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Spatio-temporal analysis of vegetation variation in the Yellow River Basin

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ABSTRACT

To understand the variation and patterns of vegetation coverage in the Yellow River Basin, as well as to promote regional ecological protection and maintain ecological construction achievements, MOD13Q1 data at a resolution of 250 m were used to calculate the annual average normalised difference vegetation index (NDVI) in a time series from 2000 to 2010. Using a variation coefficient, a Theil–Sen Median trend analysis, the Mann–Kendall test, and the Hurst index method, this study investigated the temporal and spatial variations of vegetation coverage characteristics of the Yellow River Basin. The results showed that (1) the vegetation coverage of the Yellow River appeared to have an overall trend of high in the southeast and west and low in the northwest; (2) the averaged NDVI of the whole basin fluctuated in a range of 0.3 to 0.4 from 2000 to 2010 (from 2000 to 2004 there were larger variations and these have been growing rapidly since 2005); (3) the NDVI was stable, 73.4% of the vegetation-coverage area fluctuated with a low-to-medium amplitude, while 27.6% of the area varied by a large amplitude; (4) the regions with improved vegetation coverage (62.9%) were far greater than the degraded regions (27.7%), while the sustained invariant area accounted for 9.4% of the total vegetation coverage regions; and (5) 86% of the vegetation-covered area was positively sustainable. The areas with sustainable improvement accounted for 53.7% of the total vegetation coverage area; the invariant area accounted for 7.8%. The area with sustainable degradation was 24.5%; the future variation in trends of the residual (14%) could not be determined. Therefore, continuous attention must be given to the variation in trends of vegetation in the sustainably degraded and underdetermined regions.

1. Introduction

Vegetation is characterised by inter-annual and seasonal variations. As a natural tie connecting atmosphere, water, and soil, vegetation plays a notably important role in soil conservation, atmosphere adjustment, and the maintenance of climatic and whole ecosystem stability (Sun et al., 1988). Because variations in the surface vegetation coverage affect the balance of regional ecosystems, studies on the variation in vegetation coverage is the basis of the protection of the ecological environment (Fan et al., 2012; Peng et al., 2012; Zhang et al., 2013). With wide coverage, high temporal resolution rate, and free data, sensors such as National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiameter (NOAA/AVHRR), Systeme Probatoire d'Observation dela Tarre/VEGETATION (SPOT/VGT), and moderate resolution imaging spectroradiometer (MODIS) can provide large amounts of data for monitoring the variations of vegetation coverage over long time periods (Rigina et al., 1996; Tucker et al., 2005; Ma et al., 2006; Fensholt et al., 2009, 2012a,b; Fu et al., 2014). NDVI is functionally correlated with leaf area index (LAI) and vegetation coverage (Baret et al., 1991; Gutman et al., 1998); the higher the NDVI, the larger the LAI, and the higher the vegetation coverage. Therefore, NDVI can reflect the growth status of surface vegetation and also acts as an effective index for monitoring vegetation variations (Zhao, 2003; Tucker et al., 1985). For over 20 years, NDVI data

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have been used to analyse spatial distribution characteristics in a large space scale and a long time scale (Tucker et al., 1985; Myneni et al., 1997; Senay et al., 2000; Stow et al., 2004); other methods, such as principal component analysis (Fan et al., 2012), unary linear regression (Piao et al., 2001; Song et al., 2011), variation vector analysis (Chen et al., 2002), Theil–Sen median trend analysis, the Mann–Kendall test (Pouliot et al., 2009; Fensholt et al., 2012a,b), Fourier transformation (Wang et al., 2006), and wavelet analysis method (Martínez and Gilabert, 2009) have also been employed to explore the temporal and spatial variation characteristics of the vegetation coverage. Moreover, correlation analysis has been used to investigate the correlations between inter-annual/annual variations and climate (Fensholt et al., 2012a,b; Kawabata et al., 2001; Blazkova and Beven, 2004; Zhang et al., 2010).

The Yellow River Basin is located in arid, semi-arid, and semi-humid areas in China. This river is endowed with a diversified climate, severely fluctuating topography, various types of landforms, and rich vegetation types (Liu et al., 2006). In recent years, with the change of climate and the constant intensification of human activities, this basin has exhibited vegetation changes. At present, a number of researchers have explored the vegetation changes in the Yellow River Basin. Sun et al. (2001) employed the NOAA AVHRR of 8 km to investigate the temporal and spatial distribution of vegetation from 1982 to 1999 and reported correlations of the NDVI with precipitation and temperature (Sun et al., 2001; Yang et al., 2003). Also using a NOAA AVHRR of 8 km, Li et al. (2004) studied the spatial distribution, the annual and seasonal variations of NDVI, as well as the inter-annual and annual correlations of NDVI with the precipitation and runoff in the Yellow River Basin from 1982 to 1999 (Li et al., 2004). Liu et al. (2006) used a 1 km of NOAA AVHRR to analyse the relationships of NDVI with temperature and rainfall in the Yellow River Basin. Based on the data of 1 km SPOT VGT, He et al. (2012) used the mean value method and the trend line analysis method to analyse the temporal and spatial distribution, time variation characteristics, and inter-annual variation in trends of the NDVI in the Yellow River Basin (He et al., 2012). Previous research has been primarily based on NOAA AVHRR data with spatial resolution of 1 km/8 km, or the SPOT VGT data with a 1 km spatial resolution; thus, the spatial resolution of the current research is relatively low.

For analysing the inter-annual trends of vegetation, the method of linear regression analysis has been used with NDVI time series data. Using this method, vegetation trends are calculated by regression, which can easily be affected by outliers. Few studies using the more robust Theil–Sen trend analysis and Mann–Kendall tests have been conducted to explore the inter-annual trend of vegetation.

Few of the studies on vegetation trends in the Yellow River Basin in the past have been focused on the vegetation trends for the future. This may be explained by the difficulty in simulating vegetation trends in the future through mathematical models between the NDVI and its related influencing factors. The Hurst exponent has been used to quantitatively detect the sustainability of time series data, but, to date, it has not been exploited for vegetation trend prediction in the Yellow River Basin.

For our study, we choose MOD13Q1 data with a 250 m spatial resolution. Studies have indicated that there is a greater advantage on the spectral and spatial resolution using MODIS-250 m NDVI product data, and these data could provide more precise information on the land surface compared with the SPOT/VGT-1 km NDVI, and NOAA/AVHRR-8 km NDVI data (Muchoney et al., 2000). The data used in this research is more precise when compared with previous studies. The MOD13Q1 data were pre-processed and calculated to obtain the annual average NDVI time series in the Yellow River basin from 2000 to 2010. Next, using a variation coefficient, a Theil–Sen Median trend analysis, the Mann–Kendall test, and the Hurst exponent methods, this study investigated the temporal and spatial variations, fluctuation characteristics, variation in trends, and sustainability of the vegetation coverage in the Yellow River basin. It is expected that understanding the variation characteristics and patterns of the vegetation coverage in the Yellow River Basin will promote the regional ecological protection and maintain ecological construction achievements.

2. Methods

2.1. Study area

Originating from Bayankala Mountain in the Qinghai Province in China, the Yellow River flows through 9 Provinces, including Qinghai, Sichuan, Gansu, Ningxia, the Inner Mongolia Autonomous Region, Shaanxi, Shanxi, Henan, and Shandong. In Kenli County of the Shandong Province, it merges into the Bohai Sea. The Yellow River is 1,900 km long from east to west and 1100 km long from south to north and covers an area of 79.46×10^4 km^2. The river's geographical coordinates are 39°28′ to 41°05′N and 115°25′ to 117°30′E under the WGS84/Albers Equal Area Conic projection (Fig. 1). The terrain of Yellow River basin is high in the west and low in the east. The western origination area lies at an average altitude of 4000 m and is composed of a series of mountains; the central region is in an altitude of 1000–2000 m and presents a loess landform with serious soil erosion; and the eastern area is 100 m below sea level and is mainly composed of the alluvial plain of the Yellow River (He et al., 2012). The area of the Yellow River has a continental climate. The south-eastern part belongs to semi-humid climate, the middle part has a semiarid climate, and the northwest part has a subordinate arid climate. The various landforms and complex habitats of the Yellow River Basin create favourable conditions for the development of various vegetation types (Liu et al., 2006); land-use types are mainly woodland, grassland, and farmland.

2.2. Methods

2.2.1. Data sources

MODIS NDVI data were sourced from the MODIS vegetation index product data-MOD13Q1 on the website of the United States NASA. The data, collected from February 2000 to December 2010, were in Hdf format with a spatial resolution of 250 m, and a temporal time resolution of 16 days. The data were subjected to format and projection conversions using MODIS Reprojection Tool (MRT), which can be acquired from NASA Land Processes Distributed Active Archive Center (Sioux Falls, South Dakota, U.S.A.). The original Hdf format was transformed into the Geotiff format and the original Sinusoidal projection was transformed into the WGS84/Albers Equal Area Conic projection. The converted data were re-sampled using the adjacent natural method at a resolution of 250 m. The samples obtained were processed using the internationally accepted and commonly used maximum synthesis method to yield monthly NDVI data from 2000 to 2010, to avoid the influences of clouds, atmosphere, and solar altitude angle (Piao et al., 2001; Holben, 1986). Finally, using the mean value method, the annual average NDVI data were acquired to eliminate the influence of extreme yearly abnormal climate on the growth status of vegetation (Zhang et al., 2008).

Land use/land cover data for the Yellow River Basin in 2010, at a resolution of 250 m, were provided by the project team, "The remote sensing investigation and assessment on the ten-year changes of the national ecological environment." The land use types included forest, grassland, farmland, wetland, and artificial surface.

2.2.2. Methods

The variation coefficient, Theil–Sen median trend analysis, Mann–Kendall, and Hurst exponent method were used to study the