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Evaluating the Effects of Government Policy and Drought from 1984 to 2009 on Rangeland in the Three Rivers Source Region of the Qinghai-Tibet Plateau

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Abstract: The Three Rivers Source Region of the Qinghai-Tibet Plateau is a key area that has extensive impacts on much of the population and economy of China as well as several Southeast Asian countries. The rangeland in this area has undergone degradation, the driving factors of which have been extensively investigated in previous studies. However, the effect of policy on rangeland was not analyzed by subdividing the study period according to the timing of the rangeland policies. The role of dry conditions during the process of degradation has not been studied. Therefore, the period from 1984 to 2009 was subdivided into five periods according to the timing of the relevant government policies based on long-term field investigation. The mean annual normalized difference vegetation index (NDVI) and its relationship to dry conditions, policy, temperature, precipitation, and moisture index were analyzed for the five periods. According to our analysis, dry conditions mainly occurred in non-vegetation-growing months, and they did not affect the status of the rangeland. The privatization of rangeland and livestock caused the number of livestock to increase, resulting in a decrease in the mean annual NDVI from 1984 to 1993. The policies of "Green-to-Grain" and eco-migration caused livestock numbers to decrease and the NDVI to increase after 1994. Physical factors such as temperature, precipitation, and moisture also affected the status of the rangeland. Increased temperature had positive effects on rangeland in most areas, but its effect was offset by increased numbers of livestock from 1984 to 1993. Precipitation had positive effects only in drier areas in which the precipitation in the vegetation-growing months was less than 400 mm. In general, the policies of "Green-to-Grain" and eco-migration improved the status of rangeland, and helped improve sustainable use of the rangeland. The methods used in this study could be applied to other case studies of rangeland. Governments should continue to implement compensation policies to maintain the improved condition of rangeland in the area and expand those policies to other rangeland areas.

Keywords: dry conditions; normalized difference vegetation index; rangeland policy; Three Rivers Source Region

1. Introduction

The Three Rivers Source Region is located in the eastern Qinghai-Tibetan Plateau and comprises the headwaters of the Yellow, Yangtze, and Mekong Rivers. The region is sometimes called "the Water Tower", and water from this region affects much of the population and economy of China as well as several Southeast Asian countries, such as Laos, Thailand, and Vietnam. Thus, the region plays a key ecological role, which is of global importance. Owing to the harsh natural conditions, the rangeland in this region is fragile and has undergone significant degradation. The rangeland's vegetation cover and biomass percentage of palatable herbage showed decreasing trends in the region before 2000 [1,2], and more than 20% of high-coverage rangeland was converted to lower-coverage rangeland in the headwater areas of the Yellow and Yangtze Rivers from 1986 to 2000 [2,3].

Identifying the causes of rangeland degradation is a crucial step for its conservation. However, the dominant driving forces of rangeland degradation remain poorly understood. Several previous studies concluded that climate changes were an important factor [4–6]. Among the climate factors, temperature has been reported as a major driver of rangeland degradation [7]. Climate warming decreased the production of the medicinal forb *Gentiana straminea*, increased the production of the non-palatable forb *Stellera chamaejasme*, and led to a decrease in rangeland quality [8–10]. However, in other studies, anthropogenic activities were identified as the main driving force of rangeland degradation [11,12]. The dominant cause was grazing, in which the increased demand by grazing livestock exceeded the rangeland production, resulting in degradation [13]. However, most studies did not subdivide the research period into different periods according to the timing of rangeland policies, and the role of dry conditions during the changes of rangeland status was not considered.

According to our analyses of normalized difference vegetation index (NDVI) data, the status of rangeland degradation has improved in this region in recent years. Government policy affects rangeland by changing human activities and grazing pressure, and those factors directly affect the status of the rangeland. The government implemented a series of policies between 1984 and 2009, such as privatization of livestock and rangeland, developing enclosures, the "Grain to Green" policy, and deployment of eco-migration police. We wished to investigate the effect of government policies on rangeland status in recent decades, a topic that received little attention in previous studies. To analyze the effects of policies on rangeland, the period from 1984 to 2009 was divided into different intervals according to government rangeland policy, and the relationships between rangeland status and dry conditions were analyzed; other relationships between rangeland status, and other climate factors were also studied using correlation analyses.

2. Study Area

The Three Rivers Source Region (31°28′–36°17′N, 89°37′–102°20′E) covers a total area of 363,000 km^2 and had a total population of 557,200 in 2009 (Figure 1). Most of the region's inhabitants are ethnic Tibetans, whose main land-use activity is grazing. The region includes 16 counties and one township of Geermu City. The altitude of the study area ranges from 4000 to 5800 m above mean sea level. The annual mean temperature is between 2.9 °C and −3.9 °C, and the annual average rainfall varies from 770 mm in Banma County in the south-east to 292 mm in Tanggulashan Township in the south-west, based on data from weather observation stations. Rangeland types include alpine meadow, marsh, alpine steppe, and alpine desert, with alpine meadow being the dominant type. The main livestock raised by the herdsmen are sheep and yak.

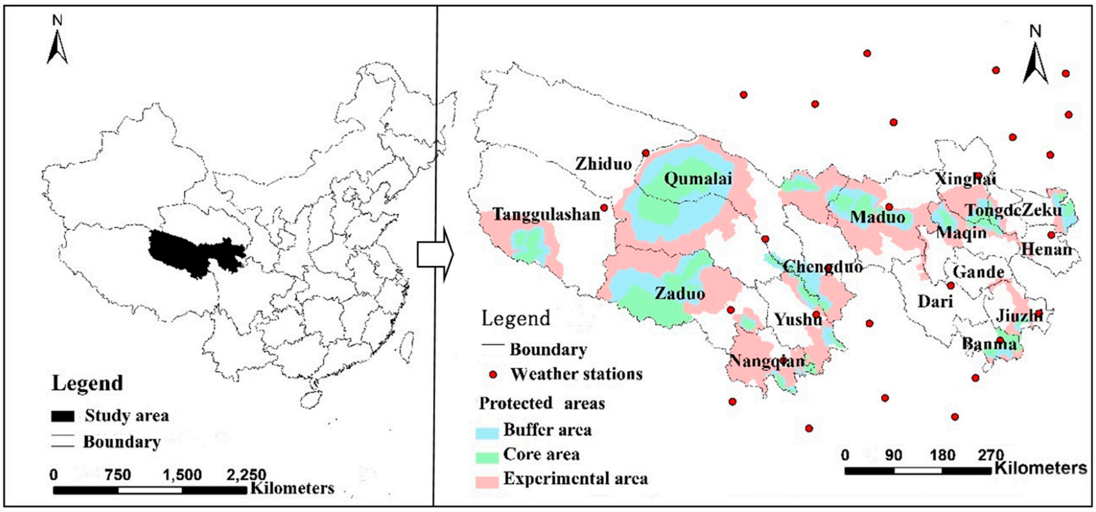


Figure 1. Location of the study area.

3. Data and Methods

3.1. Data

Seven datasets were used to analyze the effects of government policy on rangeland. The first dataset, a series of government policies executed from 1984 to 2009, was collected by field surveys comprising Participatory Rural Appraisal interviews in the summer months from 2006 to 2009. The second dataset, NDVI data, was obtained from the US Geological Survey and the SPOT-Vegetation Program (CTIV-VITO, Mol, Belgium). The temporal resolutions of Advanced Very High-Resolution Radiometer (AVHRR) and SPOT-Vegetation NDVI were 15 days and 10 days, respectively. The resolution of AVHRR NDVI from 1982 to 1997 was 8 km and the resolution of SPOT-Vegetation NDVI from 1998 to 2010 was 1 km. All of the 8 km images from 1982 to 1997 were resampled into 1 km resolution images with bilinear method in the Environment for Visualizing Images (ENVI) software. Maximum composite processing was used to obtain monthly NDVI data.

The third dataset, the standard precipitation index (SPI) for the study period, was calculated from precipitation data obtained from 13 weather observation stations in the study area, and recorded by the State Meteorological Bureau (Figure 1). The fourth dataset, moisture index (MI), was calculated using the Penman–Monteith equation and the Thornthwaite Moisture Index. The input data were daily maximum and minimum temperatures, daily precipitation, wind velocity, and actual water vapor pressure from 1984 to 2009. These data were also obtained from the 13 weather observation stations in Three Rivers Source Region and recorded by the State Meteorological Bureau. The fifth dataset, the annual mean temperature and precipitation in the vegetation-growing months, was obtained from the Data Center of the State Meteorological Bureau. The sixth dataset was livestock data, collected from local and state Statistics Bureau yearbooks. The seventh dataset, vegetation type and protected areas, was obtained from local governments.

3.2. Method

The rangeland in the region turns green in early May and the plants complete growing in late September. Therefore, monthly NDVI data for the vegetation-growing months from 1984 to 2009 were used in this study. Field surveys were conducted during July and August from 2006 to 2009. The government policies relating to rangeland were investigated through interviews with local government officers and herdsmen in Maduo, Maqin, Banma, and Yushu Counties. Following the establishment of the People’s Republic of China in 1949, livestock were owned by different collectives on the Qinghai-Tibetan Plateau. In 1984, the household contract responsibility system was implemented in the study area, and livestock and pasture were divided among individual herder families. In 1994, the Grassland Law was implemented, and pastureland was assigned to herder families; at the same time, policies supporting herdsmen with planting grass, and building enclosures, cattle and sheep circles, and houses were launched. The Grain-to-Green policy was executed in this area in 1999. In 2004, the eco-migration policy was introduced in the study area to promote ongoing improvements in the condition of the rangeland. In this study, the period between livestock privatization and pasture protection was divided into two equal-length periods. Therefore, the entire period from 1984 to 2009 was divided into five periods according to the timing of the government policies: 1984–1988, 1989–1993, 1994–1998, 1999–2003 and 2004–2009. Annual NDVI data in the vegetation-growing months during the study period were obtained from the following equation to indicate the rangeland status:

$$\mathrm{NDVI_{year}} = \Big(\sum_{\mathrm{May}}^{\mathrm{Sep}} \mathrm{NDVI_{month}} \Big)/5 \tag{1}$$

where $\mathrm{NDVI_{year}}$ is the annual NDVI value in the vegetation-growing months and $\mathrm{NDVI_{month}}$ is the monthly NDVI value. The monthly NDVI was obtained using the maximum method from several sets of NDVI data in each month. Annual NDVI data, vegetation type, and county boundary data were analyzed using ArcGIS software to obtain the annual mean NDVI of alpine rangeland for each policy period.

The SPI and MI values were calculated to analyze the relationships among range land status, dry conditions, humidity conditions, and livestock. The MI at each station for each vegetation-growing month was calculated by combining the improved Penman–Monteith equation and the Thornthwaite Moisture Index (Allen [14]; Equations (2) and (3)):

$$\mathrm{PET} = \frac{0.408\Delta(R_n - G) + r\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + r(1 + 0.34U_2)} \tag{2}$$

$$\mathrm{MI} = 100 \times \left(\frac{Precipitation}{PET} - 1 \right) \tag{3}$$

where PET is potential evapotranspiration (mm day^{-1}), R_n is net canopy radiation (MJ m^{-2} day^{-1}), G is soil heat flux (MJ m^{-2} day^{-1}), T is air temperature at 2 m height (°C), U_2 is wind velocity at 2 m height (m s^{-1}), e_a is actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure curve (kPa °C^{-1}), r is the psychrometer constant (kPa °C^{-1}), and MI is the moisture index. The values of T, U_2, and e_a were obtained from daily weather station data. The values recommended by the Food and Agriculture Organization of the United Nations (FAO) for G, Δ, r, and R_n were used. These values have been widely used for calculating PET. The MI values indicate the status of humidity conditions.

The SPI for all months from 1984 to 2009 at the 13 weather observation stations was calculated to identify the dry and non-dry months during the winter wheat growing season, according to Abramowitz and Stegun [15] and McKee [16]:

$$\mathrm{SPI} = \begin{cases} -\left(\mathrm{t} - \frac{\mathrm{c_0 + c_1 t + c_2 t^2}}{\mathrm{1 + d_1 t + d_2 t^2 + d_3 t^3}}\right) & \text{for } 0 < H_{(\mathrm{x})} \le 0.5 \\ \left(\mathrm{t} - \frac{\mathrm{c_0 + c_1 t + c_2 t^2}}{\mathrm{1 + d_1 t + d_2 t^2 + d_3 t^3}}\right) & \text{for } 0.5 < H_{(\mathrm{x})} < 1 \end{cases} \tag{4}$$

$$\mathrm{t} = \sqrt{\ln\left(\frac{1}{(H_{(\mathrm{x})})^2}\right)} \text{ for } 0 < H_{(\mathrm{x})} \le 0.5 \tag{5}$$

$$\mathrm{t} = \sqrt{\ln\left(\frac{1}{\left(1 - H_{(\mathrm{x})}\right)^2}\right)} \text{ for } 0.5 < H_{(\mathrm{x})} \le 1.0 \tag{6}$$

$$H(x) = q + (1 + q)\,G(x) \tag{7}$$

$$G(x) = \int_0^x g(x)dx \tag{8}$$

$$g(x) = \frac{1}{\beta^{\alpha}T(\alpha)}\, x^{\alpha-1}\, e^{-\frac{x}{\beta}} dx \text{ for } x > 0 \tag{9}$$

$$T(\alpha) = \int_0^{\infty} x^{\alpha-1}e^{-x}dx \tag{10}$$

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{11}$$

$$\hat{\beta} = \frac{\overline{x}}{\hat{\alpha}} \tag{12}$$

$$A = \ln(\overline{x}) - \frac{\sum \ln(x)}{n} \tag{13}$$

where A, $T(\alpha)$, $g(x)$, $G(x)$, $H(x)$, and t are intermediate (dimensionless) variables. c_0, c_1, c_2, d_1, d_2, and d_3 equal 2.515517, 0.802853, 0.010328, 1.432788, 0.189269, and 0.001308, respectively. X is monthly precipitation (mm), q is the possibility of a month without precipitation, α is a shape parameter, β is a scale parameter, and $T(\alpha)$ is the gamma function. The monthly SPI value was classified into two classes [17–19]: *no dry (>−1) and dry (≤−1).*

4. Results and Analysis

4.1. Temporal Trends of Dry

Dry conditions are an important factor affecting the rangeland status. Therefore, the SPI was calculated from the monthly precipitation at the 13 weather observation stations, and all months from 1984 to 2009 were classified into dry and non-dry months. The results are shown in Table 1. The vegetation-growing months are from May to late September, and there were almost no dry conditions during those months in the period from 1984 to 2009. This indicates that the rangeland experienced negligible effects from dry during the entire period from 1984 to 2009.

For the non-vegetation-growing months, January, February, November, and December had higher percentages of dry conditions, and March, April, and October had lower ones. The percentage of dry conditions in January, February, November, and December was higher than 70% at all weather observation stations, and the dry percentage in April and October was less than 55% at all weather observation stations. If dry conditions in non-vegetation-growing months lasted for several months, they are called “Black Disasters”, in which higher death rates of livestock are recorded, which decreases the number of livestock. Its effect improves the status of rangeland in the study area.

Table 1. Dry percentage at 13 weather observation stations from 1984 to 2009.

Month (%)	January	February	March	April	May	Junne	July	August	September	October	November	December	Total
Banma	96.7	70.0	30.0	0.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	90.0	96.7	31.9
Nangqian	96.7	93.3	76.7	26.7	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	6.7	83.3	100.0	40.3
Jiuzhi	96.7	80.0	20.0	0.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	3.3	76.7	100.0	31.4
Henan	90.0	80.0	30.0	3.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	3.3	93.3	100.0	33.3
Dari	83.3	80.0	16.7	3.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	86.7	96.7	30.6
chengduo	80.0	73.3	23.3	16.7	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	10.0	80.0	93.3	94.2
Maduo	86.7	66.7	30.0	26.7	**3.3**	**0.0**	**0.0**	**0.0**	**0.0**	10.0	86.7	93.3	33.6
Yushu	93.3	96.7	66.7	23.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	13.3	96.7	96.7	40.6
Qumalai	96.7	96.7	73.3	30.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	26.7	93.3	100.0	43.1
Zaduo	73.3	66.7	43.3	20.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	16.7	90.0	90.0	33.3
Geermu	93.3	90.0	90.0	43.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	43.3	93.3	96.7	45.8
Xinghai	86.7	90.0	56.7	23.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	16.7	90.0	93.3	38.1
Zhiduo	100.0	96.7	76.7	53.3	**3.3**	**0.0**	**0.0**	**0.0**	**3.3**	50.0	100.0	96.7	48.3

4.2. Government Policy and Rangeland NDVI

Alpine meadow is the dominant land-use type in the study area, and the NDVI of alpine meadow was used to analyze the effects of government policy on the rangeland. Annual NDVI values were obtained by calculating the monthly mean NDVI values in the vegetation-growing months using Equation (1). Then, the NDVI values in each county in the study area for each government policy period were statistically analyzed using ArcGIS software (Figure 2 and Table 2). Table 2 shows that the mean annual NDVI values in most of the counties slightly decreased in the period from 1984 to 1993, and that they increased in all counties from 1994 to 2009. The highest increase in the mean annual NDVI value occurred during the period from 2004 to 2009.

Figure 2. Surveys with herdsmen in the study area took place from 2006 to 2009.

Table 2. Mean annual normalized difference vegetation index (NDVI) values in each county in the study area for the different policy periods.

	1984–1988	1989–1993	1994–1998	1999–2003	2004–2009
Nangqian	0.431	0.421	0.425	0.454	0.478
Banma	0.497	0.487	0.510	0.529	0.566
Yushu	0.453	0.455	0.455	0.486	0.514
Jiuzhi	0.522	0.519	0.542	0.569	0.595
Zaduo	0.336	0.331	0.329	0.362	0.387
Dari	0.424	0.417	0.437	0.454	0.483
Henan	0.598	0.597	0.620	0.628	0.659
Chengduo	0.416	0.420	0.417	0.432	0.457
Maduo	0.315	0.315	0.318	0.328	0.350
Qumalai	0.284	0.293	0.291	0.299	0.315
Zhiduo	0.311	0.299	0.303	0.323	0.348
Xinghai	0.388	0.379	0.389	0.397	0.418
Tanggulashan	0.218	0.214	0.211	0.235	0.250
Tongde	0.551	0.536	0.556	0.564	0.598
Zeku	0.553	0.560	0.562	0.561	0.605
Maqin	0.436	0.441	0.467	0.461	0.486
Gande	0.522	0.525	0.551	0.543	0.568
Mean	0.427	0.424	0.434	0.448	0.475

For Nangqian County, the mean annual NDVI value was 0.431 from 1984 to 1988, and it decreased to 0.421 from 1989 to 1993. From 1994 to 1999, the mean annual NDVI value was 0.430, and it increased to 0.459 from 2000 to 2004, and to 0.481 from 2005 to 2010. For Dari County, the mean annual NDVI value was 0.424 from 1984 to 1988, and it decreased to 0.417 from 1989 to 1993. From 1994 to 1998, the mean annual NDVI value was 0.437, and it increased to 0.454 from 1999 to 2003, and to 0.483 from 2005 to 2009. For Tanggulashan Township, the mean annual NDVI value was 0.218 from 1984 to 1988, and it decreased to 0.214 from 1989 to 1993. From 1994 to 1998, the mean annual NDVI value was 0.211, and it increased to 0.235 from 1999 to 2003, and to 0.250 from 2004 to 2009.

These results indicate that the Grain-to-Green and eco-migration policies improved the status of rangeland, and that the eco-migration policy played a more important role during the period while NDVI values were changing. Livestock are a symbol of wealth in Tibetan areas, and grazing is the main human activity affecting the status of rangeland in the study area. After the privatization of livestock and pastureland, the main objective of herdsmen was maximizing their wealth, and this caused the number of livestock to increase between 1984 and 1993 (Figure 3). In 1984, there were 2.0×10^7 sheep units, which subsequently increased to 2.12×10^7 sheep units in 1994. The increase in livestock caused the status of the rangeland to deteriorate from 1984 to 1993, and the death rate of the livestock also began to increase, which resulted in a decrease in the number of livestock after 1994.

The government also realized the effects of rangeland degradation on the number of livestock, and began to provide funds to improve the condition of pastureland by building enclosures and implementing a program of rodent eradication. However, such policies resulted in only a slight increase in the NDVI values in some counties, and did not change the livestock death rate. The Green-to-Grain policy was implemented in the area, having a decrease in livestock numbers as a key objective. The number of livestock continued to decrease after 1994 and caused the mean annual NDVI to increase in all counties.

The eco-migration policy was introduced in 2004 and 16 protected areas were announced (Figure 1). The population in the core area was moved to urban areas, where houses and compensation funds were provided by the government based on the number of livestock and family size; it was also forbidden for livestock to graze in the core areas. Outside the core areas, the number of livestock was reduced to a specific level that was determined according to the estimated carrying capacity of the rangeland. This caused the number of livestock to decrease steadily and the mean annual NDVI to increase after 2004.

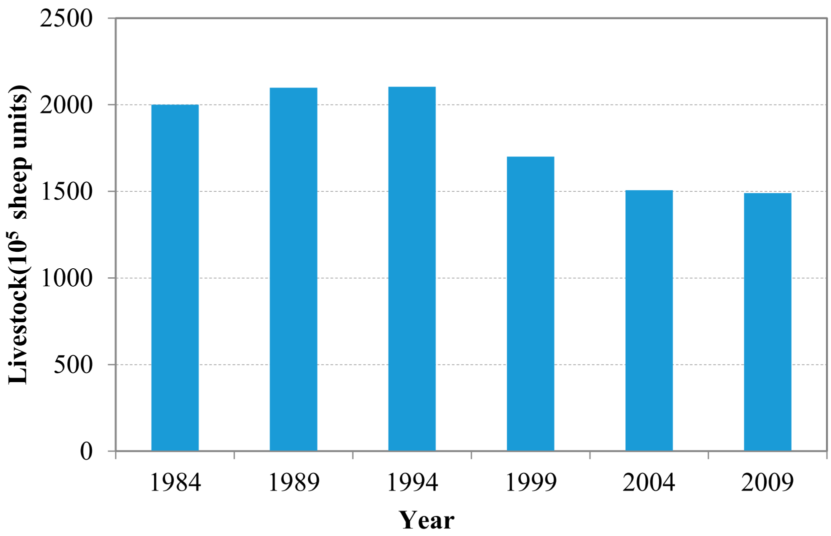


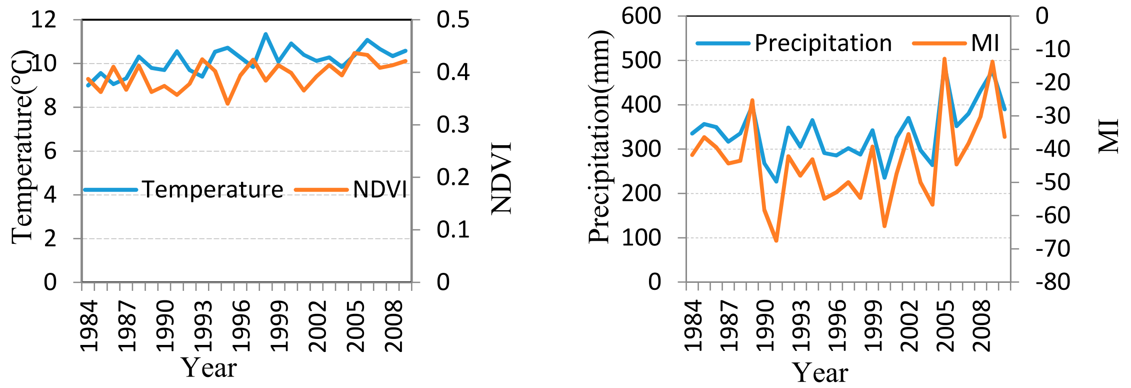
Figure 3. Number of livestock in the study area.

4.3. The Relationship between NDVI and Other Physical Factors

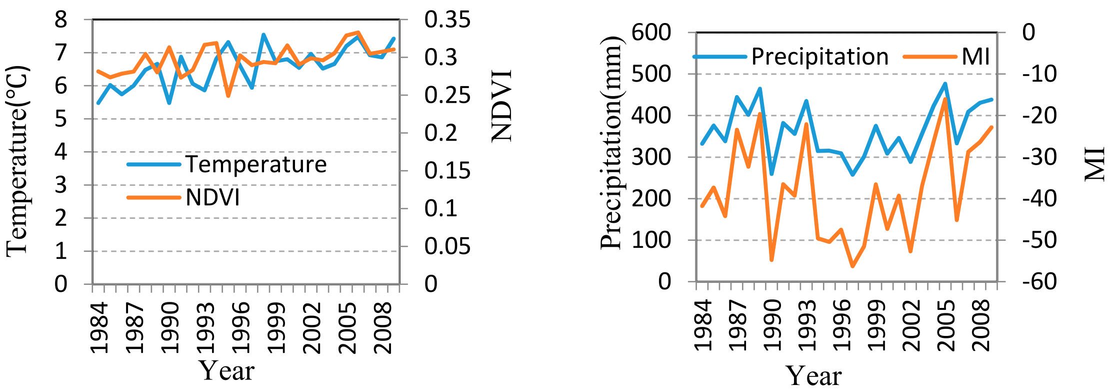
The entire period from 1984 to 2009 was divided into five periods according to the timing of government policies affecting the rangeland. Our analyses showed that policies produced significant effects on the rangeland in addition to the already-known effects of temperature, precipitation, and humidity index.

Annual humid moisture in the vegetation-growing season was calculated using the Penman–Monteith equation and the Thornthwaite Moisture Index (Figure 4). In addition, the Pearson's correlation coefficients between the MI, precipitation, and temperature with NDVI were calculated. The results are shown in Table 3. The annual humidity index and precipitation in the vegetation-growing months both showed the same trends during the period from 1984 to 2009. However, the trends in the MI and precipitation were not synchronous with the dynamics of the NDVI. The correlation coefficients between the NDVI and MI, and the NDVI and precipitation at the stations with annual precipitation higher than 400 mm were very low, and they were not significant at the 0.05% and 0.01% levels. This indicates that the precipitation and MI improved the status of alpine rangeland in the areas with annual precipitation greater than 400 mm, but that these effects were very small. However, the correlation coefficients between the NDVI and MI, and the NDVI and precipitation at the stations with precipitation less than 400 mm were markedly higher, and they were significant at the 0.05% or 0.01% levels at most of the stations. This shows that the precipitation and MI played important roles during the process of improvement in the status of alpine rangeland at the stations at which the annual precipitation in the vegetation-growing months was less than 400 mm.

The correlation coefficients between NDVI and annual mean temperature were very high at all stations, except for two stations at which the annual precipitation in the vegetation-growing months was less than 400 mm. This indicates that annual mean temperature is an important factor for rangeland NDVI. However, the trends in temperature and NDVI differed slightly among all stations before 1999, and were synchronous at all stations after 1999. The NDVI tended to decrease from 1984 to 1994 and tended to increase from 1994 to 2009. This indicates that the number of livestock had more significant effects on rangeland before 1994 than after 1994. The effects of grazing on rangeland offset the effects of increased temperature. It is also shown that the policies of Green-to-Grain and eco-migration caused the number of livestock to decrease and the temperature to play a more important role in areas with annual precipitation greater than 400 mm after 1999.



Xinghai



Qumalai

Figure 4. *Cont.*

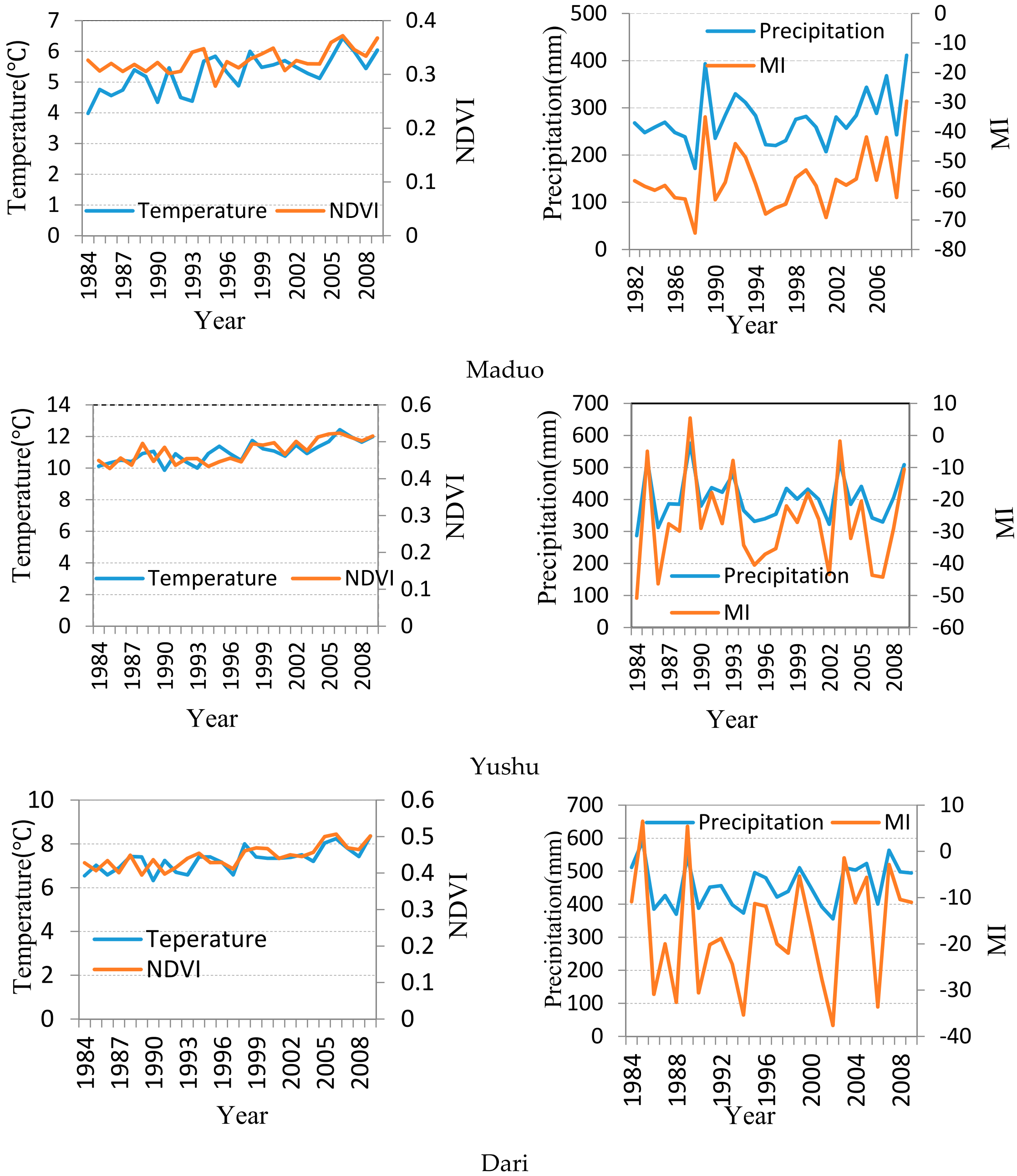


Figure 4. Trends in NDVI, precipitation, and moisture index (MI) at represented weather observation stations in the study area from 1984 to 2009. Note: for other station data, see the Appendix A (Figure A1).

Table 3. The correlation coefficients between precipitation, MI, temperature, and NDVI at weather observation stations in the study area.

Stations	Mean Precipitation (mm)	Correlation Coefficients with NDVI		
		Precipitation	MI	Temperature
Tanggulashan	266.7	0.436 *	0.448 *	0.412 *
Zhiduo	273.4	0.313	0.331	0.432 *
Maduo	275.4	0.440 *	0.442 *	0.403 *
Xinghai	336.7	0.420 *	0.368 *	0.107
Qumalai	367.8	0.183	0.197	0.233

Table 3. *Cont.*

Stations	Mean Precipitation (mm)	Correlation Coefficients with NDVI		
		Precipitation	MI	Temperature
Yushu	408.1	−0.128	−0.216	0.711 *
Chengduo	427.2	0.118	0.077	0.564 *
Dari	457.2	0.057	−0.051	0.701 *
Zaduo	466	0.129	0.192	0.483 *
Nangqian	477.4	0.228	0.168	0.547 *
Banma	534.3	−0.107	−0.143	0.755 *
Jiuzhi	577.7	0.059	−0.076	0.743 *

Note: * Indicates significance at the 0.05% or 0.01% levels.

4.4. Consistency of NDVI Values from Two Sensor Types

In this study, NDVI was determined from two remote sensor types: AVHRR and SPOT. The effect of the difference between the AVHRR and SPOT NDVI values on our results was further analyzed. Both AVHRR and SPOT recorded the NDVI values in this area from 1998 to 1999, and the difference in NDVI values from AVHRR and SPOT in May was compared between 1998 and 1999 (Table 4). Maximum composite processing was used to obtain monthly AVHRR and SPOT-Vegetation NDVI data.

Table 4 shows that the AVHRR NDVI values were a little higher than the SPOT values in the entire study area, in all years compared. For the entire area, the NDVI from AVHRR for May in 1998 and 1999 was 0.29 and 0.23, respectively. The NDVI from SPOT for May in 1998 and 1999 was 0.28 and 0.21, respectively.

The NDVI values from AVHRR were used from 1984 to 1997, and the SPOT NDVI was used from 1998 to 2009. The NDVI tended to decrease from 1984 to 1993, and this was not affected by the NDVI sensor type. The increased trend in NDVI from 1994 to 2009, affected by rangeland policies, was weakened in the SPOT-Vegetation NDVI data due to the lower NDVI values from SPOT sensors compared with the AVHRR sensors after 1998. This indicates that this difference in NDVI according to sensor type affected our trend analysis slightly, but did not change the final trend. The combined use of different remote sensors has been applied in other studies [20,21].

Table 4. The difference of NDVI from Advanced Very High-Resolution Radiometer (AVHRR) and Systeme Probatoire d'Observation de la Terre (SPOT) images.

Country	1998			1999		
	AVHRR	SPOT	Change	AVHRR	SPOT	Change
Zeku	0.43	0.40	0.03	0.27	0.27	0.00
Henan	0.47	0.45	0.02	0.40	0.38	0.02
Tongde	0.39	0.38	0.01	0.28	0.26	0.02
Xinghai	0.26	0.23	0.03	0.18	0.16	0.02
Maqin	0.29	0.29	0.01	0.23	0.20	0.03
Banma	0.38	0.37	0.01	0.32	0.25	0.06
Gande	0.38	0.35	0.03	0.30	0.25	0.05
Dari	0.29	0.28	0.01	0.24	0.21	0.03
Jiuzhi	0.40	0.40	0.00	0.32	0.31	0.02
Maduo	0.20	0.18	0.02	0.16	0.14	0.02
Yushu	0.28	0.29	−0.01	0.22	0.22	0.00
Zaduo	0.19	0.19	0.00	0.16	0.15	0.01
Chengduo	0.25	0.23	0.02	0.18	0.18	0.00
Zhiduo	0.18	0.18	0.00	0.14	0.13	0.01
Nangqian	0.29	0.29	0.00	0.23	0.24	−0.01
Qumalai	0.18	0.15	0.02	0.13	0.12	0.01
Tanggula	0.13	0.12	0.01	0.12	0.11	0.01
Total	0.29	0.28	0.01	0.23	0.21	0.02

5. Discussion

Our results are consistent with those of Zhang [22] and Gao [23]. Zhang [22] used the AVHRR and SPOT NDVI data, and the Carnegie-Ames-Stanford Approach (CASA) model to study the rangeland status and found that the NDVI values in 2009 are higher than those in 1982, indicating an increase in greenness of the rangeland in 2009. Studies conducted by Gao [23] and Zhang [24] also show that the rangeland status has been improved in recent years.

Wu [25] found fencing could significantly improve above-ground vegetation. However, our results show that fencing and grass seeding could improve the rangeland status yet to a very slight extent. One of the possible reasons is that Wu [25] only considered the rangeland within the enclosure. The effects of fencing may be under-estimated in our study as the percentage of rangeland within fence is very low.

Yak dung is the main fuel source in the Qinghai-Tibetan Plateau. Decrease in the usage of yak dung could reduce herdsmen's dependence on yak, and thus help to decrease yak number and to improve the rangeland status. Zhang [26] found that decreases in carbon emission from yak dung due to the decreased number of livestock had improved the rangeland ecosystem and the rangeland status. This is consistent with the findings of a statistically significant relationship between livestock number and the rangeland NDVI in our study.

The effects of warming trends on rangeland are still under debate. Some previous studies showed that warming has negative impacts on rangeland [27,28]. However, other studies [29] indicate that the warming trends on the Qinghai-Tibetan Plateau could enhance the above net primary production and the rangeland status. The difference was probably because those studies, unlike this study, failed to consider the influences of variations in precipitation on rangeland. Our results show that effects of warming on rangeland are dependent upon precipitation. Warming shows a positive and a negative effect on rangeland status in the areas with average annual precipitation higher and lower than 400 mm, respectively.

Grazing exclusion was executed in the core protected areas in the Three Rivers Source Region with a hope to improve the rangeland status. However, its effects on rangeland are not yet clear and still need further studies. Previous studies by Shi [30] and Shang [31] showed that although grazing exclusion could reduce soil organic carbon storage in rangeland, it could improve vegetation cover. Reduction of soil organic carbon storage in rangeland may show a negative effect on the rangeland in the future. However, Lu [32] argued that grazing exclusion wouldn't have any negative effects on rangeland soil.

Human activities are considered to be the most important driving force of rangeland changes in many studies [12,33]. Therefore, reducing livestock number is a very important policy in rangeland management, and governments should continue to execute this policy in the future to help protect the Qinghai-Tibetan rangeland.

6. Conclusions

The monthly NDVI values in the vegetation-growing months were calculated using the maximum method, and the annual mean NDVI values were obtained. The SPI was calculated using the methods of Abramowitz and Stegun [14] (1965) and McKee [15] et al. (1993). The novelty of this study is that the entire period from 1984 to 2009 was divided into five periods according to the timing of government rangeland policies, and the role of dry conditions during the rangeland changes were analyzed. The results showed that almost no dry conditions occurred in the vegetation-growing months during the period from 1984 to 2009, and that dry conditions did not affect the status of rangeland. The mean annual NDVI values in most counties slightly decreased from 1984 to 1993, and they increased in all counties from 1994 to 2009. This indicates that the privatization of livestock and pastureland caused the number of livestock to increase and resulted in deterioration of the rangeland.

The Green-to-Grain and eco-migration policies caused the number of livestock to decrease and led to an improvement in the rangeland status. Temperature has positive effects on rangeland, but its effects were offset by increased livestock amounts before 1993; precipitation had an obvious effect on rangeland where mean annual precipitation is lower than 400 mm. This also indicates that rangeland policies affected the number of livestock, and the number of livestock caused the changes of rangeland status. The government should continue to provide compensation to herders and maintain the number of livestock at lower levels to improve the rangeland status in the future. This also shows that these policies on rangeland should be expanded to other degraded rangeland areas to improve the rangeland and promote the sustainable use of rangeland.

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

Appendix A

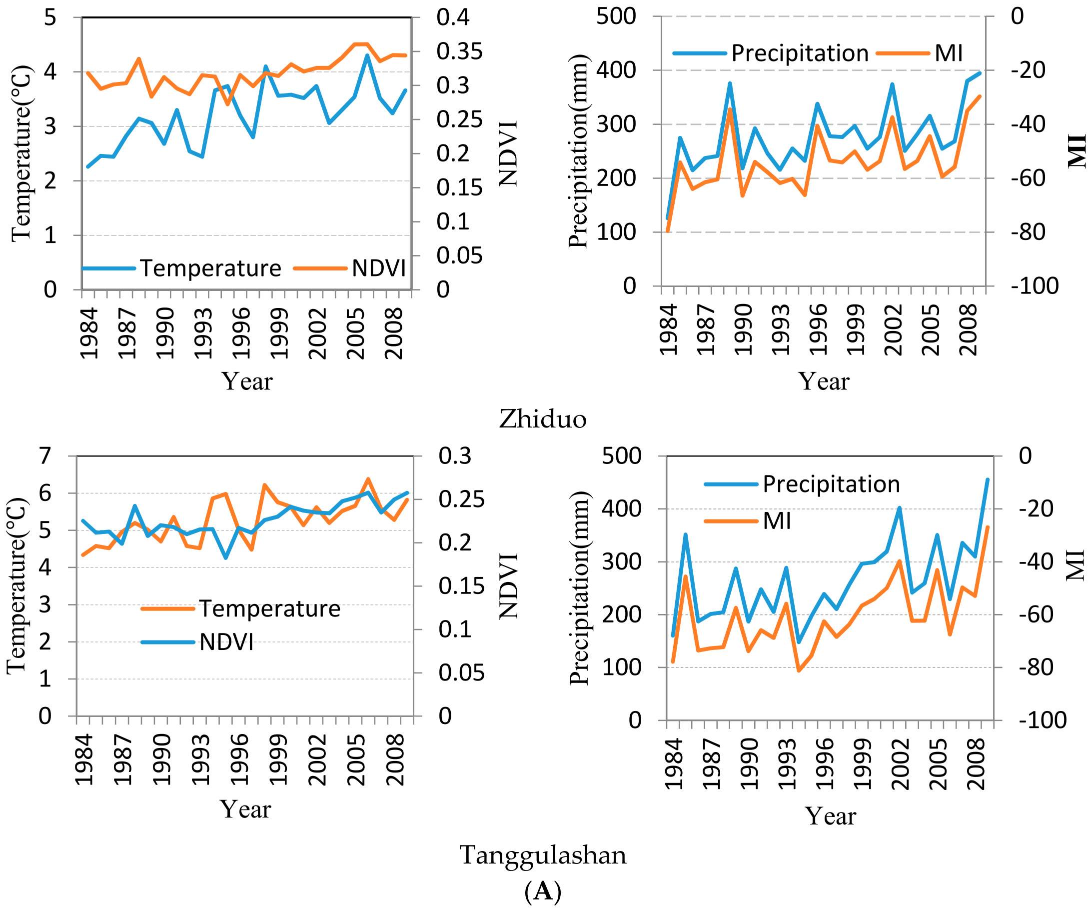
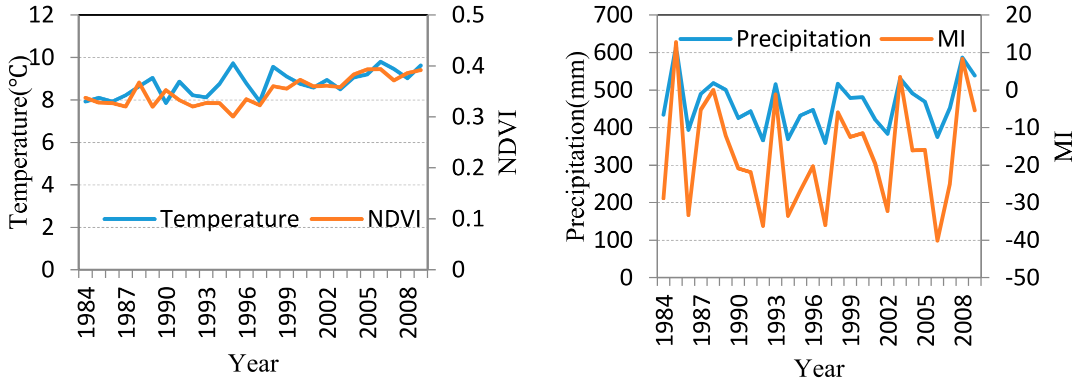
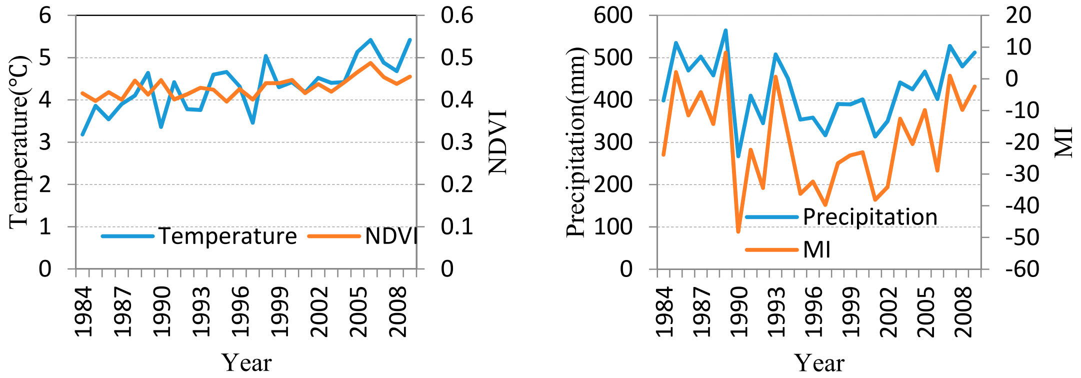


Figure A1. *Cont.*

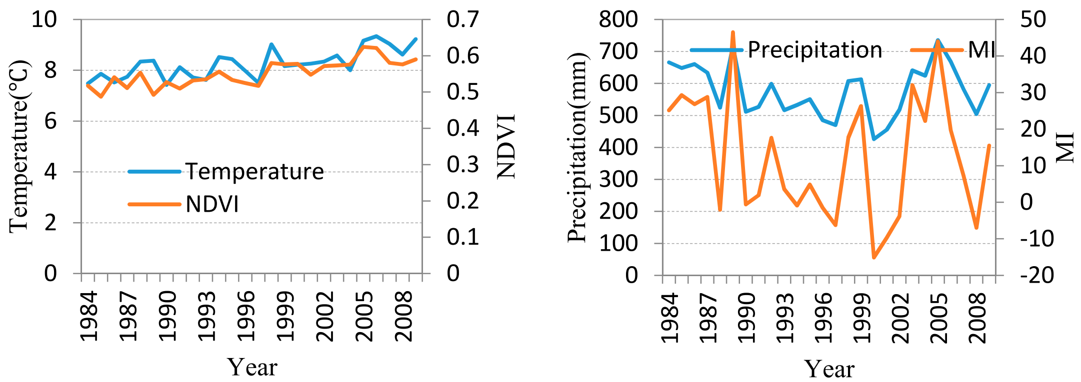


Zaduo

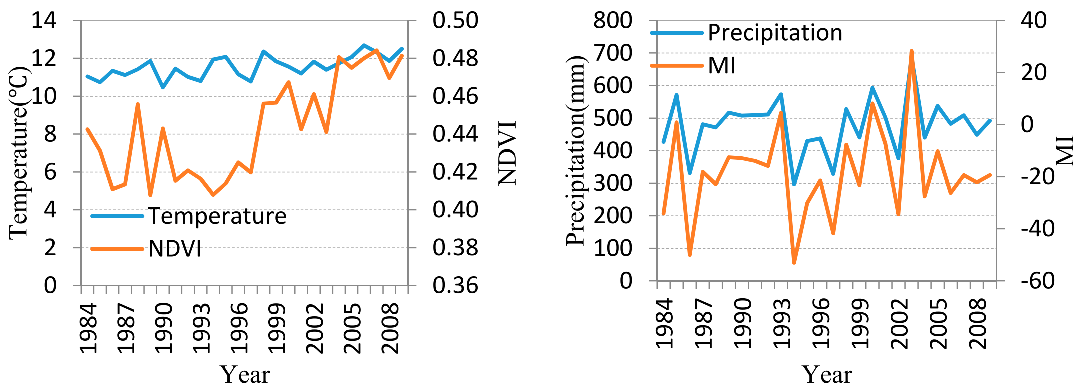


Chengduo

(**B**)

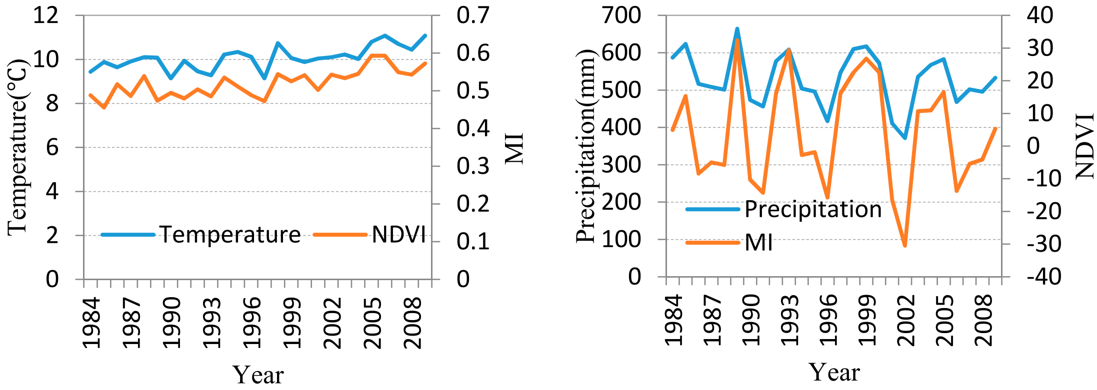


Jiuzhi



Nangqian

Figure A1. *Cont.*



Banma

(**C**)

Figure A1. Trends in NDVI, precipitation, and MI at weather observation stations in the study area from 1984 to 2009.

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