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REVIEW PAPER

Multi-perspective analysis of vegetation cover changes and driving factors of long time series based on climate and terrain data in Hanjiang River Basin, China

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Abstract

The Hanjiang River Basin is the source area of the Middle Route Project of the South-to-North Water Diversion Project, and the vegetation coverage in this basin directly affects the quality of the ecological environment. This study is based on long time series of Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data synthesized over 16 days from 2000 to 2016 in the Hanjiang River Basin. Major climatic data (temperature and rainfall) and topographic data (elevation, slope, and aspect) are employed to analyze the driving forces of NDVI changes. The results demonstrate the following: for the 2000–2016 period, the average annual NDVI is 0.823, with a change trend of 0.025 year^{-1}. The overall NDVI upstream is higher than that downstream. The average annual value of NDVI upstream is 0.844, with a change trend of 0.036 year^{-1}, and that of downstream is 0.799, with a change trend of 0.022 year^{-1}. The spatial distribution of NDVI was significantly increased in the area around the upstream section of the river and near the Danjiangkou Reservoir, and the distribution of NDVI around the central city was significantly reduced. The NDVI was positively correlated with temperature and rainfall, and the impacts differed among different regions. At elevations below 2000 m, the NDVI shows an increasing trend with increasing elevation, and at elevations exceeding 2000 m, the NDVI is negatively correlated with elevation. Slope is positively correlated with the NDVI. The influence of aspect on the NDVI was small.

Keywords Vegetation cover · Multi-perspective analysis · Long time series · Driving factors · Climate and terrain

Introduction

Vegetation constitutes the foundation of the terrestrial ecosystem and represents a natural link among the atmosphere, water, and soil, thereby playing important roles in the energy exchanges, biogeochemical cycles, and hydrological cycles at the land surface (Piao et al. 2003). Temporal and spatial variations in vegetation cover are of interest in studies of global change (Fabricante et al. 2009) and are important indicators of changes in the regional ecological environment (Lambin and Strahler 1994). The dynamic monitoring of vegetation cover change has important implications for understanding of vegetation responses to climate change and human activities and the evolution of the regional ecological environment (Mao et al. 2011). The traditional methods used to collect surface measurements of vegetation cover include the square field-of-view method (Rall 1991), the meter stick method (Adams and Arkin 1977), the point method (Zhang and Liang 1995), the grid method (Song et al. 2018), the special quasirandom structure (SQS) method (Song et al. 2018), the traversing quantum sell (TQS) method (Adams and Arkin 1977), and the photographic method (Adams and Arkin 1977). However, although each of these techniques can be used to acquire measurements of vegetation cover, they are prone to producing highly

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subjective and arbitrary results, and it is difficult to guarantee accuracy (Qin et al. 2006). Moreover, these traditional methods are difficult to operate and require advanced equipment and permissible environments to acquire dynamic measurements of the vegetation coverage over a large area. Remote sensing platforms are capable of retrieving the variations in the vegetation cover distribution at a multitude of scales, spectral resolutions, and time-phase features due to their broad coverage and continuous observation of Earth's surface (Liang et al. 2012). At present, remote sensing technology represents the primary method for studying changes in the vegetation cover. Among the many remote sensing indices, the Normalized Difference Vegetation Index (NDVI), which was proposed by Rouse et al. (1973) in 1973, is often used to characterize vegetation cover, growth, yield, and health status (Tucker 1979; Wiegand and Richardson 1987; Calvao and Palmeirim 2004). The NDVI not only effectively reflects information regarding vegetation growth and cover but also partially eliminates various atmospheric conditions, including the solar elevation angle, satellite observation angle, topography, and cloud shadows. Consequently, the NDVI is the most commonly used remote sensing index for monitoring vegetation (Vermote et al. 1997; Tang et al. 2017; Wang et al. 2013), and many scholars employ NDVI data to study changes in vegetation cover at both global and regional scales (de Jong et al. 2013; Kong et al. 2017; Julien et al. 2006; Tourre et al. 2008; Bi et al. 2013; Huber et al. 2011; Piao and Fang 2003).

Increasingly numerous remote sensing NDVI datasets are available with the ongoing development of remote sensing technologies. The Landsat Thematic Mapper (TM) sensor, the Advanced Very High Resolution Radiometer (AVHRR), the SPOT-VEGETATION program, and the Moderate Resolution Imaging Spectroradiometer (MODIS) have become the main sources of data employed to investigate changes in vegetation cover (Voorde et al. 2008; Wang et al. 2001; Li et al. 2011; Eckert et al. 2015; Jacquin et al. 2010). Among these data types, TM data have high spatial resolution but small time resolution and thus exhibit obvious shortcomings in reflecting seasonal changes over the course of a year. The AVHRR products have a global coverage with high temporal resolution but a low spatial resolution of 8 km. The spatial resolution of the SPOT-VEGETATION platform is 1 km with a temporal resolution of 10 days, neither of which is dominant. Compared with other remote sensing datasets, the MODIS sensor acquires a complete data sequence with relatively high spatiotemporal resolution, and the data are relatively easy to obtain. Since 1999, MODIS data have been widely applied to studies of environment (Fensholt et al. 2009; Zheng et al. 2016; Tucker et al. 2005), and increasing numbers of researchers are choosing MODIS NDVI products to monitor vegetation changes (Wu and Lung 2016; Tucker and Yager 2011; Ge 2010).

The dynamic changes in the vegetation cover are mainly affected by the climate and terrain. Climate change has a direct impact on vegetation growth, while terrain conditions affect the distributions of water and heat at the surface (Weiss et al. 2004; Gamer 1995). Topography is the dominant factor that determines the growth and distribution of vegetation (Liu et al. 2009; Peng et al. 2012). At present, to investigate the factors that influence changes in vegetation cover, many researchers analyze the responses of dynamic vegetation changes to temperature and rainfall variations. A few scholars (Pearson et al. 2013; Gottfried et al. 2012; Liu et al. 2013) have also analyzed topographic factors as major influences on changes in vegetation cover and ecological environment (Shary and Sharaya 2014; Cai et al. 2014). Overall, the dynamic changes in vegetation are the product of the interactions among many factors; however, few studies have examined the dynamic changes in the vegetation cover according to a comprehensive set of climatic and terrain factors. The Hanjiang River Basin in China is strategically important for flood control measures and the water supply, and the Danjiangkou Reservoir within the basin represents the core water source area for the middle route of the South-to-North Water Diversion Project. The vegetation coverage throughout the river basin directly affects the ecological environment of this water source area and, correspondingly, the water quality and water quantity therein (Zheng et al. 2013). During recent years, research on the vegetation cover throughout the Hanjiang River Basin has mainly focused on the temporal and spatial variations in vegetation cover and their influencing factors. NDVI data between 1999 and 2010 have been used to investigate the spatiotemporal variations in vegetation cover, and research on the driving forces has focused on the influences of rainfall and temperature (Li et al. 2013). The Hanjiang River Basin belongs to a subtropical monsoon climate zone; the vertical distribution of the climate therein is quite obvious, and the height and terrain both have a substantial influence on the regional climate. However, most research regarding vegetation cover in the study area has focused on the impacts of climate and on NDVI variation (Fensholt and Proud 2012). Furthermore, the study period of previous studies is only approximately 10 years, which is short. Overall, the research remains weak, lacking the long time series of vegetation coverage changes and analyses of multiple driving factors. Therefore, this study selected MODIS NDVI data from 2000 to 2016 for the Hanjiang River Basin and used trend analysis to perform. Spatial and temporal analysis of the NDVI from the basin as well as upstream and downstream regions was performed. On this basis, we studied the driving factors that affect the NDVI variations throughout the Hanjiang River Basin in addition to the ecological protection of the Hanjiang River Basin and the continued healthy operation of the middle route of the South-to-North Water Diversion Engineering to provide support. The findings reported herein provide references for an analysis of the influencing factors on vegetation cover variations in other regions.

Materials and data

Study area

The Hanjiang River is the largest tributary of the Yangtze River; it flows through Shanxi Province, Hubei Province, and Henan Province in China over a total distance of 1577 km, and its watershed area is approximately 150,700 km^2 (Fig. 1). The river basin is rich in water resources. The Danjiangkou Reservoir is the core water source area of the middle route of the South-to-North Water Diversion Project. The Hanjiang River Basin is a subtropical monsoon region with a mild climate and an annual rainfall of 873 mm, but the rainfall exhibits an uneven distribution throughout the year (Wang et al. 2017). The terrain is high in the northwest and low in the southeast, and it fluctuates greatly, with an elevation difference of approximately 3700 m (Zhang and Ren 2006). The upper valley, the middle and lower reaches of the basin, and the plain areas constitute the main agricultural regions within the drainage basin, while the other areas are mainly forestland. The main forest types, which demonstrate a good vegetation cover, comprise subtropical evergreen broad-leaved forest, evergreen broad-leaved forest, and deciduous broad-leaved mixed forest.

Data

In this paper, we selected the MODIS NDVI data from 2000 to 2016 with a temporal resolution of 16 days and a spatial resolution of 250 m (http://modis.gsfc.nasa.gov/). Four periods (2000–2015) of land use data were derived from the China National Earth System Science Data Sharing Infrastructure (www.geodata.cn). Terrain data comprising Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data with a 90-m resolution in the USA were used to obtain the elevation, slope, and aspect information through a GIS analysis function.

China Meteorological Data Service Center (CMDC) is a governmental and unified shared service platform of China Meteorological Administration; its meteorological data resources are open to domestic and global users. However, CDMC provides measurement data for China's surface sites only for the years 1960–2010; there are five such sites in the Hanjiang River Basin and surrounding areas. The research period in this study is 2000–2016; thus, the free data provided by CMDC does not cover the entire research period. The TRMM data are in good agreement with station and radar observations (George et al. 2006; Xu et al. 2015; Cong et al. 2017), but some differences exist in the applicability of the observed data and TRMM data among different regions. In the study area, Chinese researcher Li Jinggang analyzed the precipitation characteristics in the Hanjiang River Basin using TRMM 3B43 data from 1998 to 2010. The results showed that the TRMM data are highly applicable for the study of precipitation within the Hanjiang River Basin and that the results are more reliable at the macroscopic scale (Li and Huang 2011). Therefore, in this study, TRMM 3B43 monthly composite data were used as the precipitation data for the period 2000–2016, and TRMM data are from NASA (https://www.nasa.gov/); the spatial resolution is 0.05°. Furthermore, research shows that the MODIS11 C3 data and the change rule of temperature time series are close. These data can be used to study the change of surface temperature; therefore, monthly MODIS11 C3 synthesis data (http://modis.

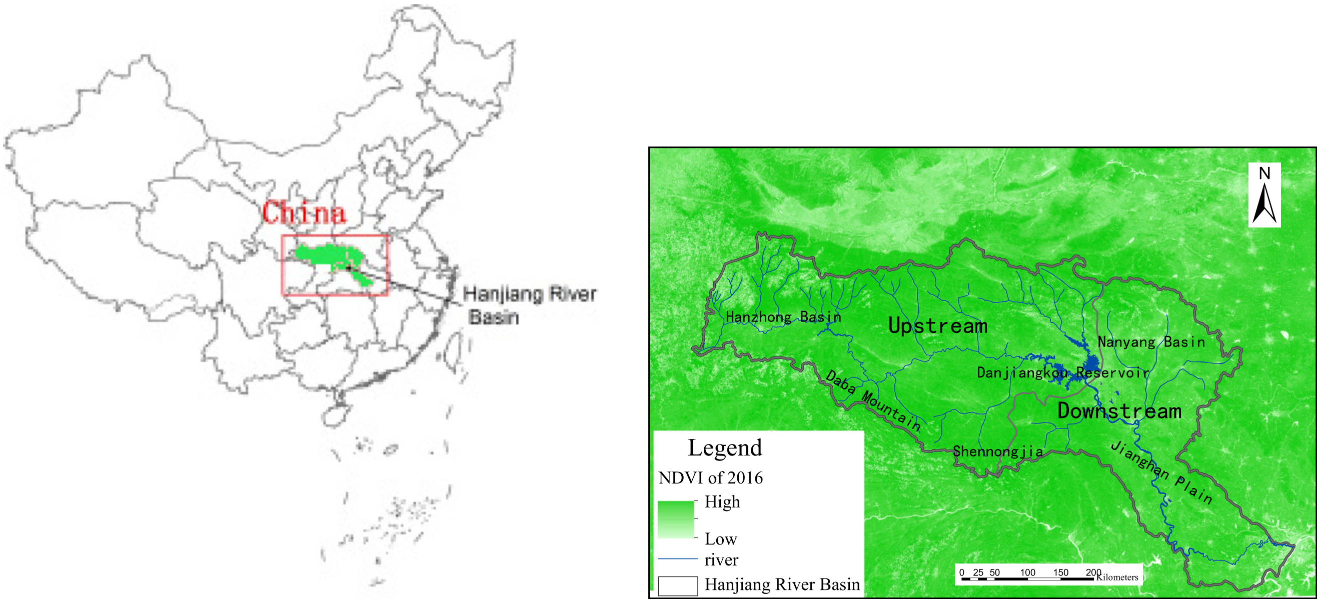


Fig. 1 Geographical location of the Hanjiang River Basin

gsfc.nasa.gov/) were selected as the temperature data in this study, and the spatial resolution is 0.05°.

Methods

Methodology for the spatial and temporal analysis of the NDVI

The maximum value composite (MVC) method was used to synthesize the monthly NDVI data based on the preprocessed time series MODIS data and obtain the annual NDVI dataset. The trend analysis method was used to investigate the annual, interannual, and spatial NDVI variation trends. This approach employs a least square method to fit the slope of the NDVI variation trend within a certain time period, and it can be used to comprehensively reflect the spatiotemporal characteristics of vegetation changes.

Linear trend estimation is used to establish a linear regression relationship between variables (x) and time (y). We assume that the linear trend equation is $y_{(x)} = a + bx$, where a is the intercept of the line and b is the slope of the line. The following is the slope from ordinary least square (OLS) regression (Li et al. 2015):

$$b = \frac{n \times \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \times \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i \right)^2} \tag{1}$$

In this paper, the slope from OLS is used to establish a linear regression relationship between year (i) and NDVI (NDVIi). The regression coefficient (θ slope) represents a trend of variable (i). The product of trend analysis represents the slope of a fitted curve. A value greater than zero indicates an increasing NDVI trend, a value equal to zero indicates that the NDVI is constant, and a value less than zero indicates a decreasing NDVI trend.

The two main types of land use in the Hanjiang River Basin are cultivated land and forestland. The cultivated land area accounts for 35% of the total area of the study area while that of forestland occupies 40% of the total. Therefore, this study considers both cultivated land and forestland as the research objects based on land use data from 2000 to 2015 for the study area. With the help of the GIS spatial analysis function, the NDVI values of cultivated land and forestland during the study period were extracted and the temporal and spatial variations in the NDVI for cultivated land and forestland were studied using the trend analysis method.

Methodology for determining the driving factors

Research on the influencing factors of NDVI variations primarily considers two aspects, namely the climate and the terrain. The temperature and rainfall are selected as the climatic factors in this study, and the elevation, slope, and aspect are the chosen terrain factors. The scaling factor of the MODIS11 C3 data is 0.02; the values are multiplied by 0.02 to obtain absolute temperature, which is then converted into degrees Celsius. The TRMM 3B43 data, which are monthly composite data that record the average monthly precipitation per hour (mm/h), are projected, transformed, cropped, and processed to obtain the precipitation data in this study, after which the average annual precipitation is obtained using the MVC method.

A correlation analysis was utilized to study the relationship between the vegetation cover variations and the climatic factors. A simple correlation analysis can consider the interactions between multiple variables, while a partial correlation analysis can measure the linear correlations between two variables from a multivariate set of parameters under the influences of other variables and effectively eliminate the effect of one variable on another. Therefore, simple correlation analysis is more reliable for determining the inherent linear relationship between two variables (Xu 2002). After obtaining the simple correlation coefficient, a partial correlation analysis is utilized to study the influences of the temperature and precipitation on the NDVI. The formula is as follows:

$$R_{ab,\ c} = \frac{R_{ab} - R_{ac} \times R_{bc}}{\sqrt{\left(1 - R_{ac}{}^2\right) \times \left(1 - R_{ba}{}^2\right)}} \tag{2}$$

where $R_{ab,\ c}$ represents the partial correlation coefficient between the variables a and b when c is the control variable; R_{ab}, R_{ac}, and R_{bc} denote the simple correlation coefficients between the variables a and b, a and c, and b and c, respectively; and $1 < R_{ab,\ c} < 1$. When $R_{ab,\ c} < 0$, the variables a and b are negatively correlated when c is the control variable; when $R_{ab,\ c} > 0$, the variables a and b are positively correlated when c is the control variable. The significance is confirmed through t test, and $P < 0.05$ indicates a significant correlation.

The elevation of the study area ranges from 2 to 3555 m, and the size of the area that exceeds 2000 m is small. Therefore, in this study, the elevation of the study area is divided into five bins with a step of 500 m: 0–500, 500–1000, 1000–1500, 1500–2000, and > 2000 m. Using slope data from the "Technical Regulation for Investigation of Status of Land Use" issued by the China Agricultural Zoning Commission, the grade is divided into five classes: ≤ 2°, 2°–6°, 6°–15°, 15°–25°, and > 25°; among these bins, < 6° represents a flat land, 6°–25° represent a gentle slope, and > 25° represents a steep slope. According to the four-way method, the study area is divided into four aspect quadrants: shady slope (toward the north, 315°–45°), semi-shady slope (northeast or northwest, 45°–90° or 270°–315°), semi-sunny slope (southeast or southwest, 90°–135° or 225°–270°), and sunny slope (toward the south, 135°–225°).

Results

Spatiotemporal characteristics of vegetation changes

Temporal variation in vegetation

From Fig. 2, the overall NDVI in the study area is increasing. The mean NDVI of the whole basin over the study period is 0.823; the minimum value appears in 2001, and the maximum value appears in 2015. The mean NDVI showed a fluctuating, upward trend over the 17 years of 0.025 year^{-1}. In 2001–2005, the value of NDVI rises steadily. In 2005–2015, the NDVI fluctuated, with high values.

The vegetation coverage in the upstream area is higher than that in the downstream area. In the upstream area, the mean NDVI over the study period is 0.844; the minimum value appears in 2000, and the maximum value appears in 2015. The overall fluctuation of NDVI in the downstream area over the 17 years was weaker than that in the upstream area, and the downstream NDVI shows a significant upward trend over the study period of 0.036 year^{-1}.

The vegetation coverage in the downstream area is lower than that in the whole watershed, with a mean NDVI of 0.799. The yearly fluctuation in the mean NDVI in the downstream area over the 17-year period is greater than that in the upstream area, showing a continuous growth trend over 2001–2007 and a downward trend over 2007–2014; in 2001, 2010, and 2014, the NDVI markedly decreased, but it continued to fluctuate over the whole study period. The minimum value appears in 2001, and the maximum value appears in 2015; the trend was 0.022 year^{-1}.

Spatial pattern of vegetation dynamics

Based on a univariate regression model, the annual variation trend in the NDVI from 2000 to 2016 was analyzed at the pixel scale. The results demonstrate that the vegetation coverage in 87.0% of the study area showed an increasing trend, the vegetation coverage in 12.6% of the study area showed a decreasing trend, and the vegetation coverage was unchanged in 0.38% of the study area (Fig. 3). Only a few regions changed significantly ($P < 0.1$); the remaining changes were not significant. Areas of growth in NDVI are mainly distributed around the upstream region, with a significant increase in the vicinity of the Danjiangkou Reservoir ($P < 0.1$). The areas with decreasing trends were concentrated near the downstream region and the upper basin, and the NDVI around the central cities showed significant downward trends ($P < 0.1$).

Meteorological factors and NDVI correlations

There was a significantly positive correlation between NDVI and temperature for the whole area ($P < 0.1$) of 0.668, and rainfall also showed a significantly positive correlation with the NDVI ($P < 0.1$) of 0.840. The spatial distributions of the correlations between the NDVI and the meteorological factors in the Hanjiang River Basin were studied based on the pixel variations. The NDVI exhibited a positive correlation with the temperature in 81% of the study area while the area with a negative temperature correlation accounted for 19% of the total. The positively correlated areas were mainly distributed in the central and western regions of the basin, while the negatively correlated regions were concentrated in the eastern and southeastern parts of the study area. The NDVI showed a positive correlation with the rainfall in 86% of the total area and a negative correlation with the rainfall in 14% of the study area. The positively correlated areas were located in most of the central and western parts of the basin, and the

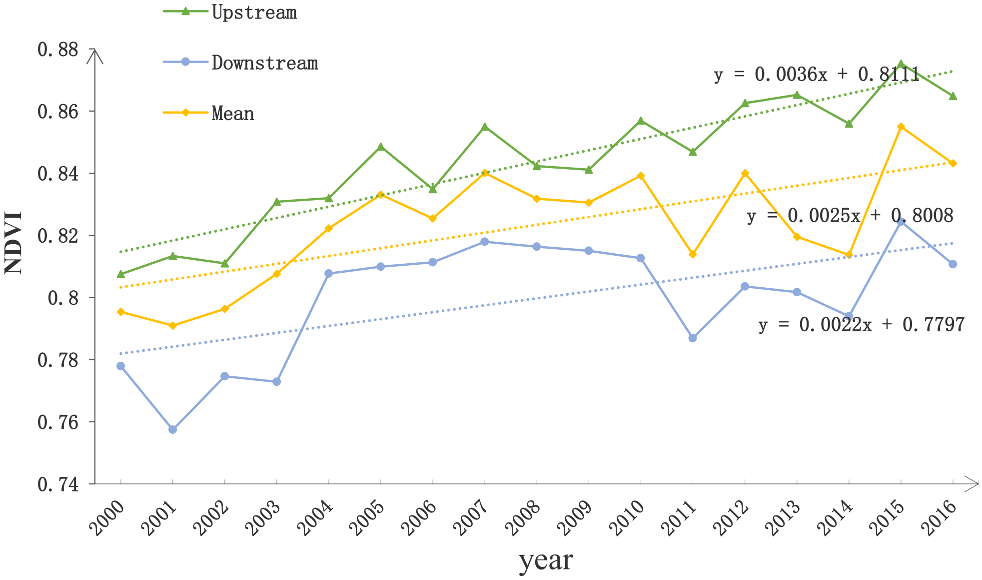


Fig. 2 Interannual NDVI variations and trends

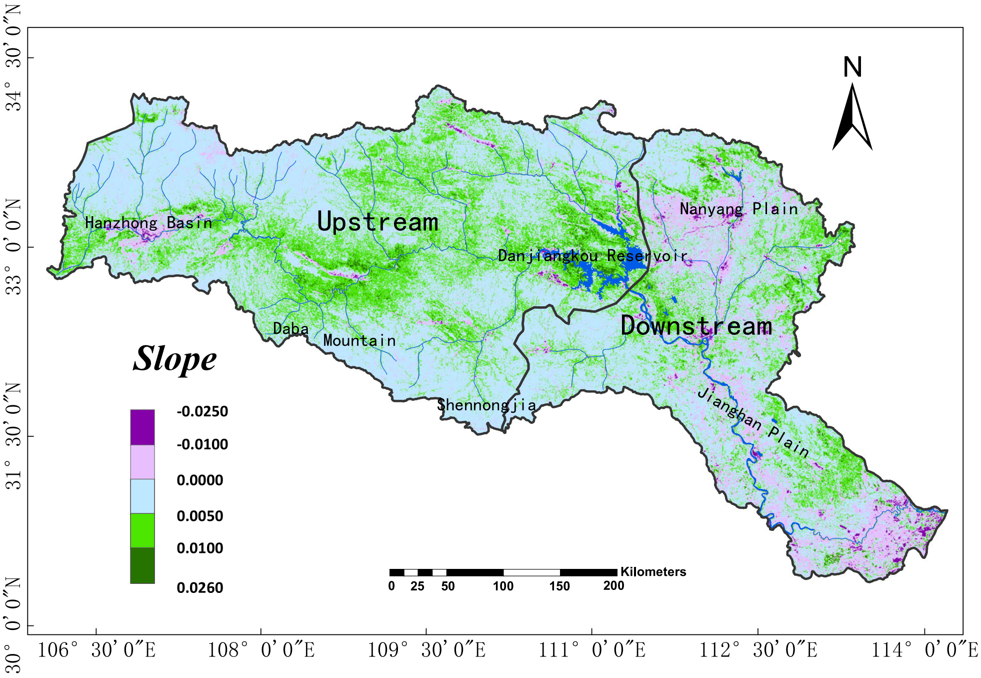


Fig. 3 Spatial variations in the NDVI

negatively correlated areas were concentrated in the western, eastern, and southeastern parts of the basin.

After removing the influences of the precipitation and the air temperature, the correlations between the NDVI and the rainfall and temperature were weakened. The results of the partial correlation analysis are shown in Fig. 4c, d. The areas with negative correlations between temperature and NDVI accounted for 46% of the total area, although they failed to pass the significance test at a 90% confidence level. Areas with positive correlations accounted for 54% of the study area, of which only 1.4% showed significant correlations ($P < 0.1$) at a confidence level of 90%. The positively correlated regions were mainly distributed in the western and middle parts of the basin with a significant positively correlated area in the western region of the basin. The negatively correlated regions were concentrated in the eastern, central, and southeastern parts of the basin. The areas with positive correlations between rainfall and NDVI accounted for 85% of the total area, of which 19.3% showed significant correlations ($P < 0.1$) at a confidence level of 90%, while only 1.5% of the total area had significantly positive correlations at a confidence level of 95% ($P < 0.1$). The positively correlated regions were distributed throughout most of the study area with significantly positive correlations mainly in the southern and southeastern parts of the basin. Areas with negative correlations accounted for 15% of the total area, although they were not significant at a confidence level of 90%. The negatively correlated regions were concentrated in the western part of the basin.

Influence of the topography on the NDVI

Elevation

As shown in Fig. 5a, b, areas with an elevation below 500 m comprised 43% of the study area, areas with elevations of 500–1000 m accounted for 28% of the study area, areas with elevations of 1000–1500 m accounted for 19% of the study area, and areas with elevations of 1500–2000 and > 2000 m comprised 7 and 3% of the study area, respectively. The eastern and southeastern parts of the basin are characterized by lower-elevation terrain, while higher terrain is distributed throughout the southern portion of the basin and the mountainous area to the northwest. The maximum NDVI appears at elevations of 1500–2000 m, the minimum NDVI is detected below an elevation of 500 m, and the NDVI is relatively high at elevations above 1000 m. In the areas below an elevation of 2000 m, the NDVI increases with an increase in the elevation; meanwhile, in the areas where the elevation is greater than 2000 m, the NDVI value decreases as the elevation increases.

Analysis of the NDVI trends in the different elevation ranges from 2000 to 2016 (Fig. 5c) reveals that the NDVI change rates over the entire elevation gradient are all above zero, indicating that the NDVI values at different elevation ranges tended to increase over the 17-year period. A difference is observed in the NDVI change rate between different elevation zones, however. In the range of 500–1000 m, the NDVI value increased from 0.81 to 0.87, with a change rate of 0.04 year^{-1}; this elevation range had the most pronounced increasing trend. In the range of 1000–1500 m, the NDVI

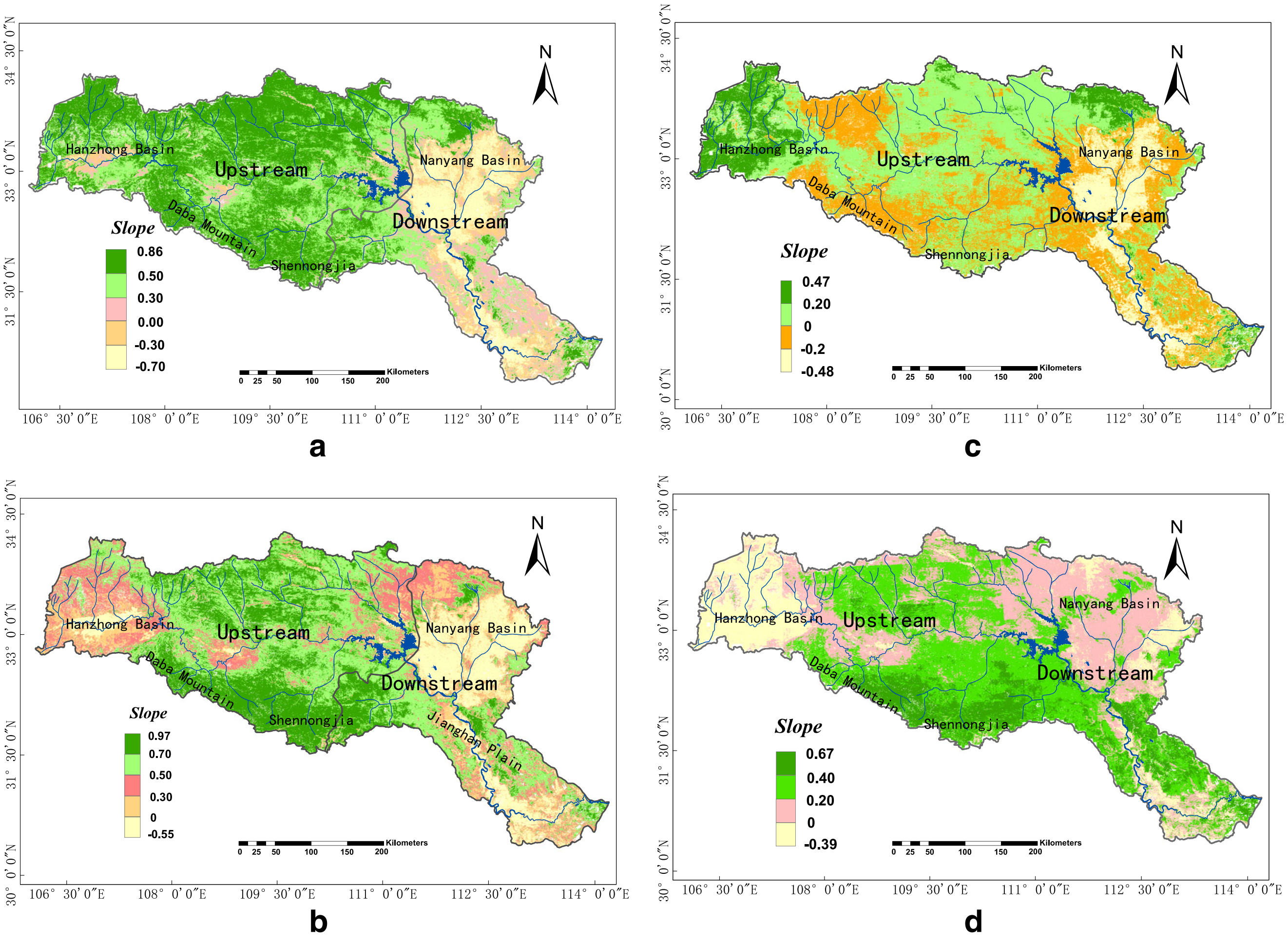


Fig. 4 **a** Plotted results of simple correlation analyses of temperature and NDVI. **b** Plotted results of simple correlation analyses of rainfall and NDVI. **c** Plotted results of partial correlation analyses of temperature and NDVI. **d** Plotted results of partial correlation analyses of rainfall and NDVI

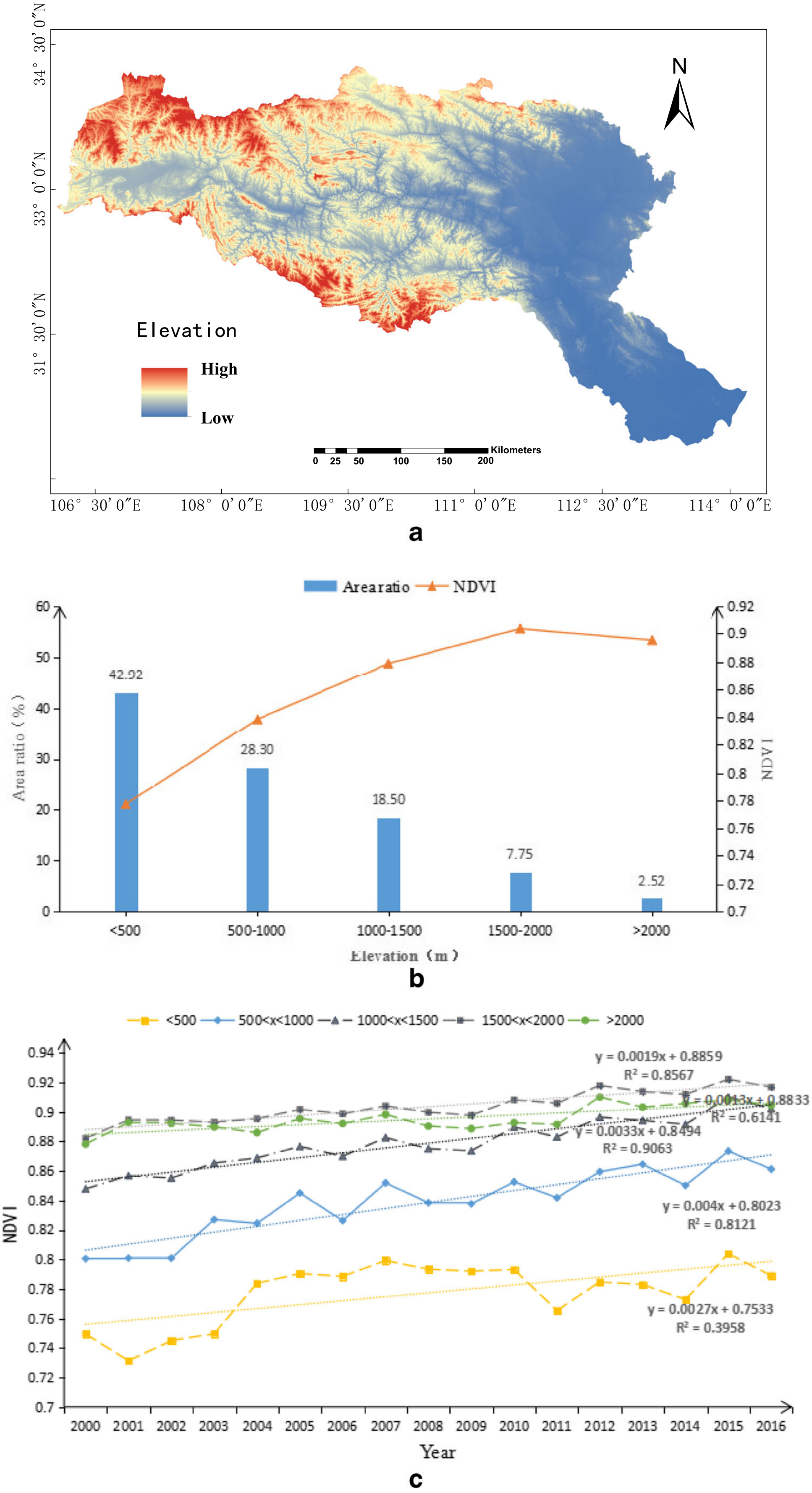
value varied from 0.85 to 0.91, and the change rate was 0.033 year^{-1}. At elevations below 500 m, the NDVI value ranged from 0.73 to 0.81, with a change rate of 0.027 year^{-1}. At elevations of 1500–2000 m, the NDVI ranged from 0.88 to 0.93, with a change rate of 0.019 year^{-1}. The NDVI trend was 0.013 year^{-1} at elevations exceeding 2000 m, and the increasing trend in this elevation range was the weakest among the increasing trends.

Slope and aspect

As shown in Fig. 6a, b, areas with a slope of 15°–25° accounted for 26% of the study area, areas with a slope of less than 2° comprised 24% of the study area, and areas with a slope of 2°–6° accounted for 11% of the study area, the smallest total area among the different slope bins. The areas with slopes of 6°–15° and with slopes exceeding 25° respectively accounted for 18 and 20% of the study area. The areas with lower slope angles are distributed throughout the eastern and western basin areas and in the southeastern farming areas in the plains. The areas with higher slope angles are distributed in the mountainous areas to the south and northwest. The annual average NDVI was lower in the areas with slopes of less than 2° and slopes of 2°–6°, and those areas exhibited little difference. In the areas with slope angles exceeding 6°, the NDVI showed an increasing trend with an increase in the slope.

As apparent in Fig. 6c, the NDVI clearly shows consistent trends in areas with slopes of 6°–15°, 15°–25°, and > 25°; however, the NDVI variation in the areas with slopes of < 2° and 2°–6° was more complex, and the NDVI changed with slope. The average NDVI among the different slopes showed an overall increasing trend over the past 17 years. Among the different slope ranges, the range of 6°–15° showed the most obvious increase in the NDVI, with NDVI values ranging from 0.78 to 0.87 and a trend of 0.04 year^{-1}. The NDVI values for vegetation in regions with predominantly flat terrain (less than 2°) were distributed between 0.73 and 0.80, with a change rate of 0.014 year^{-1}, and the NDVI trends for slope angles of 2°–6°, 15°–25°, and > 25° were 0.031/10a, 0.037/10a, and 0.033 year^{-1}, respectively.

Fig. 5 **a** Elevation distribution. **b** Average annual NDVI values at different ranges of elevation. **c** NDVI trends for different elevation ranges



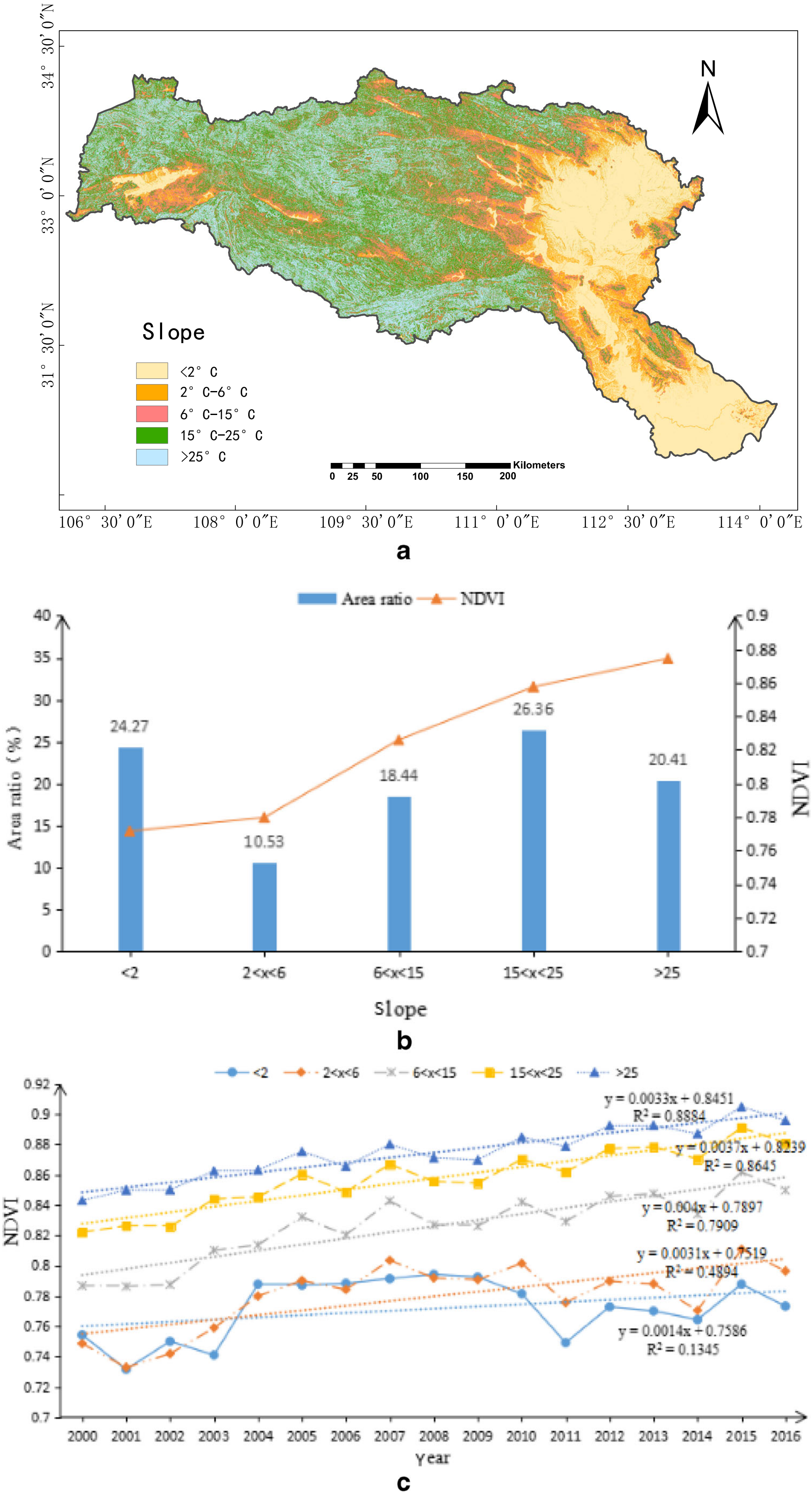


Fig. 6 **a** Slope distribution. **b** Average annual NDVI values for different slope ranges. **c** NDVI trends for different slope ranges

The study area is divided into four aspect quadrants, namely sunny slope, semi-sunny slope, shady slope, and semi-shady slope, which account for 25, 26, 24, and 25% of the total study area, respectively. The average NDVI values among the four quadrants do not exhibit substantial differences. To analyze the NDVI trends among the different aspects over the past 17 years, the annual mean values for each of the four aspect quadrants are respectively calculated. As shown in Fig. 7c, the NDVI variation trends for sunny slopes, shady slopes, semi-sunny slopes, and semi-shady slopes are all consistent with one another, and the difference in the NDVI is small.

Analysis

Spatial and temporal analysis of the NDVI

Over the entire 17-year study period, the NDVI of the Hanjiang River Basin showed an overall upward trend with an average of 0.82. This is because the Hanjiang River Basin is a water source area for the middle route of the South-to-North Water Diversion Project. The government has recently been enhancing ecological protection work throughout the country; as a consequence, the vegetation coverage in the drainage basin has been improved. Over the 17-year period, the total vegetation showed a slight increasing trend, and only some areas showed significant changes. Areas of significantly increased NDVI values are located near the Danjiangkou Reservoir, which serves as the core water source area for the middle route of the South-to-North Water Diversion Project. In recent years, the government has enhanced ecological protection practices; the associated implementation of a project aimed at returning farmland to forestland has significantly increased the coverage of vegetation, leading to a swift increase in the NDVI (Zhou et al. 2015). The reduced area is the surrounding areas of big cities. These areas are flat, the natural conditions are superior, and social and economic development is better. With the acceleration of urbanization, cultivated land and woodland have been converted into construction land, resulting in a declining NDVI trend.

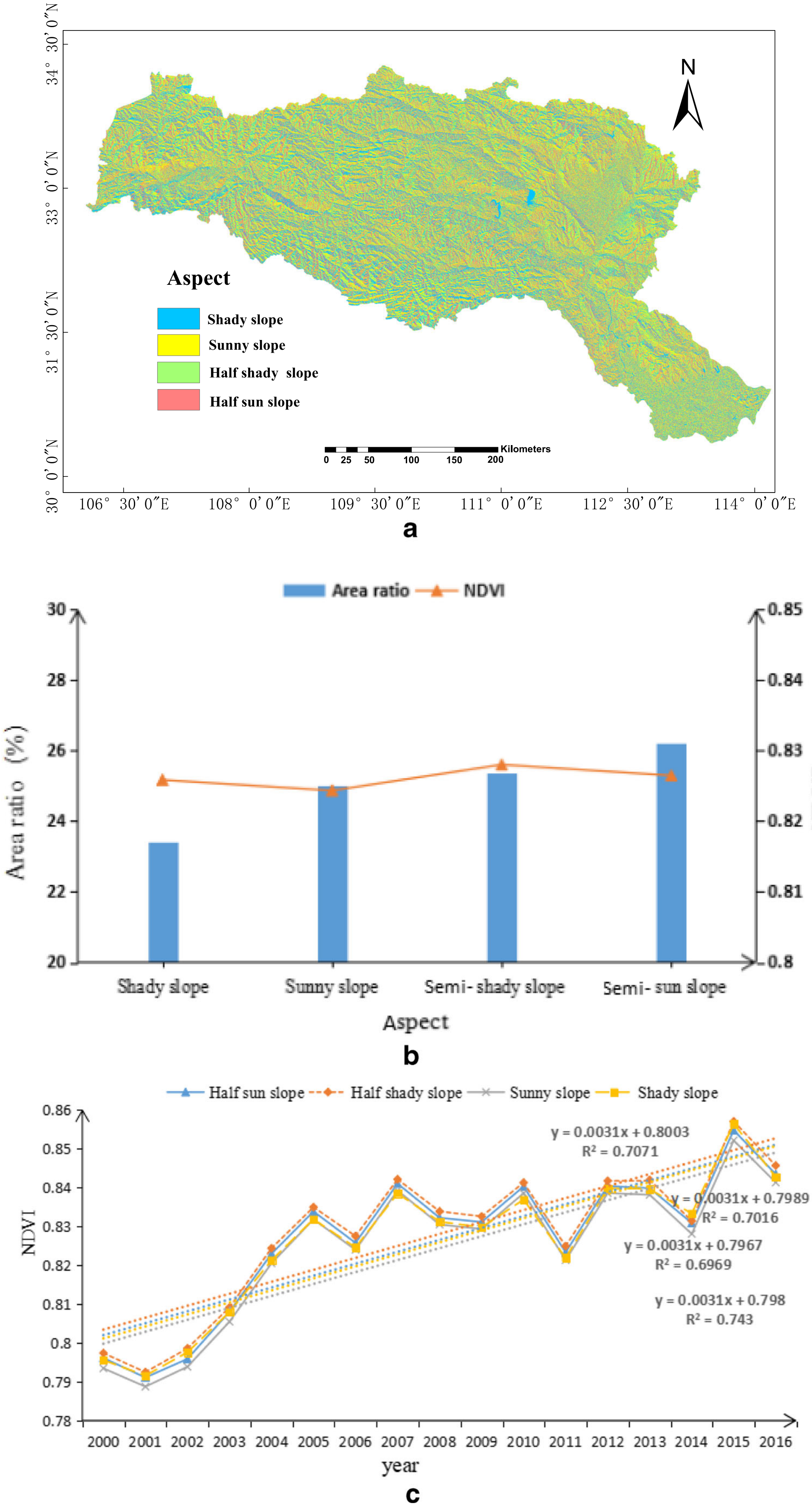
As a whole, the vegetation coverage in the upstream region is better than that in the downstream region. Forestland is the main land use type in the upstream region, with 68.58% of the forestland in the study area distributed in this region. Since the implementation of the South-to-North Water Transfer Project, ecological protection work in the upstream area has been strengthened continuously. As a result, the upstream NDVI in the river basin increased markedly over the past 17 years, with little fluctuation. The downstream region comprises farming areas, and the cultivated land area accounts for 62.01% of the total land area. Despite the rapid development of society and economy in the lower reaches of the basin, the ecological environment of the region is gradually improving, but there remains the problem of the reduction of cultivated land and woodland in some areas. In the lower reaches of the river basin, which are low-altitude areas, the influences of anthropogenic and climate factors are strong, so the vegetation coverage is worse than it is in the upstream area. The study area is located in the middle section of the South-to-North Water Transfer Project, and the Danjiangkou Reservoir is the core water source area of the South-to-North Water Diversion. Water transfer will have an impact on the cover of the upstream and downstream regions. In the upstream region, the elevation of the dam increases the ecological adjustment function of the water resource supply and the hydrological regulation in the region, and the vegetation cover is markedly improved. For the downstream region, the water quality and quantity are greatly reduced; as the water level decreases, the area of sand will expand, and the vegetation cover will be affected.

The downstream NDVI decreased markedly in 2001, 2010, and 2014, potentially due to climatic factors. Sudden natural disasters of drought and flooding affected crop growth in 2001. According to the China Weather Network (http://www.weather.com.cn/zt/kpzt/1244064.shtml), in the first half of 2001, the Hanjiang River Basin experienced a severe drought, and in the second half of that year, it experienced floods. The NDVI value dropped abruptly in 2001. The NDVI in 2010 may have been affected by flooding. According to the Tencent News Network (http://news.qq.com/a/20100720/000659.htm), great floods occurred in the Yangtze and Hanjiang rivers in 2010, and the NDVI value of cultivated land decreased rapidly. The decrease in 2014 is due to drought; according to China's central government portal (http://www.gov.cn/xinwen/2014-03/21/content_2643307.htm), severe drought occurred from October 2013 to 2014 in the upper reaches and middle reaches of the Hanjiang River, and crop production decreased significantly, resulting in a decrease in NDVI values in 2014.

The influence of meteorological factors on NDVI

A negative correlation between the NDVI and temperature and precipitation is observed in the eastern plain region of the basin (Fig. 6a, b). This region is a primarily agricultural area affected by crop harvesting during the harvest period coincident with rising temperatures, which cause the NDVI to decrease. Meanwhile, because of the abundance of water resources and the good condition of the irrigation system in the Hanjiang River Basin, the cultivated land is less dependent upon precipitation, although too much precipitation could easily cause a flood disaster. A strong positive correlation is observed in the Dabashan and Shennongjia areas in the southern part of the basin, which exhibit higher vegetation coverage of forestland than do the vegetation coverage of forestland in the northern regions. The abundant precipitation and suitable temperatures therein promote the growth of vegetation.

Fig. 7 **a** Aspect distribution. **b** Aspect quadrants and average annual NDVI values for different slope types. **c** NDVI trends for different slope types



Excluding the effects of rainfall and the air temperature, the correlations in the eastern and southeastern parts of the basin are significantly lower. Cultivated land is mainly distributed in this area. The lower reaches of the Hanjiang River Basin are rich in water resources; this greatly reduces the dependence of the vegetation on precipitation. Higher temperatures and greater amounts of precipitation are mostly distributed during the summer and autumn, which affect the crop maturity and, therefore, the correlation between the regional vegetation cover and the rainfall and temperature. This agricultural cultivation area is also greatly influenced by human factors. In the Shennongjia and Dabashan areas, the NDVI shows a weakly negative correlation with the temperature and a significantly positive correlation with the precipitation primarily because the maximum vegetation cover in this area occurs in August. The rapidly increasing summer temperatures accelerate surface evaporation; as a result, the development of a dry soil layer in the area has a significantly inhibitory effect on the vegetation growth. At this time, precipitation is very important to vegetation growth; moreover, the gradient of the topography in this area is steep, and the degree to which vegetation is affected by the terrain is highly dependent on the precipitation (Li et al. 2010; Zhang et al. 2002). In the western part of the basin, the relationship between the NDVI and the rainfall is relatively low, but the NDVI has a strongly positive correlation with the temperature; because of the flat topography in the upper basin and the developed river system within the valley, the temperature promotes vegetation growth. In the central part of the basin, the simple correlation coefficients between the NDVI and the precipitation and air temperature are high, but the partial correlation coefficients are greatly reduced, thereby representing a relatively low correlation overall. This shows that the integrated influences of the precipitation and temperature in the central part of the basin are larger and that their impact on the NDVI is smaller.

The influence of terrain factors on NDVI

Elevation

In the study area, the areas below an elevation of 500 m are utilized mainly for crops, while those at an altitude of 500–1000 m are mainly composed of deciduous broad-leaved forests and crops. Those areas at an elevation of 1000–1500 m are mostly comprised of deciduous broad-leaved forests, while coniferous forests comprise the areas at elevations of 1500–2000 m, and those exceeding 2000 m primarily comprise coniferous forests (Zhang and Ren 2006). Crops reach maturity during the harvest season in May–June and September–October each year, causing the NDVI to decrease rapidly. Overall, the crop NDVI is lower than that of forestland. Therefore, the annual average NDVI in the range of elevations below 500 m is the lowest, followed by those at 500–1000 m, and the NDVI at elevations of 1000–1500 m are relatively higher. Broad-leaved deciduous forests have higher vegetation coverage during the summer than during the other months, and their area declines during the winter coincident with a rapid decrease in the NDVI. However, the NDVI of coniferous forest was slightly lower than that of broad-leaved forest during summer and higher during the winter. The average annual NDVI was higher for coniferous forest than for broad-leaved forest, and that in the elevation range of 1000–1500 m was lower than that at elevations exceeding 2000 m. Compared with broad-leaved forests and coniferous forests, coniferous-broad-leaved mixed forests are less affected by seasonal changes during the winter and summer, and a higher NDVI is maintained for coniferous and broad-leaved mixed forest during the winter; thus, the average annual NDVI of 1500–2000 m is the highest.

The NDVI increased slowly in areas with higher elevations and lower elevations and increased rapidly in the middle-elevation regions. The changes in the NDVI in the lower-elevation zones below 1000 m were more complicated, which is consistent with the NDVI trend in areas of higher elevations above 1000 m. The lower-elevation areas are dominated by crops or crops mixed with forestland. The vegetation coverage therein is greatly affected by agricultural and human activities. Meanwhile, the implementation of a policy to return grain plots to forested land will promote an increase in the vegetation cover. However, the steeper terrain at higher altitudes may be less disturbed by human factors, and thus, the vegetation changes therein are relatively stable.

Slope and aspect

The main distribution of cultivated land is located in the areas with slope angles of less than 2°; due to the crop growth cycle in those regions, the NDVI is low. Slopes of less than 6° are mainly distributed throughout the plains of the middle and lower reaches of the Hanjiang River Basin and the Hanzhong Basin. The terrain of this area is gentle, and the main vegetation cover type is cultivated land; consequently, the average annual NDVI is low. The proportion of arable land gradually decreased with an increase in the slope gradient in the areas with slope gradients greater than 6°. Meanwhile, the areas with larger gradients are mainly distributed throughout the Qinba Mountains and the Shennongjia area. The natural ecological environment is good, and thus, the vegetation coverage is high. With ongoing afforestation, the protection and closure of hillsides, and other policies, the regional vegetation coverage is relatively high.

Based on the NDVI trend for the different slope bins, the lower-gradient slopes are mainly composed of cultivated land. Due to human interference, the NDVI in those areas fluctuated greatly. Moreover, the proportion of forestland increased in the areas with larger slopes, leading to higher vegetation coverage, and the overall changes tended to be stable. The regional growth of the vegetation coverage was not obvious. Meanwhile, the vegetation coverage at gradients of 6°–15° exhibited a good growth trend. Due to the convenience of tillage, these areas can also avoid human interference and other factors. With the implementation of a policy aimed at returning farmland to forestland, the vegetation coverage in the area is increasing. Because of the minimal changes in the vegetation NDVI and the consistent NDVI trend among the different slopes, the slope aspect did not constitute a primary topographic factor that affected the vegetation cover change in this period.

Suggestions for improving the vegetation coverage

The comprehensive analysis results in this paper demonstrate a trend of vegetation degradation within the basin on either side of the middle and lower reaches of the Hanjiang River Basin and in the areas surrounding the center of the city. In these areas characterized by low-lying vegetation cover, the correlations between the NDVI and the precipitation and temperature are low, and human factors constitute the main factors affecting changes in the vegetation coverage. In this regard, the relevant governmental departments should delineate explicit urban growth boundaries, protect agricultural land use and natural ecological spaces outside of the city, compile regional scientific development plans, and increase protection measures for basic farmland and forestland (Zhang et al. 2017). The vegetation coverage is good in the Qinling Mountains situated along the northwestern part of the basin, the Dabashan to the south, and in the Shennongjia area in the southern part of the basin. The vegetation coverage showed an increasing trend during recent years. However, this area should be subjected to ecological restoration, specifically the restoration of vegetation along barren hillsides and slopes. In particular, the western region of the river basin is strongly dependent on the air temperature. During future regional ecological construction efforts, tree species that are less sensitive than others to temperature changes should be introduced to improve the survival rate and conservation rate of afforestation endeavors (Li et al. 2009). Agricultural areas primarily constitute the upper reaches of the Hanjiang River on both sides of the river, and the regional vegetation cover increased more evidently therein. However, the vegetation coverage in some areas is still relatively low, and precipitation distribution in those areas is small. While promoting the development and protection of arable land, additional attention should be paid to the construction of regional infrastructure irrigation facilities.

Discussion

Since temperature and precipitation stations were difficult to acquire in the study area for the past 17 years, MOD11C3 and TRMM 3B43 data were used to analyze the temperature and rainfall in this study. However, there are differences among TRMM 3B43 data, MOD11C3 data, and observation data, and the applicability of TRMM data in different regions varies. To verify the accuracy of the TRMM and MOD11C3 data, data of average temperature (°C) and monthly mean precipitation (mm) for five sites, which were provided free of charge by CMDC, were selected. A total of 660 sample points were selected, and the site data and measurement data were analyzed by scatter fitting. The results are as follows:

Figure 8 shows that the MOD11C3 and TRMM data are well matched with the site data. The goodness of fit between MOD11C3 and the observed monthly mean temperature of the sites is $R_2 = 0.9115$, and the root-mean-square error (RMSE) is 4.864. The goodness of fit of the TRMM data and the monthly average precipitation measured at the stations is $R_2 = 0.7659$, and the RMSE is 36.454. The results show that the MOD11C3 and TRMM data are highly applicable to the study area at the monthly scale.

In addition, two methods are primarily used for the synthesis of the NDVI data, namely the mean value method and the MVC method. The Hanjiang River Basin is a region rich in various vegetation cover types; however, there are spatial differences in the types of vegetation and their growth periods throughout the basin (Chen et al. 2004). Unfortunately, the mean value method obscures the differences among different vegetation types, and it cannot effectively avoid interference from outliers, thereby imposing a notable impact on the accuracy of the results. Therefore, this study adopts the MVC method, which is capable of effectively avoiding the influences of outliers and ultimately improving the data accuracy.

The air temperature and precipitation are selected as the climate factors in this study because they represent the two main climatic factors in climate change; moreover, they are the most important influences on changes in the NDVI (Jiang et al. 2014). The elevation, slope, and aspect of the topography are also selected because the elevation will affect the type and spatial distribution of vegetation. Furthermore, there are differences in the temperature, precipitation, and light distributions at different elevations, which will consequently affect the vegetation coverage. The slope will also influence the vegetation growth by affecting the soil moisture and soil nutrients. Furthermore, the aspect affects the light distribution, causing differences in the vegetation types and growth conditions among different slopes. In addition to the implementation of both climatic and terrain factors, human activities are also important influences on the vegetation cover, especially in low-lying areas. Increasingly frequent human activities constitute a highly important factor that affects vegetation cover changes; for example, man-made ecological afforestation projects would cause a substantial increase in the vegetation coverage. However, there is no unified quantitative standard for the relative contributions from man-made factors to

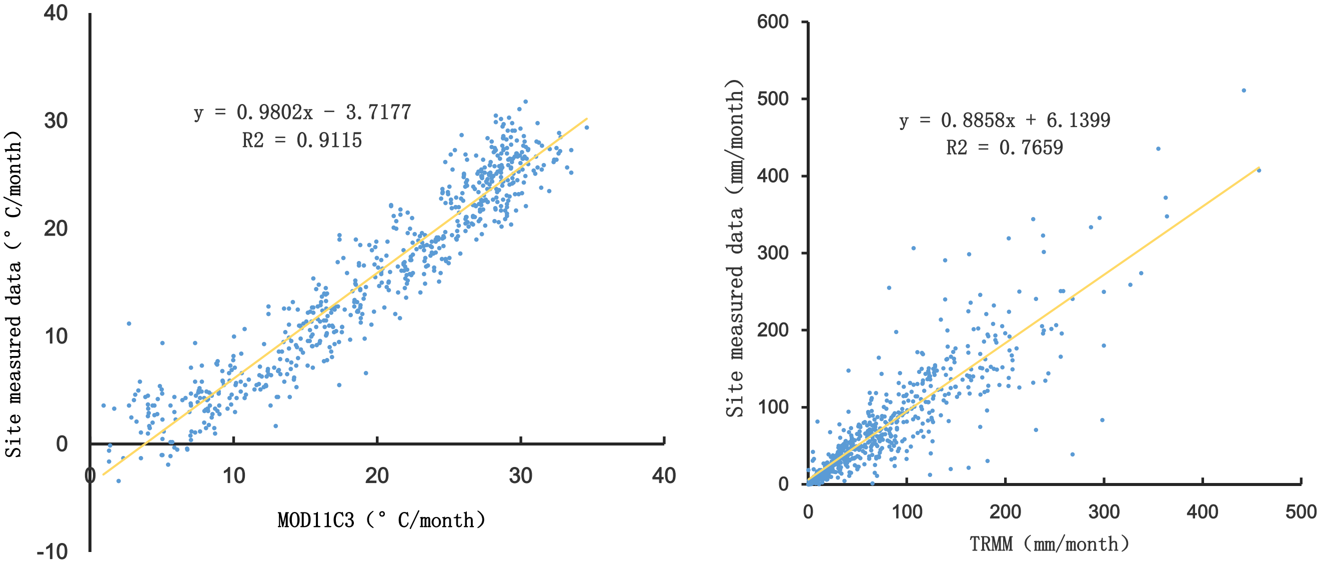


Fig. 8 Verification of TRMM and MOD11C3 data with the observed data

changes in vegetation cover (Li et al. 2017); thus, it is difficult to carry out a quantitative analysis. Therefore, this study does not conduct an in-depth analysis of the influences of human factors on the vegetation cover; rather, this will constitute the focus of future research.

Conclusions

Based on temporal MODIS NDVI data, the trend analysis method was used to study the temporal and spatial variations in the vegetation cover throughout the Hanjiang River Basin from 2000 to 2016. The main factors affecting the variations in the vegetation cover were investigated based on meteorological and topographical data. The main conclusions are as follows:

(1) In the past 17 years, the overall growth rate of NDVI in the study area was 0.025/10a. Vegetation cover is greater in the upstream region than in the downstream region, and the NDVI changes in the upstream region are small, with little fluctuation, whereas the changes downstream are larger.

(2) The areas with increasing trends are mainly distributed in the upstream region, whereas the areas with decreasing trends are concentrated in the downstream region of the basin. Areas of significant increases in the spatial distribution of vegetation cover are mainly located near the Danjiangkou Reservoir, and significant reductions in the distribution of cover are observed near central cities around the region.

(3) The NDVI in the study area showed a significantly positive correlation with both the rainfall and the air temperature. The correlations between the NDVI and the rainfall and temperature are different among different areas. The precipitation has a significant impact on the forestland in the Dabashan and Shennongjia areas in the southern parts of the basin. Meanwhile, the temperature has a significant impact on the lower valley in the upper reaches of the basin. Both the rainfall and the air temperature have little effects on the farming areas in the plain, while they have a greater combined impact on the central region of the basin with smaller individual effects.

(4) In the area at elevations below 2000 m, the vegetation coverage showed an increasing trend with an increase in the elevation. The vegetation cover in the elevation range of 500–1000 m exhibited a tendency of rapid growth, while the vegetation above 1500 m tended to be stable. With an increase in the slope, the vegetation coverage showed an increasing trend. Furthermore, the vegetation growth trend was high on slopes of 6°–15°. The vegetation coverage among different slopes showed an increasing trend, but the differences were not obvious. However, the slope orientation did not constitute a primary factor affecting the vegetation coverage.

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References

Adams JE, Arkin GF (1977) A light interception method for measuring row crop ground cover. Soil Sci Soc Am J 41(4):789–792

Bi J, Xu L, Samanta A et al (2013) Divergent Arctic-boreal vegetation changes between North America and Eurasia over the past 30 years. Remote Sens 5(5):2093–2112

Cai H, He ZW, An YL et al (2014) Correlation intensity of vegetation coverage and topographic factors in Chishui watershed based on RS and GIS. Earth Environ 42(4):1672–9250

Calvao T, Palmeirim J (2004) Mapping Mediterranean scrub with satellite imagery: biomass estimation and spectral behaviour. Int J Remote Sens 25(16):3113–3126

Chen J, Jonsson P, Tamura M, Gua ZH, Eklundh L, Matsushita B (2004) A simple method for reconstructing a high-quality NDVI time series data set based on the Savitzky-Golay filter. Remote Sens Environ 91:332–344

Cong DM, Zhao SH, Chen C et al (2017) Characterization of droughts during 2001-2014 based on remote sensing: a case study of Northeast China. Ecol Inform 39:56–57

de Jong R, Verbesselt J, Zeileis A, Schaepman M (2013) Shifts in global vegetation activity trends. Remote Sens 5(3):1117–1133

Eckert S, Husler F, Liniger H et al (2015) Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. J Arid Environ 16–28

Fabricante I, Oesterheld M, Paruelo JM (2009) Annual and seasonalvariation of NDVI explained by current and previous precipitation across Northern Patagonia. J Arid Environ 73:745–753

Fensholt R, Proud SR (2012) Evaluation of earth observation based global long term vegetation trends—comparing GIMMS and global NDVI time series. Remote Sens Environ 119(3):131–147

Fensholt R, Rasmussen K, Nielsen T et al (2009) Evaluation of earth observation based long term vegetation trends—intercomparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOTVGT data. Remote Sens Environ 113(9):1886–1898

Gamer W (1995) Comparing global models of terrestrial net primary productivity (NPP): overview and key results. Glob Chang Biol 5: 1–15

Ge J (2010) MODIS observed impacts of intensive agriculture on surface temperature in the Southern Great Plains. Int J Climatol 30(13): 1994–2003

George JH, Robert FA, David TB et al (2006) The TRMM Multi-satellite Precipitation Analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. J Hydrometeorol 8(1): 38–55

Gottfried M, Pauli H, Futschik A et al (2012) Continent-wide response of mountain vegetation to climate change. Nat Clim Chang 2:111–115

Huber S, Fensholt R, Rasmussen K (2011) Water availability as the driver of vegetation dynamics in the African Sahel from 1982 to 2007. Glob Planet Chang 186–195

Jacquin A, Sheeren D, Lacombe J-P (2010) Vegetation cover degradation assessment in Madagascar savanna based on trend analysis of MODIS NDVI time series. Int J Appl Earth Obs Geoinf S3–S10

Jiang HT, Tashpolat TIYIP, Karim A et al (2014) Responses of NDVI to the variation of precipitation and temperature in the Ebinur Lake Basin. J Desert Res 34(6):1001–4675

Julien Y, Sobrino JA, Verhoef W (2006) Changes in land surface temperatures and NDVI values over Europe between 1982 and 1999. Remote Sens Environ 103:43–55

Kong DD, Zhang Q, Singh VP et al (2017) Seasonal vegetation response to climate change in the Northern Hemisphere (1982–2013). Glob Planet Chang 148:1–8

Lambin EF, Strahler AH (1994) Indicators of land-cover change for change vector analysis in multi-temporal space at coarse spatial scales. Int J Remote Sens 15:2099–2119

Li JG, Huang SF (2011) Variation characteristics analysis of the precipitation from 1998 to 2010 in Hanjiang Basin based on the TRMM data. SNWD Water Sci & Tech 9(6):48–53

Li K, Liu FY, Zhang CH (2009) Essential characteristic of climate plant recovery in dry-hot valley. World Forestry Research 22:24–27

Li DK, Fan JZ, Wang J (2010) Characteristics and causes of vegetation coverage changes in Shaanxi Province in the past ten years. Chin J Appl Ecol 21(11)

Li H, Liu GH, Fu BJ (2011) Response of vegetation to climate change and human activity based on NDVI in the Three-River Headwaters Region. Acta Ecol Sin 31(19):5495–5504

Li XY, Ren ZY, Zhang C (2013) The correlation analysis and space-time changes of NDVI and hydro-thermal index in Hanjiang basin. Geogr Res 32(09):1623–1633

Li Z, Chen Y, Li WH et al (2015) Potential impacts of climate change on vegetation dynamics in Central Asia. J Geophys Res Atmos 120:12, 345–12,356

Li Z, Sun RH, Zhang JH (2017) Temporal-spatial analysis of vegetation coverage dynamicsin Beijing-Tianjin-Hebei metropolitan regions. Acta Ecol Sin 37(22):1–9

Liang S, Li X, Wang J (2012) Advanced remote sensing: terrestrial information extraction and applications. Pennsylvania, Academic 30(32-33):475

Liu L, Jing X, Wang J et al (2009) Analysis of the changes of vegetation coverage of western Beijing mountainous areas using remote sensing and GIS. Environ Monit Assess 153(1–4):339–349

Liu JH, Wu JJ, Wu ZT et al (2013) Response of NDVI dynamics to precipitation in the Beijing-Tianjin sandstorm source region. Int J Remote Sens 34(15):5331–5350

Mao DH, Wang ZM, Song KS et al (2011) The vegetation NDVI variation and its responses to climate change and LUCC from 1982 to 2006 year in northeast permafrost region. Chin Environ Sci 31(2): 283–292

Pearson RG, Phillips SJ, Loranty MM et al (2013) Shifts in Arctic vegetation and associated feedbacks under climate change. Nat Clim Chang 3:673–677

Peng J, Liu YH, Shen H et al (2012) Vegetation coverage change and associated driving forces in mountain areas of Northwestern Yunnan, China using RS and GIS. Environ Monit Assess 184(8): 4787–4798

Piao SL, Fang JY (2003) Seasonal variation of response of terrestrial vegetation to climate change in China from 1982 to 1999. Geogr J 58(01):119–125

Piao SL, Fang JY, Zhou LM et al (2003) Interannual variations of monthly and seasonal normalized difference vegetation index (NDVI) in China from 1982 to 1999. J Geophys Res 108(D14):4401

Qin W, Zhu QK, Zhang XX et al (2006) Review of vegetation covering and its measuring and calculating method. J Northwest Sci Tech Univ Agric For (Nat Sci Ed) 34(9):163–170

Rall (1991) Research methods of soil erosion. Science, Beijing, pp 157–170

Rouse JW, Haas RH, Deering DW et al (1973) Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation. Progress Report RSC 1978-1, Remote Sensing Center, Texas A & M University, pp 75–76

Shary PA, Sharaya LS (2014) Change in NDVI of forest ecosystems in Northern Caucasus as a function of topography and climate. Contemp Probl Ecol 7(7):855–863

Song LL, Bai ZK, Fan X et al. (2018) Effect of biological soil crust on photographically measured value of vegetation coverage. Acta Ecol Sin 38(4):1272–1283

Tang ZG, Ma JH, Peng HH et al (2017) Spatiotemporal changes of vegetation and their responses to temperature and precipitation in upper Shiyang River basin. Adv Space Res 60:969–979

Tourre YM, Jarlan L, Lacaux JP, Rotela CH, Lafaye M (2008) Spatio-temporal variability of NDVI—precipitation over southernmost South America: possible linkages between climate signals and epidemics. Environ Res Lett 3(4):044008

Tucker CJ (1979) Red and photographic infrared linear combinations for monitoring vegetation. Rem Sens Environ 8(2):127–150

Tucker CJ, Yager KA (2011) Ten years of MODIS in space: lessons learned and future perspectives. Ital J Remote Sens 43(3):7–18

Tucker CJ, Pinzon JE, Brown ME et al (2005) An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. Int J Remote Sens 26(20):4485–4498

Vermote E, Tanre D, Deuze JL et al (1997) Second simulaion of the satellite signal in the solar spectrum (6S): an overview. IEEE Trans Geosci Remote Sens 35(3):675–686

Voorde TVD, Vlaeminck J, Canters F (2008) Comparing different approaches for mapping urban vegetation cover from Landsat ETM+ data: a case study on Brussels. Sensors 8:3880–3839

Wang J, Price KP, Rich PM (2001) Spatial patterns of NDVI in response to precipitation and temperature in the Central Great Plains. Int J Remote Sens 22:18

Wang L, Wang H, Lu YL et al (2013) The research and application of NDVI in crop monitoring. CJARRP 34(4):43–50

Wang PT, Zhang LW, Li YJ et al. (2017) Spatio-temporal characteristics of the trade-off and synergy relationships among multiple ecosystem services in the Upper Reaches of Hanjiang River Basin. Acta Geographica Sinica 72(11):2064–2078.

Weiss JL, Gutzler DS, Coonrod JEA et al (2004) Seasonal and inter-annual relationships between vegetation and climate in Central New Mexico, USA. J Arid Environ 57:507–534

Wiegand CL, Richardson AJ (1987) Spectral components analysis: rationale and results for three crops. Int J Remote Sens 8:1011–1032

Wu CD, Lung SCC (2016) Application of 3-D urbanization index to assess impact of urbanization on air temperature. Sci Rep 6:1–9

Xu JH (2002) Mathematical methods in modern geography, 2nd edn. Higher Education, Beijing, pp 43–47

Xu G, Xu X, Liu M, Sun AY, Wang K et al (2015) Spatial downscaling of TRMM precipitation product using a combined multifractal and regression approach: demonstration for South China. Water 7(6): 3083–3102

Zhang GH, Liang YM (1995) Study on runoff starting time of artificial grassland in loess hilly region. J Soil Water Conserv 9(3):78–83

Zhang J, Ren ZY (2006) Spatiotemporal pattern of net primary productivity in the Hanjiang River Basin. Acta Ecol Sin 36(23):7667–7677

Zhang XM, Wang KL, Yue YM et al. (2017) Factors impacting on vegetation dynamics and spatial non-stationary relationships in karst regions of southwest China. Acta Ecol Sin 37(12):4008–4018

Zhang Y, Zhang Q-C, Liu B-Y (2002) Study on vegetation coverage and height variation in northern Loess Plateau. Adv Earth Science 17(2): 268–272 in Chinese

Zheng XD, Lu F, Jing M (2013) Hanjiang River Basin precipitation multiple time scales characteristics and with circulation factors correlation analysis. Adv Earth Sci 28(05):618–626

Zheng W, Li X, Yin L, Wang Y (2016) The retrieved urban LST in Beijing based on TM, HJ-1B and MODIS. Arab J Sci Eng 41(6): 2325–2332

Zhou C, Ding XH, Li GP, Wang HZ (2015) Ecological compensation standards in the water source area of the Middle Route Project of the South-North Water Transfer Project. Resour Sci 37(4):792–804