Chin. Geogra. Sci. 2018 Vol. 28 No. 3 pp. 470–481
https://doi.org/10.1007/s11769-018-0952-8

Springer Science Press
www.springerlink.com/content/1002-0063

Impacts of Drought and Human Activity on Vegetation Growth in the Grain for Green Program Region, China

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Abstract: The Chinese government adopted six ecological restoration programs to improve its natural environments. Although these programs have proven successful in improving local environments, some studies have questioned their performance when regions suffer from drought. Whether we should consider the effects of drought on vegetation change in assessments of the benefits of ecological restoration programs is unclear. Therefore, taking the Grain for Green Program (GGP) region as a study area, we estimated vegetation growth in the region from 2000–2010 to clarify the trends in vegetation and their driving forces. Results showed that: 1) vegetation growth increased in the GGP region during 2000–2010, with 59.4% of the area showing an increase in the Normalized Difference Vegetation Index (NDVI). This confirmed the benefits of the ecological restoration program. 2) Drought can affect the vegetation change trend, but human activity plays a significant role in altering vegetation growth, and the slight downward trend in the NDVI was not consistent with the severity of the drought. Positive human activity led to increased NDVI in 89.13% of areas. Of these, 22.52% suffered drought, but positive human activity offset the damage in part. 3) Results of this research suggest that appropriate human activity can maximize the benefits of ecological restoration programs and minimize the effects of extreme weather. We therefore recommend incorporating eco-risk assessment and scientific management mechanisms in the design and management of ecosystem restoration programs.

Keywords: Grain for Green Program; Normalized Difference Vegetation Index (NDVI); climate fluctuation; human activity; China

Citation: WANG Hao, LIU Guohua, LI Zongshan, YE Xin, FU Bojie, LV Yihe, 2018. Impacts of Drought and Human Activity on Vegetation Growth in the Grain for Green Program Region, China. *Chinese Geographical Science*, 28(3): 470–481. https://doi.org/10.1007/s11769-018-0952-8

1 Introduction

Because of the rapid development of China's economy, environmental problems have become increasingly serious during the past three decades (Xu et al., 2006). To address such problems as desertification, soil erosion, and sand storms, among others, the Chinese government has initiated six ecological restoration programs, including the 'Three-North Shelterbelt Project', the 'Natural Forest Protect Project', and the 'Grain for Green Program' (Yin and Yin, 2010; Wu et al., 2012; Lü et al., 2015). Among these, the Grain for Green Program (GGP) has become one of the world's most ambitious ecosystem restoration programs (Chen et al., 2009), and as a result, the environment in the program's regions has changed significantly. Several studies have reported that because of afforestation and reforestation programs, the vegetation growth in China has increased since 1982 (Piao et al., 2003; Peng et al., 2011). However, vegetation growth is sensitive to climate factors (temperature

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Received date: 2017-05-02; accepted date: 2017-08-29

Foundation item: Under the auspices of the National Key R&D Program of China (No. 2017YFC0504701), Science and Technology Service Network Initiative Project of Chinese Academy of Sciences (No. KFJ-STS-ZDTP-036), Fundamental Research Funds for the Central Universities (No. GK201703053), China Postdoctoral Science Foundation (No. 2017M623114)

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and precipitation), and therefore, climate change influences the effectiveness of ecological restoration programs (Herrmann et al., 2005; Xu et al., 2011). Specifically, China is suffering a distinct climate change trend in which the arid and semiarid area in northern China is becoming warmer and wetter (Shi et al., 2007; Yao et al., 2013). Meanwhile, southern China has experienced severe droughts in recent decades (Chen and Sun, 2015; Lian et al., 2015; Wang et al., 2015), yet the effects of ecological restoration programs and climate change on vegetation growth remain to be explored.

Further, debate continues about the effectiveness of ecological restoration programs. On one hand, many studies have found that such programs reduce land deterioration, and increase vegetation coverage and soil carbon storage (Feng et al., 2013; Deng et al., 2014a; 2014b). Zhang et al. (2013) pointed out that, since the implementation of the GGP, the vegetation coverage on the Loess Plateau has increased remarkably. Further, because young, growing forests sequester carbon more rapidly than older forests do, the new forests planted in the GGP region should, theoretically, have a huge carbon sequestration potential (Mu et al., 2014). On the other hand, several studies have indicated that, when limited by climate changes such as drought, ecological programs have not worked well in some regions (Wang and Cao, 2011; Wu et al., 2014). Wang et al. (2010) reported that, in the Three-North program region, the survival of the trees and shrubs planted has been low because of drought. Cao (2008) asserted further that afforestation in semiarid and arid areas could lead to a high risk of ecosystem deterioration and wind erosion. The main reasons for these conflicting results are the roles of climate and human activity on vegetation change. Whether drought or human activity decreases vegetation growth in the regions, whether drought can affect the outcomes of the programs significantly or not, and whether we should consider drought when assessing the benefits of ecological restoration programs are questions that have no clear answers.

It is crucial to use optimal remote data to estimate the effects of drought and human activity on vegetation growth. The Normalized Difference Vegetation Index (NDVI) is calculated as the difference between the red and near infrared bands. It is sensitive to vegetation changes, and many previous studies have demonstrated the accuracy of these data (Fang et al., 2004; Xin et al., 2008; Wang et al., 2011). Based on NDVI data, Wang et al. (2015) assessed vegetation growth in hilly southern China, while Slayback et al. (2003) and Li et al. (2011) expanded the study area to the national and global scales. Therefore, NDVI data have proven reliable in estimating vegetation growth. Accordingly, this study adopted NDVI remote data as an indicator of vegetation changes.

In summary, based on the annual average NDVI remote data and annual precipitation data, this study chose the GGP region as the study area, and estimated the spatio-temporal patterns of the vegetation and the Precipitation Anomaly Index (PAI) from 2000–2010. Based on the results of a residual analysis, we assessed the separate effects of drought and human activity on the NDVI. The purpose of the study overall was to investigate the role of drought and human activity in changing vegetation growth. More specifically, by analyzing the change trends of PAI and NDVI, and combining the assessment of the correlation between drought, human activity and vegetation growth, we aimed to find out: 1) if drought decrease the vegetation growth in the GGP region; 2) if drought offset the benefits of the GGP; and 3) if drought should be considered while assessing the effectiveness of ecological restoration programs. This study could provide scientific basis for future research in planning and implementing ecological restoration programs.

2 Materials and Methods

2.1 Study area

The Chinese government initiated the GGP in 1999, with the objective of halting erosion, protecting biodiversity, and improving ecological environments by encouraging farmers to convert abandoned farmland and degenerated grassland to trees and grass (Ostwald et al., 2007). The Chinese government has invested over 430 billion yuan (RMB) in this program, which has been implemented in 1897 counties in 25 provinces, municipalities, and autonomous regions located in China, the combined areas of which include nearly 74% of China's land area (Fig. 1) (Uchida et al., 2005; Liu et al., 2008). Due to the large scale of the program area, the natural environment, hydrothermal conditions and topography of the GGP region are quite diverse. Based on local natural conditions, the GGP region can be divided into 10 types of areas, including the Southwest mountain

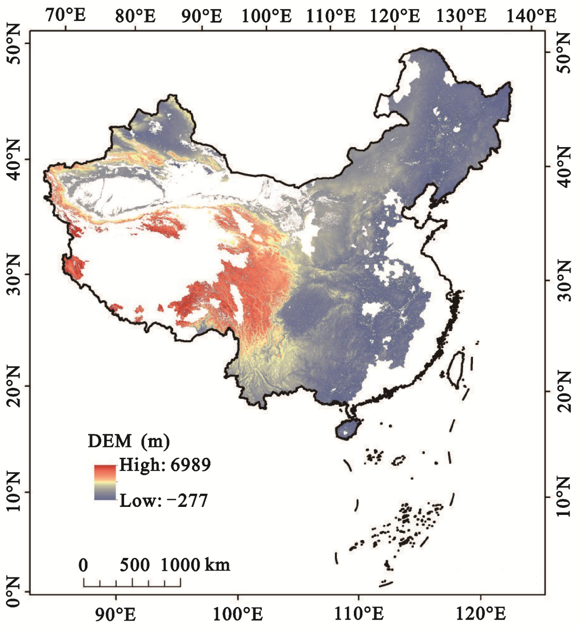

Fig. 1 Topographical view of the Grain for Green Program region in China, based on DEM map with 90-m resolution. Data are from http://datamirror.csdb.cn/

valley area, the Middle and lower reaches of the Yangtze River, Yunnan-Guizhou plateau area, Loess hilly and gully area and so on (Wang and Chen, 2006). By the end of 2012, 9.06 and 0.64 million ha of cropland had been converted to forest and grassland, respectively (Song et al., 2014). The GGP's eventual goal is to convert all of the steep slope lands into forest and bring the most severe farmland desertification under control, thereby increasing China's grassland and forest coverage by 4.5% and improving China's natural environments significantly (Deng and Shangguan, 2011).

2.2 Data set

The climatic data (2000 to 2010) used in this study were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). We estimated the spatio-temporal patterns of annual precipitation in the study area using data from 676 stations. The Kriging interpolation method was used to produce the spatial maps, the resolution of which was resampled to 1 km to fit the NDVI data.

This study used the annual average NDVI data (2000 to 2010) from the International Scientific and Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn), which have a resolution of 1km. To minimize the disturbance in the NDVI trends attributable to bare soil and sparsely vegetated areas, we excluded all grid cells in the average annual NDVI with a value less than 0.05 (Slayback et al., 2003; Wang et al., 2011).

2.3 Precipitation Anomaly Index (PAI)

To evaluate the drought events, the study adopted the Precipitation Anomaly Index (PAI), which is calculated as follows:

$$PAI = \frac{P_i - \overline{P_i}}{\overline{P_i}} \tag{1}$$

where P_i denotes the precipitation at time i, and $\overline{P_i}$ denotes average precipitation, which was calculated using the data from 2000 to 2010. The PAI can reflect the difference between the precipitation at time i and the average precipitation throughout the period (Wang et al., 2014). It is a spatio-temporal index that evaluates drought caused by anomalous precipitation (Wang et al., 2013). The PAI typically is used to assess drought events in China on month, season, or year scales (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China, 2006). Table 1 shows the classification of drought based on the PAI (China Meteorological Administration, 2006).

2.4 Methods

To estimate the correlation between the NDVI and PAI, we used the formula for the correlation coefficient.

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

where r refers to the Pearson correlation coefficient, i is the year, n is the number of years, and x_i and y_i indicate the NDVI and PAI data at time i, respectively (Piao et

Table 1 Classification of drought intensity

Intensity	PAI value
Drought-free	–0.15<PAI
Slight drought	–0.30< PAI≤–0.15
Moderate drought	–0.40< PAI≤–0.30
Severe drought	–0.45< PAI≤–0.40
Extreme drought	PAI≤–0.45

Note: PAI is the Precipitation Anomaly Index al., 2006; Zhao and Running, 2010; Fensholt and Proud, 2012).

NDVI residuals, the difference between the NDVI observed and predicted, were then computed for each year andpixel to distinguish the effects of drought and human activity on NDVI (Evans and Geerken, 2004; Wessels et al., 2007). We adopted three types of NDVI in the residual analysis. First was the predicted NDVI ($NDVI_P$), in which we estimated the linear regression between the annual average PAI and annual average NDVI for each pixel (Wu et al., 2014). The results of the linear regression indicated the vegetation growth without human disturbance. The second was the observed NDVI ($NDVI_O$), which derives from the annual average NDVI remote data. Changes in the $NDVI_O$ indicate the effects on vegetation of both drought and human activity. The third was the NDVI residuals ($NDVI_R$), which were the difference between the NDVI predicted and observed:

$$NDVI_R = NDVI_O - NDVI_P \tag{3}$$

The residuals signify changes in the NDVI response attributable to causes other than drought. Positive residuals indicate an area that is experiencing human-induced improvement, while negative residuals indicate human-induced degradation (Gang et al., 2014; Yang et al., 2016). The study calculated the linear trend in the residuals to estimate the changing trend in vegetation growth affected by human activity (Cao et al., 2006; Yi et al., 2014).

3 Results

3.1 Temporal trends of PAI and NDVI

NDVI and PAI were used to estimate the changing trends in vegetation and drought in the GGP region. Fig. 2 shows the annual average NDVI and PAI from 2000 to 2010. In the GGP region, NDVI showed an increasing trend in the last decade, with a change rate of 0.0009/yr. This change process can be divided into two parts: the NDVI increased until 2002; from 2003 to 2010, the trend fluctuated over years, with a peak in 2008 and a trough in 2009. The lower values in 2006 and 2009 may be the reason that the NDVI change trend was not significant.

As with the annual average NDVI trend, the annual average PAI in the GGP region has shown an increasing trend over the past 11 years, with a change rate of 0.0146/yr. Essentially, the change process in the PAI was consistent in part with that in the NDVI. Both the NDVI and the PAI values were low in 2001, 2006, and 2009. From an annual perspective, there were three dry years (2001, 2006, and 2009) in the GGP region based on the PAI value (PAI< –0.1). In 2005, there was an obvious conflict between the PAI and the NDVI values: the NDVI value was relatively lower, while the climate was not experiencing drought. In general, there were some associations between the NDVI and the PAI.

3.2 Spatial patterns of PAI and NDVI

The spatial distribution of the NDVI in the GGP region was showed in Fig. 3a, regions with a positive value indicate an increasing trend, while those with a negative value indicate a decreasing trend. The results showed that 59.4% of the region showed an increasing trend in the NDVI, and 10.22% of the region showed a significant increasing trend at 0.95 confidential intervals. The areas in which the NDVI increased were located primarily in the Loess Plateau, specifically in the Lüliang Mountains area, Northern Shaanxi Province, and southern Gansu Province. Meanwhile, the decreasing trend in the NDVI was located largely in the Tianshan Mountains, Hunshadake Sandy Land area, and the middle of the Sichuan Basin. Only 3.65% of the study area showed a significant decreasing trend in NDVI at 0.95 confidential intervals (Table 2).

The spatial distribution of the PAI and NDVI showed an obvious association (Fig. 3b). As with the NDVI, the areas in which the PAI increased (drought reduced) also were concentrated in the Lüliang Mountains area, southern Gansu, and the Qaidam Basin area. Similarly, in areas in which the the PAI decreased (drought aggravated), such as the Tianshan Mountains and the middle

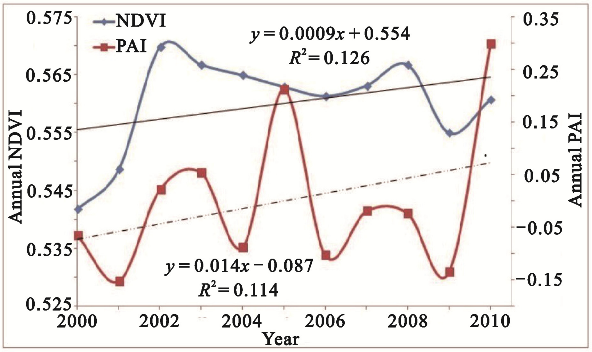

Fig. 2 Interannual variations in the annual average NDVI and PAI in the Grain for Green Program region from 2000 to 2010

of the Sichuan Basin, the NDVI decreased as well. Further, to validate the correlation between the NDVI and drought, the correlation coefficient between the NDVI and PAI was calculated for each pixel (Fig. 4). The results showed that 70.64% of the study area showed a positive correlation between the NDVI and PAI. The same region shows 10.76% having an extremely significant positive correlation at 0.95 confidential intervals and 17.35% having a significant positive correlation at 0.9 confidential intervals (Table 3).

3.3 Drought influence on vegetation growth

To analyze the effects of drought on the vegetation growth, we chose three drought years (2001, 2006, and 2009), and a special year (2005) to evaluate drought's influence on the NDVI. Fig. 5 shows the spatial patterns of the PAI and the annual percentage of NDVI anomalies. The results indicated that the spatial patterns of the vegetation growth were essentially consistent with the drought. In the drought areas, the NDVI generally showed a negative variation, such as in the Hunshadake Sandy Land in 2001, the Mu Us Sandy land in 2005, the Sichuan Basin area in 2006, and the Hunshadake Sandy Land in 2009. However, the decreased level of the NDVI was not consistent with the intensity of the drought. For example, in 2001 and 2009, there was an extreme drought in the Dabie Mountain area and the Tarim Basin area, during which the NDVI fell by less than 20%, and this slight decrease may be attributable to the ecological restoration activity, which offset the negative influence of the drought. In 2005, the drought was non-significant on both the temporal and spatial levels, and, therefore, the relatively low value of the NDVI may have resulted from human activity.

3.4 Influence of human activity on vegetation growth

We used residual analysis to investigate the effect of human activity on vegetation growth (Fig. 6). The results showed that 54.47% of the region experienced human-induced improvement, and 8.08% of the region showed a significant improvement at the 0.95 confidence intervals. The improvement methods include enclosure of grassland, afforestation, and grain for green. These areas were located primarily in the Loess Plateau, which indicated that the GGP produced notable results in this region. However, 45.53% of the region experienced human-induced degradation, and 4.43% of the region showed a significant trend in degradation at the 0.95 confidence intervals (Table 4). These areas were scattered in the Hunshadake Sandy Land, southern Greater Khingan, and the middle of the Sichuan Basin. The negative effects of human activity likely include deforestation and urban expansion. Compared with Fig. 3a, the spatial pattern of the NDVI change trend was consistent with the spatial pattern of the residual analysis,

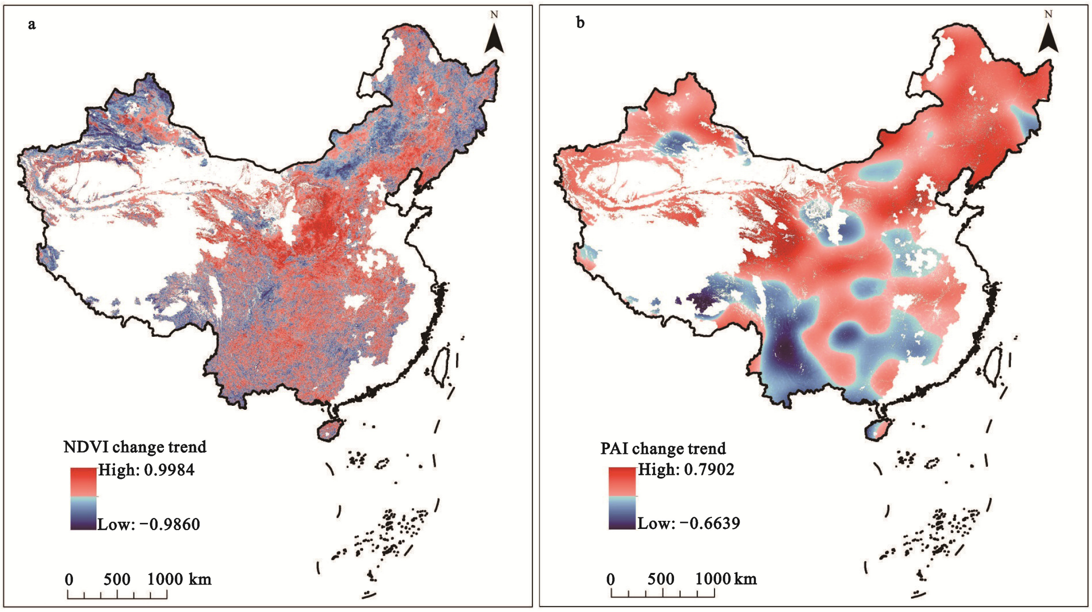

Fig. 3 Spatial changing trends of Normalized Difference Vegetation Index (NDVI) (a) and Precipitation Anomaly Index (PAI) in the Grain for Green Program region from 2000 to 2010

Table 2 Spatial changes of PAI and NDVI in the Grain for Green Program region from 2000 to 2010 (%)

Variable	Increasing	Decreasing	Increasing significantly	Decreasing significantly
PAI	74.05	25.95	4.59	0.48
NDVI	59.4	40.6	10.22	3.65

Notes: Increasing/decreasing significantly indicates areas (percentages) that changed significantly at the 0.95 confidence intervals

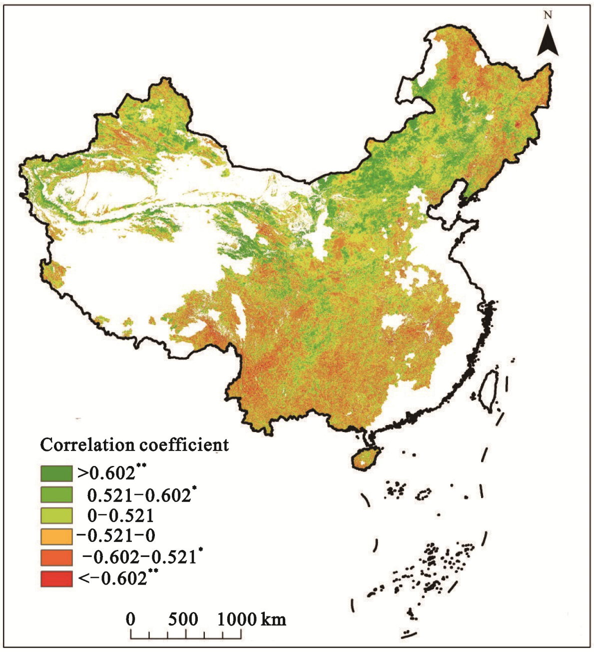

Fig. 4 Spatial patterns of the correlation between the NDVI and PAI in the Grain for Green Program region from 2000 to 2010. **: $P < 0.05$; *: $P < 0.1$

Table 3 Correlation analysis between PAI and NDVI

Correlations	Area percentage (%)
Positive correlation	70.64
Negative correlation	29.36
Extremely significant positive correlation**	10.76
Significant positive correlation*	17.35
Extremely significant negative correlation**	1.15
Significant negative correlation*	2.32

Notes: Positive/negative correlations are the areas (percentages) with positive/negative linear trends between PAI and NDVI. **: $P < 0.05$; *: $P < 0.1$

indicating that human activity plays an important role in vegetation growth. As the results in Figs. 3 and 6, human activity can change vegetation growth more efficiently. For example, in the east of the Loess Plateau, despite a serious drought, the NDVI increased significantly because of human-induced improvement.

3.5 Driving factors in NDVI change

To investigate the driving factors in the NDVI change in the GGP region, we distinguished between the increased and decreased parts of the NDVI, and compared them to different combinations of drought and human activity (Fig. 7). In Fig. 7a, the favorable climate and human-induced improvement affected 66.61% of the area with increased NDVI. Although 22.52% of the region suffered from drought, the NDVI still increased because of human-induced improvement. Only 10.87% of the area in which NDVI increased was affected by the favorable climate, and human-induced degradation was found in this area (Fig. 8). Meanwhile, in the area in which NDVI decreased (Fig. 7b), where the climate was favorable, 69.09% of the area was affected by human-induced degradation. Further, both drought and human-induced degradation affected 28.97% of this region. The drought offset the benefit of human-induced improvements only in 1.94% of the area in which NDVI decreased (Fig. 8).

4 Discussion

4.1 Trend of vegetation growth in the GGP region and method evaluation

Distinguishing the relative roles climate and human activity play in vegetation growth has practical significance in planning and implementing ecological restoration programs. However, there are still some limitations in previous research (Ma et al., 2007; Zhou et al., 2015). Most studies have focused on descriptive analyses, such as correlations and principal component analysis, which can not describe the spatio-temporal distribution of vegetation growth and its driving factors (Wrbka et al., 2004; Millington et al., 2007). Evans and Geerken (2004) used a residual analysis instead to study the correlation between precipitation and NDVI in arid areas, and proposed a new method to distinguish the effects of climate and human factors on vegetation growth. Several recent studies confirmed the effectiveness of this method further (Herrmann et al., 2005; Wu et al., 2014). Cao et al. (2006) used residual analysis to evaluate the effect of human activities on the degree of degradation in the Xilinguole grassland, and Sun et al. (2010) used the same method to study the driving forces of vegetation growth in the Inner Mongolia region. Therefore, we used the same methodology to investigate the changing

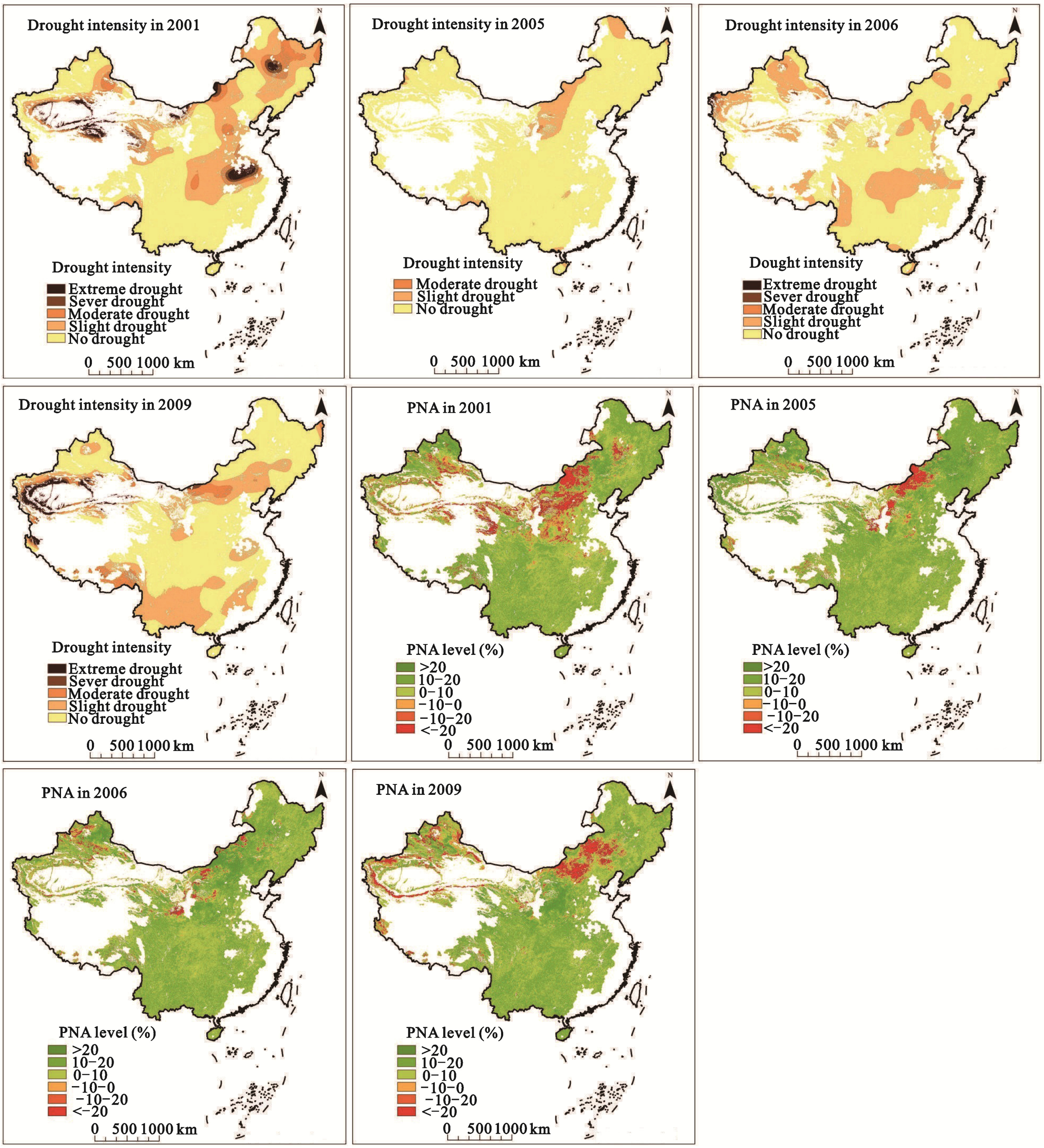

Fig. 5 Spatial patterns of the annual drought and the annual PNA (percentage of NDVI anomalies) in the Grain for Green Program region. Annual drought was calculated from the Precipitation Anomaly Index

trends and driving forces of vegetation growth in this study.

The results indicated that the benefits of the ecological restoration program in the GGP region are clear, as vegetation growth generally has shown an increasing trend from 2000 to 2010. In this region, 59.4% of the area showed an increasing trend in the NDVI and 10.22% showed a significant increasing trend at the 0.95 confidence intervals (Fig. 3a). Other related studies have confirmed the importance and effectiveness of restoration programs. Chang et al. (2011) reported that such programs increased the quality of vegetation and increased soil carbon storage in the Loess Plateau. Cai et al. (2014) also found that the vegetation in southern

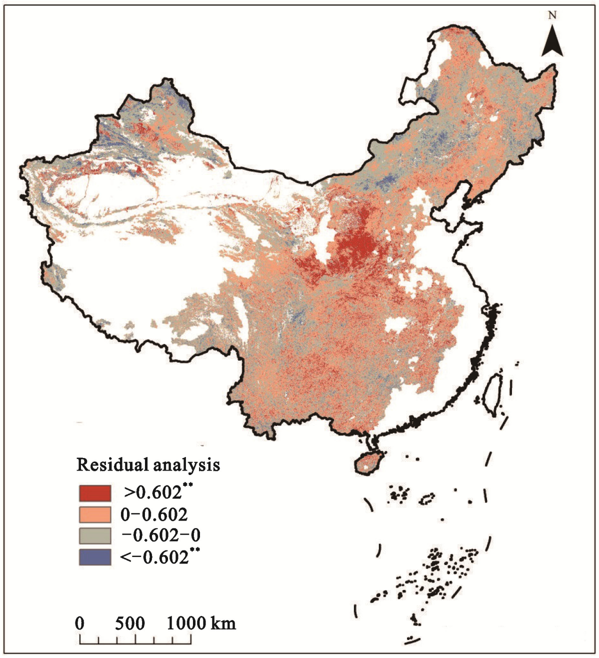

Fig. 6 Spatial pattern of residual analysis in the Grain for Green Program region. **: $P < 0.05$

Table 4 Spatial statistics of the residual analysis

Scene	Area percentage (%)
Human-induced improvement	54.47
Human-induced degradation	45.53
Significant human-induced improvement**	8.08
Significant human-induced degradation**	4.43

Note: **: $P < 0.05$

China had recovered under the influence of the GGP. In fact, human-induced improvements, such as afforestation and agricultural management, may be the main reasons for the progress of greening in China's vegetation over the last three decades (Piao et al., 2015), which confirms that, at least in the GGP region, the vegetation quality generally has improved and recovered because of the program.

Although the residual analysis may be a relatively accurate method to estimate the driving factors of vegetation growth, it still has some limitations. For example, vegetation succession, such as from scrub to grassland, which may have experienced restoration, showed an insignificant change in NDVI. However, because of the limited spatial resolution of the remote data and the validation method, it is difficult to distinguish the forces that drive these kinds of changes (Verdoodt and Van Ranst, 2006). Thus, the methodology adopted in this study may lead to errors at the local scale, but it still is a novel method to estimate the spatial distribution of the change trends and driving forces of vegetation growth at regional and global scales (Gang et al., 2014).

4.2 Driving factors of vegetation growth in the GGP region

There was an obvious association between vegetation growth and drought: 70.64% and 10.76% of the study area showed a positive or a significant positive correla-

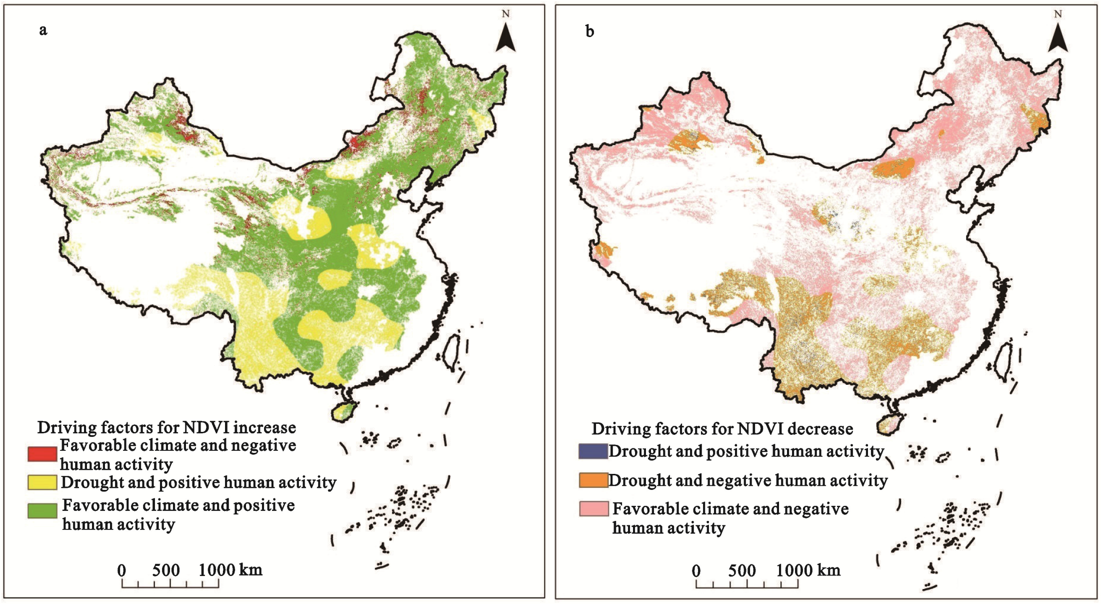

Fig. 7 Spatial patterns of the NDVI change factors in the NDVI increased area (a) and decreased area (b) in the Grain for Green Program region

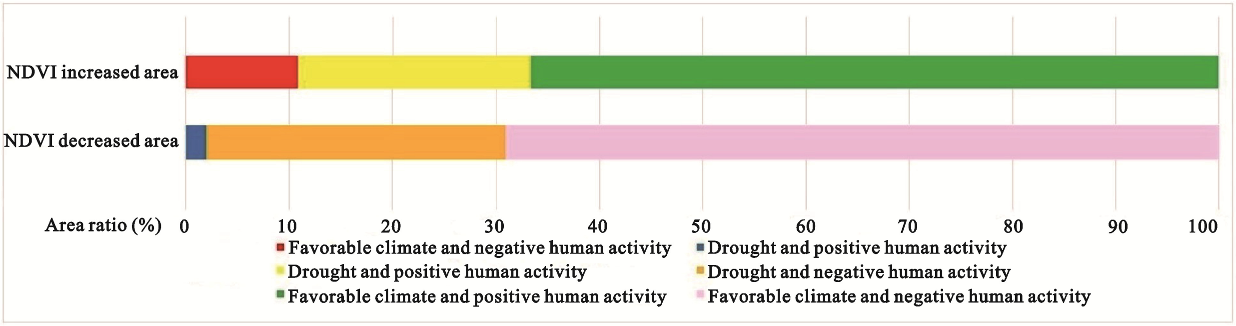

Fig. 8 Spatial statistics of the NDVI change factors in NDVI increased/decreased areas

tion between the NDVI and the PAI (Fig. 4). Drought influences not only photosynthesis and vegetative respiration, but also increases evapotranspiration and reduces soil moisture (Miyashita et al., 2005; Brohan et al., 2006). Several modeling studies have projected that drought events will increase in China in the future (Xu et al., 2012; 2013; Leng et al., 2015), thereby increasing the risk of pest infestations and disease, both of which contribute to ecological uncertainty, including in restoration program regions (Song et al., 2009). Because the potential effects of drought on vegetation growth can not be ignored, we recommend that eco-risk assessment and scientific management mechanisms should be incorporated in the design and management of ecosystem restoration programs.

However, compared with climatic factors, human activity affects vegetation growth more directly and efficiently (Zhang et al., 2015). Our results showed that the decrease in the NDVI did not match well with the intensity of the drought. Nor can we explain the changing trends of the NDVI with droughts alone. Human activity may be another cause (Fig. 5). 89.13% of the areas in which the NDVI increased were affected by positive human activity. Of these areas, 22.52% suffered drought, but the positive human activities offset the damage in part (Fig. 7a). Indeed, ecological restoration programs bring several benefits to local environments, such as an increase in vegetation coverage (Lü et al., 2012), decrease in soil erosion (Deng et al., 2012), and increase in soil organic carbon (Song et al., 2014). It has been reported that the increase in the enhanced vegetation index (EVI) and leaf area index of forests in the ecological restoration region was driven not by climatic factors, but by the GGP (Xiao, 2014). Research on the change in soil erosion from the end of the 1980s to 2010 found that, because of the success of the GGP and other environmental protection measures, soil erosion in China increased before 2000, but decreased thereafter (Wang et al., 2016). Moreover, carbon fixation will benefit in particular because, with the implementation of the GGP, increasing forested areas will increase soil carbon fixation (Deng et al., 2014b). Thus, overall, human activity plays a dominant role in fluctuating vegetation growth.

However, we also should be aware of the destructive influence of human activity on vegetation. Our research confirmed that 69.09% of the area in which the NDVI decreased was affected by human-induced degradation, and 28.97% of this region was affected by both drought and human-induced degradation (Fig. 7b). The continuous growth in population, landscape fragmentation caused by urban expansion, and excessive deforestation and overgrazing have all contributed to pressures on the natural environment (Pimentel and Pimentel, 2006; Dewan and Yamaguchi, 2009; Luck et al., 2009). Therefore, implementing ecological programs is more than necessary, and requires long-term persistence to achieve more and sustained ecological benefits in the future. Because human activity is the predominant factor in vegetation change, to maximize restoration results in the face of extreme climatic conditions, we must be cautious about the measures we choose for ecological restoration (Wang et al., 2007; Normile, 2007). Cao et al. (2011) stated that, in the arid and semi-arid areas of North China, regardless of the arid and rainless natural environment, poor selection of tree species for the GGP led not only to a low vegetation survival rate, but also to deterioration in the soil ecosystem because of trees' large demand for water. Consequently, when considering local precipitation and water use efficiency, it is essential to select suitable plant species when implementing future ecological restoration projects in arid areas

(Cao et al., 2009; Wang et al., 2015).

5 Conclusions

In this study, we found that the GGP region in China experienced a significant environmental change from 2000 to 2010 because of climate variation and human activity. The NDVI in this area improved clearly, which likely is attributable to the ecological restoration programs, and human activity played a dominant role in changing vegetation growth. However, against the background of global climate change, extreme weather and climate events such as drought continue to increase, these kinds of changes will certainly affect, and might even offset, the benefits of ecological restoration. Positive human activity can contribute to a continual growth in NDVI despite droughts, and the findings of this research suggest that appropriate human activity can maximize the benefits of ecological restoration programs and minimize the negative effects of extreme weather. The selection of appropriate plants for ecological programs in the GGP region also is a helpful method to deal with climate variation. Future studies should consider extreme weather events as one of the factors that can affect the efficacy of ecological projects, and we recommend incorporating eco-risk assessment and scientific management mechanisms in the design and management of ecosystem restoration programs.

References

Brohan P, Kennedy J J, Harris I et al., 2006. Uncertainty estimates in regional and global observed temperature changes: a new data set from 1850. *Journal of Geophysical Research: Atmospheres*, 111(D12): D12106. doi: 10.1029/2005JD006548

Cai H Y, Yang X H, Wang K J et al., 2014. Is forest restoration in the southwest china karst promoted mainly by climate change or human-induced factors? *Remote Sensing*, 6(10): 9895–9910. doi: 10.3390/rs6109895

Cao S X, 2008. Why large-scale afforestation efforts in China have failed to solve the desertification problem. *Environmental Science & Technology*, 42(6): 1826–1831. doi: 10. 1021/es0870597

Cao S X, Chen L, Shankman D et al., 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. *Earth-Science Reviews*, 104(4): 240–245. doi: 10.1016/j.earscirev.2010.11.002

Cao S X, Chen L, Yu X X, 2009. Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: a case study in northern Shaanxi Province. *Journal of Applied Ecology*, 46 (3): 536–543. doi: 10.1111/j.1365-2664.2008.01605.x

Cao Xin, Gu Zhihui, Chen Jin et al., 2006. Analysis of human-induced steppe degradation based on remote sensing in Xilin Gole, Inner Mongolia, China. *Journal of Plant Ecology*, 30(2): 268–277. (in Chinese)

Chang R Y, Fu B J, Liu G H et al., 2011. Soil carbon sequestration potential for 'Grain for Green' project in Loess Plateau, China. *Environmental Management*, 48(6): 1158–1172. doi: 10.1007/s00267-011-9682-8

Chen H P, Sun J Q, 2015. Changes in climate extreme events in China associated with warming. *International Journal of Climatology*, 35(10): 2735–2751. doi: 10.1002/joc.4168

Chen X D, Lupi F, He G M et al., 2009. Factors affecting land reconversion plans following a payment for ecosystem service program. *Biological Conservation*, 142(8): 1740–1747. doi: 10.1016/j.biocon.2009.03.012

China Meteorological Administration, 2006. *GB/T 20481-2006 Classification of meteorological drought category*. Beijing: Standards Press of China, 39. (in Chinese)

Deng L, Liu G B, Shangguan Z P, 2014a. Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: a synthesis. *Global Change Biology*, 20(11): 3544–3556. doi: 10.1111/gcb.12508

Deng L, Shangguan Z P, 2011. Food security and farmers' income: impacts of the grain for green programme on rural households in China. *Journal of Food, Agriculture & Environment*, 9(3–4): 826–831.

Deng L, Shangguan Z P, Sweeney S, 2014b. 'Grain for Green' driven land use change and carbon sequestration on the Loess Plateau, China. *Scientific Reports*, 4: 7039. doi: 10.1038/srep07039

Deng L, Shangguan Z P, Li R, 2012. Effects of the grain-for-green program on soil erosion in China. *International Journal of Sediment Research*, 27(1): 120–127. doi: 10.1016/S1001-6279(12)60021-3

Dewan A M, Yamaguchi Y, 2009. Land use and land cover change in Greater Dhaka, Bangladesh: using remote sensing to promote sustainable urbanization. *Applied Geography*, 29 (3): 390–401. doi: 10.1016/j.apgeog.2008.12.005

Evans J, Geerken R, 2004. Discrimination between climate and human-induced dryland degradation. *Journal of Arid Environments*, 57(4): 535–554. doi: 10.1016/S0140-1963(03)00121-6

Fang J Y, Piao S L, He J S et al., 2004. Increasing terrestrial vegetation activity in China, 1982–1999. *Science in China Series C: Life Sciences*, 47 (3): 229–240. doi: 10.1007/BF03182768

Feng X M, Fu B J, Lu N et al., 2013. How ecological restoration alters ecosystem services: an analysis of carbon sequestration in China's Loess Plateau. *Scientific Reports*, 3: 2846. doi: 10.1038/srep02846

Fensholt R, Proud S R, 2012. Evaluation of Earth Observation based global long term vegetation trends: comparing GIMMS and MODIS global NDVI time series. *Remote Sensing of Environment*, 119: 131–147. doi: 10.1016/j.rse.2011.12. 015

Gang C C, Zhou W, Chen Y Z et al., 2014. Quantitative assessment of the contributions of climate change and human activities on global grassland degradation. *Environmental Earth Sciences*, 72(11): 4273–4282. doi: 10.1007/s12665-014-3322-6

Herrmann S M, Anyamba A, Tucker C J, 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, 15(4): 394–404. doi: 10.1016/j.gloenvcha.2005.08.004

Leng G Y, Tang Q H, Rayburg S, 2015. Climate change impacts on meteorological, agricultural and hydrological droughts in China. *Global and Planetary Change*, 126: 23–34. doi: 10.1016/j.gloplacha.2015.01.003

Li Z S, Liu G H, Fu B J etal., 2011. The potential influence of seasonal climate variables on the net primary production of forests in Eastern China. *Environmental Management*, 48(6): 1173–1181. doi: 10.1007/s00267-011-9710-8

Lian Y Q, You G J Y, Lin K R et al., 2015. Characteristics of climate change in southwest China karst region and their potential environmental impacts. *Environmental Earth Sciences*, 74(2): 937–944. doi: 10.1007/s12665-014-3847-8

Liu J G, Li S X, Ouyang Z Y et al., 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America*, 105(28): 9477–9482. doi: 10.1073/pnas.0706436105

Lü Y H, Fu B J, Feng X M et al., 2012. A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the Loess Plateau of China. *PLoS One*, 7(2): e31782. doi: 10.1371/journal.pone.0031782

Lü Y H, Zhang L W, Feng X M et al., 2015. Recent ecological transitions in China: greening, browning, and influential factors. *Scientific Reports*, 5: 8732. doi: 10.1038/srep08732

Luck G W, Smallbone L T, O'Brien R, 2009. Socio-economics and vegetation change in urban eosystems: patterns in space and time. *Ecosystems*, 12 (4): 604–620. doi: 10.1007/s10021-009-9244-6

Ma Y H, Fan S Y, Zhou L H et al., 2007. The temporal change of driving factors during the course of land desertification in arid region of North China: the case of Minqin County. *Environmental Geology*, 51(6): 999–1008. doi:10.1007/s00254-006-0369-z

Millington J D A, Perry G L W, Romero-Calcerrada R, 2007. Regression techniques for examining land use/cover change: a case study of a Mediterranean landscape. *Ecosystems*, 10(4): 562–578. doi:10.1007/s10021-007-9020-4

Miyashita K, Tanakamaru S, Maitani T et al., 2005. Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. *Environmental and Experimental Botany*, 53(2): 205–214. doi: 10.1016/j.envexpbot.2004.03.015

Mu L, Liang Y L, Han R L, 2014. Assessment of the soil organic carbon sink in a project for the conversion of farmland to forestland: a Case study in Zichang County, Shaanxi, China. *PLoS One*, 9(4): e94770. doi: 10.1371/journal.pone.0094770

Normile D, 2007. Ecology. Getting at the roots of killer dust storms. *Science*, 317(5836): 314–316. doi: 10.1126/science.317.5836.314

Ostwald M, Simelton E, Chen D L et al., 2007. Relation between vegetation changes, climate variables and land-use policy in Shaanxi province, China. *Geografiska Annaler: Series A, Physical Geography*, 89(4): 223–236. doi: 10.1111/j.1468-0459.2007.00322.x

Peng S S, Chen A P, Xu L et al., 2011. Recent change of vegetation growth trend in China. *Environmental Research Letters*, 6(4): 044027. doi: 10.1088/1748-9326/6/4/044027

Piao S L, Fang J Y, Zhou L M et al., 2003. Interannual variations of monthly and seasonal Normalized Difference Vegetation Index (NDVI) in China from 1982 to 1999. *Journal of Geophysical Research*: *Atmospheres*, 108(D14): 4401, doi: 10.1029/2002JD002848

Piao S L, Yin G D, Tan J G et al., 2015. Detection and attribution of vegetation greening trend in China over the last 30 years. *Global Change Biology*, 21(4): 1601–1609. doi: 10.1111/gcb.12795

Piao S L, Mohammat A, Fang J Y et al., 2006. NDVI-based increase in growth of temperate grasslands and its responses to climate changes in China. *Global Environmental Change*, 16(4): 340–348. doi: 10.1016/j.gloenvcha.2006.02.002

Pimentel D, Pimentel M, 2006. Global environmental resources versus world population growth. *Ecological Economics*, 59(2): 195–198. doi: 10.1016/j.ecolecon.2005.11.034

Shi Y F, Shen Y P, Kang E et al., 2007. Recent and Future Climate Change in Northwest China. *Climatic Change*, 80(3–4): 379–393. doi: 10.1007/s10584-006-9121-7

Slayback D A, Pinzon J E, Los S O et al., 2003. Northern hemisphere photosynthetic trends 1982-99. *Global Change Biology*, 9(1): 1–15. doi: 10.1046/j.1365-2486.2003.00507.x

Song Lining, Zhu Jiaojun, Yan Qiaoling, 2009. Review on the shelter forest decline. *Chinese Journal of Ecology*, 28(9): 1684–1690. (in Chinese)

Song X Z, Peng C H, Zhou G M et al., 2014. Chinese Grain for Green Program led to highly increased soil organic carbon levels: A meta-analysis. *Scientific Reports*, 4: 4460. doi: 10.1038/srep04460

Sun Yanling, Guo Peng, Yan Xiaodong et al., 2010. Dynamics of vegetation cover and its relationship with climate change and human activities in Inner Mongolia. *Journal of Natural Resources*, 25(3): 407–414. (in Chinese)

Uchida E, Xu J T, Rozelle S, 2005. Grain for Green: cost- effectiveness and sustainability of China's conservation set-aside program. *Land Economics*, 81(2): 247–264. doi: 10.3368/le.81.2.247

Verdoodt A, Van Ranst E, 2006. Environmental assessment tools for multi-scale land resources information systems: a case study of Rwanda. *Agriculture, Ecosystems & Environment*, 114(2–4): 170–184. doi: 10.1016/j.agee.2005.10.006

Wang C, Ouyang H, Maclaren V et al., 2007. Evaluation of the economic and environmental impact of converting cropland to forest: a case study in Dunhua county, China. *Journal of Environmental Management*, 85(3): 746–756. doi: 10.1016/j.jenvman.2006.04.025

Wang Jinsong, Li Yiping, Ren Yulong et al., 2013. Comparison among several drought indices in the Yellow River Valley. *Journal of Natural Resources*, 28(8): 1337–1349. (in Chinese)

Wang J H, Jiang D, Huang Y H et al., 2014. Drought analysis of the Haihe river basin based on GRACE terrestrial water storage. *Scientific World Journal*, 2014: 578372. doi: 10.1155/2014/578372

Wang J, Wang K L, Zhang M Y et al., 2015. Impacts of climate change and human activities on vegetation cover in hilly southern China. *Ecological Engineering*, 81: 451–461. doi: 10.1016/j.ecoleng.2015.04.022

Wang Run Ping, Chen Kai, 2006. Analysis of the Situation and Problems in Reverting Farmland to Forests and Grassland in China. *Research of Soil and Water Conservation*, 13(5): 188–192. (in Chinese)

Wang X H, Piao S L, Ciais P et al., 2011. Spring temperature change and its implication in the change of vegetation growth in North America from 1982 to 2006. *Proceedings of the National Academy of Sciences of the United States of America*, 108(4): 1240–1245. doi: 10.1073/pnas.1014425108

Wang X M, Zhang C X, Hasi E et al., 2010. Has the Three Norths Forest Shelterbelt Program solved the desertification and dust storm problems in arid and semiarid China? *Journal of Arid Environments*, 74 (1): 13–22. doi: 10.1016/j.jaridenv.2009.08.001

Wang X, Zhao X L, Zhang Z X et al., 2016. Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010. *Catena*, 137: 256–268. doi: 10.1016/j.catena.2015.10.004

Wang Y F, Cao S X, 2011. Carbon sequestration may have negative impacts on ecosystem health. *Environmental Science & Technology*, 45(5): 1759–1760. doi: 10.1021/es200042s

Wessels K J, Prince S D, Malherbe J et al., 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *Journal of Arid Environments*, 68(2): 271–297. doi: 10.1016/j.jaridenv.2006.05.015

Wrbka T, Erb K H, Schulz N B et al.,2004. Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. *Land Use Policy*, 21(3): 289–306. doi: 10.1016/j.landusepol.2003.10.012

Wu J J, Zhao L, Zheng Y T et al., 2012. Regional differences in the relationship between climatic factors, vegetation, land surface conditions, and dust weather in China's Beijing-Tianjin Sand Source Region. *Natural Hazards*, 62(1): 31–44. doi: 10.1007/s11069-011-0039-7

Wu Z T, Wu J J, He B et al., 2014. Drought offset ecological restoration program-induced increase in vegetation activity in the Beijing-Tianjin Sand Source Region, China. *Environmental Science & Technology*, 48 (20): 12108–12117. doi: 10.1021/es502408n

Xiao J F, 2014. Satellite evidence for significant biophysical consequences of the 'Grain for Green' Program on the Loess Plateau in China. *Journal of Geophysical Research: Biogeosciences*, 119(12): 2261–2275. doi: 10.1002/2014JG002820

Xin Z B, Xu J X, Zheng W, 2008. Spatiotemporal variations of vegetation cover on the Chinese Loess Plateau (1981–2006): impacts of climate changes and human activities. *Science in China Series D: Earth Sciences*, 51(1): 67–78. doi: 10.1007/s11430 007-0137-2

Xu J T, Yin R S, Li Z et al., 2006. China's ecological rehabilitation: Unprecedented efforts, dramatic impacts, and requisite policies. *Ecological Economics*, 57 (4): 595–607. doi:10.1016/j.ecolecon.2005.05.008

Xu J J, Shi Y, Gao X J, 2012. Changes in extreme events as simulated by a high-resolution regional climate model for the next 20–30 years over China. *Atmospheric and Oceanic Science Letters*, 5(6): 483–488.

Xu J Y, Shi Y, Gao X J et al., 2013. Projected changes in climate extremes over China in the 21st century from a high resolution regional climate model (RegCM3). *Chinese Science Bulletin*, 58 (12): 1443–1452. doi: 10.1007/s11434012-5548-6

Xu L, Samanta A, Costa M H et al., 2001. Widespread decline in greenness of Amazonian vegetation due to the 2010 drought. *Geophysical Research Letters*, 38(7): L07402. doi: 10.1029/2011GL046824

Yang Y, Wang Z Q, Li J L et al., 2016. Comparative assessment of grassland degradation dynamics in response to climate variation and human activities in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013. *Journal of Arid Environments*, 135: 164–172. doi: 10.1016/j.jaridenv.2016.09.004

Yao Junqiang, Yang Qing, Chen Yaning et al., 2013. Climate change in arid areas of Northwest China in past 50 years and its effects on the local ecological environment. *Chinese Journal of Ecology*, 32(5): 1283–1291

Yi Lang, Ren Zhiyuan, Zhang Chong et al., 2014. Vegetation cover, climate and human activities on the Loess Plateau. *Resources Science*, 36 (1): 166–174. (in Chinese)

Yin R S, Yin G P, 2010. China's primary programs of terrestrial ecosystem restoration: initiation, implementation, and challenges. *Environmental Management*, 45(3): 429–441. doi: 10.1007/s00267-009-9373-x

Zhang B Q, Wu P T, Zhao X N et al., 2013. Changes in vegetation condition in areas with different gradients (1980–2010) on the Loess Plateau, China. *Environmental Earth Sciences*, 68(8): 2427–2438. doi: 10.1007/s12665-012-1927-1

Zhang J E, Wang T M, Ge J P, 2015. Assessing vegetation cover dynamics induced by policy-driven ecological restoration and implication to soil erosion in Southern China. *PLoS One*, 10(6): e0131352. doi: 10.1371/journal.pone.0131352

Zhao M S, Running S W, 2010. Drought-induced reduction in global terrestrial net primary production from 2000 through 2009. *Science*, 329(5994): 940–943. doi: 10.1126/science.1192666

Zhou W, Gang C C, Zhou F C et al., 2015. Quantitative assessment of the individual contribution of climate and human factors to desertification in northwest China using net primary productivity as an indicator. *Ecological Indicators*, 48, 560–569. doi: 10.1016/j.ecolind.2014.08.043