Front. Earth Sci. 2014, 8(1): 93–103
DOI 10.1007/s11707-013-0390-y

RESEARCH ARTICLE

The impacts of climate change and human activities on grassland productivity in Qinghai Province, China

Fang YIN[1,2,3], Xiangzheng DENG (✉)[2,3], Qin JIN[4], Yongwei YUAN[5], Chunhong ZHAO[1,2,3]

1 Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
2 University of Chinese Academy of Sciences, Beijing 100049, China
3 Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China
4 School of Mathematics and Physics, China University of Geosciences, Wuhan 430074, China
5 Faculty of Resource and Environmental Science, Hubei University, Wuhan 430062, China

Abstract Qinghai Province, which is the source of three major rivers (i.e., Yangtze River, Yellow River and Lancang River) in East Asia, has experienced severe grassland degradation in past decades. The aim of this work was to analyze the impacts of climate change and human activities on grassland ecosystem at different spatial and temporal scales. For this purpose, the regression and residual analysis were used based on the data from remote sensing data and meteorological stations. The results show that the effect of climate change was much greater in the areas exhibiting vigorous vegetation growth. The grassland degradation was strongly correlated with the climate factors in the study area except Haixi Prefecture. Temporal and spatial heterogeneity in the quality of grassland were also detected, which was probably mainly because of the effects of human activities. In the 1980s, human activities and grassland vegetation growth were in equilibrium, which means the influence of human activities was in balance with that of climate change. However, in the 1990s, significant grassland degradation linked to human activities was observed, primarily in the Three-River Headwaters Region. Since the 21[st] century, this adverse trend continued in the Qinghai Lake area and near the northern provincial boundaries, opposite to what were observed in the eastern part of study. These results are consistent with the currently status of grassland degradation in Qinghai Province, which could serve as a basis for the local grassland management and restoration programs.

Keywords climate change, human activities, grassland degradation, spatial distribution, residual analysis

Received February 26, 2013; accepted May 23, 2013

E-mail: dengxz.ccap@igsnrr.ac.cn

1 Introduction

Grassland degradation is defined as the deterioration of ecological and evolutionary processes in a grassland ecosystem. Specifically, its structural characteristics, energy flows, nutrient cycles, and biological communities (plant, animal, and microbial communities) are festered. In general, grassland degradation includes the degradation in the quality, productivity, economic potential, biological diversity of grass or complexity and resilience of grassland ecosystem as well as the deterioration in the local environment and recovery functions (Olivia et al., 2011). These negative results may be traced to human activities and/or natural factors (Yang et al., 2007; Xu et al., 2009) Grasslands represent the largest ecosystem in Qinghai Province, China, where it plays a dominant role in maintaining the service functions of other regional ecosystems (Rubio and Bochet, 1998; Wang and Cheng, 2001). Owing to the special location on the Qinghai-Tibet plateau, where is characteristic by cool and semi-arid climate, the grassland resources not only provide the basis of the local economy based on animal husbandry, but also play an important role in the soil and water conservation and biodiversity conservation in the headstreams of the Yangtze River, Yellow River and Lancang River. The local grassland has exhibited a steady trend of comprehensive degradation during past decades, with negative effects on the local ecosystems and quality of life (Reynolds and Stafford-Smith, 2002; Fu et al., 2007; Liu et al., 2008; Huang et al., 2009; Liu et al., 2011; Ouyang et al., 2012). The area of grassland under severe degradation was 0.12×10^8 hm^2 in 2008, accounting for 58% of the total area of grassland. Compared with that in the 1950s, the current yield per unit area has decreased by 30%–50%. Furthermore, the proportion of high quality forage grass has decreased by 20%–30%, while that of grasslands of poisonous and harmful weeds has increased by 70%–80%. In addition, the total grassland vegetation coverage has decreased by 15%–25% and the favorable grass height has decreased by 30%–50%. During the 1980s and 1990s, the mean grassland degradation rate near the source of the Yellow River increased in comparison to that in the 1970s (Zhao et al., 2000; Zhao and Zhou, 2005). In addition to the pre-existing accumulative negative effects of serious overgrazing, the grassland degradation in the Qinghai-Tibet Plateau has further aggravated because of climate change and become a major socioeconomic and ecological issue (Cui et al., 2007). In view of the key roles of grasslands in the provision of ecosystem services, it is of great importance to ascertain the key influencing factors of grassland degradation (Meadows and Hoffman, 2002) and their temporal and spatial variation and analyze how these factors influence the grassland degradation (Nicholson et al., 1998; Nicholson, 2005; Salvati and Zitti, 2005, 2008, 2009), all of which are essential for providing realistic recommendations on the grassland restoration (Kosmas et al, 2000; Henderson-Sellers et al., 2008).

Various studies have been conducted to investigate the causes of grassland degradation (Fu et al., 2007; Salvati et al., 2008), and the climate change and excessive grazing are found to be the most influential factors of grassland degradation. Li (2011) systematically analyzed the current resource utilization and environmental challenges in the Three-River Headwaters Region and concluded that the human activities in past decades were the major reason for grassland degradation, probably because the impacts of climate change work more slowly (Hoffman and Todd, 2000). It is evident that climate change and human activities are the main factors resulting in grassland degradation (Zheng et al., 2006), where natural factors and pre-existing ecological fragility play a certain role underlying this process (Tanrivermis, 2003).

However, little is known about the quantification and characterization of the differences between the impacts of climate change and human activities (Latorre et al., 2001; Feoli et al., 2002; Feoli et al., 2003), which could serve as a basis for grassland recovery. Some studies based on the data retrieved from remote sensing have been conducted to investigate this issue with various methods (Hill et al., 2008), among which the residual analysis can isolate the influence of human factors (Latorre et al., 2001) through analyzing the specific relationship between climate change and change in grassland vegetation (Evans and Geerken, 2004). The residual analysis can not only identify human factors but also characterize separately the influences of climate change and human activities. Elhag and Walker (2009) explored the influence of climate change and human activities on land desertification in the arid and semi-arid regions of Sudan with the regression analysis and residual analysis on the basis of the remote sensing data.

The aim of this study was to investigate the effective method to analyze the various impacts of climate change and human activities on grassland ecosystems, and provide a strong scientific foundation for the targeted restoration and management of grasslands in Qinghai Province. For this purpose, a set of grid data from multiple sources (i.e., remote sensing and meteorological observation), were firstly collected and processed in this study. Then the regression and residual analysis were used to separate the impacts of climate change on grassland from that of human activities.

2 Materials and methods

2.1 Overview of the study area

Qinghai Province is located in northwestern China (89°35' E to 103°04' E and 31°40' N to 39°19' N). The entire province is a plateau with an average elevation of 3,000 m and comprises of complex terrain and diverse landforms. The climate is dry and continental with low annual rainfall and high evapotranspiration. The annual average temperature and precipitation range from −5.7°C to −8.5°C, and 50 mm to 450 mm, respectively. The province is the source of three major rivers in East Asian (Yangtze River, Yellow River and Lancang River). Qinghai Lake, which is the largest inland saltwater lake in China, is also located in this province. The total area in Qinghai Province is 721,654 km^2, accounting for 7.69% of the total land area in China. However, most of this land is of poor soil quality, comprising parts of the Gobi Desert and badlands subject to wind erosion. As a result, 42% of the land in the province is unsuitable for either farming or grazing, consequently grassland accounts for 53% of the land area (Fig. 1).

2.2 Research approach

In general, residual analysis involves an initial regression analysis between grassland productivity (represented as NDVI) and climatic factors. The residuals between the actual NDVI values and those predicted values based on climatic conditions are assumed to equate to the contribution of human activities. This approach highlights the impacts of climate change and human activities on grasslands, but neglects other influencing factors. Qinghai Province is a typical region with fragile regional ecosystems, which means any study on grasslands needs to consider the effects of the natural environment as well. Compared with the impacts of human activities and climatic factors, those of the natural environment are inherent. To some degree, the coefficients of regression between NDVI and climatic factors may reflect the distinct impacts of the natural environment in separate pixels. Furthermore, the temporal impacts of the natural environ-

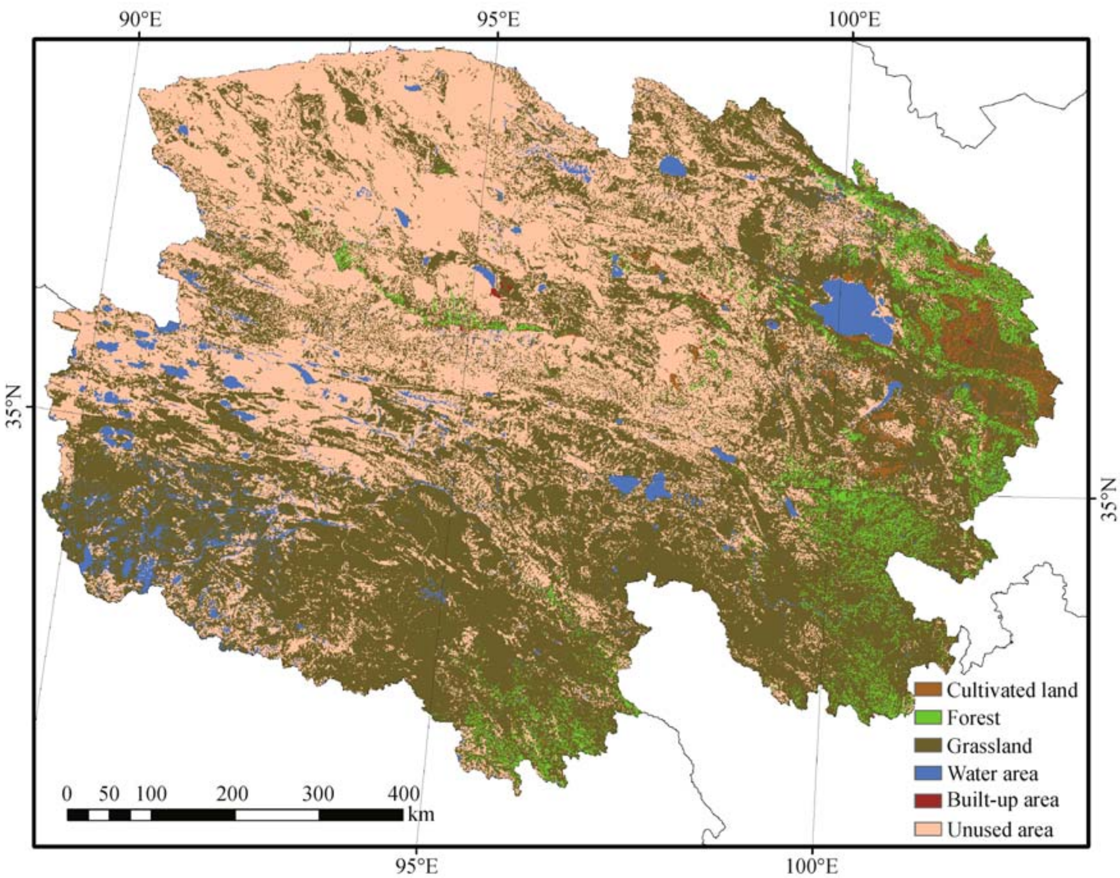

Fig. 1 Location of the study area and distribution of land use types.

ment and that of human activities are both reflected by the residuals. However, over a relatively short period, the effect of human activities becomes more obvious than that of the natural environment, thereby masking the contribution of the latter. Therefore, we believe that the residuals could also be because it can reflect the contributions of human activities alone. In comparison, if the inter-annual changes in residuals show random variation around zero, it indicates that human activity has no significant impacts on the grassland ecosystem. On the other hand, a downward trend in these inter-annual changes indicates grassland degradation because of a human-induced decrease in grassland productivity. In this study, we adopted a fitting method between the lag terms and the *n*-times power terms of precipitation, temperature and NDVI, in order to determine the respective effects of both temperature and precipitation on NDVI based on an R^2 set. This set consisted of every 1 km×1 km pixel in Qinghai Province. Based on this, we subsequently conducted residual analysis. To account for differences in the impacts of human activities in different years (Bakr et al., 2012), the period from July 1980 to July 2008 was divided into three sub-periods: July 1981 to December 1990, January 1991 to December 2000 and January 2001 to July 2008. Residual analysis was conducted separately in each of these temporal categories to resolve spatial differences in the impacts of human activities on grassland ecosystems in different time periods.

2.3 Indicators and data

2.3.1 Indicator selection

NDVI is one of the most commonly used indicators for vegetation monitoring (Tucker, 1979; Tucker et al., 1991), and previous studies have shown that NDVI is strongly correlated with the green vegetation coverage (Beck et al., 2006; Elhag and Walker, 2009). However, such vegetation includes not only grassland, but also farmland and forest land. We calculated the grid component proportions of six kinds of land use types (arable land, woodland, grassland, waters, construction land and unused land) in each grid in 1988, 1995, and 2005 and used them in the following formula:

$$I = G/(G + C + F), \quad (1)$$

where I represents the contribution of grassland to NDVI; and G, C, and F denote the grid component proportions of grassland, arable land, and woodland, respectively. If $I = 1$, it indicates that the entire grid is composed of grassland. If $G + C + F = 0$, we set $I = 0$.

To distinguish the impacts of climate change and human activities on grasslands, previous studies usually used either precipitation (Wessels et al., 2007; Elhag and Walker, 2009; Ferrara et al., 2012) or temperature (Evans and Geerken, 2004; Cao et al., 2006) as the climate indices. However, between 1980 and 2010, precipitation in Qinghai Province fluctuated widely (Fig. 2(a)), and temperature in this region experienced a significant increase (Fig. 2(b)). Therefore, both precipitation and temperature over the past 30 years should be incorporated into the characterization of climate change.

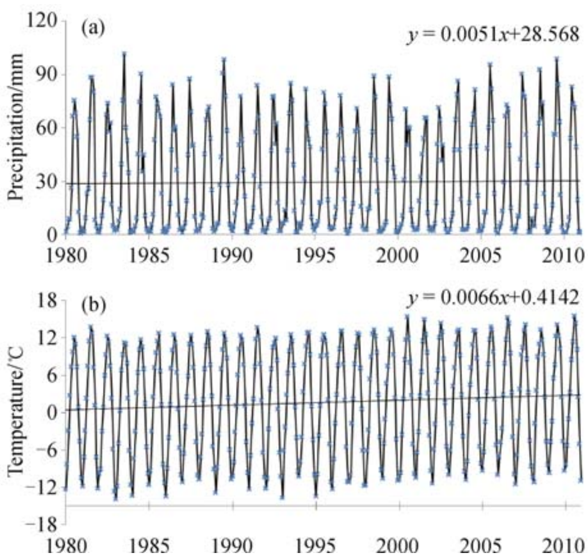

Fig. 2 Variation in annual precipitation and annual average temperature in Qinghai Province between 1980 and 2010.

2.3.2 Data sources and processing methods

Some of the NDVI data used here was obtained from the GIMMS NDVI dataset produced by the GLCF (Global Land Cover Facility) research group at the University of Maryland (Prince, 1987; Prince and Goward, 1995; Running et al. 1999; Anyamba and Tucker, 2005) from July 1981 to December 2006, with a spatial resolution of 8 km × 8 km and a temporal resolution of 15 days. SPOT VEGETATION data (ten day ensembles) were derived from a dataset developed over the period April 1998 to December 2010, with a spatial resolution of l km × l km. Based on the period when the two datasets overlapped (1998 to 2006), we performed correlation analysis between the maximum monthly NDVI and other factors, following which we established a linear regression equation to extend the GIMMS (Global Inventory Modeling and Mapping Studies) dataset from 2007 to 2008. This helped eliminate any sensor errors in the other two datasets (Zhang et al., 2011). To ensure data quality, we used reliable and internationally recognized data pretreatment processes (Townshend et al., 1994). In order to eliminate cloud contamination effects and the noise caused by other atmospheric phenomena, we included a smoothing method proposed by Chen et al. (2004) based on the Savitzky-Golay filter.

Daily temperature and precipitation data (together referred to as climatic data here after) between 1980 and 2008 were obtained from 39 meteorological stations run by the China Meteorological Administration (Fig. 3), and these original data were interpolated into 1 km × 1 km grid data. For temperature, the interpolation method was based on the latitude, longitude and DEM (Pan et al., 2004), while precipitation was interpolated with the Kriging interpolation method. Since climate data exhibits large magnitude differences at both the daily and seasonal scales, we measured the relationship between NDVI and monthly average temperature and monthly precipitation during the research period.

3 Results and discussion

3.1 Impacts of climate change and human activities on grassland degradation

As shown in Table 1, I values was greater than 0.5 over 95% of the grids in the study area, which indicate that NDVI could be used as grassland vegetation index for the purposes of this study. There is often a small lag effect of precipitation and temperature on NDVI. In addition, previous studies found that these relationships were always non-linear. Precipitation and temperature above or below the optimal levels for grass vegetative growth will have adverse effects on NDVI. Therefore, we used monthly precipitation, temperature and NDVI data to generate precipitation and temperature lag variables with different power terms. These were then subjected to a goodness-of-fit test against NDVI (Table 2).

Based on the goodness-of-fit test, the best relationship (R^2= 0.9143) was obtained with a quadratic fit of temperature and precipitation to NDVI. Thus, in each grid pixel, NDVI is positively related with the second order lag of precipitation (P_{t-2}) and temperature squared (T^2).

$$NDVI = a \cdot T^2 + b \cdot P_{t-2} + c. \qquad (2)$$

The correlation coefficients in the regression model are shown in Fig. 4. Within Qinghai Province, NDVI shows a strong response to climate change when the correlation coefficient was greater than or equal to 0.5. In terms of spatial distribution, the correlation coefficient showed a gradually increasing trend from northwest to southeast on the whole.

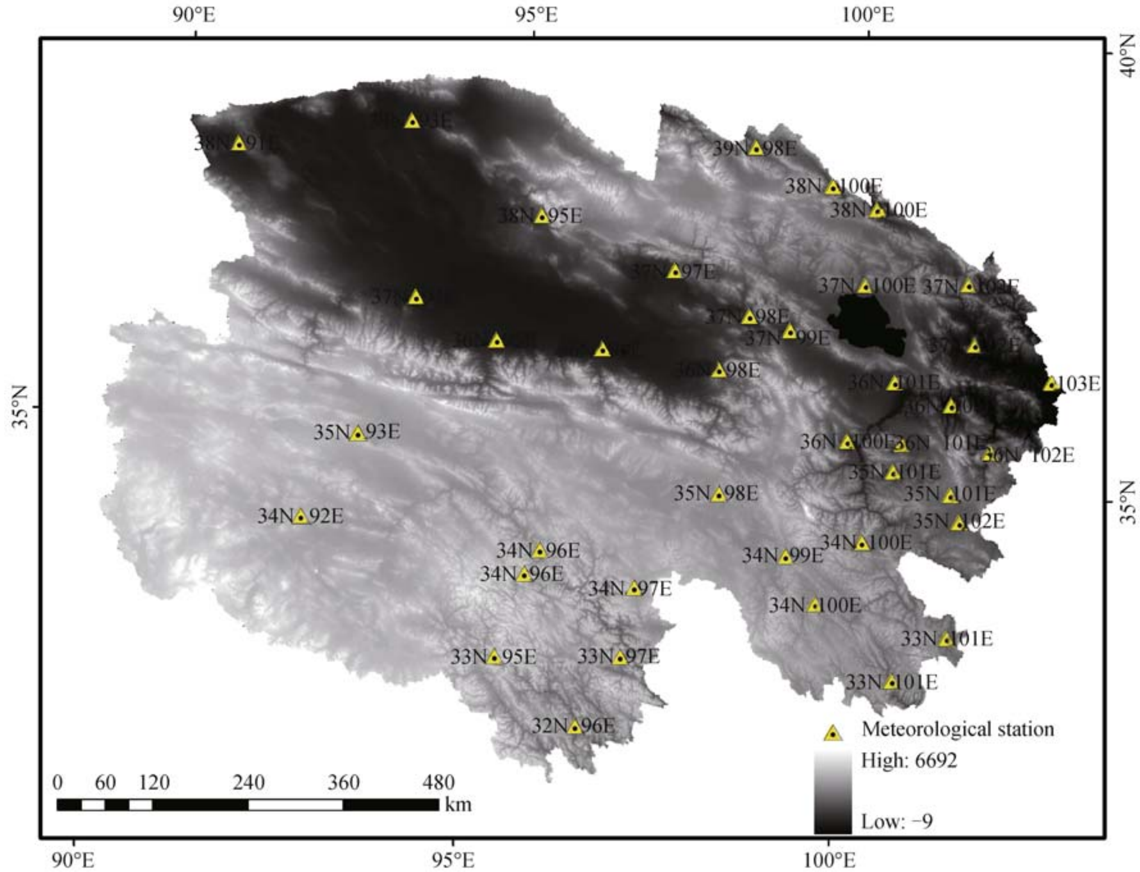

Fig. 3 Distribution of meteorological stations in Qinghai Province.

Table 1 Grid component proportions at different levels of contribution rates (I) of grassland to NDVI

Year	$I = 1$	$0.5 < I < 1$	$I > 0.5$	$0 < I < 0.5$	$I = 0$	$I < 0.5$
1988	86.00	9.11	95.11	4.11	0.78	4.89
1995	86.71	8.52	95.23	3.95	0.83	4.78
2005	86.56	8.52	95.08	3.90	1.03	4.93
Average	86.42	8.71	95.13	3.98	0.88	4.86

Table 2 The goodness-of-fit test with precipitation (P) and temperature (T) lag variables with varying powers against NDVI (R-Squared values)

	P	P^2	P^3	P_{t-1}	P_{t-2}	P_{t-3}
T	0.7867	0.7873	0.7863	0.8934	0.8913	0.8742
T^2	0.7079	0.7923	0.7911	0.9110	0.9143	0.8918
T^3	0.7851	0.7498	0.7346	0.8985	0.8769	0.8302
T_{t-1}	0.8891	0.8926	0.8877	0.8731	0.8778	0.8878
T_{t-2}	0.8155	0.7682	0.6915	0.7977	0.4552	0.6761
T_{t-3}	0.7777	0.6697	0.5322	0.8116	0.5790	0.0700

Next, we characterized this coefficient at the county scale, eliminating those extremely low values (mean of 0.13) in the Haixi Mongolian and Tibetan Autonomous State in the north. The coefficients were all greater than 0.75 in the east part, including Datong, Huangzhong, Huangyuan counties, and in the southeast, including Zeku,

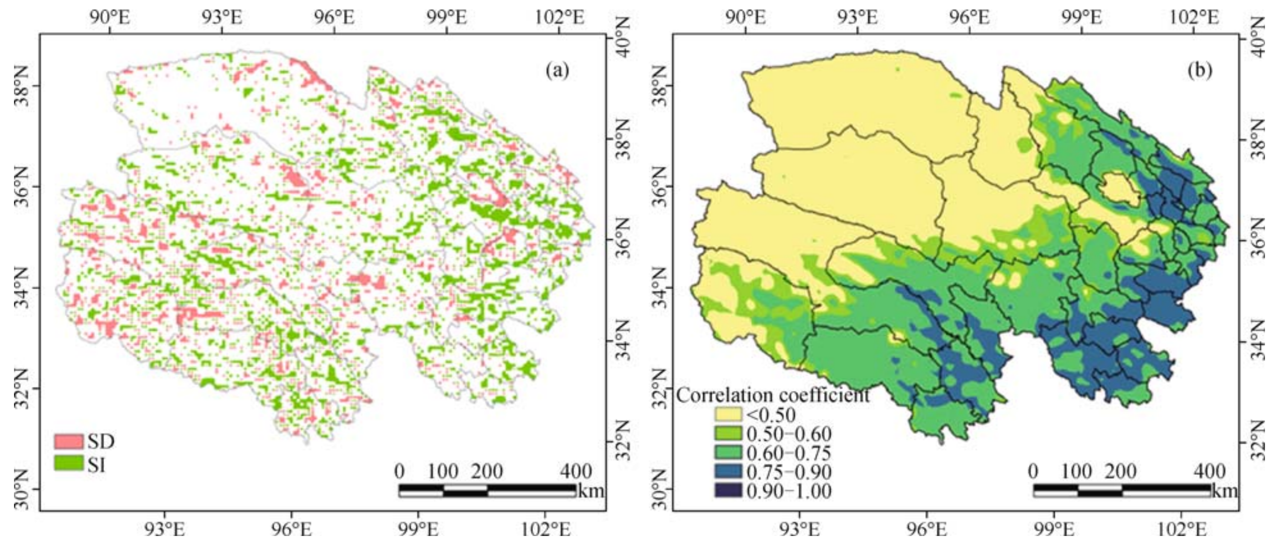

Fig. 4 Significance of NDVI trends (SD and SI denote the significance of decreasing and increasing trends respectively) (a); Distribution of correlation coefficients of climatic factors with NDVI (b). All measurements span the period of 1981–2008.

Henan, Gande, Dari, and Jiuzhi counties (Table 3). Thus, precipitation and temperature displayed a very significant correlation with grass growth and productivity in most part of the study area from 1981 to 2008.

We established regression relationships between NDVI and climatic factors in each pixel and performed a time series analysis to obtain the corresponding residuals from July 1981 to July 2008 every ten-years as well as over the entire 30 years (Fig. 5(a)). The mean residual slopes were between -0.0005 and 0.0005. This suggests that human activities had little effects on grass growth during past 30-years on the whole. On the other hand, more than 90% of the residual slopes were negative, particularly in the regions bordering Qinghai Lake, which indicates that human activities had a widespread negative impact on grass growth, particularly near the lake.

During the period of 1981–1990, the average residual slope was -0.13×10^{-3} (Fig. 5(b)), but most of the residual slopes were distributed around 0. No strong trend was noticed with respects to increasing or decreasing residuals. Residual negative slopes were primarily observed in the southern part of the province such as the counties of Zhiduo, Dari, and Maduo, and in certain northeastern parts of the province, including the counties of Qilian, Tianjun, and Gangcha. The positive residuals distributed primarily in the northern and eastern parts of the province, especially in the eastern parts of Datong, Dule, and Guide counties, where absolute values were relatively large. There was a

Table 3 Correlation coefficients between NDVI and climatic factors in various cities and counties of Qinghai Province

County	Correlation coefficient	County	Correlation coefficient	County	Correlation coefficient
Xining	0.7471	Tongren	0.7370	Maduo	0.6601
Datong	0.7958	Jianzha	0.7165	Yushu	0.7367
Pingan	0.7452	Zeku	0.7789	Zaduo	0.6867
Minghe	0.7341	Henan	0.7874	Chengduo	0.7305
Dule	0.7057	Gonghe	0.5477	Zhiduo	0.4321
Huangzhong	0.8176	Rongde	0.7123	Nangqian	0.7099
Huangyuan	0.8118	Guide	0.5734	Qumalai	0.5973
Huzhu	0.7761	Xinghai	0.6462	Haixi	0.1304
Hualong	0.6469	Guinan	0.6067	Geermu	0.3142
Dunhua	0.7327	Maqin	0.7258	Delingha	0.2901
Menyuan	0.6975	Banma	0.7441	Wulan	0.4341
Qilian	0.6574	Gande	0.7663	Dulan	0.3751
Haiyan	0.7033	Dari	0.7610	Tianjun	0.5470
Gangcha	0.7166	Jiuzhi	0.7555		

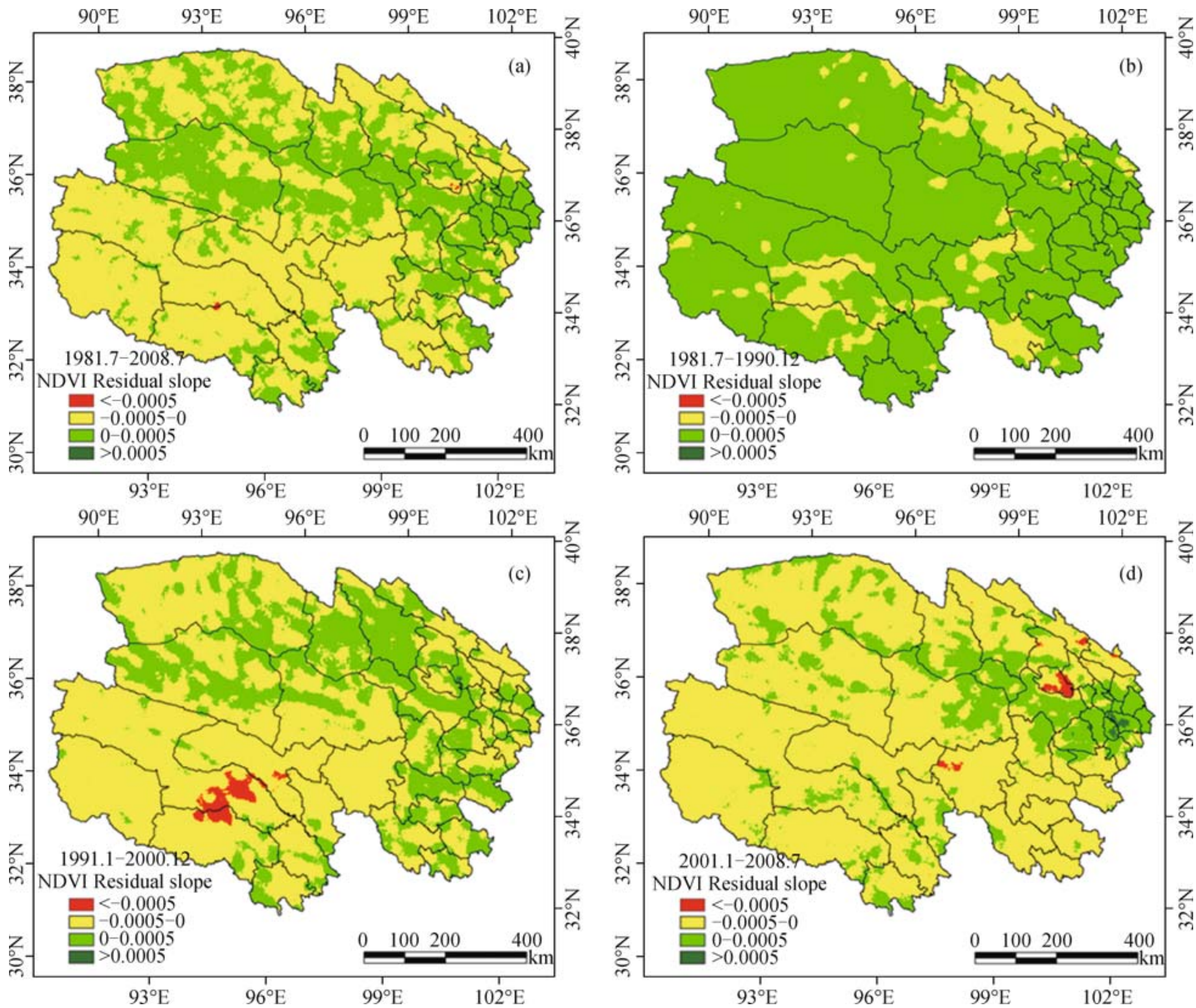

Fig. 5 Spatial distribution of residual slopes for NDVI in different periods.

sharp separation between the zones with positive and negative residuals. This indicates that human activities had a marginal impact on grassland productivity over the period 1981–1990; furthermore, human activity appeared to inhibit grassland degradation in the counties with relatively large positive residuals.

In contrast to the aforementioned trends in the 1980s, the range and spatial distribution in the residual slopes were very different over the period 1991–2000 (Fig. 5(c)). The areas with negative residual slopes in the western regions of the province displayed evidence of significant expansion since the preceding decade, particularly in the Three Rivers Headwaters Region. In this region, the absolute values of the negative residual slopes were significantly higher than those in other regions. These observations suggest that in the 1990s, the negative impacts of human activities on grasslands expanded and escalated relative to the 1980s, especially in the Three-River Headwaters Region.

The residual slopes exhibited a more dispersed pattern in comparison to that in the 1990s after 2000 (Fig. 5(d)). The area of regions with the largest absolute values of negative slopes decreased, opposite to what were observed in the largest absolute values of positive slopes. In certain areas, such as the regions bordering Qinghai Lake (Jianzha and Hualong counties), the absolute values of the negative residuals increased significantly. This suggests that range of activities has increased over time, which has consequently eased the negative impacts in most of the region. This was reflected in the improved grassland productivities in eastern counties after 2000. In contrast, the negative effects of human activities in the regions bordering Qinghai Lake have been gradually exacerbated.

Results of the NDVI residuals trend (RESTREND) analysis were evaluated with the t statistic of two-tail t distribution at the 95% confidence interval. If $t < -t_{0.05}$ $(n\text{-}2)$, the statistically significant decreasing trend was considered to decrease, indicating human induced land degeneration.

For $t > t_{0.05}$ (n-2), the significantly increasing trend was recognized as human induced land improvement. Finally, $|t| < t_{0.05}$ (n-2) signified no statistical significance of trends. NDVI was also regressed to analyze trends in vegetation dynamics. Regressions were implemented with Spatial Analysis extension of ArcGIS and Stata. RESTREND analysis has been used to detect human-induced land degradation by separating it from vegetation dynamics due to climate change. R^2 of residual trends are shown in Fig. 6. It is evident that human activities resulted in the increase of grass cover (positive trends of residuals shown in red, Fig. 6(a)) in the whole region during the study period. Limited areas in the south experienced the decline in vegetation cover caused by human influence (negative trends shown in green, Fig. 6(a)). Further partitioning of anthropogenic influence by time periods reveals the spatial-temporal heterogeneity of its effects on vegetation cover. We noted that human activities resulted in significantly serious land degradation at the beginning of the study period (1981–1990, Fig. 6(b)), while sufficiently more human induced land degradation is observed during 1994–2006, especially in the northwest and southeast of Qinghai (Fig. 6(c)). Climate effects on grassland dynamics are more pronounced during 2001–2008 because human influence did not have much effect on land degradation (Fig. 6(d)).

3.2 Discussion

With regression and variance analysis based on the panel data, we quantified the influence of climate change and human activities on grassland desertification in Qinghai Province. The purpose of this analysis was to determine the spatial and temporal variations in these factors to provide a theoretical basis for the management of desertification and restoration of grasslands. It was evident that the grasslands in most part of the province were significantly influenced

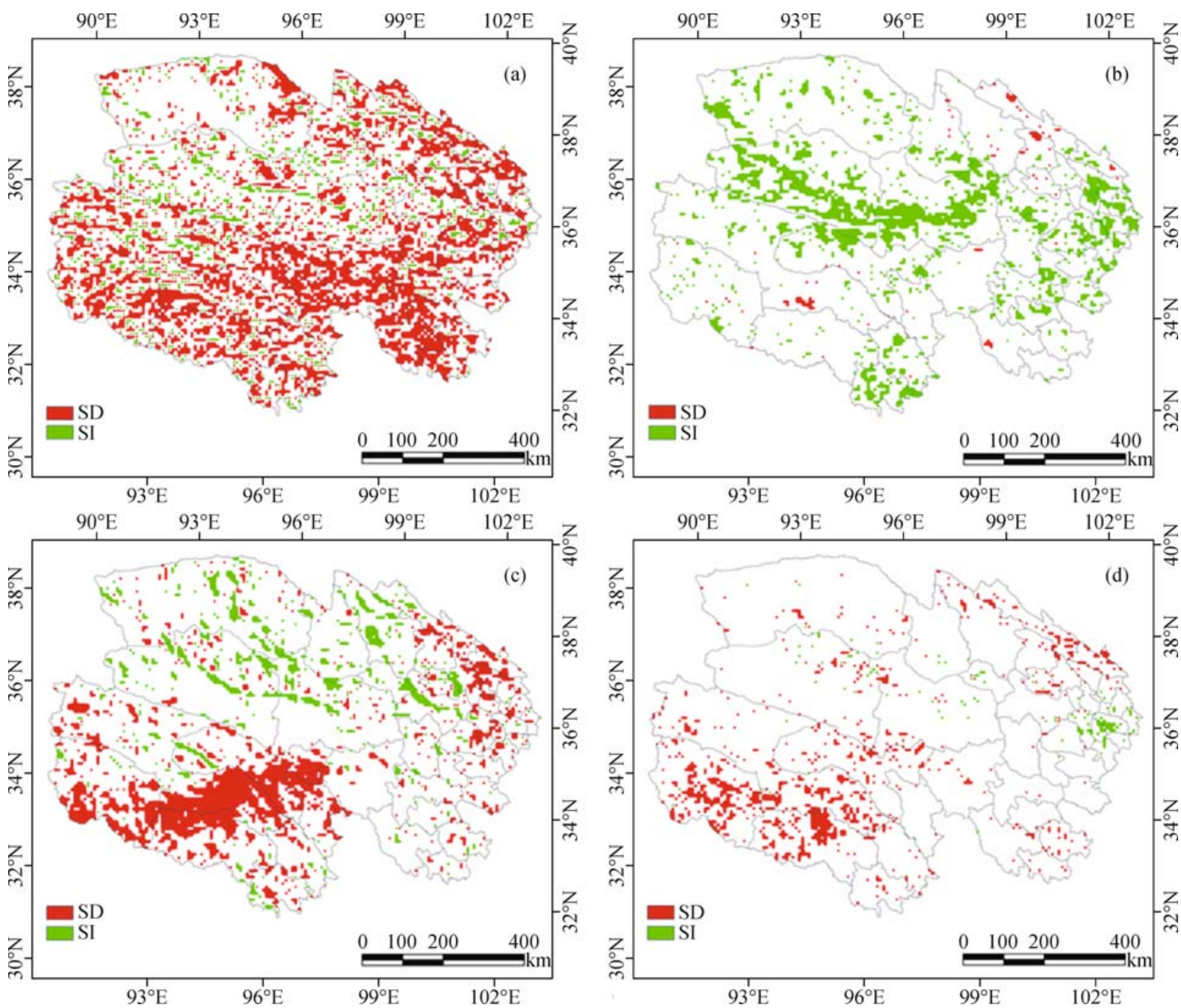

Fig. 6 Map of NDVI max trends at the different period of 1981–2008 (a), 1981–1990 (b),1991–2000 (c), 2001–2008 (d) (t-test, 95% confidence 1 interval). Pixels colored in red have statistically significant decreasing trends (SD) of NDVI max and green pixels have significant increasing trends (SI) of NDVI max.

by climatic factors such as temperature and precipitation over the past 30 years. At the same time, the influence of human activities displayed significant spatial and temporal variations. In the 1980s, the influence of human activities on grassland productivity was minimal; the latter occupied a state of equilibrium. In the 1990s, human activities began to exert a significant adverse effect on grasslands in the Three-River Headwaters Region (UNCED, 1992; UNCCD, 1994). Since the 21st century, there has been an increasing trend of adverse human influence on grasslands in the Qinghai Lake area and in areas near the province's borders (Loumou et al., 2000). However, eastern counties exhibited signs that human activities promoted grassland recovery. Despite a sharp decrease in the number of livestock slaughtered in the Three-River Headwaters Region (Fig. 7) between the late 1980s and 2000 (Li, 2011), grasslands exhibited signs of constantly worsening degradation. On the other hand, our methods and results were consistent with the findings that the number of livestock in Zhiduo County peaked in the late 1990s (Li and Sun, 2009), which apparently intensified grassland degradation.

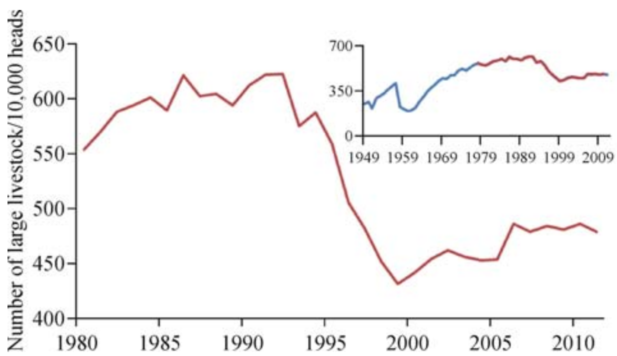

Fig. 7 Number of large animals (livestock, 10,000 heads) in Qinghai from 1949 to 2011.

In 1999, the state development planning commission listed Hualong County as the national ecological environment construction key demonstration county, which led to the implementation of the second phase of three years' worth of ecological engineering. This has led to the realization of remarkable benefits in this county (Wang and Hao, 2004). In addition, the outline of the tenth five-year plan regarding the national economic and social development in Huangnan made Jianza County the focus for the promotion of the construction of model eco-friendly counties. Simultaneously, the government in this county is currently actively promoting grassland ecological protection support incentives (Jing et al., 2006; Oñate and Peco, 2005), which has obtained significant effects. This largely explains why human activity promoted the significant recovery of grassland ecosystems in Jianza and Hualong counties.

4 Conclusions

Based on the regression and residual analysis of the relationship between climate indicators and grassland NDVI, we separately quantified the effects of human activities and climatic factors. In addition, the methods enabled the analysis of spatial and temporal variations in human activities with respects to their effects on grasslands. Our results fitted well with the currently recognized status of grassland degradation in Qinghai Province, and the results could serve as a basis for the development of grassland restoration and ecological system construction programs in the province.

In this study, we found that human activities had and will continue to have an adverse effect on grassland productivity. Accordingly, it is necessary for the government and other organizations to conduct new and more effective programs of grassland protection and/or restoration, particularly in the Three-River Headwaters Region and the Qinghai Lake area. The Three-River Headwaters Region represents both an area of enriched grassland resources and a national key ecological protection zone in Qinghai Province. Any focus on grassland restoration should involve strengthening ecological protection and developing eco-friendly animal husbandry programs.

Acknowledgements This research was supported by the National Basic Research Program of China (No. 2012CB955700). Data supports from projects of the National Natural Science Foundation of China (Grant No. 71225005) and the Exploratory Forefront Project for the Strategic Science Plan in IGSNRR, CAS are also appreciated.

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