Vegetation dynamics based on NDVI in Yangtze River Basin (China) during 1982-2015

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Abstract. Knowledge of vegetation dynamics is important for the sustainability of natural resources and understanding the changes in ecosystems and its impact to earth’s environment. We have carried out analysis of GIMMS (Global inventory modelling and mapping studies) NDVI3g (third generation normalized difference vegetation data for the period 1982-2015). Based on the Linear Regression (LR) analysis, the Mann-Kendall (MK) test with Sen’s slope estimator and Kriging interpolation method, we have investigated the spatiotemporal variations of vegetation NDVI in the Yangtze River Basin (YRB). The results show pronounced increase in the annual mean NDVI at the rate of 0.01/10yr during 1982-2015, with significant turning point (TP) around 1994. The spatial distribution of the annual mean NDVI reasonably increased in the northern, eastern and south-western YRB, while decreased in the Yangtze River Delta (YRD) and parts of the southern YRB during 1982-2015. Pronounced change in NDVI trend is found in different seasons, for example, the increasing trend during spring (0.02/10yr) and in autumn (0.02/10yr) was higher compared to winter (0.006/10yr) and summer (0.002/10yr) seasons.

1. Introduction

Vegetation, as an important component of terrestrial ecosystems, plays an important role in regulation of runoff, climatic regulation, water and soil conservation [1]. In recent decades, vegetation dynamics were affected by warming climate and human activities [2-4]. Therefore, understanding vegetation dynamics will be of vital importance for sustainable development of the terrestrial ecosystems.

Earlier studies have investigated vegetation dynamics at the global or regional scale. The NDVI is an indicator of vegetation greenness and productivity [5]. A higher NDVI value implies a larger green vegetation density [2]. The NDVI has been commonly used to detect vegetation dynamics [6-7]. Global mean NDVI shows pronounced trends over half (56.3%) of land surface during 1982-2011, and almost half (46.1%) of the surface shows obvious seasonal variations [8]. Ichii et al. (2002) have found an increase of NDVI in mid and high-latitude regions, whereas a decrease in southern semiarid regions during 1982-1990 [9]. Ichii et al. (2002) have found an increase of NDVI in mid and high-latitude regions, whereas a decrease in southern semiarid regions during 1982-1990 [9]. China has experienced a significant increasing trend at the rate of 0.007/10yr in growing seasonal mean NDVI during 1982-2010, but in contrast the increasing rate over the past decade decreased compared to those during 1982-1999 [10,11]. Wang et al. (2015) found an increasing trend in NDVI in the central, eastern and southern China [3].

The vegetation cover in the YRB is an important ecological barrier to maintain ecological balance. Therefore, research on the vegetation dynamic will be of vital importance for sustainable development of the terrestrial ecosystems. The objectives of this paper are to investigate the spatiotemporal variations of vegetation in YRB at annual and seasonal scales during 1982-2015.
2. Materials and methods

2.1. Study area
Yangtze River, the longest river in Asia, originates from the Tibetan Plateau in western China, flowing 6300 km long from western mountainous areas to the eastern plain, and finally discharges into the East China Sea, with a 6000 m drop in elevation [12]. The drainage basin is located between 91-122° E and 25-35° N (Fig. 1), covering 1.8×10⁶ km², which accounts for nearly 20% of the whole China [13]. The upper and mid-lower YRB are affected by the Indian summer monsoon and the East Asian summer monsoon, two independent parts of the Asia monsoon [14]. Under the influence of monsoon, the YRB shows a distinct annual cycle of dry and wet seasons [15].

![Fig. 1 Location of the YRB in China](image)

2.2. Date
We have used the NDVI3g from the newest version of the GIMMS generated by the AVHRR sensor on the NOAA POES series [8]. The GIMMS NDVI3g datasets are produced in a geographical latitude/longitude projection with a spatial resolution of 8 km and a temporal interval of 15 days, which has been corrected to remove the non-vegetation effects [6]. It has been widely used for monitoring vegetation growth at regional and global scales.

2.3. Methods
This study investigates the trends in the annual and seasonal NDVI using the Linear Regression (LR) analysis and the Mann-Kendall (MK) test with Sen's slope estimator [16].

3. Vegetation dynamic in YRB

3.1. Changes in annual mean NDVI
Fig. 2a shows annual mean NDVI (about 0.54) over the whole YRB during 1982-2015, with a maximum value 0.56 in the year 2015 and a minimum value of 0.49 in the year 1984. The temporal variations of annual mean NDVI trends detected by MK test and the Linear Regression (LR) analysis
were given in Table 1 according to the confidence levels of 10%, 5% and 1%, respectively. The changes of annual mean NDVI shows a significant increasing trend at the rate of 0.01/10yr ($Z_{MK} = 3.17$, $p <0.001$) over the whole study area during 1982-2015 (Table 1). The significant increase was characterized by a staircase form instead of a monotonic increasing trend, with significant turning point (TP) around 1994 (Fig. 2f). The annual mean NDVI in YRB was relatively low with the value 0.52 before TP and relatively high with the value 0.55 after TP (Fig. 2a). However, the changes of annual mean NDVI before and after TP was slight without showing the statistically confidence level (Table 1).

![Fig.2 Annual (a) and seasonal (b-e) mean NDVI of YRB during 1982-2015 and their Accumulated Anomaly Curve (f)](image)

The change in annual mean NDVI pattern was found to be spatially heterogeneous during 1982-2015, before and after TP (Fig. 3). The annual mean NDVI shows an increase in parts of the northern, eastern and western YRB during 1982-2015, with the change rate up to 0.04/10yr (Fig. 3a-b). A significant decreasing trend was mainly detected in Yangtze River Delta (YRD) during 1982-2015, with the rate as low as -0.02/10yr. Figs.3 (c-d) show decrease (although not statistically significant) in the annual mean NDVI in most parts of YRB before TP, however, a significant increasing trend was observed in the western parts of Yangtze River in Qinghai-Tibetan Plateau (QTP). Figs.3 (e-f) show decrease in the annual mean NDVI at the rate of 0–0.03/10yr in YRD and south-central YRB after TP and an increase at the rate of 0–0.03/10yr in other parts of YRB.
Table 1. Trend test results (/10yr) of annual and seasonal NDVI in YRB during 1982-2015, before and after the TP based on MK and LR (after the bias) analysis

|             | Trend during 1982-2015 | Trend before TP | Trend after TP |
|-------------|-------------------------|-----------------|---------------|
| Annual      | 0.01***/0.01***         | -0.001/-0.001   | 0.004/0.004   |
| Spring      | 3.17/0.000              | 0.55/0.93      | 0.82/0.41    |
| Summer      | 0.02***/0.02***         | 0.01/0.01      | 0.01/0.01    |
| Autumn      | 4.12/0.000              | 0.59/0.37      | 0.84/0.26    |
| Winter      | 0.002/0.002             | 0.02*/0.02*    | 0.01/0.01    |
| Winter      | 0.47/0.58               | 2.12/0.06      | 1.44/0.21    |
| Winter      | 0.02***/0.02***         | 0.00/0.00      | 0.00/0.00    |
| Winter      | 2.70/0.000              | 0.06/0.82      | -0.45/0.90   |
| Winter      | 0.006/0.006             | -0.004/-0.01   | 0.006/0.006  |
| Winter      | 1.25/0.18               | 1.25/0.18      | 0.39/0.59    |

0.000 denote <0.001. *Trends at the 10% confidence level, **Trends at the 5% confidence level, ***Trends at the 1% confidence level.

3.2. Seasonal variations of NDVI

The mean NDVI during spring (March-May), summer (June-August), autumn (September-November) and winter (December-February) was approximately 0.50, 0.67, 0.56 and 0.41, respectively during 1982-2015 (Figs. 2b-e), and increased at the rate of 0.02/10yr ($Z_{MK} = 4.12$, $p < 0.001$), 0.002/10yr ($Z_{MK} = 0.47$, $p = 0.58$), 0.02/10yr ($Z_{MK} = 2.70$, $p < 0.001$) and 0.006/10yr ($Z_{MK} = 1.25$, $p = 0.18$).
respectively (Table 1). A significant TP of NDVI during spring, summer, autumn and winter was found in 1996, 1997, 1994 and 1994, respectively (Fig. 2f). The mean NDVI during spring, summer and autumn was 0.47 and 0.52, 0.68 and 0.67, 0.54 and 0.58, 0.40 and 0.41, respectively before and after TP (Figs. 2b-e). The seasonal changes in NDVI before and after TP did not reach to the statistically confidence level except the trend before TP during summer season (Table 1).

The seasonal changes in NDVI also show strong spatial heterogeneity during 1982-2015 (Fig. 4). Parts of the eastern YRB shows a significant and continuous increase in vegetation greenness (NDVI 0.00~0.03/10yr), especially during spring season. However, in most parts of YRD vegetation greenness decrease (NDVI -0.03~0.00/10yr), especially during summer season. NDVI shows seasonal dependence and shows spatial variability. Most parts of the central-south YRB shows an increasing trend during spring (NDVI 0.00~0.05/10yr), and shows decreasing trend during winter season (NDVI 0.00~0.03/10yr) (Figs.4a, d). In addition, the mean NDVI in the north-western parts of YRB increase during summer and decrease during autumn (Figs.4b, c).

![Spatial distribution of NDVI variation trend in spring, summer autumn and winter (a-d) in YRB during 1982-2015](image)

Fig. 4 Spatial distribution of NDVI variation trend in spring, summer autumn and winter (a-d) in YRB during 1982-2015

Conclusion

In general, annual mean NDVI over the whole YRB increased at the rate of 0.01/10yr during 1982-2015, with significant TP around 1994. The mean NDVI during spring and autumn also show significant increasing trends over the whole study area. The annual mean NDVI increased in the northern, eastern and parts of the south-western YRB, while decreased in YRD and parts of the southern YRB during 1982-2015. The seasonal NDVI also shows strong spatial heterogeneity.

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