sustainability

MDPI

Article

Analysis of the Driving Forces in Vegetation Variation in the Grain for Green Program Region, China

Hao Wang [1,*], Guohua Liu [2], Zongshan Li [2], Ye Xin [3], Bojie Fu [2] and Yihe Lv [2]

1 Department of Geography, School of Geography and Tourism, Shaanxi Normal University, Xi'an 710119, China
2 State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Science, Chinese Academy of Sciences, Beijing 100085, China; ghliu@rcees.ac.cn (G.L.); zsli_st@rcees.ac.cn (Z.L.); bfu@rcees.ac.cn (B.F.); lyh@rcees.ac.cn (Y.L.)
3 Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection, Nanjing 210042, China; xinyechn@163.com
* Correspondence: foreva@snnu.edu.cn; Tel.: +86-029-8531-0525

Received: 24 August 2017; Accepted: 11 October 2017; Published: 16 October 2017

Abstract: The Chinese government introduced six ecological restoration programs to improve its natural environment. Although these programs have proven successful in improving local environmental conditions, some studies have questioned their effectiveness when regions suffer from extreme weather conditions. Using the Grain for Green Program (GGP) region as a study area, we estimated vegetation activities in the GGP region from 2000 to 2010 to clarify the trends in vegetation growth and their driving forces. The results showed that: (1) vegetation activities improved in the GGP region during 2000–2010, with 58.94% of the area showing an increased trend in the NDVI (normalized difference vegetation index); (2) 26.33% of the increased vegetation was caused by human interference, and 11.61% by climate variation, human activity was the dominant cause, and resulted in 54.68% of the degradation compared to 4.74% from climate change; and, (3) the contribution of different land use types to the NDVI interannual variations showed that high contribution regions were focused in the arid and semiarid areas, where the vegetation growth is associated with variations in precipitation and temperature. However, conversions between farmland and grassland or forest had a significant effect on the change in the NDVI trend. Therefore, although climate conditions can affect vegetation growth, human activities are more important in vegetation changes, and appropriate human activities would contribute to its continual improvement. Hence, we recommend establishing an assessment and scientific management mechanism for eco-risks in the design and management of ecosystem restoration programs.

Keywords: grain for green program; NDVI; climate fluctuation; human activity

1. Introduction

For many years, especially before the end of the 20th century, the sustained development of China's economy has been accompanied by severe ecological problems, such as land desertification, soil erosion, vegetation degradation, and biodiversity loss [1,2]. To solve these problems, the Chinese government introduced six ecological restoration programs, among which are the "Three-North Shelterbelt Project", the "Natural Forest Protect Project", and the "Grain for Green Program" (GGP) [3–5]. Several studies have reported that these programs have improved the local environment significantly [6–8], and among them, the GGP has become one of the largest-scale ecosystem projects in the world [9]. From 1999 to 2008, the Chinese government invested approximately 28.8 billion USD in the GGP, and helped 0.12 billion farmers restore sloping croplands to economic woodland, artificial forest, and grassland [10]. Therefore, vegetation restoration in the GGP region is an area of interest for research on the effectiveness of ecological restoration programs. Generally, researchers believe that ecological restoration programs reduce land degradation, increase vegetation coverage, and improve soil carbon storage [11–13]. However, the findings of several recent studies have challenged these conclusions [14,15]. Wang et al. pointed out a low survival rate of the planted trees and shrubs were found in the GGP region because of the climate change [16]. Cao stated further that afforestation could cause increasing ecosystem deterioration and wind erosion in semiarid and arid areas [17]. The principal reasons for these conflicting results are the effects of climate change and human activity in restoring vegetation.

On the one hand, climate change affects vegetation growth directly—links between climatic variables and vegetation have been demonstrated conclusively [18–21]. For example, increased temperature and precipitation have extended the growing season of the vegetation in the Loess Plateau. However, if the rainfall fails to offset the increased evapotranspiration caused by the warming climate, the length of the growing season will be shortened [22]. On the other hand, human activity also affects vegetation growth [23–25]. The negative effects of activities such as urbanization and overgrazing, among many, have caused different levels of soil degradation and erosion, and become the primary factors that degrade vegetation cover [26,27]. Equally important, positive human activities such as enclosure of grazing, returning farmland to forest and grassland, reforestation, and afforestation can contribute to increased soil conservation and water preservation ability, which lead to sustained vegetation growth [28,29]. Even so, we believe that past research has made insufficient efforts to study the relation between climate change and human activity, both of which influence vegetation growth positively/negatively. Research that relies solely on climate change or human activity data will fail to illuminate the relation between vegetation growth and its driving forces fully [30,31]. Neglecting human activity, while exaggerating the effect of climate change may underestimate the benefits of ecological restoration programs. Similarly, neglecting climatic conditions in assessment of ecological restoration programs may fail to improve the local environment.

Whether a decreasing trend in vegetation in restoration program regions is caused by climate change or human activity remains unclear. It is also is unclear whether extreme weather has a significant influence on the results of ecological restoration programs or whether it should be considered when assessing their benefits. To address both of these issues, this study chose the GGP region as the study area and adopted the normalized difference vegetation index (NDVI), remote data, and climatic data in the GGP region to identify the spatio-temporal patterns in vegetation from 2000–2010. Based on the land use data and the results of the residual analysis, we separated the effects of climate and human activity on the NDVI. The study's final objective was to identify the influence of human activity on vegetation growth by calculating the contribution rate of different land use types, and investigating the importance of considering climate change as a feature in assessing the efficacy of ecological restoration programs.

2. Data and Methods

2.1. Study Area

The Chinese government introduced the GGP in 1999. The program's objective was to halt erosion, protect biodiversity, and improve the ecological environment by encouraging farmers to convert abandoned farmland and degenerated grassland to trees and grasses [32]. The government has invested over 430 billion Yuan in the program, and it has been implemented in 1897 counties in 25 provinces in China, which together cover 74% of China's total land area (Figure 1) [33,34]. By late 2012, the GGP had converted 9.7 million hectares of farmland into forest and grassland [35]. The final goal of the GGP is to convert all of the region's steep slope lands into forest to control the most severe farmland desertification and increase China's grassland and forestland coverage by 4.5%, thereby improving its natural environment significantly [36].

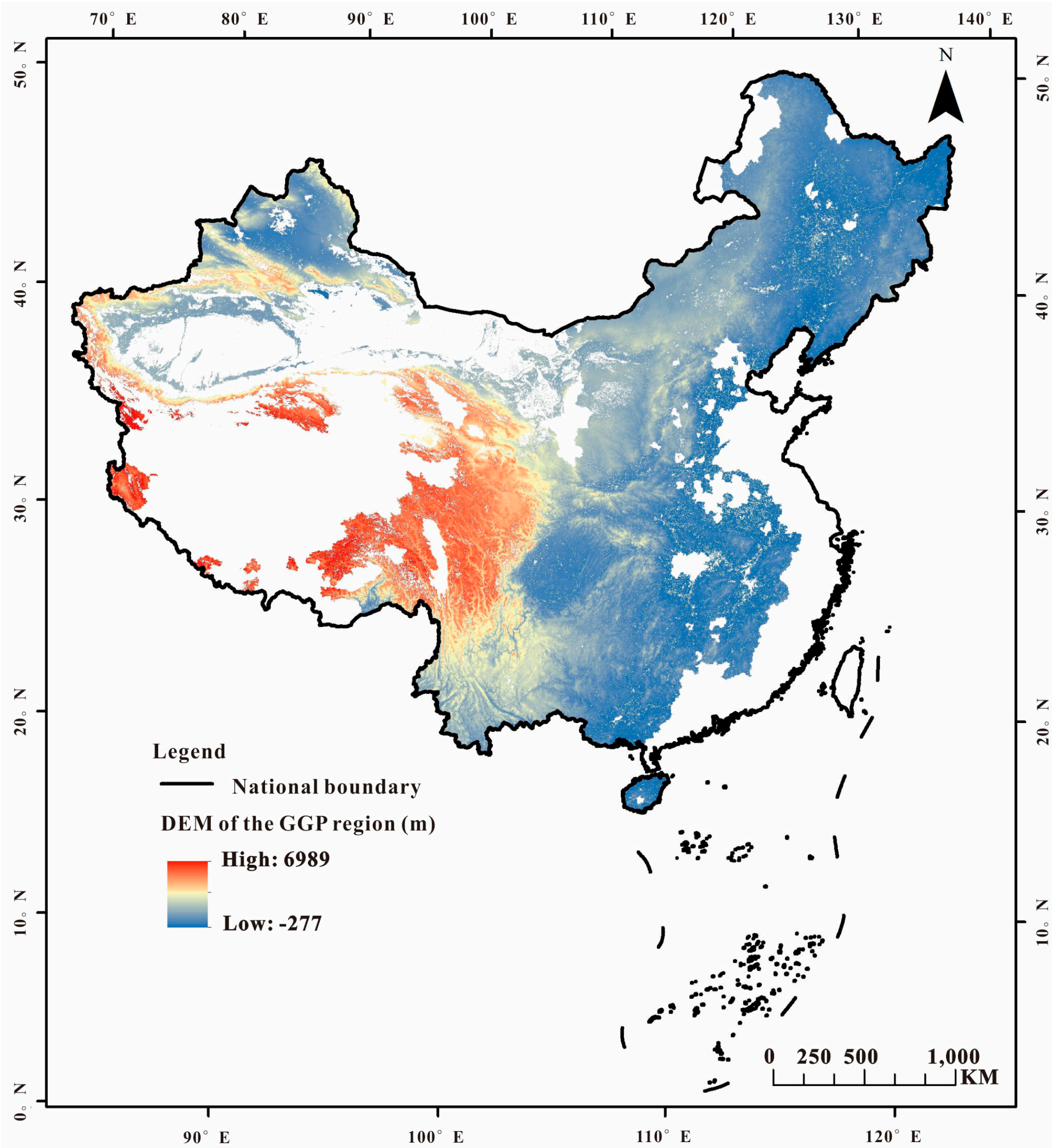

Figure 1. Location of the Grain for Green Program (GGP) in China.

2.2. Dataset

This study adopted the annual average temperature and annual precipitation data (2000 to 2010) from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). Using data from 676 stations in China, we estimated the spatio-temporal patterns of the climatic factors in the study area. To produce the spatial maps, we used the Kriging interpolation method, and the resolution of the maps was 1 km.

The 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 1 km. To minimize disturbance in the NDVI trends, such as those attributable to bare soil and sparsely vegetated areas, we excluded all of the grid cells with an average annual NDVI value less than 0.05 [37,38].

Land use maps for the GGP region in 2000 and 2010 were obtained from the Center for Earth Observation and Digital Earth, China (http://www.ceode.cas.cn/sjyhfw/). Based on the Landsat satellite remote data and the vegetation type map, a series of 30-m resolution land use maps was created with an accuracy rate greater than 94%.

2.3. Methods

To measure the vegetation dynamics, the following formula of ordinary least-squares regression was applied to examine the linear trends in the NDVI data:

$$Slope = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n}(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n}(\sum_{i=1}^{n} x_i)^2} \quad (1)$$

where x_i is the years' order from 1 to n, n is the number of years, and y_i signifies the NDVI variables when time is x_i. Regions with a positive slope value indicate an increasing trend, while those with a negative slope value indicate a decreasing trend [39,40].

Three forms of the NDVI were computed for each year and each pixel to distinguish the effect of climate and human activity on vegetation [40,41]. First was the predicted NDVI, in which we estimated the linear regression for each pixel between the annual precipitation, annual average temperature, and the annual NDVI using the following formula:

$$NDVI_P = aP + bT + c \quad (2)$$

where $NDVI_P$ indicates the predicted NDVI without human disturbance, P and T are annual precipitation, and annual average temperature, respectively, a and b are regression coefficients, and c is a regression constant. The effect of climate change on vegetation can be defined by the slopes of the $\mathrm{NDVI_P}$ ($\mathrm{S_p}$) according to Equation (1). A positive value indicates that climate change improves vegetation growth, while a negative value indicates that climate change degrades vegetation growth.

The second was the actual NDVI ($NDVI_A$), which was derived from the annual average NDVI data. The effects of both climate change and human activity on vegetation can be defined by the slopes of the $NDVI_A$ ($\mathrm{S_A}$). A positive value of $\mathrm{S_A}$ indicates that vegetation growth during this period is improved. In contrast, a negative value indicates that vegetation growth during this period is degraded.

The third NDVI was the NDVI residuals ($NDVI_R$), which were the disparity between the actual NDVI ($NDVI_A$) and the predicted NDVI ($NDVI_P$):

$$NDVI_R = NDVI_A - NDVI_P \quad (3)$$

The slope of the $NDVI_R$ ($\mathrm{S_R}$) signifies changes in the vegetation for reasons other than climate change. A positive value indicates human-induced improvement, while a negative value indicates human-induced degradation in an area [42,43].

Accordingly, six scenarios can be defined by the slopes of the $NDVI_A$ ($\mathrm{S_A}$), the $NDVI_P$ ($\mathrm{S_p}$), and the $NDVI_R$ ($\mathrm{S_R}$) (Table 1). Based on the changing trends in the three NDVIs, the scenarios can distinguish between climate and human factors in changing vegetation growth in the study area [44,45]. However, when $\mathrm{S_A} > 0$, $\mathrm{S_p} < 0$, $\mathrm{S_R} < 0$, or $\mathrm{S_A} < 0$, $\mathrm{S_p} > 0$, and $\mathrm{S_R} > 0$, an error scenario may occur, indicating that vegetation growth increased, but climate and human factors promoted degradation, or the vegetation growth decreased, but climate and human factors promoted vegetation growth. Because of the different scales of the dataset, this error may occur only in a few areas (less than 1%). According to previous research, this does not affect the accuracy of the final results [46,47].

To estimate the contribution of different land use types to the NDVI interannual variations, an index was adopted that scores individual geographic locations according to the consistency, over time, with which the local NDVI flux resembles the sign and magnitude of GGP region NDVI [48].

$$f_j = \frac{\sum_t \frac{x_{jt}|X_t|}{X_t}}{\sum_t |X_t|} \quad (4)$$

where x_{jt} is the anomaly for land use type j at time t, t is the order of the year, and X_t is the GGP anomaly, so that $X_t = \sum_j X_{jt}$. The equation shows that f_j is the average relative anomaly x_{jt}/X_t for region j, weighted by the GGP anomaly $|X_t|$. A positive result indicates a greater contribution that affects the NDVI change trend in the GGP region. In this research, the index adopted does not reflect the variation of NDVI in different areas; rather, it achieves a comparison of these areas' relative contribution in governing the NDVI in the GGP region.

Table 1. Scenarios that distinguishing climate and human factors in changing vegetation growth.

	SP	SR	Roles of Climate and Human Factors
Vegetation growth increased (SA > 0)			
Scenario1	<0	>0	Vegetation restoration attributable largely to human factors
Scenario 2	>0	<0	Vegetation restoration attributable largely to climate factors
Scenario 3	>0	>0	Vegetation restoration attributable largely to both climate and human factors
Vegetation growth decreased (SA < 0)			
Scenario 1	>0	<0	Vegetation degradation attributable largely to human factors
Scenario 2	<0	>0	Vegetation degradation attributable largely to climate factors
Scenario 3	<0	<0	Vegetation degradation attributable largely to both climate and human factors

S_A is the slope value of the actual NDVI, S_P is the slope value of the potential NDVI, and S_R is the slope value of the residual NDVI.

3. Results

3.1. Spatio-Temporal Vegetation Patterns

The spatial distribution of NDVI showed varied characteristics in the GGP region from 2000 to 2010 (Figure 2). Over half (58.94%) of the region showed an increasing trend in the NDVI during the time the study covered. Regions showed an extremely significant increasing trend in NDVI at the 0.95 confidence intervals, which account for 11.22% of total vegetation, as compared to those areas with extremely significant NDVI decreasing trend at 0.95 confidence intervals, which account for 3.91% (Table 2). The NDVI increased areas were chiefly found in the Loess Plateau, specifically in the Lüliang Mountains area, Northern Shaanxi, and southern Gansu. Meanwhile, the decreasing trend of the NDVI was located mainly in the Tian Shan Mountains, northwest of the Hunshadake Sandy Land area and the middle of the Sichuan Basin.

Table 2. Spatial changes in normalized difference vegetation index (NDVI) in the GGP region from 2000 to 2010.

Variables	NDVI
Increasing (%)	58.94
Increasing significantly (%)	16.3
Increasing extremely significantly (%)	11.22
Decreasing	41.06
Decreasing significantly (%)	6.58
Decreasing extremely significantly (%)	3.91

Note: significantly indicates areas that changed significantly at the 0.90 confidence intervals. Extremely significantly indicates areas that changed significantly at the 0.95 confidence levels.

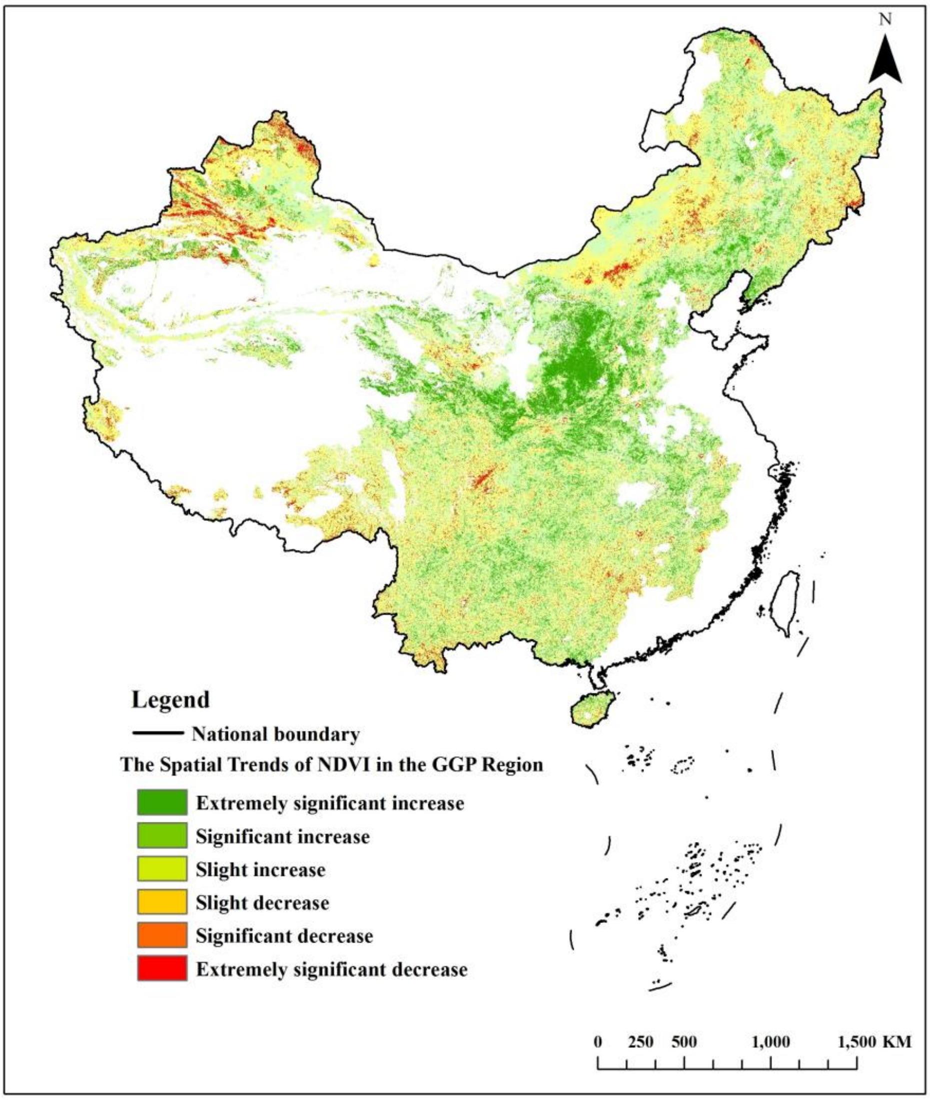

Figure 2. Spatial pattern of the NDVI change trend in the GGPregion from 2000 to 2010.

3.2. Effects of Climate Change and Human Activity on Vegetation

Vegetation restoration caused by climate change or human activity was analyzed, and is shown in Figure 3a. The results demonstrated that the combined effects contributed the most to restoration (62.06%), followed by human activity (26.33%), and climate change (11.61%). Vegetation restoration attributable to human activity was found primarily in the Loess Plateau and the North China Plain, which indicates that ecological projects such as the GGP have achieved notable results in these regions. Vegetation restoration attributable to climate change was scattered in arid and semiarid areas of China, in which vegetation growth is relatively sensitive to temperature and precipitation changes.

The driving factors of vegetation degradation also were analyzed, and are shown in Figure 3b. Degradation attributable to human activity was distributed widely in the GGP region and accounted for 54.68% of the degraded area. Climate change and the joint effects caused 4.47% and 40.58% of the degradation, respectively. When human activity and the joint effects were considered together, over 95% of the vegetation degradation was caused by human activity. These findings show that vegetation degradation has reached an alarming scale, with much of it being related to human activity, especially in regions with fragile ecological environments, including the arid and semiarid areas and the mountainous areas of southwest China.

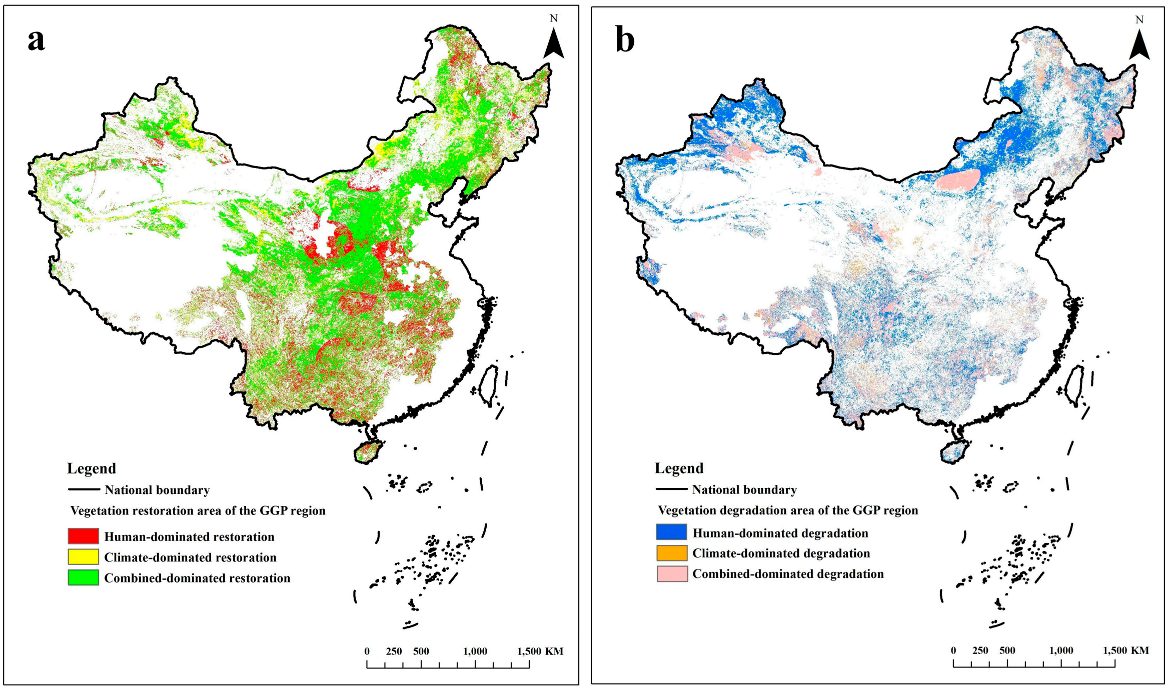

Figure 3. Spatial pattern of driving factors of vegetation restoration (**a**) and degradation (**b**) in the GGP region.

3.3. Vegetation Variation Affected by Human Activity

3.3.1. Land Use Change

To investigate the effect of human activity on vegetation variation, the change in land use and the contribution of various land use types to the NDVI interannual variations were analyzed. In accordance with the land use change transfer matrix in Table 3, forest and urban land increased by 0.77% and 21.67%, respectively, in the last 11 years. The principal increase in forest was attributable to farmland conversion that corresponds to the introduction of the GGP. Meanwhile, urban land increased significantly, largely because of conversion from farmland, indicating that the process of urbanization in the GGP region has been impressive; thus, its accompanying ecological problems should be given close attention in the future. Because of the land use change, which is associated closely with vegetation restoration and urbanization, there had been a significant decrease in farmland. Although forest, grassland, and wetland had been converted to new farmland, the net change in farmland was still negative. Grassland in the GGP region showed a negative growth trend, and significant mutual transformation between grassland and forest had occurred, the effect of which on the NDVI change trend needs to be studied further.

Table 3. The conversion of land use change in percent during 2000–2010 in the GGP region (Unit: %).

Land Use Type	Forest	Grassland	Wetland	Farmland	Urban Land	Bare Land	Net Change
Forest	98.97	0.25	0.01	0.51	0.13	0.12	0.77
Grassland	0.87	97.93	0.07	0.73	0.19	0.21	−0.78
Wet land	0.27	1.14	93.09	3.65	0.32	1.53	−1.70
Farmland	1.45	0.93	0.10	95.93	1.30	0.29	−1.72
Urban land	0.08	0.08	0.01	0.48	99.26	0.08	21.67
Bare land	0.17	0.32	0.09	0.27	0.11	99.04	−0.15

3.3.2. Contribution of Different Land Use and Land Use Change Types to the NDVI Interannual Variations

To investigate more closely the way in which land use and land use change influence the variations in interannual NDVI, we partitioned NDVI in the GGP region among land use types in accordance with the contribution of individual regions (grid cells or land use types) in the whole area. The contribution rate of each land use type overall was the sum of both the positive and negative contributions of each grid cell (Tables 4 and 5). The results are shown in Figure 4: high contribution regions chiefly were in the arid and semiarid areas in China, especially in the Loess Plateau and Inner Mongolia regions. The contribution rate on the NDVI interannual variations of unchanged land use types were, in order, grassland (37%), farmland (31%), forest (20%), and wetland (1%) (Table 4). For land use types that changed from 2000 to 2010, the changes between farmland and grassland or farmland and forest made greater contributions. Specifically, four of the top five high contribution land use changes occurred between farmland and grassland or forest: grassland to farmland (6.27‰), farmland to grassland (4.49‰), forest to farmland (3.68‰), and farmland to forest (2.81‰) (Table 5). This indicates that the conversion between farmland and grassland or forest had a greater effect on NDVI interannual variations than did the transition between land use types with vegetation-coverage and those without vegetation. Thus, the introduction of the GGP affected the vegetation change trends significantly.

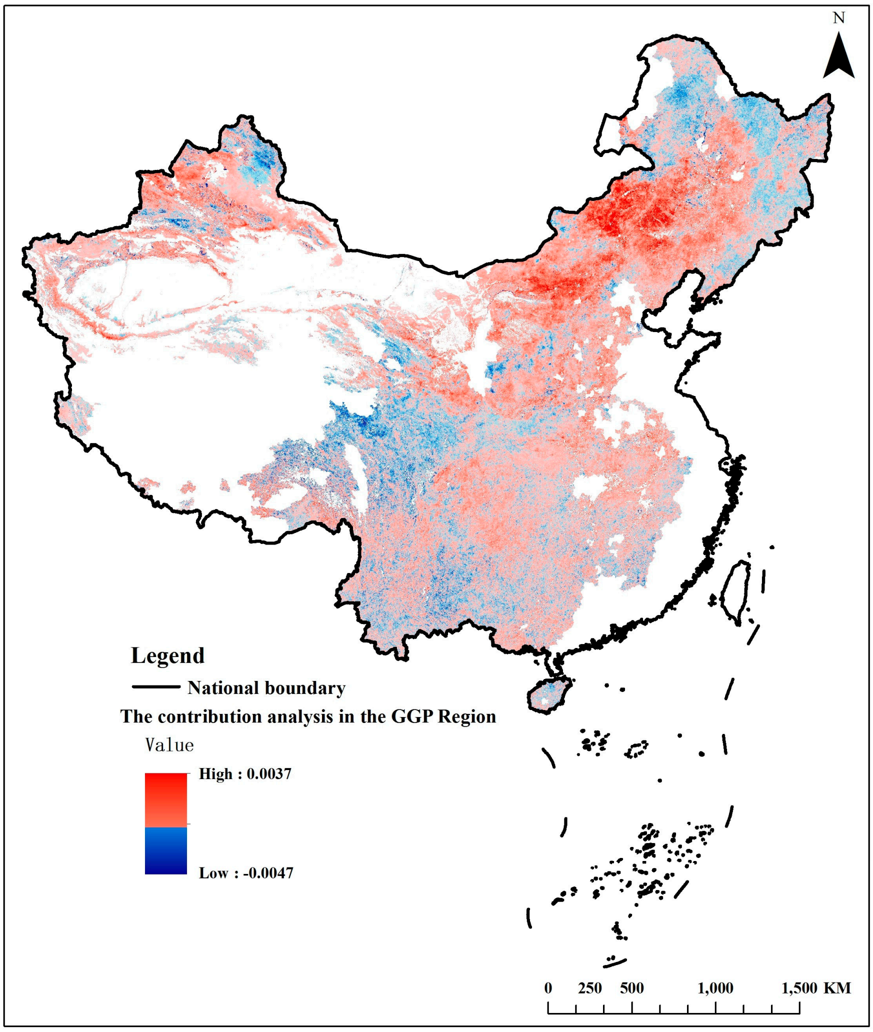

Figure 4. Spatial pattern of the local NDVI contribution to the NDVI interannual variations in the GGP region.

Table 4. Statistics of the contribution rate of unchanged land use types to the NDVI interannual variations in the GGP region.

Land Use Types	Contribution Rate to the NDVI Interannual Variations
Grassland	37%
Farmland	31%
Forest	20%
Wet land	1%

Table 5. Statistics of the contribution rate of changed land use types to the NDVI interannual variations in the GGP region.

Land Use Changes	Contribution Rate to the NDVI Interannual Variations
Grassland to farmland	6.27‰
Grassland to forest	5.86‰
Farmland to grassland	4.49‰
Forest to farmland	3.68‰
Farmland to forest	2.81‰
Bare land to farmland	1.66‰
Forest to grassland	1.48‰
Farmland to urban land	1.23‰
Grassland to urban land	1.07‰
Bare land to grassland	1.05‰

4. Discussion

4.1. Methodology

Climate change and human activity are the two primary driving forces in vegetation variation. Previous studies have tried to distinguish their relative roles in affecting vegetation variation using various methods. However, most studies have focused on statistical methods, such as correlation analysis and principal component analysis [49,50]. Without considering the spatio-temporal differences in vegetation growth fully, these methods fail to reflect the spatial distribution and varying trends in the driving forces in vegetation growth [51,52]. Several recent studies have offered a new method to solve this problem by comparing actual and predicted vegetation growth [43,46]. Wu et al. designed this methodology to investigate the role of droughts and human activity in vegetation growth in the Beijing-Tianjin Sand Source Region [15]. Gang et al. assessed the contribution of climate and human activity in grassland change trends on the global scale [40]. Therefore, this study adopted the same methodology to investigate the driving force of vegetation variation in the GGP region.

The results indicated that the vegetation conditions had improved in the GGP region in the last decade because of restoration activities, as the NDVI in this area generally showed an increasing trend from 2000 to 2010. The research also showed demonstrated that 58.94% of the program area showed an increased trend in the NDVI and 11.22% showed a significant increasing trend at 0.95 confidence intervals. This result is consistent with those of related studies, which have shown clearly improved vegetation quality in the afforestation area [53,54]. Chang et al. concluded that because of the GGP, vegetation and soil carbon storage had increased in the Loess Plateau area [55]. Piao et al. reported that the primary reason for the improvements in China's vegetation was human activity, such as afforestation and agricultural management [56]. Therefore, implementing ecological restoration programs, including the GGP, was both necessary and effective.

Although the residual of the NDVI (difference between actual and predicted NDVI) identified the driving forces of vegetation growth successfully, this method still has its limitations. The predicted NDVI is estimated with the assumption of an ideal environment in which only temperature and precipitation affect vegetation growth [41,57]. Thus, the relative roles of climate and human activity in vegetation variation are based on the hypothesis that vegetation growth is affected only by those factors [58,59]. However, other factors also affect vegetation growth trends, such as animal species, forest fires, pests, and diseases. Future studies should investigate these influential processes.

4.2. Driving Forces

Climate change, including temperature and precipitation changes, may be a principal factor in vegetation growth [60]. According to this research, 11.61% of the restoration was induced by climate change and was concentrated in China's arid and semiarid areas. Previous studies have found that the vegetation in water-limited areas is sensitive to climate variation, especially precipitation changes [61,62]. The most recent studies have also shown that there was a rising trend in both temperature and precipitation in northwest China, and the precipitation there had increased significantly since the 1980s [63,64]. A pure increase in temperature will accelerate evapotranspiration and decrease soil moisture, which leads to drought and limits vegetation growth [65]. However, the significant increase in precipitation, which offsets the loss of water and improves soil moisture, helps vegetation survive a drought. Meanwhile, clouds accompany precipitation, and also reduce the evapotranspiration of vegetation, thereby increasing water use efficiency further [66]. Therefore, the improved vegetation growth in water-limited areas is indeed affected by climate change.

Although climate factors can affect vegetation growth in water-limited areas, human activity plays a more significant role in changing vegetation trends. Our results showed that 26.33% of the restoration in which the NDVI increased and 54.68% of the degradation in the area in which the NDVI decreased was related to human activity. Moreover, taking both human activity and the joint effects into consideration, human behavior led to over 95% of the vegetation degradation. When compared to climatic factors, human activity affects vegetation growth more directly and efficiently [29]. The continuous growth in population, overgrazing, excessive wood cutting, landscape fragmentation caused by urban expansion, and conversion of grassland into cropland have all exerted pressure on the natural environment and contributed significantly to vegetative degradation [67–69]. Thus, the destructive influence of human activity on vegetation is the main cause of its degradation.

At the same time, positive human activities, such as ecological restoration programs, can promote local vegetation restoration and bring several benefits to the local environment, such as increasing the vegetation cover, reducing soil erosion, and increasing soil organic carbon [3,35,70]. Our research confirmed that, in accordance with the land use change transfer matrix, the primary increase in forest and grassland derived from farmland, which was consistent with the introduction of the GGP. The statistics on the contributions of changed land use types to the NDVI interannual variations showed that conversion between farmland and grassland or farmland and forest accounted for the higher contributions. Thus, land use changes caused by human activity can have beneficial effects onvegetation change trends. Xiao reported that the GGP increased the enhanced vegetation index (EVI), and the leaf area index of forest in the Loess Plateau. Similarly [71], Wang et al. stated that, because of the success of the GGP and other environmental protection measures, soil erosion in China decreased appreciably from 2000 to 2010 [61]. In fact, carbon fixation in the GGP region also should increase, because larger forests facilitate soil carbon fixation [12]. Therefore, the introduction of ecological programs, including prohibiting grazing, converting croplands to grasslands and forests, and natural forest regulations, should, with patience and persistence, yield even greater ecological benefits.

5. Conclusions

This study assessed the effects of climate change and human activity on vegetation growth in the GGP region from 2000–2010. The results showed that vegetation activity increased in the GGP region. The vegetation in the arid and semiarid areas is sensitive to climate variation, especially precipitation change. Thus, climate change has become a key factor that affects vegetation growth in such areas. However, human activity exerted a greater influence on vegetation change trends. The results of this research showed that human activity played a more direct and efficient role in changing vegetation growth. The destructive influence of negative human activity was the primary reason for vegetation degradation in the area in which the NDVI decreased. Meanwhile, the land use change contribution rate analysis showed that the conversions between farmland and grassland or forest had a significant effect on the NDVI change trend. Therefore, positive human activities, such as the introduction of ecological programs, can contribute to continued improvement in vegetation.

The methodology of comparing actual and predicted vegetation growth based on NDVI variations in this study proved to be relatively accurate and can be applied in other ecological restoration program regions to distinguish the driving forces of vegetation growth. Further, as the roles of climate change and human activity are highly divergent in China, future studies should consider the climate factors that might affect the effectiveness of new ecological projects. Therefore, we recommend an eco-risk assessment and scientific management mechanism in the design and implementation of ecosystem restoration projects.

Acknowledgments: This research was funded by the National Key R & D Program of China (2017YFC0504701), Fundamental Research Funds for the Central Universities (No. GK201703053), the National Key Research and Development Plan of China (2016YFC0501601).

Author Contributions: Hao Wang analyzed the related data and wrote the manuscript; Guohua Liu, Yihe Lv and Zongshan Li designed the framework of the research and revised the manuscript; Bojie Fu gave important advice about the content and writing; and Ye Xin provided the land use types and NPP data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xu, J.T.; Yin, R.S.; Li, Z.; Liu, C. China's ecological rehabilitation: Unprecedented efforts, dramatic impacts, and requisite policies. *Ecol. Econ.* **2006**, *57*, 595–607. [CrossRef]
2. Liu, J.G.; Diamond, J. China's environment in a globalizing world. *Nature* **2005**, *435*, 1179–1186. [CrossRef] [PubMed]
3. Lu, Y.H.; Zhang, L.W.; Feng, X.M.; Zeng, Y.; Fu, B.J.; Yao, X.L.; Li, J.R.; Wu, B.F. Recent ecological transitions in China: greening, browning, and influential factors. *Sci. Rep.* **2015**, *5*, 8732. [CrossRef] [PubMed]
4. Yin, R.S.; Yin, G.P. China's primary programs of terrestrial ecosystem restoration: Initiation, implementation, and challenges. *Environ. Manag.* **2010**, *45*, 429–441. [CrossRef] [PubMed]
5. Wu, J.J.; Zhao, L.; Zheng, Y.T.; Lu, A. Regional differences in the relationship between climatic factors, vegetation, land surface conditions, and dust weather in China's Beijing-Tianjin Sand Source Region. *Nat. Hazards* **2011**, *62*, 31–44. [CrossRef]
6. Lu, Y.H.; Fu, B.J.; Feng, X.M.; Zeng, Y.; Chang, R.Y.; Sun, G.; Wu, B.F. A policy-driven large scale ecological restoration: Quantifying ecosystem services changes in the Loess Plateau of China. *PLoS ONE* **2012**, *7*, e31782. [CrossRef]
7. Piao, S.L.; Fang, J.Y.; Zhou, L.M.; Guo, Q.H.; Henderson, M.; Ji, W.; Li, Y.; Tao, S. Interannual variations of monthly and seasonal Normalized Difference Vegetation Index (NDVI) in China from 1982 to 1999. *J. Geophys. Res.* **2003**, *108*, 4401. [CrossRef]
8. Peng, S.S.; Chen, A.P.; Xu, L.; Cao, C.X.; Fang, J.Y.; Mayneni, R.B.; Pinzon, J.E.; Tucher, C.J.; Piao, S.L. Recent change of vegetation growth trend in China. *Environ. Res. Lett.* **2011**, *6*, 044027. [CrossRef]
9. Chen, X.D.; Lupi, F.; He, G.M.; Quyang, Z.Y.; Liu, J.G. Factors affecting land reconversion plans following a payment for ecosystem service program. *Biol. Conserv.* **2009**, *142*, 1740–1747. [CrossRef]
10. Li, Y.C. Grain for Green program is a great concrete action towards the ecological civilization in China: Summary of a decade program implementation. *For. Constr.* **2009**, *27*, 3–13. (In Chinese)
11. Feng, X.M.; Fu, B.J.; Lu, N.; Zeng, Y.; Wu, B.F. How ecological restoration alters ecosystem services: An analysis of carbon sequestration in China's Loess Plateau. *Sci. Rep.* **2013**, *3*, 2846. [CrossRef] [PubMed]
12. Deng, L.; Liu, G.B.; Shangguan, Z.P. Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: A synthesis. *Glob. Chang. Biol.* **2014**, *20*, 3544–3556. [CrossRef] [PubMed]
13. Deng, L.; Shangguan, Z.P.; Sweeney, S. "Grain for Green" driven land use change and carbon sequestration on the Loess Plateau, China. *Sci. Rep.* **2014**, *4*, 7039. [CrossRef] [PubMed]

14. Wang, Y.F.; Cao, S.X. Carbon sequestration may have negative impacts on ecosystem health. *Environ. Sci. Technol.* **2011**, *45*, 1759–1760. [CrossRef] [PubMed]
15. Wu, Z.T.; Wu, J.J.; He, B.; Liu, G.H.; Wang, Q.F.; Zhang, H.; Liu, Y. Drought offset ecological restoration program-induced increase in vegetation activity in the Beijing-Tianjin Sand Source Region, China. *Environ. Sci. Technol.* **2014**, *48*, 12108–12117. [CrossRef] [PubMed]
16. Wang, X.M.; Zhang, C.X.; Hasi, E.; Dong, Z.B. Has the Three Norths Forest Shelterbelt Program solved the desertification and dust storm problems in arid and semiarid China? *J. Arid Environ.* **2010**, *74*, 13–22. [CrossRef]
17. Cao, S.X. Why Large-Scale Afforestation Efforts in China Have Failed To Solve the Desertification Problem. *Environ. Sci. Technol.* **2008**, *42*, 1826–1831. [CrossRef] [PubMed]
18. Piao, S.L.; Fang, J.Y.; Ji, W.; Guo, Q.H.; Ke, J.H.; Tao, S. Variation in a satellite-based vegetation index in relation to climate in China. *J. Veg. Sci.* **2004**, *15*, 219–226. [CrossRef]
19. Parmesan, C.; Yohe, G. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **2003**, *421*, 37–42. [CrossRef] [PubMed]
20. Yao, J.Q.; Yang, Q.; Chen, Y.N. Climate change in arid areas of Northwest China in past 50 years and its effects on the local ecological environment. *Chin. J. Ecol.* **2013**, *32*, 1283–1291.
21. Wang, J.; Wang, K.L.; Zhang, M.Y.; Zhang, C. Impacts of climate change and human activities on vegetation cover in hilly southern China. *Ecol. Eng.* **2015**, *81*, 451–461. [CrossRef]
22. Wang, H.; Liu, G.H.; Li, Z.S.; Xin, Y.; Wang, M.; Gong, L. Driving force and changing trends of vegetation phenology in the Loess Plateau of China from 2000 to 2010. *J. Mt. Sci.* **2016**, *13*, 844–856. [CrossRef]
23. Chen, B.; Zhang, X.; Tao, J.; Wu, J.S.; Wang, J.S.; Shi, P.L.; Zhang, Y.J.; Yu, C. Q. The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. *Agric. For. Meteorol.* **2014**, *189–190*, 11–18. [CrossRef]
24. Li, A.; Wu, J.; Huang, J. Distinguishing between human-induced and climate-driven vegetation changes: A critical application of RESTREND in inner Mongolia. *Landsc. Ecol.* **2012**, *27*, 969–982. [CrossRef]
25. Nowacki, G.J.; Abrams, M.D. Is climate an important driver of post-European vegetation change in the Eastern United States? *Glob. Chang. Biol.* **2015**, *21*, 314–334. [CrossRef] [PubMed]
26. Ma, E.; Deng, X.; Zhang, Q.; Liu, A. Spatial Variation of Surface Energy Fluxes Due to Land Use Changes across China. *Energies* **2014**, *7*, 2194–2206. [CrossRef]
27. Liu, Y.; Wang, Y.; Peng, J.; Du, Y.Y.; Liu, X.F.; Li, S.S.; Zhang, D.H. Correlations between Urbanization and Vegetation Degradation across the World's Metropolises Using DMSP/OLS Nighttime Light Data. *Remote Sens.* **2015**, *7*, 2067–2088. [CrossRef]
28. Zhang, B.Q.; Wu, P.T.; Zhao, X.N.; Wang, Y.; Gao, X. Changes in vegetation condition in areas with different gradients (1980–2010) on the Loess Plateau, China. *Environ. Earth Sci.* **2012**, *68*, 2427–2438. [CrossRef]
29. Zhang, J.; Wang, T.M.; Ge, J. Assessing Vegetation Cover Dynamics Induced by Policy-Driven Ecological Restoration and Implication to Soil Erosion in Southern China. *PLoS ONE* **2015**, *10*, e0131352. [CrossRef] [PubMed]
30. Wang, J.; Meng, J.J.; Cai, Y.L. Assessing vegetation dynamics impacted by climate change in the southwestern karst region of China with AVHRR NDVI and AVHRR NPP time-series. *Environ. Geol.* **2008**, *54*, 1185–1195. [CrossRef]
31. Wang, J.; Wang, K.L.; Zhang, M.Y.; Duan, Y.F. Temporal-Spatial Variation in NDVI and Drivers in Hilly Terrain of Southern China. *Resour. Sci.* **2014**, *36*, 1712–1723. (In Chinese)
32. Ostwald, M.; Simelton, E.; Chen, D.; Liu, A. Relation between vegetation changes, climate variables and land-use policy in Shaanxi province, China. *Geogr. Ann. Ser. A Phys. Geogr.* **2007**, *89A*, 223–236. [CrossRef]
33. Emi, U.; Xu, J.T.; Scott, R. Grain for Green: Cost-Effectiveness and Sustainability of China's Conservation Set-Aside Program. *Land Econ.* **2005**, *81*, 247–264. [CrossRef]
34. Liu, J.G.; Li, S.X.; Ouyang, Z.Y.; Tam, C.; Chen, X.D. Ecological and socioeconomic effects of China's policies for ecosystem services. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9477–9482. [CrossRef] [PubMed]
35. Song, X.Z.; Peng, C.H.; Zhou, G.M.; Jiang, H.; Wang, W.F. Chinese Grain for Green Program led to highly increased soil organic carbon levels: A meta-analysis. *Sci. Rep.* **2014**, *4*, 4460. [CrossRef] [PubMed]
36. Shangguan, Z.P.; Deng, L. Food security and farmers' income: Impacts of the grain for green programme on rural households in China. *J. Food Agric. Environ.* **2011**, *9*, 826–831.

37. Slayback, D.A.; Pinzon, J.E.; Los, S.O.; Tucker, C.J. Northern hemisphere photosynthetic trends 1982–1999. *Glob. Chang. Biol.* **2003**, *9*, 1–15. [CrossRef]
38. Wang, X.H.; Piao, S.L.; Ciais, P.; Li, G.S.; Friedlingstein, P.; Koven, C.; Chen, A. Spring temperature change and its implication in the change of vegetation growth in North America from 1982 to 2006. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 1240–1245. [CrossRef] [PubMed]
39. Wang, H.; Liu, G.H.; Li, Z.S.; Xin, Y.; Wang, M.; Gong, L. Impacts of climate change on net primary productivity in arid and semiarid regions of China. *Chin. Geogr. Sci.* **2015**, *26*, 35–47. [CrossRef]
40. Gang, C.C.; Zhou, W.; Chen, Y.Z.; Wang, Z.Q.; Sun, Z.G.; Li, J.L.; Qi, J.G.; Odeh, I. Quantitative assessment of the contributions of climate change and human activities on global grassland degradation. *Environ. Earth Sci.* **2014**, *72*, 4273–4282. [CrossRef]
41. Yang, Y.; Wang, Z.Q.; Li, J.L.; Gang, C.C.; Zhang, Y.Z.; Zhang, Y.; Odeh, I.; Qi, J.G. Comparative assessment of grassland degradation dynamics inresponse to climate variation and human activities in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013. *J. Arid Environ.* **2016**, *135*, 164–172. [CrossRef]
42. Evans, J.; Geerken, R. Discrimination between climate and human-induced dryland degradation. *J. Arid Environ.* **2004**, *57*, 535–554. [CrossRef]
43. Wessels, K.J.; Prince, S.D.; Malherbe, J.; Small, J.; Frost, P.E.; VanZyl, D. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *J. Arid Environ.* **2007**, *68*, 271–297. [CrossRef]
44. Zhang, C.X.; Wang, X.; Li, J.C.; Hua, T. Roles of climate changes and human interventions in land degradation: A case study by net primary productivity analysis in China's Shiyanghe Basin. *Environ. Earth Sci.* **2011**, *64*, 2183–2193. [CrossRef]
45. Zhou, W.; Li, J.L.; Mu, S.J.; Gang, C.C.; Sun, Z.G. Effects of ecological restoration-induced land-use change and improved management on grassland net primary productivity in the Shiyanghe River Basin, north-west China. *Grass Forage Sci.* **2013**, *69*, 596–610. [CrossRef]
46. Xu, D.Y.; Kang, K.X.; Zhuang, D.F.; Pan, J.J. Multi-scale quantitative assessment of the relative roles of climate change and human activities in desertification: A case study of the Ordos Plateau, China. *J. Arid Environ.* **2010**, *74*, 498–507. [CrossRef]
47. Zhou, W.; Gang, C.; Zhou, L.; Chen, Y.Z.; Li, J.L.; Ju, W.M.; Odeh, I. Dynamic of grassland vegetation degradation and its quantitative assessment in the northwest China. *Acta Oecol.* **2014**, *55*, 86–89. [CrossRef]
48. Ahlstrom, A.; Raupach, M.R.; Schurgers, G.; Smith, B.; Arneth, A.; Jung, M.; Reichstein, M.; Canadell, J.G.; Friedlingstein, P.; Jain, A.K. The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink. *Science* **2015**, *348*, 8958–8999. [CrossRef] [PubMed]
49. Zhou, W.; Gang, C.C.; Zhou, F.C.; Li, J.L.; Dong, X.G.; Zhao, C.Z. Quantitative assessment of the individual contribution of climate and human factors to desertification in northwest China using net primary productivity as an indicator. *Ecol. Indic.* **2015**, *48*, 560–569. [CrossRef]
50. Ma, Y.H.; Fan, S.Y.; Zhou, L.H.; Dong, Z.Y.; Zhang, K.; Feng, J.M. The temporal change of driving factors during the course of land desertification in arid region of North China: The case of Minqin County. *Environ. Geol.* **2007**, *51*, 999–1008. [CrossRef]
51. Millington, J.D.A.; Perry, G.L.W.; Romero-Calcerrada, R. Regression techniques for examining land use/cover change: A case study of a Mediterranean landscape. *Ecosystems* **2007**, *10*, 562–578. [CrossRef]
52. Wrbka, T.; Erb, K.; Schulz, N.B.; Peterseil, J.; Hahn, C.; Haberl, H. Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. *Land Use Policy* **2004**, *21*, 289–306. [CrossRef]
53. Cai, H.Y.; Yang, X.H.; Wang, K.J.; Xiao, L.L. Is Forest Restoration in the Southwest China Karst Promoted Mainly by Climate Change or Human-Induced Factors? *Remote Sens.* **2014**, *6*, 9895–9910. [CrossRef]
54. Wang, Y.; Tan, Y.G.; Bureau, Z.M. Research on the Variation of Vegetation NDVI and Its Relationship with Climate Factors in Northern China. *J. Shanxi Afric. Sci.* **2014**, *42*, 890–895. (In Chinese)
55. Chang, R.Y.; Fu, B.J.; Liu, G.H.; Liu, S.G. Soil carbon sequestration potential for "Grain for Green" project in Loess Plateau, China. *Environ. Manag.* **2011**, *48*, 1158–1172. [CrossRef] [PubMed]
56. Piao, S.L.; Yin, G.D.; Tan, J.G.; Cheng, L.; Huang, M.T.; Li, Y.; Liu, R.G.; Mao, J.F.; Myneni, R.B.; Peng, S.S.; et al. Detection and attribution of vegetation greening trend in China over the last 30 years. *Glob. Chang. Biol.* **2015**, *21*, 1601–1609. [CrossRef] [PubMed]

57. Yi, L.; Ren, Z.Y.; Zhang, C.; Liu, W. Vegetation cover, climate and human activities on the loess plateau. *Resour. Sci.* **2014**, *36*, 166–174. (In Chinese)
58. Cao, X.; Gu, Z.H.; Chen, J.; Liu, J.; Shi, P.J. Analysis of human_induced steppe degradation based on remote sensing in xilin gole, inner mongolia, China. *J. Plant Ecol.* **2006**, *30*, 268–277. (In Chinese)
59. Wang, Q.; Zhang, B.; Dai, S.P.; Zhang, F.F.; Zhao, Y.F.; Yin, H.X.; He, X.Q. Analysis of the vegetation cover chang and its relationship with factors in the Three-North Shelter Forest Program. *China Environ. Sci.* **2012**, *32*, 1302–1308. (In Chinese)
60. Zheng, Y.R.; Xie, Z.X.; Robert, C.; Jiang, L.H.; Shimizu, H. Did climate drive ecosystem change and induce desertification in Otindag sandy land, China over the past 40 years? *J. Arid Environ.* **2006**, *64*, 523–541. [CrossRef]
61. Wang, X.; Zhao, X.L.; Zhang, Z.X.; Yi, L.; Zuo, L.J.; Wen, Q.K.; Liu, F.; Xu, J.Y.; Hu, S.G.; Liu, B. Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010. *Catena* **2016**, *137*, 256–268. [CrossRef]
62. Herrmann, S.M.; Anyamba, A.; Tucker, C.J. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Glob. Environ. Chang.* **2005**, *15*, 394–404. [CrossRef]
63. Shi, Y.; Shen, Y.; Kang, E.; Li, D.L.; Ding, Y.J.; Zhang, G.W.; Hu, R.J. Recent and Future Climate Change in Northwest China. *Clim. Chang.* **2006**, *80*, 379–393. [CrossRef]
64. Zhai, P.M.; Zhuang, X.B.; Wan, H.; Pan, X. Trends in Total Precipitation and Frequency of Daily Precipitation Extremes over China. *J. Clim.* **2005**, *18*, 1096–1108. [CrossRef]
65. Mabutt, J.A. Impacts of carbon dioxide warming on climate and man in the semi-arid tropics. *Clim. Chang.* **1989**, *15*, 191–221. [CrossRef]
66. Nan, C.; Piao, S.L.; Chen, A.P.; Wang, X.H.; Lin, X.; Chen, S.P.; Han, S.J.; Zhou, G.S.; Zhang, X.P. Spring vegetation green-up date in China inferred from SPOT NDVI data: A multiple model analysis. *Agric. For. Meteorol.* **2012**, *165*, 104–113. [CrossRef]
67. Pimentel, D.; Pimentel, M. Global environmental resources versus world population growth. *Ecol. Econ.* **2006**, *59*, 195–198. [CrossRef]
68. Dewan, A.M.; Yamaguchi, Y. Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Appl. Geogr.* **2009**, *29*, 390–401. [CrossRef]
69. Luck, G.W.; Smallbone, L.T.; O'Brien, R. Socio-Economics and Vegetation Change in Urban Ecosystems: Patterns in Space and Time. *Ecosystems* **2009**, *12*, 604–620. [CrossRef]
70. Deng, L.; Shangguan, Z.P.; Li, R. Effects of the grain-for-green program on soil erosion in China. *Int. J. Sediment. Res.* **2012**, *27*, 120–127. [CrossRef]
71. Xiao, J.F. Satellite evidence for significant biophysical consequences of the "Grain for Green" Program on the Loess Plateau in China. *J. Geophys. Res.* **2014**, *119*, 2261–2275. [CrossRef]