study, the correlation coefficient of NDVI with temperature and rainfall from 2003 to 2016 is calculated as follows:

$$ R = \frac{n \sum_{i=1}^{n} X_i \times NDVI_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} NDVI_i}{\left[ n \sum_{i=1}^{n} X_i^2 - \left( \sum_{i=1}^{n} X_i \right)^2 \right] \times \left[ n \sum_{i=1}^{n} NDVI_i^2 - \left( \sum_{i=1}^{n} NDVI_i \right)^2 \right]^{1/2}} $$

In equation (2), X_i is the average value of climate factors in the i year; R is the correlation coefficient between NDVI and climate factors from 2003 to 2016.

3. Result and analysis
3.1. Spatial distribution characteristics of NDVI
Based on the annual NDVI values of the study area in recent 14 years, the scale of NDVI values of vegetation in the basin in recent 14 years was analyzed. Combined with the characteristics of regional coverage, it is divided into five types: extremely low, low, medium, high and high coverage. The scope and characteristics are shown in table 1.

| Coverage          | Vegetation   | Characteristic                             |
|-------------------|--------------|--------------------------------------------|
| Extremely Low     | <0.1         | Water areas, Bare fields, Residents        |
| Low               | 0.1~0.3      | Wastelands, Open forest lands              |
| Medium            | 0.3~0.5      | Croplands, Medium yield of grasslands      |
| Above Average     | 0.5~0.7      | Forest lands, Beach wetlands               |
| High              | >0.7         | High yield of grasslands, Dense woodlands  |

Table 1. Vegetation cover classification table.

Based on the classification criteria of vegetation cover, the spatial distribution of vegetation cover in the Haihe River Basin from 2003 to 2016 is shown in figure 1. From figure 1, we can see that NDVI less than 0.1 in the Haihe river basin is a very low value area, which is only found in the Bohai Sea area, and mainly consists of wetlands and construction land; low coverage is mainly distributed in urban centers and around the Bohai Sea, and mainly consists of construction land; moderate coverage is mainly middle-grade grasslands and farmland; high coverage NDVI value is 0.5~0.7, which is mainly composed of forest land and beach wetlands; and the Haihe river basin has a vegetation cover of 0.5~0.7, which is mainly composed of forest land and beach wetlands. The high coverage areas with NDVI values greater than 0.7 in the basin are very large, and they are mainly highly productive grassland and dense woodland. Thus, it can be seen that the NDVI value in the Haihe River Basin has been relatively high over the past 14 years, and the low value areas are only distributed in the Bohai Bay area and some urban centers.

Figure 1. Spatial distribution of different vegetation coverage in the Haihe River Basin from 2003 to 2016.

3.2. Time variation characteristics of NDVI
Select the annual NDVI maximum generation data set from 2003 to 2016 to make a line chart and fit the variation trend of NDVI in the recent 14 years to obtain the inter-annual variation of NDVI in Haihe River Basin from 2003 to 2016. The results are shown in figure 2.

Figure 2. Inter-annual variation of NDVI in the Haihe River Basin from 2003 to 2016.

3.3. Analysis of trends in NDVI

Slope trend analysis was used to analyze the inter-annual change of vegetation cover in the study area in the past 14 years, and a spatial distribution of NDVI trend was obtained (Figure 3), with the range of Slope values from -0.035 to 0.055. The study showed that there were obvious differences in the spatial distribution of vegetation change trends. According to the NDVI trend of the study area, the vegetation change was classified into five levels, namely, severe degradation, slight degradation, almost unchanged, slight improvement, and significant improvement. The results are shown in figure 3 and table 2, respectively.

Figure 3. Trends of NDVI in the Haihe River Basin from 2003 to 2016.
Table 2. Statistics of trends of changed area.

| Trends of NDVI | Type                | Area($\times 10^4km^2$) | Proportion/% |
|----------------|---------------------|--------------------------|--------------|
| $S \leq -0.004$| Severe degradation  | 0.14                     | 0.45         |
| $-0.004 < S \leq -0.001$| Slight degradation  | 0.15                     | 0.36         |
| $-0.001 \leq S < 0.001$| Invariant          | 1.65                     | 5.19         |
| $0.001 \leq S < 0.004$| Slight improvement | 6.20                     | 19.50        |
| $S \geq 0.004$ | Obvious improvement | 23.70                    | 74.50        |

As can be seen from figure 3 and table 2, the areas of vegetation improvement in the study area over the last 14 years are much larger than the areas of degradation. The area of the improved area accounts for 94% of the whole watershed, covering an area of 0.81% and 5.19% of the degraded area, which is mainly distributed in the watershed. In summary, there are significant spatial differences in vegetation changes over the past 14 years, and human activities have both promoted and inhibited the cover of surface vegetation, and the vegetation in most areas of the study area has improved significantly.

3.4. Analysis of the driving forces of vegetation change and climate factor

Climate change is considered to be one of the major factors causing changes in land cover. The study of the relationship between vegetation cover and climate through NDVI has been the subject of global change research at home and abroad. In order to show the trend relationship between vegetation cover and precipitation and mean air temperature changes in the study area more visually, the rainfall and air temperature data of the study area were overlaid with the interannual variation of NDVI in the study area, respectively, and the results are shown in Fig. 4 and Fig. 5.

![Figure 4](image1.png)  
**Figure 4.** The relationship between NDVI and rainfall in the Haihe River Basin.

![Figure 5](image2.png)  
**Figure 5.** The relationship between NDVI and temperature in the Haihe River Basin.

The correlation analysis of NDVI with temperature and precipitation in the study area. NDVI showed a negative correlation with rainfall and NDVI showed a positive correlation with temperature. The correlation coefficient shows that the temperature has a weak effect on vegetation. Within a certain range, rainfall can promote the growth of vegetation, and with the increase in temperature and decrease in rainfall, the vegetation cover decreases.
4. Conclusion

(1) From 2003 to 2016, the NDVI of the study area showed an overall upward trend, with the growth rate of 0.021/10a, and the range of vegetation NDVI value ranged from 0.62 to 0.72. During this period, NDVI experienced four rapid growth periods, namely, 2003-2004, 2007-2008, 2011-2013 and 2014-2016, with a growth rate of 12.6%.

(2) According to the study of the interannual variation trend of regional NDVI value, it can be seen that the vegetation spatial change is mainly improved, accounting for 94% of the basin area, indicating that the vegetation in most areas of the region has been significantly improved.

(3) The correlation analysis of vegetation change in Haihe River Basin was carried out through annual rainfall and annual temperature. The results show that the correlation between rainfall and NDVI is strong, and rainfall can promote the growth of vegetation in a certain range, which indicates that rainfall is a significant climate factor affecting regional vegetation coverage; the correlation between temperature and NDVI is weak, indicating that the influence of temperature on vegetation growth is relatively weak.

Acknowledgments
Funded projects: National Natural Science Foundation of China (No. 41961063); National Culture and Tourism Science and Technology Innovation Project (2019-011).
Guangxi Natural Science Foundation Innovation Team Project (2019GXNSFGA245001).

References
[1] Hao Z, Gao X and Zhou X 2018 J. Exploration and prospect of river and lake health assessment in Haihe River Basin China Water Resources
[2] Luo Y, Xu L and Rysz M, et al. 2011 J. Occurrence and Transport of Tetracycline, Sulfonamide, Quinolone, and Macrolide Antibiotics in the Haihe River Basin, China Environmental Science & Technology 45(5): 1827-1833
[3] Li L and Zheng H 2000 J. Environmental and Ecological Water Consumption of River Systems in HaiheLuanhe Basins
[4] Piirimäe K, Pachel K and Reihan A 2010 J. Adaptation of a method for involving environmental aspects in spatial planning of river basin management--a case study of the Narva River basin/Keskkonnaaspekti ruumilisse planeerimisse haaramise meetodi kohandamine vesikonna veemajandusega--Narva joe valg Estonian Journal of Ecology 59(4): 302-320
[5] Kang Y J, Guang L I and Hou Z 2015 J. Developed green water conservancy project to improve the ecological environment of Haihe River basin Water Sciences & Engineering Technology
[6] Chen Q, Liu J and Ho K C, et al. 2012 J. Development of a relative risk model for evaluating ecological risk of water environment in the Haihe River Basin estuary area Science of the Total Environment 420(none): 79-89
[7] Kiang J E and Eltahir E A B 1999 J. Role of ecosystem dynamics in biosphere-atmosphere interaction over the coastal region of West Africa Journal of Geophysical Research
[8] Mao D, Wang Z, Luo L and et al. 2010 J. Growing-season normal difference vegetation index, NDVI, response to climate changes and increased carbon dioxide concentration in frozen areas of Northeast China during 1982–2008 Acta Scientiae Circumstantiae 30(11): 2332-2343
[9] Defries R S and Townshend J R G 1994 J. NDVI-Derived Land Cover Classification at a Global Scale International Journal of Remote Sensing 15(17):3567-3586
[10] Li, Xiaowen, Gao, et al. 2002 J. Bi-directional normalized difference vegetation index: concept and application Progress in Natural Science
[11] Grime J P 1979 J. Ecological Classification. (Book Reviews: Plant Strategies and Vegetation Processes) Science 206(22): 1176-1177
[12] Jia L C, Sui Q H and Lai D H, et al 2009 J. Climate suitability and its change trend of double-cropping rice in Huaihe River Basin *Chinese Journal of Ecology*

[13] Anyamba A and Tucker C J 2005 J. Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003 *Journal of Arid Environments* 63(3): 596-614

[14] Ichii K, Kawabata A and Yamaguchi Y 2002 J. Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982-1990 *International Journal of Remote Sensing* 23(18): 3873-3878.