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Vegetation Restoration in Response to Climatic and Anthropogenic Changes in the Loess Plateau, China

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Abstract: A thorough understanding of the vegetation succession in relation to both climatic changes and anthropogenic activities is vital for the formulation of adaptation strategies that address potential ecosystem challenges. Various climatic factors such as temperature, precipitation, and solar radiation, as well as anthropogenic factors such as ecological engineering and population migration, will affect the conditions for vegetation. However, the relationships among various factors remain unclear and the response of vegetation to climate change and anthropogenic activities in the Loess Plateau of China has not been well established. This study investigated the spatio-temporal characteristics and relationships between vegetation coverage and climatic factors in the Loess Plateau for the period of 1985–2015. Further analysis separated the anthropogenic and climatic factors on vegetation succession based on residual analysis. The results showed that the normalized difference vegetation index (NDVI) followed a significant upward trend with annual change rates of 0.15% during 1985–2015. The trend of human-induced NDVI increase was consistent with the spatial distribution of increasing forest areas in the eastern part of the Loess Plateau. Eco-restoration projects were the main driving factors that promoted vegetation coverage on the Loess Plateau. Furthermore, these results demonstrated that migrants to cities in the Loess Plateau could relieve ecological pressures and promote vegetation restoration. Therefore, the government should strive to increase population mobility and restore vegetation to sustain this particularly fragile ecological environment.

Keywords: vegetation restoration; climate change; anthropogenic activities; Loess Plateau; the Grain for Green Project

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1 Introduction

Vegetation plays a significant role in reflecting and characterizing the interchange of energy, soil ecosystems, carbon cycle, and regional human activities of the Earth's surface (Gelfand et al., 2011; Fu et al., 2017; Li et al., 2017). Vegetation succession is a complex and time-consuming process, which is influenced by climatic change, land-use change, ecological engineering, urbanization, and other factors (Jia et al., 2014; Cao et al., 2018). Under the influence of global warming and with the aim to achieve a sustainable development, research on the vegetation succession and its driving factors has become a global concern.

The Loess Plateau is located in the middle and upper reaches of the Yellow River and is an ecologically fragile zone and an area that is very sensitive to climate change (Liu et al., 2015; Fu et al., 2017). Loess is a highly erosion-prone soil that is susceptible to the forces of both wind and water (Feng et al., 2019). The Loess

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Plateau has long been known for its severe droughts, erosion, sparse vegetation, low agricultural productivity, and the poverty of its farmers (Liu et al., 2006). Recently, the Chinese government recognized the severity of these issues and recognized the region as significant for the ecological security of China as a whole. Consequently, large-scale ecological restoration and conservation programs have been implemented, such as the 'Natural Forest Conservation Program' and the 'Grain-for-Green Program' (Feng et al., 2016). The last few decades have also produced evidence of an accelerating trend of climate change in this region in particular and vegetation cover has been increasing on the Loess Plateau (Ostwald and Chen, 2006; Li et al., 2017; Liu et al., 2018a).

The normalized difference vegetation index (NDVI) has a good correlation with vegetation cover density, biomass, and the leaf area index, and is therefore widely used to monitor changes of vegetation cover (Tucker et al., 2005; Pinzon and Tucker, 2014). In general, changes in vegetation cover caused by both climate factors and human activities will affect global and regional vegetation green spaces. Discussions have been published with regard to the impacts of climate change and human activities on vegetation coverage change in the Loess Plateau (Jian et al., 2015; Li et al., 2017). Less attention has been focused on the long-term fluctuations of vegetation coverage variations. However, such long-term studies are required to detect the response of vegetation coverage to both climate change and human activities. Using a short-term analysis often fails to meet the requirements of dynamic changes of vegetation coverage and its response to both climate change and human activities. Thus, it likely yields a more precise result to extend the time series via continuous observation.

Moreover, previous studies only assessed vegetation changes and their responses to climate change and human activities, both individually and collectively (Evans and Geerken, 2004; Lioubimtseva, 2015; Wang et al., 2015; De Beurs et al., 2015). Several previous studies also investigated the influence of climate change and human activities on vegetation coverages variations in the Loess Plateau (Ostwald and Chen, 2006; Fu et al., 2017; Li et al., 2017). In association with these, the frequency and severity of extreme weather events, such as extreme precipitation, had increased in the lower Yellow River (Li et al., 2012), these events were essentially caused by climate change and exacerbated by the influence of human activities. In these evaluations, the process of vegetation restoration was affected both by climate change and human activities, which provided interactions between ecological effects and socio-economic driver (Wang et al., 2015; Liu et al., 2018b). However, most research concerning vegetation growth focused on the combined effects of climate change and human activity assesses via NDVI trends. Despite significant efforts that have been made to investigate the responses of vegetation variations to climatic change on the Loess Plateau (Xin et al., 2007; Yi et al., 2014), the effect of human activities on vegetation coverage has not been discussed under the background of lucid waters and lush mountains during the new period of China. In addition, time series analyses based on short periods often fail to meet the requirements of the dynamic change of vegetation cover and population migration before and after the implementation of afforestation projects. Therefore, the different contributions of both climate change and human activities to vegetation restoration in the Loess Plateau need to be further studied.

The aim of this study is as following: 1) what are the dynamic characteristics of vegetation in the Loess Plateau and their relationship with climatic factors. 2) How the impacts of climate change and human activities on vegetation change can be separated. 3) What are the trends of separated human-induced vegetation to the ecological restoration projects and the change of population migration. The obtained results provide a better understanding of the characteristics of vegetation change and the interaction between climate change and human activities. Furthermore, this paper provides important insights into the implementation of vegetation management and ecological restoration projects.

2 Data and Methods

2.1 Study area and data sources

The Loess Plateau of China (33°43′07″N–41°16′07″N, 100°54′07″E–114°33′07″E) is the deepest and largest loess deposit in the world. Its depth is more than 300 m, reaching an area of 6.4×10^5 km^2 in the middle and upper reaches of China's Yellow River (Huanghe River), including part of Shanxi, eastern Gansu, south central Ningxia, northern Shaanxi, central Inner Mongolia, western Henan, and northeastern Qinghai (Qu et al., 2019a). The Loess Plateau is also home to more than 50 million people (Wang et al., 2018). This area accounts for 6.67% of China's land area and feeds 8.5% of the Chinese population (Lü et al., 2012).

The Loess Plateau was divided into six natural zones: the hilly and gully loess, earth-rock mountain, irrigation, sand and desert, valley plain, and loess gully region (Fig. 1), according to the outline of the comprehensive Management Plan for the Loess Plateau Region (2010–2030) (Cao et al., 2018)

The area comprises three climatic zones (semi-humid, sub-arid, and arid) and has a temperate continental climate with a common amount of annual precipitation of 500 mm, ranging from 300 to 700 mm (Fu et al., 2016) and annual mean temperatures ranging from 4℃ to 14℃. The 400 mm annual precipitation isopleth divides the Loess Plateau into two distinct areas (southeast and northwest), and the boundary passes through Yulin, Jingbian, Huanxian, and northern Guyuan (Tsunekawa et al., 2014). The Loess Plateau has experienced a significant land cover change, especially with regard to reforestation due to the implementation of many ecological projects such as 'Grain-for-Green' and 'Gully-Land-Consolidation' (Liu and Li, 2017; Li et al., 2019). Therefore, under relatively suitable climate conditions, anthropogenic factors are greatly influencing vegetation restoration (Liu et al., 2018b).

The NDVI datasets used for this study were obtained from the National Oceanic and Atmospheric Administration (NOAA) and the dataset used version 3g.v0 with a spatial resolution of 1/12 degree and a temporal resolution of 15 d. Climate datasets, consisting of the daily temperature, and precipitation from 1985 to 2015 were obtained from the Chinese Meteorological Science Data Sharing Service Network (http://cdc.cma.gov.cn/home.do), and solar radiation were obtained from European Centre for Medium-Range Weather Forecasts ERA-interim (https://www.ecmwf.int/). The land use datasets were derived from the Landsat TM/ETM (Thematic Mapper / Enhanced Thematic Mapper) data at a spatial resolution of 30 m to show the land cover changes from 1990 to 2010 and are available from the Data Center for Resources and Environment Sciences, Chinese Academy of sciences (http://www.resdc.cn/). In detail, land cover data for 1990, 2000, and 2010 were produced and used for this analysis corresponding to population data. The population data within the Plateau, including permanent residents, immigration, and emigration, were derived from the fifth (2000) and sixth (2010) national censuses, which were conducted at county level with the latest data as the seventh (2020) national censuses had not been released. Both land use and population spatial distribution data were resampled and transformed to the same coordinate system to match the corresponding NDVI data.

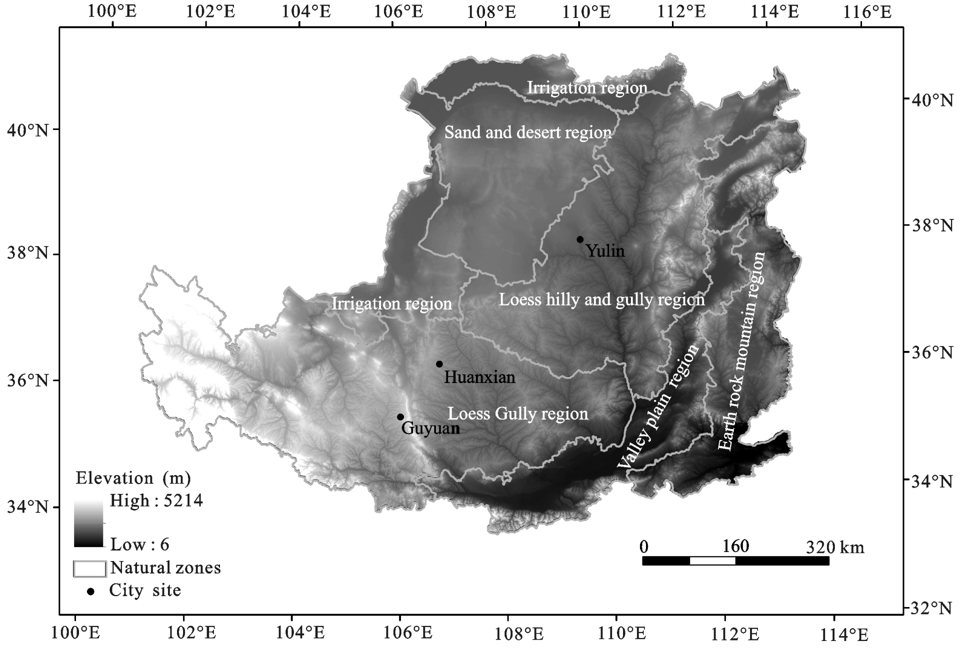

Fig. 1 The digital elevation map showing the boundaries and natural zones of the Loess Plateau, China

2.2 Methods

2.2.1 Regression model of the NDVI and climate factors

To establish an ideal regression equation between the NDVI and climate factors, it is theoretically necessary to select vegetation that is completely free of impacts of human activity (Wang et al., 2015). Since many projects or scale restoration measures have been implemented since 1999, it has been assumed that a balance existed between the vegetation system, human activities, and climatic factors in the study area before 1999. With the data on climatic factors being compiled over a five-year moving window, the data over the period of 1994–1998 was used to analyze the NDVI regression and climate change. The monthly mean statistics and the correlation of the annual NDVI and monthly precipitation (P), temperature (T), and solar radiation (R) were calculated for the five-year window.

2.2.2 Residual analysis

Residual analysis was utilized to separate the effects of climate and human activities on vegetation growth. This method could be used to identify the dominant drivers of vegetation dynamics by calculating the residuals between real NDVI and simulated NDVI (Wessels et al., 2012). The best relationship between NDVI and climatic factors was obtained when the multiple correlation regression was used. Moreover, the predicted NDVI could be computed using this relationship, and then, the NDVI residuals were acquired via the differences. According to the period before the implementation of the 'Grain-for-Green Project', the spatial relationship model between the NDVI and climate factors was established. Based on the climate data from 2001 to 2015, the climatic conditions have been defined as different climate change scenarios, thus simulating the spatial pattern of NDVI in each year without implementing ecological restoration and construction measures. Then, the residuals can be calculated via the differences between the observed NDVI and the simulated NDVI, which reflect the effects of human activities on vegetation trends (Peng et al., 2010).

2.2.3 Correlation analysis

Correlation analysis was applied to identify the relationship between climate change and vegetation coverage or the variation trends of vegetation and terrain factors.

3 Results

3.1 Temporal changes of vegetation coverage

By analyzing the trend of the annual average NDVI, the changes indicated a significant ascending trend for vegetation with annual change rates of 0.0015 during 1985–2015 (P = 0.001) (Fig. 2). For the entire Loess Plateau, peaks of the NDVI trend occurred in 1990 and 2012, and troughs were observed in 1993 and 2000.. The NDVI trend fluctuated considerably and presented a weak increase before 2000 and a trend of steadily positive growth in the 2000s, which was 5.7 times faster in the 2000s than that before 2000.

The rate of NDVI change (S) was calculated at the pixel scale and was classified as seven grades:1) significantly improved, $S > 0.010$; 2) moderately improved, $0.010 \geq S > 0.005$; 3) slightly improved, $0.005 \geq S > 0.001$; 4) unchanged, $0.001 \geq S > -0.001$; 5) slightly degraded, $-0.001 \geq S > -0.005$; 6) moderately degraded, $-0.005 \geq S > -0.010$; 7) seriously degraded, $S \leq -0.010$ (Hou et al., 2010) , and general trends of variation in NDVI of the Loess Plateau was given in Table 1. In the Loess Gully region, an area of 61 437.2 km^2 significantly improved over time, accounting for 44.82% of all the Loess Plateau significantly improved regions. The proportions of moderate improvement and slight improvement were 37.36% and 25.84% of the Loess Gully region, respectively; and the total degraded area was only 1.96%. Hilly and gully loess regions showed a similar pattern, and the significantly improved area covered 52 921.8 km^2 accounting for 38.60% of all significantly improved regions. The proportions of moderate

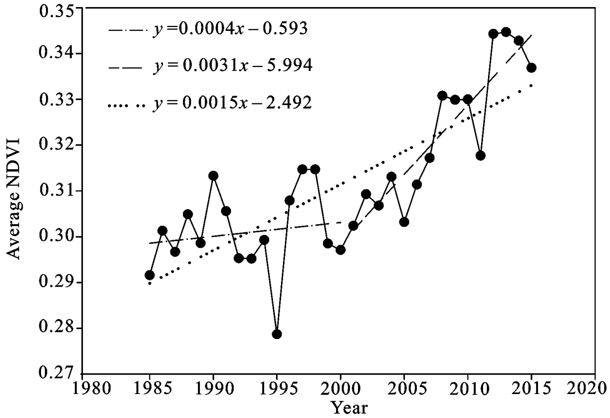

Fig. 2 Annual changes and linear trends of the average normalized difference vegetation index, (NDVI) in the Loess Plateau during 1985–2015

Table 1 Variation trend of normalized difference vegetation index (NDVI) during 1985–2015 in natural zones of the Loess Plateau (10 km^2)

Grade	Loess Gully region	Valley plain region	Irrigation region	Loess hilly and gully region	Sand and desert region	Earth-rock mountain region
Seriously degraded	20.69	127.89	17.50	0.00	19.07	64.59
Moderately degraded	55.16	383.66	99.15	12.69	19.07	284.20
Slightly degraded	310.29	590.72	379.12	171.33	374.96	813.85
Unchanged	703.32	468.92	606.59	368.04	1131.23	729.88
Slightly improved	5088.73	1516.39	2426.36	2588.98	5058.75	2816.18
Moderately improved	7350.39	2131.47	1843.10	5679.27	1525.25	2913.06
Significantly improved	6143.72	1181.44	460.78	5292.19	146.17	484.43
Total area	19672.30	6400.50	5832.60	14112.50	8274.48	8106.20

improvement and slight improvement were 40.24% and 18.35% of the region, respectively, the proportion of all the improved area was 96.09%, and the total degraded area was only 1.30%. In contrast, the valley plain region and earth-rock mountain region had a relatively high degraded proportion. In the valley plain region, the proportions of severely degraded and moderately degraded areas were 51.21% and 44.93% of all regions. Similarly, the proportion of moderate degradation in the earth-rock mountain region was 33.28%, and the degraded area covered 14.34% of all earth-rock mountains. The significantly improved area was 14617 km^2 in the sand and desert region, accounting for 1.77% of the sand and desert regions, and the proportion of degraded area was below 5%, indicating that most areas either remained unchanged or improved slightly. In the irrigation region, 81.10% of the areas in the NDVI improved, and the proportions of slightly improved, moderately improved, and significantly improved areas were 41.60%, 31.60%, and 7.90%, respectively.

3.2 Spatial distribution of vegetation coverage in the Loess Plateau

In the Loess Plateau, the largest revegetation project in the world, the 'Grain-for-Green Project', was launched in 1999. Since then, vegetation coverage began to increase (Fu et al., 2017), which was a turning point for the Loess Plateau. According to the vegetation coverage grade metods (Ding et al., 2009), the Loess Plateau based on their fractional coverage was divided into five categories: high coverage, moderately high coverage, moderate coverage, low coverage and bare soil. Coverage of more than 90% in the Loess Plateau increased significantly, especially in areas that previously had low and moderate coverage. The spatial variation of fractional vegetation coverage grades and the fractional vegetation rate of change on the Loess Plateau are shown in Fig. 3.

Most areas of the Loess Plateau had moderately high coverage in 2015. In the valley plain region and earth-rock mountain region, more than 90% of the area had high or moderately high coverage. In the valley plain region, 96.26% (6.16 × 10^4 km^2) of the area had high or moderately high coverage, 3.65% (2.34 × 10^3 km^2) had moderate coverage and the rest 0.09% (59.87 km^2) had low coverage, which was mostly distributed in the northeast. In the earth-rock mountain region, moderately high coverage and high coverage were 91.18% (7.39 × 10^4 km^2), 69.38% (5.62 × 10^4 km^2), and 21.80% (1.77 × 10^4 km^2), respectively. In the irrigation region, from north to south, the coverage increased gradually. Areas with moderate coverage were distributed in the middle, moderately high coverage, and high-coverage areas were mainly distributed in the south, occupying 25.23% (4.96 × 10^4 km^2), 48.77% (9.60 × 10^4 km^2) and 15.26% (3.01 × 10^4 km^2), respectively. Areas with low coverage and bare soil concentrated in the middle north of the loess gully region next to the irrigation region, accounting for 10.05% (1.98 × 10^4 km^2) and 0.68% (1.34 × 10^3 km^2), respectively; hilly and gully loess regions and sand and desert regions had relative low coverage. 40.80% of the hilly and gully loess region had moderately high coverage, which was mainly distributed in the east edge of the region. In the sand and desert region, 37.77% (3.12 × 10^4 km^2) of the area had moderately high coverage, which was concentrated in the east. The area with high coverage was small, accounting for 0.44% (366.94 km^2). Areas with low coverage and bare soil grades were distributed in the middle and west, occupying 46.93% (3.88 × 10^4 km^2) and 14.86% (1.23 × 10^4 km^2), respectively.

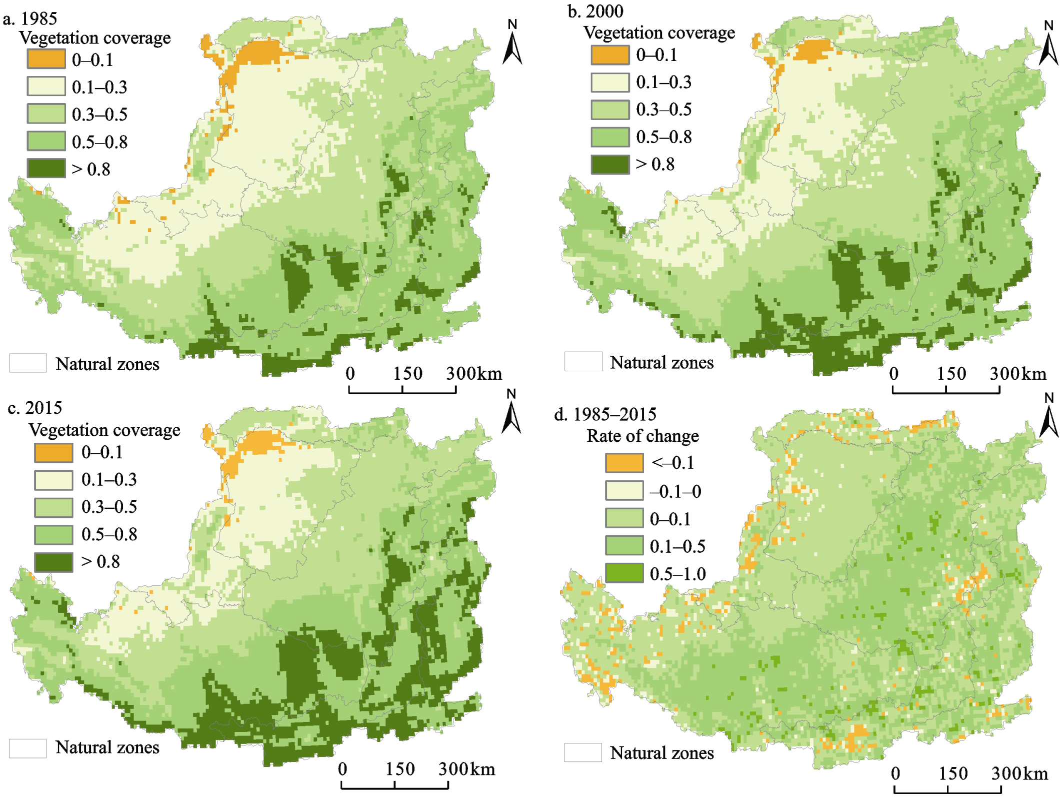

Fig. 3 Dynamic fractional vegetation coverage on the Loess Plateau in 1985(a), 2000(b), and 2015(c), and the change of vegetation coverage during 1985–2015 (d)

3.3 Trends of residual analysis

Residual analysis can be used to distinguish the effect of human activities on vegetation coverage. Random sampling of 16% of the pixels shows that the correlation coefficient between NDVI and climate change is significant at 95%.

Residual slopes of the Loess Plateau ranged between −0.0165 and 0.0355. The area of 28.47% was negatively distributed, mainly in the southwest of the irrigation region, the west of the loess gully area, and the south of the valley plain area (Fig. 4). In these regions, the increase of vegetation coverage did not meet the expectations, indicating that anthropogenic active negative or indeterminacy impact, such as land use change, urbanization, and agricultural production may lead to vegetation degradation. The area of 71.53% was positively distributed, mainly in the earth-rock mountainous areas and hilly and gully loess areas, almost all of which are distributed in the valley plain areas and desert areas, with minor distributions in the loess gully areas and irrigation areas. Vegetation coverage growth is higher than climate change expectations which suggesting that the increase of vegetation coverage is the result of the effectiveness of anthropogenic active positive impact, such as vegetation restoration ecological engineering, slope and river engineering measures, and the migration of the local population.

3.4 Relationship between vegetation growth trends and anthropogenic drivers

Under the influence of anthropogenic drivers, the Loess Plateau, especially during the decades, experienced a dramatic transformation, including land-cover and land-use change, ecological restoration projects and the building of terraces, dams, reservoirs landscape engineering (Fu et al., 2017). In addition, the development of industrialization and urbanization created more jobs, and much of the rural population moved to the cities, reducing their dependence on reclaimed cultivated land and broadening their sources of income (Cao et al., 2018). The population migration in the Loess Plateau resulted in great changes to the vegetation. On the basis of previous study, we focused on the relationship between

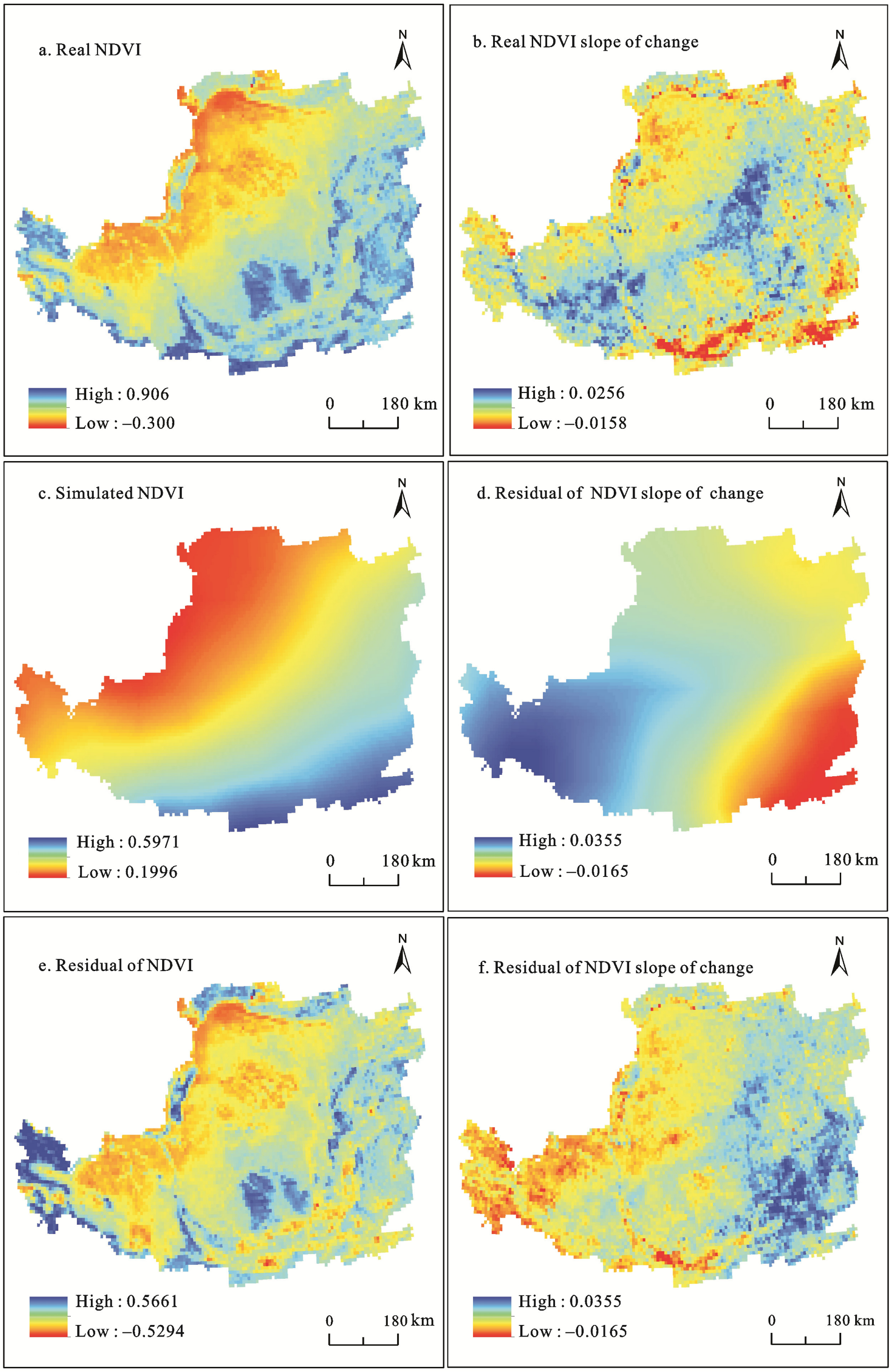

Fig. 4 Real normalized difference vegetation index, (NDVI) (a), stimulated NDVI (c), residual of NDVI (e) and corresponding slope of change (b, d, f) in the Loess Plateau during 2001–2015

vegetation growth trends and the population migration. Changes of the population migration rate was calculated from 2000 to 2010. Furthermore, the average population migration rate (M) was divided into six classifications (Table 2), which were separated by magnitude. The annual NDVI trends for these six classifications were all above 0. When M was above 0.1, the environmental conditions were clearly affected. Moreover, the rate change in population migration (RC) was also separated into six categories (Table 2). From the change of population migration rate among different classifications, the trends in annual NDVI increased constantly from RC1 to RC3 and the residual NDVI peaked when the rate change in population migration was RC2 (Fig. 5). So the population migration contributed to vegetation growth and alleviated the pressure of the ecosystem (Jia et al., 2014; Qu et al., 2019b).

Population mobility was correlated positively with annual NDVI ($r = 0.02$), while rate changes in population mobility were negatively correlated with annual NDVI ($r = -0.16$; $P < 0.01$). The results of spearman correlation analysis are shown in Fig. 6. The population migration rate of the remaining NDVI group was significantly positive ($r = 0.05$; $P < 0.01$), while that of the remaining NDVI group was negative ($r = -0.10$; $P < 0.01$), Especially when the population mobility changes were < -0.20 and ranging between -0.10 and 0, population migration decreased the people's interference with vegetation restoration. Areas with high migration rate, poor or primitive ecological environment, or rapid urbanization development are typically characterized by vegetation degradation.

Table 2 Classification standard of average and rate changes of population migration

Group	Average population migration rate	Group	changes of rate in population migration
M1	<−0.10	RC1	< −0.20
M2	[−0.10, −0.03)	RC2	[0.20, −0.10)
M3	[−0.03, 0)	RC3	[−0.1, −0.05)
M4	[0, 0.03)	RC4	[−0.05, 0)
M5	[0.03, 0.10)	RC5	[0, 0.10]
M6	≥ 0.10	RC6	≥ 0.10

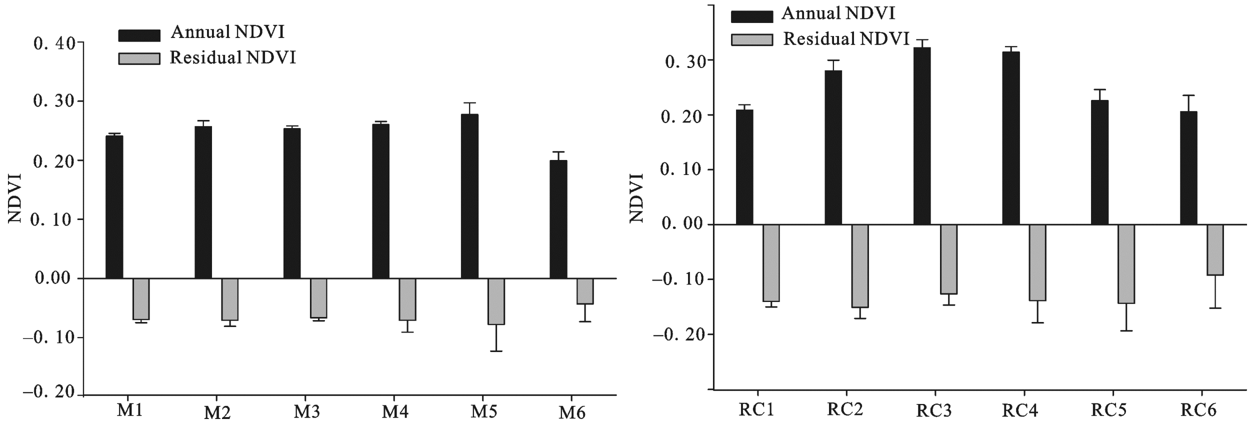

Fig. 5 Trends of annual NDVI and residual NDVI in different population migration groups. M1, M2, M3, M4, M5 and M6 represent different population migration rates in Table 2. RC1, RC2, RC3, RC4, RC5 and RC6 represent different change rates in population migration in Table 2

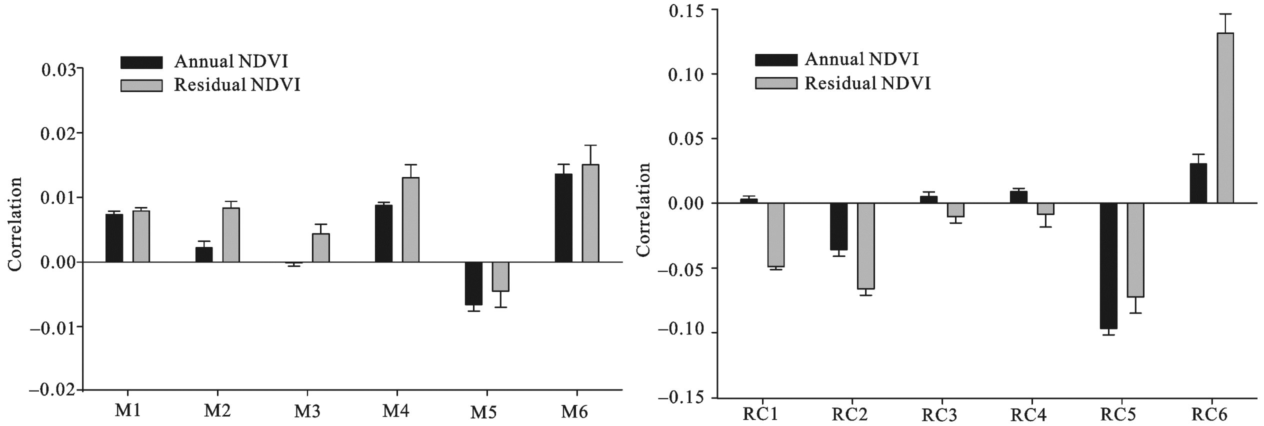

Fig. 6 Correlation between population migration (a) and rate changes in population migration (b) and the annual normalized difference vegetation index (NDVI) or residual NDVI in different population migration groups. M1, M2, M3, M4, M5 and M6 represent different population migration rates in Table 2. RC1, RC2, RC3, RC4, RC5 and RC6 represent different change rates in population migration in Table 2

4 Discussion

4.1 Trends of vegetation coverage and its response to separated climatic changes

The vegetation coverage of the Loess Plateau increased during the recent 30 yr, which is consistent with the results of previous studies (Wang et al., 2015; Cao et al., 2018). The improved procedure can be divided into two stages at around 2000. The vegetation coverage of the late period (2001–2015) was 5.7 times higher than that of the earlier period (1985–2000). Previous studies attributed this result to human activities, namely the transformation from farmland to forests (Zhu et al., 2016; Hua et al., 2017). Other studies attributed this to human activities and climate change arguing that the vegetation restoration of the Mu Us Sandy Land was the result of the joint effects of climate change, ecological restoration, and agricultural activities (Li et al., 2017). To separate and analyze the effects of climate and human factors on the NDVI, a residual analysis method based on the NDVI climate model was adopted in this study. Since the Loess Plateau is located in an area with limited water supply, precipitation greatly impacts vegetation, and precipitation has become a restrictive factor for vegetation growth in most areas. The response of vegetation coverage on the Loess Plateau to precipitation is stronger than that of temperature, which is consistent with previous research (Sun et al., 2015; Wang et al., 2017).

4.2 Human-induced contribution to vegetation restoration

Long-term climatic and anthropogenic changes have restored the diverse land-use types of the Loess Plateau (Zhou et al., 2014). In this process, human activities are the principal influencing factors for long term vegetation restoration. Therefore, the quantitative determination of the impact of human factors on vegetation change is very important to optimize the follow-up management of vegetation ecosystem. This study shows that human activities exert positive effects (in the southwest and central regions), negative effects (in the West and North regions), and no significant effects on vegetation change. A strong consistency exists between areas where human factors exert a positive impact on NDVI and areas where forest land increased in the middle of the Loess Plateau. Land use change caused by afforestation is the main anthropogenic factor that promotes vegetation growth in the Loess Plateau, which is consistent with the previous findings (Liu , 2015; Fu et al., 2017). The area of returning farmland to forest is mainly distributed in the northern margin of the sandy area, while the negative effects of human factors on vegetation are mainly concentrated in irrigation areas and desert areas. One reason for this specific concentration of this negative impact in these areas is that over the past few decades, vegetation types have changed. Large deciduous broad-leaved forests have been replaced by orchards and other economically attractive forests, woodlands, shrubs, and grasslands (Wang et al., 2018). In addition, the construction of check dams and gully reclamation measures have been implemented in the gully area, which has consequently increased the area of cultivated land and increased the productivity of cultivated land (Liu and Li, 2017). Although all land with a slope exceeding 15 degrees is used for purposes other than farmland, the main function of the NDVI value is less than that of large-area broadleaf forests. Moreover, the afforestation efficiency of sandy and desert areas in western China is relatively poor, which also leads to a negative value of NDVI residues in the Loess Plateau (Xin et al., 2007).

4.3 Impact of migration population on vegetation trends

The development of industrialization and urbanization created a large number of non-agricultural jobs, which enabled farmers to leave the rural land, reduced their dependence on traditional crops, and promoted the abandonment of sloping farmland (Liu et al., 2015). In addition, industrialization and urbanization have also attracted rural population to cities, thus reducing their interference on vegetation restoration, and creating a positive environment for ecological restoration. In the entire Loess Plateau, the urbanization rate and the floating population of the county reflect the change of human disturbance to a certain extent. Both have significant positive correlations with the trend of the national development index ($P < 0.05$) (Cao et al., 2018). In addition, the migration of the rural population to cities promoted the transformation of energy consumption structure of rural households, thus leading to the transformation of traditional fuel wood to clean, efficient, and environmentally friendly energy, as well as the rural transformation (Qu et al., 2017; Liu, 2018).

4.4 Potential applications and some limitations in our assessment

Based on the simplicity of evaluation method, TPR (temperature, precipitation and solar radiation)-based NDVI model and the non-linear regression evaluation method of anthropogenic contributions to vegetation cover change could have some potential applications in other regions with large-area human activities besides the Loess Plateau region. However, there are some limitations in our assessment. Firstly, there are uncertainties in data combination from different sources. The NDVI data used in this study are from the National Oceanic and Atmospheric Administration (NOAA) the version 3g.v0 data set with spatial resolution of 8 km, while the climate data set is from the meteorological station. Although these data are converted into annual average temperature and precipitation by Kriging interpolation method with spatial resolution of 8 km to match NDVI, it is difficult to ensure complete consistency. The disadvantage of regression method also leads to uncertainty, that is, non-linear regression method can not fully describe the relationship between NDVI and environmental variables as vegetation cover change is a complex multi-period interaction process. What's more, other factors affecting vegetation change, such as evaporation, atmospheric carbon dioxide concentration, nitrogen deposition and water-rich, should also be considered. In addition, frequent extreme weather events in recent years have become a serious threat to the growth of vegetation (Sun et al., 2016).

5 Conclusions

This study analyzed the space-time variability of vegetation coverage in the Loess Plateau during 1985–2015 using the NDVI data. The contributions of climate change and human activities to vegetation restoration were separated based on a spatial NDVI-climate gridded model using residual analysis. The results show that an overall slightly increasing trend in vegetation was prevailing during 1985–2000 in the Loess Plateau, while a significant increasing trend was found from 2001 to 2015. The area with the highest growth was the gully area of the Loess Plateau. The Loess Plateau experienced increased temperature and decreased precipitation. Areas with ecological restoration forest coverage increased from 14.47% to 21.7% during 2001–2010. In the valley plain region and earth-rock mountain region, more than 90% of the area had high or moderately high coverage, especially in the valley plain region. Residual slopes of the Loess Plateau ranged between −0.0165 and 0.0355. The area of 28.47% was negatively distributed, mainly in the southwest of the irrigation area, the west of the loess gully area, and the south of the valley plain area. The area of 71.53% was positively distributed, mainly in the earth-rock mountainous areas and hilly and gully loess areas, almost all of which were distributed in the valley plain areas and desert areas, with minor distributions in the loess gully areas and irrigation areas. Furthermore, population migration to cities also contributed to ecological restoration. The population migration decreased the negative disturbance to forestland, and promoted vegetation restoration by facilitating the abandonment of sloping farm land. From the perspective of social-economic-ecological functions. principal influencing factors Future research will focus on the driving mechanism of emigration evolution and its resource and environmental effects

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