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ORIGINAL ARTICLE

Assessing vegetation dynamics in the Three-North Shelter Forest region of China using AVHRR NDVI data

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Abstract The Three-North Shelter Forest Programme (TNSFP) covers 551 Chinese counties and an area of 4,069,000 km^2 mostly in arid and semi-arid regions. In this paper, we discuss the temporal and spatial changes in value of the normalized-difference vegetation index (NDVI) in this region, and the relationships between NDVI and climatic factors (temperature and precipitation) based on NOAA Advanced Very High Resolution Radiometer Global Inventory Modeling and Mapping Studies NDVI data with 8-km resolution from 1982 to 2006. During the past 25 years, the vegetation cover has generally increased in eastern regions of China and the oasis in the north piedmont of Tianshan Mountains, but has decreased northwest of Xinjiang and in the Hulunbeier Plateau. The multi-year monthly average NDVI distribution map showed that NDVI increased from April to August, but in the western and northern plateau areas, the lower temperatures and high altitude created a shorter growing season (1 or 2 months). The vegetation of the study area has generally increased in the regions covered by the TNSFP. Linear regression analysis of the vegetation cover showed an increasing trend over large areas. The largest annual growth rate per pixel (the slope of the regression) was 0.009; the largest negative annual change was −0.004. The correlation between NDVI and precipitation was higher than that between NDVI and temperature, suggesting that precipitation is the most important factor that affects NDVI changes in the study area, especially for temperate desert vegetation in northwestern China.

Keywords Three-North Shelter Forest Programme (TNSFP) · NDVI · Vegetation cover changes · Climate factor · Dryland

Introduction

Starting in the twentieth century, serious global changes have begun that are leading to problems such as a lack of fresh water, desertification, food shortages, the greenhouse effect, biodiversity loss, and unsustainable and unbalanced regional development, and these have been exacerbated by natural phenomena such as unusually strong El Niño events. These issues threaten the future development of human society and the health of Earth's ecosystems (Zhang 2002; Tsunekawa et al. 2005). Vegetation is a sensitive indicator of human activity and the impacts of a changing climate on the environment (Zhou et al. 1999). Because of the tight relationship between vegetation cover and climatic factors, climate change research often uses changes in vegetation cover as a proxy for climate impacts. Vegetation changes are particularly significant because they affect the atmospheric energy balance, and play an important role in climate hydrological and biochemical cycles (Michael and Wilfried 2003).

TNSFP is a huge ecological restoration effort being implemented in three parts (the northwestern, northern, and

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northeastern regions) of China (Mather 1993). Its main purposes are to restore and protect regional vegetation in the project areas, thereby improving eco-environmental quality and ecosystem services (Wu et al. 2009). In addition to its huge geographic extent, the project has a long duration (it extends until 2050) and coordinates the efforts of many government departments and administrative units. Given the project's scope and importance, it is important to monitor its long-term progress until the project is complete (Li and Zhai 2002).

Remote sensing provides a quick, effective, and comprehensive way to monitor natural processes by providing macro-scale data on surface conditions that reveal the dynamic variation in these conditions and allow the detection and forecasting of trends (Zhang et al. 2001). The use of remote-sensing data has become a primary means to measure vegetation cover, and especially to support large-scale and long-term regional studies (Shen and Wang 2001). Particularly in the past 20 years, remote-sensing technology has advanced greatly, and vegetation dynamics research based on this technology has increased greatly in scope and details that can be determined. The using of sensors with high temporal resolution, such as NOAA's Advanced Very High Resolution Radiometer (AVHRR), provides a reliable data source to support studies of vegetation dynamics.

Study area

TNSFP is known as the "Green Great Wall" because it covers most of the Northern China, ranging between 73°26′E and 127°50′E and between 33°30′N and 50°12′N (Fig. 1). In 1979, the central government decided to combat severe environmental degradation, including declining vegetation cover and expanding desertification, by planting shelter forests throughout the Northern China. The programme covers 551 counties in 13 provinces and autonomous regions, from Bin County of Heilongjiang Province in the east to the Wuzibieli Mountain pass in the west, a distance of 4,480 km from east to west and 560 to 1,460 km from south to north. The entire area covers 4,069,000 km^2, and accounts for 42.4% of China's land area (Dai et al. 2000; Jiang et al. 2009).

Rainfall in this region decreases moving from east to west and from south to north. In southeast of Ili river region of Xinjiang Uigur Autonomous Region and Datong River areas of Qinghai Province, the rainfall is greater than 400 mm. To the west of Erenhot, and in Urad Qianqi, the Helan Mountains, and the northwestern Qilian Mountains, annual precipitation averages less than 200 mm. In the Tengger Desert, the Badain Jaran Desert in southern Xinjiang Province, and the Qaidam Basin, annual precipitation averages less than 100 mm; most of this region has precipitation between 20 and 50 mm, and it represents the driest place in China. Arid and semi-arid regions account for two-thirds of the Three-North Shelter Forest region, which seriously constrains ecological restoration.

The temperature differences across the region are equally dramatic. The annual average temperature increases from ca. 14°C in the southern tip to −9.7°C in the northeastern corner, with the mean temperature in most areas ranging between 2 and 8°C. Affected by the atmospheric circulation patterns and other factors such as local topography (including large mountain ranges and plateaus), wind speed and direction change significantly throughout the study area, but the dominant winds come from the west, the northwest, and the east. The annual average wind speed ranges from 2 to 5 m/s, with an average maximum wind speed ranging from 19 to 30 m/s. The number of days per

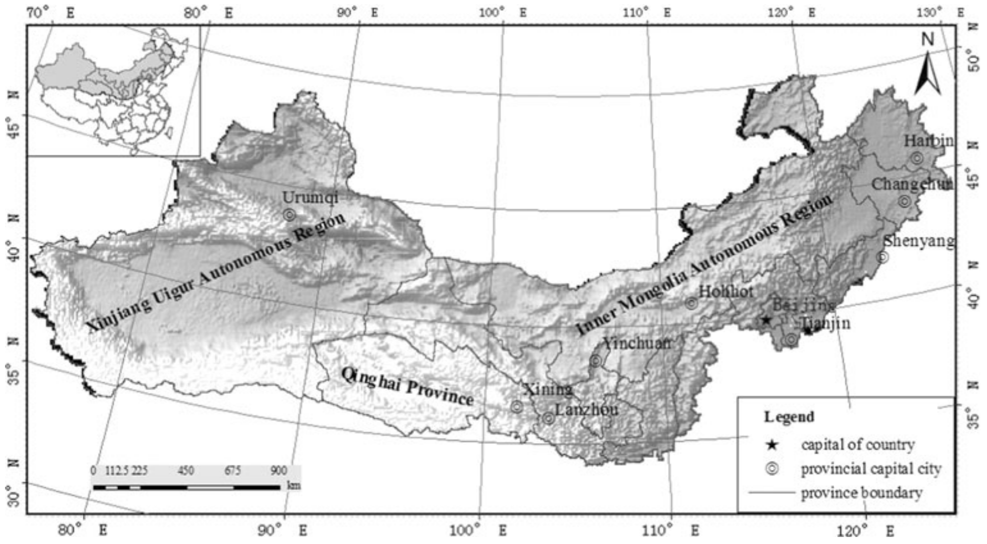


Fig. 1 Location of the study area

year with winds of rank 8 (winds in category 8 of the Beaufort scale >17 m/s) and above is between 20 and 70 days. The sandstorm frequency is high throughout the northwestern part of this region (Zhang et al. 2008). The total annual sunshine duration ranges between 2,400 and 3,400 h, with values greater than 3,000 h in the northwestern arid region.

Data and methods

Data

The remote-sensing data that were used in this research comprised digital images from which normalized-difference vegetation index (NDVI) values calculated by NOAA were extracted throughout the study area and synthesized based on the NOAA/AVHRR half-monthly estimates, obtained from the Global Inventory Modeling and Mapping Studies (GIMMS) data center at the Goddard Space Flight Center. Geometric, radiation, and atmospheric corrections were performed according to the methods of Pinzon (2002) and Tucker et al. (2005). For every day and every track image, bad lines and clouds were removed after geometric correction. The following formula was used to extract NDVI values from the AVHRR data:

$$\mathrm{NDVI} = 1{,}000 \times (\mathrm{b2} - \mathrm{b1})/(\mathrm{b2} + \mathrm{b1}) \tag{1}$$

where, b1 and b2 represent the first and second AVHRR channels, respectively. Using this equation, NDVI values ranging from -1 to 1 are generated. The image data is stored in the form of an Albers Equal-area Conic Projection, with an 8-km spatial resolution and a time resolution of 15 days. Data for the study area was available from January 1982 to December 2006. The data can be downloaded from the University of Maryland's FTP site (ftp://ftp.glcf.umiacs.umd.edu).

To reduce the influence of clouds, the atmosphere, and the solar elevation angle, this research performed preprocessing such as geometric, radiation, and atmospheric corrections using the maximum-value composite (MVC) method, using version 9.2 of the ArcInfo GIS software (ESRI, Redlands, CA), and used the boundary of the study area in the GIS software to define the data for the Three-North Shelter Forest region and used the software's MAX command to identify the monthly and annual maximum NDVI values based on the half-monthly GIMMS NDVI in the Arc/Info-Grid environment. Because the annual maximum NDVI value does a good job of reflecting the vegetation cover, MVC method was used to identify the annual maximum NDVI (Zhang and Song 2003; Zhou et al. 2003).

The meteorological data comprised annual average temperature and precipitation values from 1982 to 2006 at 202 stations distributed throughout the Three-North Shelter Forest region; the data was provided by the National Meteorological Bureau of China. The research used the latitude and longitude of each station to extract the corresponding NDVI values, allowing us to generate a monthly NDVI sequence from 1982 to 2006 for each station. The correlation coefficients were calculated (as described in the next section) between NDVI and the temperature and precipitation at each station during the study period to determine the strength of the relationship between NDVI and these climatic factors. These correlations represented the sensitivity of the regional vegetation to these climatic factors (Broge and Leblanc 2001; Major et al. 1990; Lyon et al. 1998).

Methods

Mean and difference values

In the analysis of the temporal and spatial changes in the NDVI values for a region, the author calculated the mean NDVI value for each pixel in the region on each date, and then calculated the difference in NDVI values between two dates and used this value to define the nature of the changes during a period.

Correlation analysis

This research used the correlation analysis described by Li et al. (2007). It based on the following formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}\left[\left(x_i - \overline{X}\right)\left(y_i - \overline{Y}\right)\right]}{\sqrt{\sum_{i=1}^{n}\left(x_i - \overline{X}\right)^2 \sum_{i=1}^{n}\left(y_i - \overline{Y}\right)^2}} \tag{2}$$

where n is the number of samples, $\overline{X}$ is the mean of variable x, $\overline{Y}$ is the mean of variable y, i is a specific sample, and r_{xy} is the correlation coefficient between x and y.

It can monitor the trends for vegetation cover using r_{xy}: when $r_{xy} > 0$, the vegetation cover is increasing; when $r_{xy} < 0$, the vegetation cover is decreasing.

Linear regression analysis

Linear regression was used to simulate the NDVI trend for each pixel during the study period. Stow et al. (2003) used this method to calculate the vegetation's greenness rate of change (GRC). GRC is defined as the slope of the smallest power-function linear regression equation for the inter-annual changes in synthetic NDVI during a period. Least-squares method was used to simulate the temporal trends in average NDVI in the study area (Micael 2000):

$$\Theta_{\text{slope}} = \frac{n \times \sum_{i=1}^{n} i \times \text{NDVI}_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} \text{NDVI}_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \quad (3)$$

where, Θ_{slope} is the slope of this trend line, n is the length of the simulation time ($n = 25$ years in the present study), i is the year number, and NDVI_i is the average NDVI value of the first i years. The result reflects the trend for the annual average NDVI during the study period.

With $\Theta_{\text{slope}} > 0$, NDVI values increased during the study period; otherwise, NDVI values decreased ($\Theta_{\text{slope}} < 0$) or remained constant ($\Theta_{\text{slope}} = 0$).

Results

Monthly trends in vegetation cover during the study period

Figure 2 summarizes the seasonal changes in mean NDVI values throughout the study area for the whole study period. NDVI values increased from April to their maximum value in August. NDVI then declined steadily to reach its annual minimum from December to February. Thus, the overall pattern of vegetation distribution in the study area can be represented by changes in the summer value.

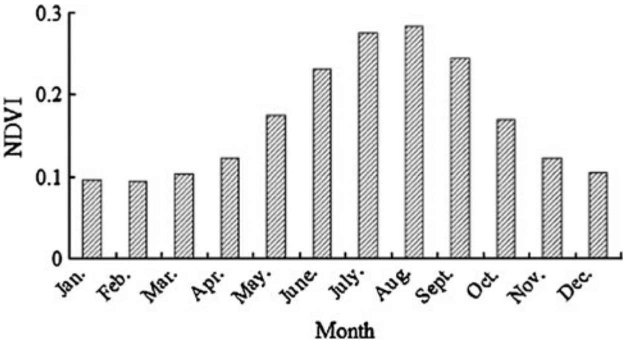


Fig. 2 Mean NDVI values for the study area as a whole in each month from 1982 to 2006

Spatial trends in vegetation cover during different periods

To describe vegetation cover changes during the phases of TNSFP, this research divided the project's periods from 1978 to 2010 into four periods (1982–1985, 1992–1995, 1997–2000, and 2003–2006), and then calculated the average NDVI value for the first four periods of the project. Y_k has been used to represent the vegetation cover in each of these periods. The paper then used the difference between the values in two consecutive periods to represent the overall trend. Figures 3, 4, and 5 present the results of this analysis. In these maps, Y_k was divided into five categories based on the magnitude of the change: decreased severely, decreased slightly, unchanged, increased slightly, and increased greatly (Table 1).

Figure 3 shows that during the second period, NDVI increased throughout most of the study area, and particularly in Lindian County of Heilongjiang Province, Qinggang County, northwestern and southeastern Jilin Province, the midwestern part of Liaoning Province, Dong Ujimqin Qi region of Inner Mongolia, Qingshuihe County, and the Hexi Corridor Oasis in Gansu Province. The increases in Xinjiang Province were mainly distributed in the Tianshan Mountains and in northern and southern oasis areas; the southern part includes the upper reaches of the Tarim River, which include Akto, Shache, Markit, and Awat counties. The northern regions include Yumin, Shawan, and Manas counties. Compared with the first period, the number of the pixels in which $Y_k \leq 0.1$ was 169 in the second period, accounting for 0.27% of the total area; that is, Y_k decreased seriously in only 0.27% of the area. The

Fig. 3 The change in mean NDVI between the second period (1992–1995) and the first period (1982–1985) in the Three-North Shelter Forest region

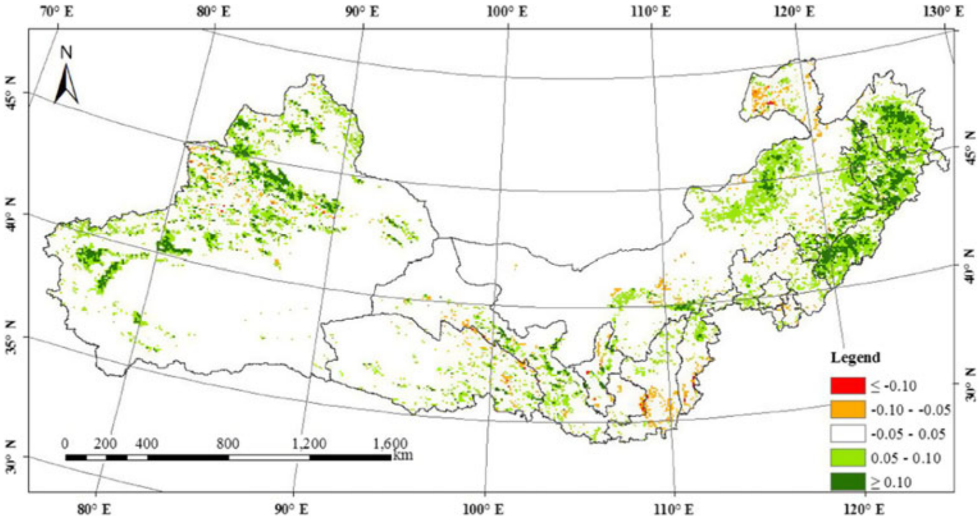


Fig. 4 The change in mean NDVI between the third period (1997–2000) and the first period (1982–1985) in the Three-North Shelter Forest region

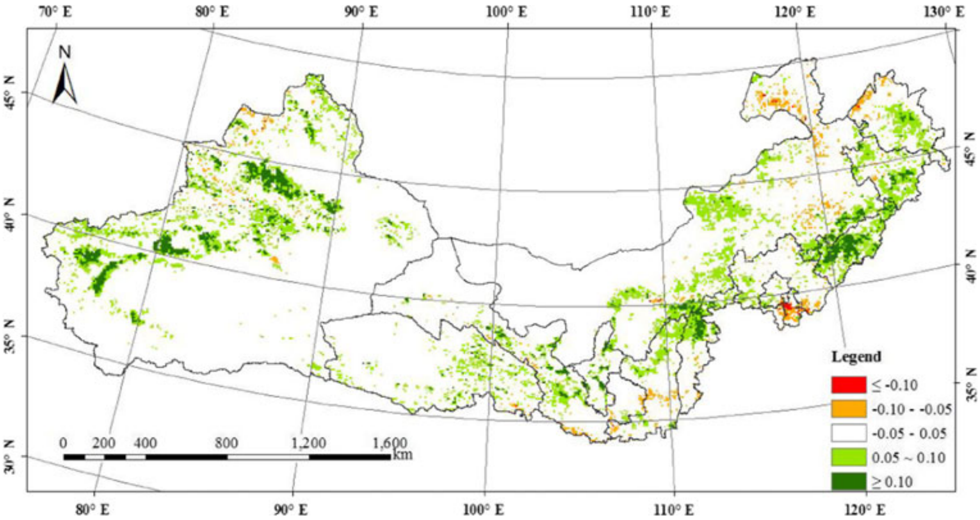
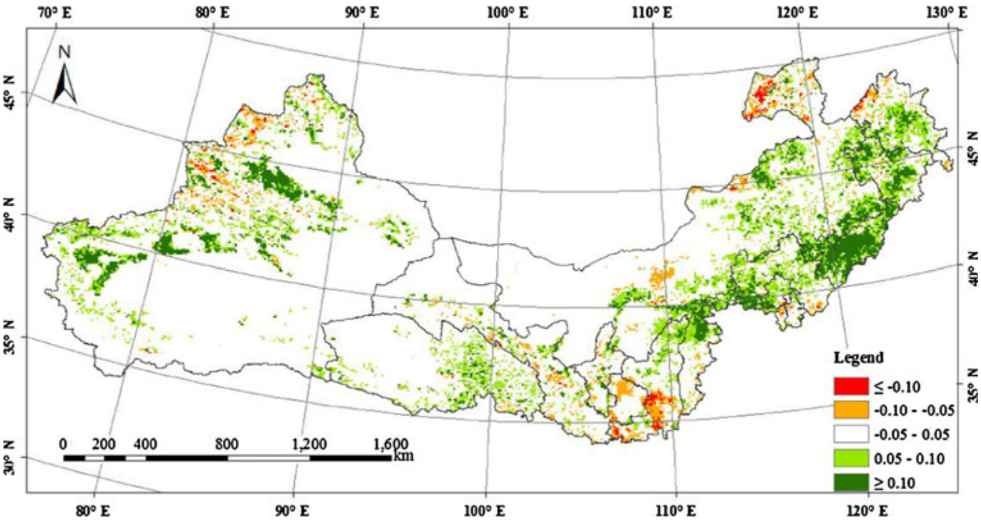


Fig. 5 The change in mean NDVI between the fourth period (2003–2006) and the first period (1982–1985) in the Three-North Shelter Forest region



area in which Y_k decreased slightly accounted for 1.96% of the total area, whereas NDVI in 82.38% of the area remained unchanged, and NDVI increased greatly in 11.42 and 3.96% of the area, respectively. The area in which NDVI did not change was mainly concentrated in the northwestern extremely arid desert and Gobi Desert areas, the Inner Mongolia Plateau, the Ordos Plateau, the eastern part of Gansu Province, and northern parts of Shaanxi Province. In these areas, NDVI was not greatly affected by TNSFP.

Compared with the two previous periods, NDVI increased more slowly during the third period, and there were regions where the vegetation cover decreased severely (Fig. 4). These were mainly distributed near Tianjin City, Xin Barag Youqi, and Xin Barag Zuoqi on the Hulunbeier Plateau. Liu et al. (2008) and other studies have shown that there was decreased volatility in NDVI from 1982 to 2003 in the Tianjin region. There was significant inter-annual variation, mainly because the annual average temperature has increased significantly during this period, whereas the annual average precipitation has decreased. This warming and drying trend was obvious in the Tianjin region because of the effects of a prolonged drought. Vegetation growth gradually declined. Y_k increased faster during this period than during the previous two periods in Xinjiang Province, but the vegetation cover also increased greatly in Shanxi Province. In some areas, Y_k increased from its previous values of 0.05–0.10 to values greater than 0.1. Compared with the previous phase, the increase in vegetation cover in northern Shaanxi Province also accelerated.

Figure 5 shows that between the fourth period and the first period, vegetation cover declined in Xin Barag Youqi, in the northwestern part of Xinjiang Province, in the northwestern part of the Guanzhong Plain, and in the western part of Shaanxi Province. Except for these areas,

Table 1 The changes in NDVI during three phases of TNSFP

Change in NDVI	Meaning	2nd period–1st period		3rd period–1st period		4th period–1st period	
		Number of pixels	% of total area	Number of pixels	% of total area	Number of pixels	% of total area
≤−0.10	Decreased severely	169	0.27	168	0.26	375	0.59
−0.10 to −0.05	Decreased slightly	1,247	1.96	1,334	2.10	2,303	3.63
−0.05 to 0.05	Unchanged	52,324	82.38	52,791	83.11	49,313	77.63
0.05 to 0.10	Increased slightly	7,257	11.42	7,120	11.21	7,445	11.72
≥0.10	Increased greatly	2,518	3.96	2,109	3.32	4,086	6.43

First period, 1982–1985; second period, 1992–1995; third period, 1997–2000; fourth period, 2003–2006; pixel size = 8 × 8 km

the vegetation cover increased greatly in most of the region. The increases were mainly in the southern Tianshan Mountains and in northern and southern oasis areas, in the three provinces (Heilongjiang Province, Jilin Province and Liaoning Province), in the northern part of Shanxi Province, and in the Taihang Mountains. Compared with the previous two periods, the vegetation cover increased greatly in areas surrounding Beijing. This is because Beijing won the right to host the 2008 Olympic Games, and starting in 2001, Beijing's managers implemented wide-scale revegetation. As a result of these efforts, Beijing's forest cover reached 51.6% by 2008. Compared with the first period, the vegetation cover decreased severely in parts of the study area (0.59% of the total), and slight decreases occurred in an additional 3.63% of the area. The area in which NDVI did not change was smaller than in the previous two phases, but still accounted for 77.63% of the area. NDVI increased in 11.72% of the area, and increased greatly in 6.43% of the area, both of which are bigger increases than during the previous two phases.

The results in Figs. 3, 4, 5 and Table 1 show that the vegetation cover in the Three-North Shelter Forest region generally improved from 1982 to 2006.

Vegetation changes from 1982 to 2006

To facilitate the analysis of trends in the spatial distribution of the NDVI changes from 1982 to 2006, the research performed linear regression analysis for the summer NDVI value of each pixel in a given year as a function of the year. Figure 6 presents the slope values that resulted from this regression analysis. It also calculated Pearson's correlation coefficient for the relationship between the summer NDVI values over time; Fig. 7 presents the values that were significant ($P < 0.05$).

In order to analyze the NDVI spatial distribution trend from 1982 to 2006, the paper made a linear regression analysis for the summer NDVI of each pixel during the past 25 years. The Pearson's correlation coefficients and the slope map were acquired by calculating the correlation coefficients that have passed the 0.05 significance level test ($P < 0.05$). The linear regression results (Fig. 6) show that the vegetation cover increased over large areas. The regions with increases were mainly distributed in the northeastern plains, the northeastern part of the study area, the central and eastern parts of Inner Mongolia, the northern part of Shanxi Province, the eastern part of

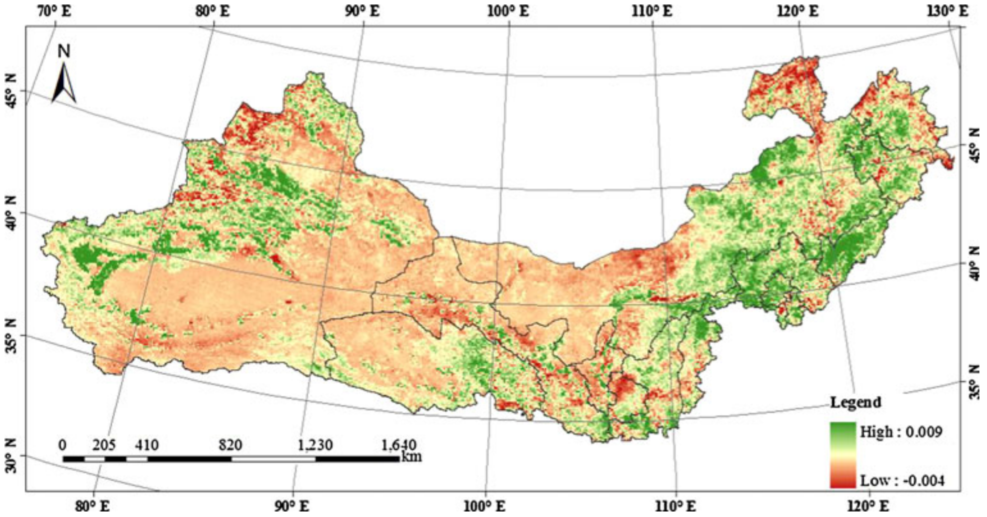


Fig. 6 Map of the distribution of slopes of the linear regression for the change in summer NDVI as a function of the year from 1982 to 2006 ($P < 0.05$)

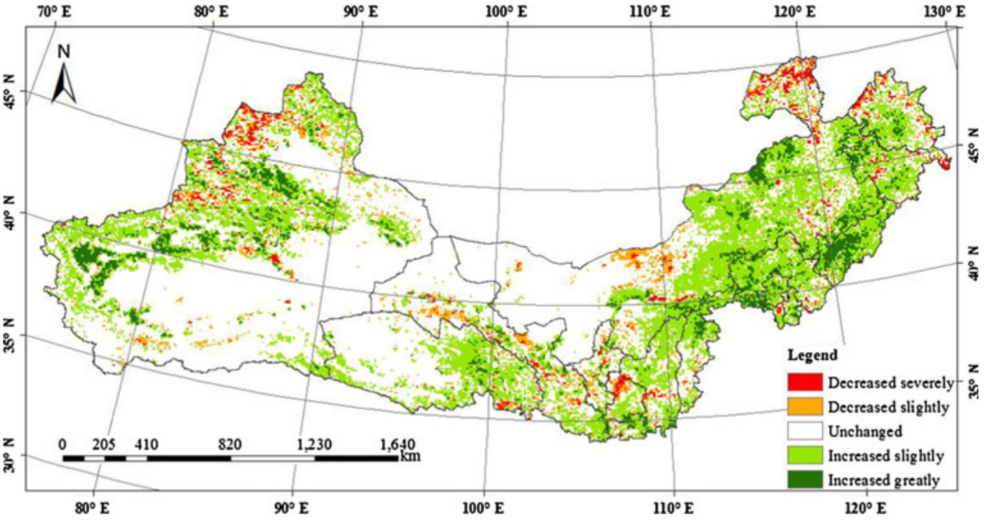


Fig. 7 Map of the distribution of statistically significant ($P < 0.05$) changes in summer NDVI from 1982 to 2006

Qinghai Province, and the western part of Xinjiang Province. Vegetation cover decreased mainly in the Hulunbeir Plateau (including the Xin Barag Youqi, Xin Barag Zuoqi, and Hailar City regions). The northwestern part of the Xinjiang Uygur Autonomous Region (including Toli and Yining counties) and the southern part of Weili County, between the Peacock River and the Tarim River, as well as Yumen City, Yongchang County, Huan County of Gansu Province, and the Guinan County of Qinghai Province, showed various degrees of vegetation decline. The pixels with the largest average annual growth rate had slopes of 0.009/year, whereas the pixels with the most negative average annual rate of change had slopes of −0.004/yr ($n = 25$, $P < 0.05$).

The distribution of NDVI changes from 1982 to 2006 (Fig. 7), which shows increased vegetation cover in most of the eastern, southern, and northwestern parts of the study area. The significant increases were concentrated in the eastern region and the Tianshan area, which are the areas where TNSFP concentrated. In total, 34.92% of the pixels showed increased vegetation cover, of which 5.77% showed large increases (Table 2). The areas where vegetation cover declined were mainly distributed in the northwestern part of Xinjiang Province and in the Hulunbeier Plateau (including the Xin Barag Youqi, Xin Barag Zuoqi, and Hailar City areas); the pixels in which vegetation cover declined accounted for 8.12% of the study area, of which 2.38% represented severe declines. In 56.96% of the pixels, the vegetation cover remained stable, with no significant change. The unchanged regions were mainly distributed in the northwestern part of the study area, in the extremely arid desert and Gobi Desert regions, as well as in other areas that are difficult for humans to use and develop.

Relationship between seasonal maximum NDVI and annual temperature

Figure 8 shows the distribution of the correlation coefficients for the relationship between NDVI and annual mean temperature at each meteorological station. The positive and negative correlation coefficients coexisted throughout the study area. Significant negative correlations were mainly found in the boundary area among Shaanxi, Gansu, and Ningxia provinces and in the northwestern part of Xinjiang Province. Because of the dry weather in these areas, the increase in temperature that has occurred during the study period aggravated the soil dryness, and vegetation productivity declined. Liang and Xie (2006) reported a significant negative correlation between temperature and vegetation net primary productivity in arid and semi-arid regions of China. Higher temperatures also decreased net primary productivity in a hilly area of the Loess Plateau (Shi et al. 2005).

The current global warming is the most significant form of climate change observed in the past 100 years. Kumar et al. (2009) noted that the global mean surface temperature

Table 2 Changes in vegetation cover from 1982 to 2006 in the Three-North Shelter Forest region (areas for which correlations were significant at $P < 0.05$)

	Unchanged	Decreased severely	Decreased slightly	Increased slightly	Increased greatly
Number of pixels (8 × 8 km)	35,972	1,503	3,626	18,408	3,647
% of total area	56.96	2.38	5.74	29.15	5.77

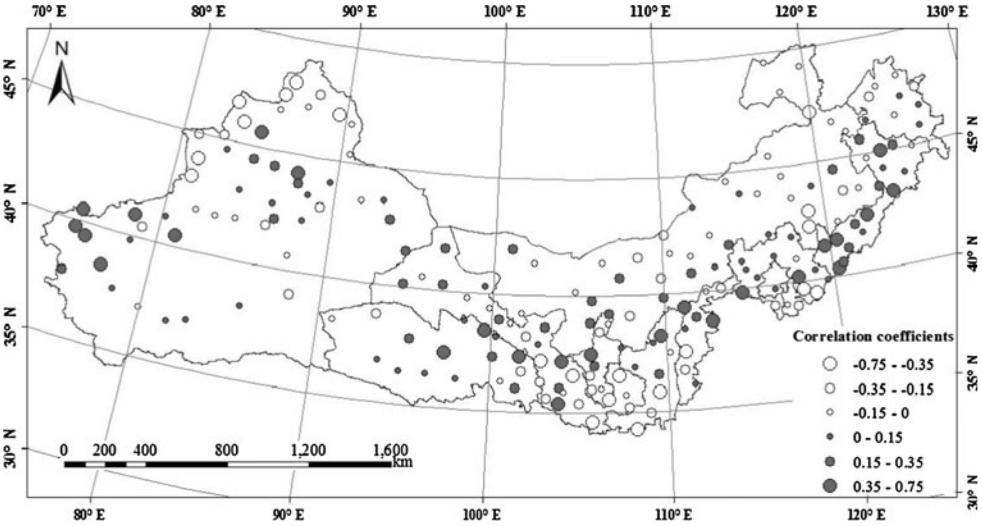


Fig. 8 Distribution of correlation coefficient between NDVI and the annual average temperature at the meteorological stations throughout the study area ($n = 25$). $r_{0.1} = 0.337$, $P = 0.1$; $r_{0.05} = 0.396$, $P = 0.05$

has increased by 0.6 over the last 100 years. This warming trend has had both positive and negative effects on vegetation growth in China. The rising temperature has prolonged the growing season, improved photosynthetic efficiency, and increased plant productivity. On the other hand, the warming has increased evapotranspiration and soil drying, thereby aggravating water stress. As a result, photosynthetic rates have decreased, particularly in arid and semi-arid regions, leading to a decline in productivity. The areas with positive correlations between NDVI and temperature accounted for 51.98% of the study area, of which significantly positive correlations accounted for 12.87% of the total ($P < 0.1$). NDVI was negatively correlated with temperature in 48.20% of the study area. The impact of temperature on NDVI differed among the regions. The regions with a significantly negative correlation between NDVI and annual average temperature were regions with a lack of water. Higher temperatures increased evapotranspiration and because there was insufficient water, this limited the growth of plants. In summer, high temperatures are conducive to plant growth when water is sufficient, whereas lower temperatures inhibited plant growth.

The result showed positive correlations between NDVI and temperature in the western part of Xinjiang Province and in the Qilian Mountains, where the correlation coefficients were greater than 0.4 ($P < 0.05$). The major cause of this relationship was that the water supply in these areas mainly comes from snowmelt water from high mountains. Therefore, temperature was the dominant factor that influenced the changes in NDVI. In addition, regions with significantly positive correlations are in the northeastern part of the study area (mainly in western Liaoning and Jilin provinces). The areas with no correlation between NDVI and temperature were mainly distributed in the extremely arid zones of northwestern China and in the Gobi Desert areas. Because the underlying surface of most of these areas is the Gobi Desert, the vegetation cover is very low (NDVI < 0.1), so the correlation between NDVI and temperature may not be relevant in these regions.

Relationships between seasonal maximum NDVI and annual precipitation

Figure 9 shows that there were considerably more positive correlations between NDVI and precipitation than that between NDVI and temperature. This is consistent with the conclusions of many previous studies, which found a significantly positive correlation between NDVI and precipitation but not between NDVI and temperature in the study area (Wang et al. 2003; Ji and Peters 2004; Chen et al. 2001; Li et al. 2005). Most of the study area has an arid or semi-arid climate. Precipitation therefore plays a decisive role in vegetation growth. When precipitation increases, it can improve the moisture supply enough to increase photosynthetic rates, thereby increasing productivity and survival. In the most arid regions, precipitation and the changes it causes in soil moisture dynamics are the major factor that affects vegetation growth and development.

Most of the meteorological stations in the study area (76.24%) showed a positive correlation between NDVI and precipitation, and 26.24% of these were significant ($P < 0.1$). The regions with positive correlations mainly included the western part of Xinjiang Province, the region along the Tarim River and the Peacock River in Xinjiang Province, Gansu Province, and the Ningxia and Inner Mongolia Autonomous regions. All these regions have arid or semi-arid climates.

In addition to the independent correlations for temperature and precipitation, 76 meteorological stations had a positive correlation between NDVI and both temperature and precipitation. At 36 of these sites, the relationship

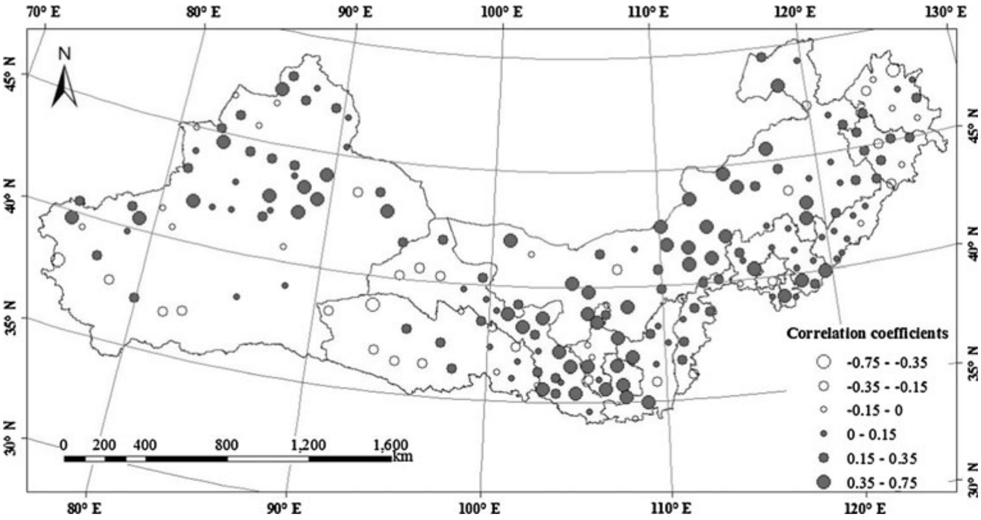


Fig. 9 Distribution of correlation coefficient between NDVI and the annual total precipitation at meteorological stations throughout the study area ($n = 25$). $r_{0.1} = 0.337$, $P = 0.1$; $r_{0.05} = 0.396$, $P = 0.05$

between NDVI and precipitation was stronger than that between NDVI and temperature, more than half of these regions have an arid or semi-arid climate. If the rate of temperature increase is greater than the rate of precipitation increase, then the resulting net increase in evapotranspiration would cause further drying of the soil and reduced vegetation growth. Therefore, soil moisture (under the joint influence of precipitation and heat balance) remains the most important cause of reduced vegetation growth in the study area.

Discussion and conclusions

The study used GIMMS NDVI data to analyze the temporal and spatial changes in NDVI from 1982 to 2006 in the parts of northern China affected by TNSFP, and analyzed the relationships between NDVI and two key climatic factors (temperature and precipitation), as well as the spatial distribution of these relationships. The results showed that:

1. The map of the average monthly NDVI for the study period as a whole showed that the NDVI value increased from April to reach a maximum in August (i.e., the summer growing season). However, in the western and northern plateau regions, the lower temperatures and higher altitude decreased the growing season to only 1 or 2 months.
2. The maps of differences between periods showed an overall increase in NDVI in each period. The area in which NDVI increased was larger than the area in which it decreased, and the areas where vegetation cover increased were those where TNSFP focused its efforts.
3. Linear regression analysis showed an increasing trend for vegetation cover over large areas. These were mainly distributed in the northeastern China Plain, the Northern China, central and eastern parts of Inner Mongolia, the northern part of Shanxi Province, the eastern part of Qinghai Province, and some regions of Xinjiang Province. The areas that showed a decrease in vegetation cover were mainly distributed in the Hulunbeier Plateau and northwestern Xinjiang Province. The largest average NDVI growth rate per pixel over the study period was 0.009/year, and the largest rate of decrease was −0.004/year ($n = 25$, $P < 0.05$).
4. The analysis of the correlations between climatic factors and NDVI showed that the relationship between NDVI and precipitation was stronger than the correlation between NDVI and temperature. Sites with positive and negative correlations overlapped for both climatic parameters. For temperature, 51.98% of the sites showed a positive correlation between NDVI and temperature, of which 12.87% were significant ($P < 0.1$). In contrast, 48.02% of the sites had a negative correlation between NDVI and temperature. For precipitation, 76.24% of the sites had a positive correlation between NDVI and precipitation, of which 26.24% were significant ($P < 0.1$). The analysis also showed that the net effect of climate change differed among the regions of the study area.

This research effectively revealed changes in the region's ecosystems. The results lay the foundation for future in-depth research and analysis of the mechanisms responsible for changes in surface vegetation. NDVI is a major index that integrates the effects of many factors that influence the state of ground vegetation. It includes both the impact of climatic factors and that of human activities. By analyzing the relationship between NDVI and climatic factors, it becomes possible to deduce the impact of human activities on vegetation. For example, where the relationship between NDVI and climatic factors is not obvious or significant despite significant changes in NDVI, this suggests that human activity is the main factor responsible for the NDVI changes.

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