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RESEARCH ARTICLE

Effect of climate and ecological restoration on vegetation changes in the "Three-River Headwaters" region based on remote sensing technology

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Abstract

Surface temperature and precipitation are factors effecting vegetation growth. Vegetation coverage change is one of the important factors influencing global and regional climate change. Dynamic monitoring of vegetation change can reflect the trend of climate change to a certain extent. Three-River Headwaters are located in the hinterland of the Qinghai-Tibet Plateau. It has the characteristics of "high, cold, and dry" (higher altitude, cold and dry weather) and its ecosystem is fragile. In recent years, with the global climate change, a series of eco-environmental problems such as river flow cutoff, permafrost degradation, and vegetation destruction has occurred in the headwaters area, which are closely related to climate and vegetation changes. At the same time, in order to solve the problem of ecological environment degradation in the region, various ecological restoration policies have implemented. Several uncertainties in the relationship between vegetation and climate change in the Three-River Headwaters region. This study aims to find out the uncertainties. In this study, the spatial distribution of vegetation coverage was calculated by using *NDVI* (normalized difference vegetation index) from the first-level product of MODIS (moderate resolution imaging spectroradiometer) remote sensing data. Combining policy factors, the relationship between rainfall, surface temperature, and vegetation growth status were analyzed. The results show that during the study period (1948–2019), the temperature rose significantly and the rainfall increased especially after the implementation of ecological restoration policy (after 2000). Vegetation coverage increased year-by-year (2000–2015). The rainfall effect on surface temperature and vegetation growth, when the summer rainfall increased, the temperature decreased, leads to vegetation coverage decreased (for example, 2001, 2003, 2008 and 2011); the dependence of vegetation on rainfall has obvious lag in Three-River Headwaters in summer. In the years with suitable rainfall and higher temperature in summer, the vegetation grows better and the vegetation coverage increases. This is mainly because the Three-River Headwaters is located in the alpine zone, and vegetation growth is more dependent on temperature. The implementation of ecological restoration policy promotes vegetation coverage. Studying the impact of climate and policy factors on vegetation cover is of great scientific significance and practical value for understanding the ecological restoration mechanism in high cold and arid regions.

Keywords Three-River Headwaters · MODIS · *NDVI* · Precipitation · Surface temperature · Ecological restoration

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Introduction

Vegetation, as a comprehensive indicator of ecological environment changes, is an important parameter for evaluating the quality of ecological environment. Vegetation changes largely reflect the regional environmental status (Zhang et al. 2011; Liu et al. 2015; Yang et al. 2018). Precipitation is the main limiting factor for vegetation growth; however, surface temperature is a good representation in variation of vegetation (Qiu et al. 2019; Huang et al. 2016). Vegetation has obvious characteristics of seasonal and interannual variations, which has a certain relationship with soil, atmosphere, and moisture. Fractional vegetation coverage (FVC) is a parameter to characterize the vegetation cover and plays an important role in the atmosphere, soil, hydrosphere, and biosphere (Gitelson et al. 2002; Tong et al. 2016). Changes in natural environment caused by human activities are also an essential indicator for describing ecosystems (Sellers et al. 1996; Liu et al. 2009).

Three-River Headwaters (TRH) region is the headwaters of the Yangtze River, the Lancang River, and the Yellow River. TRH is located in Qinghai province, hinterland of Qinghai-Tibet Plateau Northwest China called as “Water Tower” of china. It is an important ecological barrier for ecological security and regional sustainable development in the middle and lower reaches of China’s rivers and Southeast Asian countries, as well as one of the most vulnerable and sensitive regions of China’s terrestrial ecosystem (Fan et al. 2010). As the hinterland and the world’s “third pole” Qinghai-Tibet Plateau, TRH has a unique and typical alpine vegetation system, which plays a vital role in the study of global climate change and vegetation response to climate change (Zhao 2009) . In the past few decades, under the dual effects of global climate change and human activities, the ecological degradation of the TRH has been obvious, which includes grassland degradation, land desertification, and decline in agricultural and livestock production (Tang et al. 2006; Li et al. 2004). In this view, Qinghai Province established a provincial-level nature reserve (*Natural Protecting Areas of TRH*) in TRH area in 2000, which approved as a national-level nature reserve (*National Nature Reserve of Three Rivers Source*) in 2003. In 2005, the State Council planned to invest 1.2 billion dollars to start the ecological environmental protection and construction project of TRH (*Overall Plan for Ecological Protection and Construction of TRH in Qinghai Province*), and implemented ecological projects such as returning grazing land to grassland, controlling black soil area and protecting wetland (Qinghai People’s Publishing House 2002; Li et al. 2011). In this context, accurately understanding the vegetation change trend and its main influencing factors of the TRH since 2000 is of great significance for the formulation of national ecological protection policies and the evaluation of the effectiveness of ecological engineering.

Traditionally, the measurement and evaluation of vegetation coverage have realized by visual evaluation, sampling, and instrument methods (Xing et al. 2009; Zhang et al. 2003). However, these methods are time-consuming and labor-intensive; it is difficult to obtain the spatial and temporal distribution characteristic of surface data. Remote sensing technology facilitates dynamic and continuous monitoring of vegetation conditions.

The normalized difference vegetation index (*NDVI*) is the most commonly used index to represent the vegetation status. It is closely related to the vegetation coverage, growth status, biomass, photosynthesis intensity and can objectively reflect the vegetation coverage information in the study area on a large space–time scale. It is considered as an effective index for detecting the changes of regional vegetation and ecological environment (Li et al. 2012, 2013; Wardlow and Egbert 2008) . The aim is to comprehensively understand the ecological environment of TRH area in China, to provide decision support for the ecological environment protection and construction by using vegetation index product *NDVI* to calculate the vegetation coverage, to study its changes and relationship with climate change.

Materials and methods

The study site

TRH is located in the hinterland of the Qinghai-Tibet Plateau (31° 39′ ~ 36° 12′ N, 89° 45′ ~ 102° 23′ E, Fig. 1). North and south edges are the Tanggula Mountains and the Kunlun Mountains respectively. The southern edge is the western section of the Tanggula Mountains. The highest peak is eastern part of the Geladandong snow mountain at the headwaters of the Yangtze River. Between the mountains is a wide valley lake basin. The climate in the region characterized by low temperature, precipitation and higher wind speeds (Qinghai People’s Publishing House 2002; Dong et al. 2002; Xiong et al. 2020). It covers an area of 35.66×10^4 km^2 with a regional elevation of 2000 to 6600 m, and average elevation is over 4000 m (Shi et al. 2016). The area is typical plateau continental monsoon area, experiencing dry and wet seasons. The average annual temperature range is − 5.38° C to 4.14° C. The annual precipitation is 262.2 ~ 772.8 mm, of which > 80% occurs in the rainy season from May to October, and the annual evapotranspiration is 730 ~ 1700 mm (Liu et al. 2020; Gafforov et al. 2020; Liang et al. 2013; He et al. 2020).

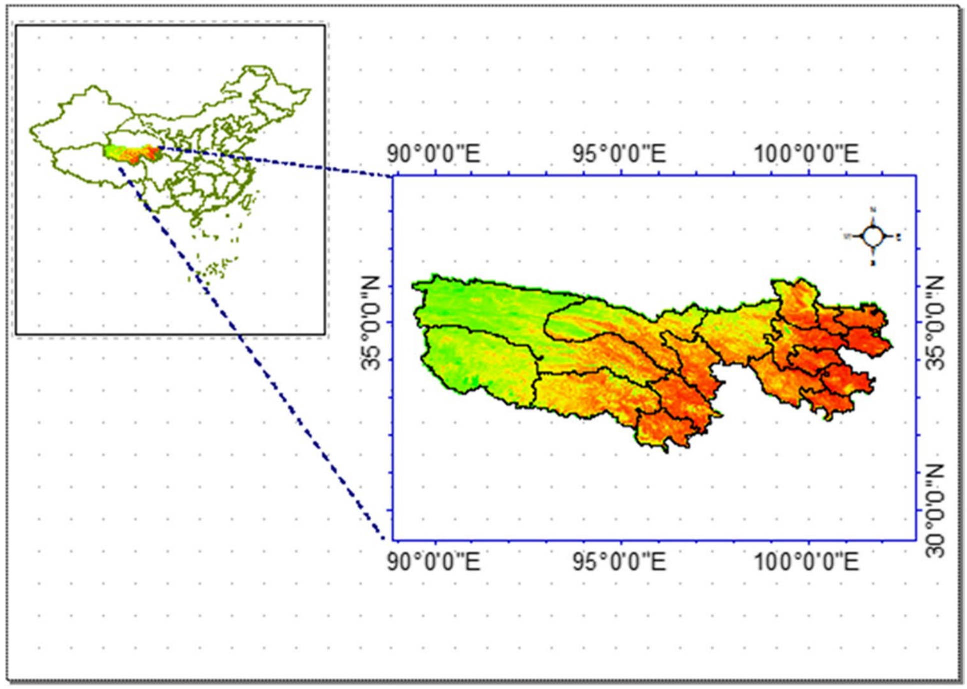

Fig. 1 Geographic location of the study area

The swamps, permafrost, rivers, lakes, and glaciers in this area are widely spread, with complex terrain, rich in species, rich with natural resources, and unique alpine ecosystems. It is one of the classic representatives of the plateau ecological environment system. The climate is cold and the environment is fragile. Its vegetation is more sensitive to climate change (Science Press 2001; Pei et al. 2019).

Data

MODIS NDVI

NDVI measures the difference between near infrared (which strong vegetation reflection) and red bands (which vegetation absorption) to quantify vegetation. *NDVI* always ranges from − 1 to 1, but there are not clear boundaries for every type of land cover. For example, when its value is negative, it is most likely water or snow. On the other hand, if the *NDVI* value is close to 1, it is likely to be dense green leaves. When *NDVI* is close to zero, represents there is no vegetation, and it may even be an urbanized area or bare land. *NDVI* uses the near-infrared (NIR) and red bands in its formula. The calculation method of *NDVI* is as follows:

$$NDVI = \frac{(NIR - \text{Red})}{(NIR + \text{Red})} \quad (1)$$

NIR and Red stand for near-infrared and red bands in Formula 1.

Healthy vegetation (chlorophyll) reflects more NIR and green light than other wavelengths. However, it can absorb more red and blue light. This formula generates a value between − 1 and 1. If the reflectance is lower value in the red band and higher in the NIR band, a higher *NDVI* value, vice versa. Overall, *NDVI* is a standardized method to measure healthy vegetation. When *NDVI* is higher, vegetation is healthier. When *NDVI* is low, there is little or no vegetation. In general, if you want to obtain the vegetation changes over time, you must make atmospheric correction to the image. (GIS Geography, https://gisgeography.com/ndvi-normalized-difference-vegetation-index/).

Vegetation index comes from the atmospheric corrected reflectance in red and near-infrared bands. It retrieved from daily, atmospheric corrected bidirectional surface reflectance. *NDVI* product more effectively characterizes the global area of vegetation state and process (MODIS, https://modis.gsfc.nasa.gov/data/dataprod/mod13.php). Multitemporal *NDVI* values in this research were derived from MODIS (moderate resolution imaging spectroradiometer) Terra and Aqua satellite sensor. All *NDVI* images covering the study area were downloaded from Geospatial Data Clouds, Computer Network Information Center, Chines Academy of Sciences (http://www.gscloud.cn/), which is a monthly synthetic product of MODND1D from 2000 to 2015, with a spatial resolution of 500 m. The calculation method is to take the daily maximum values within the month. Its coordinate system is EPSG: 4326 (WGS84).

Fractional vegetation coverage

Fractional vegetation coverage (FVC) is a vital evaluating for ecosystem condition, and used to monitor vegetation growth. FVC is the vertical projection area of vegetation (including leaves, buds, or stems) to the ground surface, expressed as the percentage or fraction of reference area (Gitelson et al. 2002; Purvedorj et al. 1998; Chen and Chen 2006; Zhang et al. 2019a, b; Godínez-Alvarez et al. 2009) . FVC derived from MODIS NDVI and calculated by the ERDAS remote sensing image processing software. The function is Formula 2 (Gutman and Ignatov 1998; Maselli et al. 2014; Liu et al. 2019):

$$FC = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}) \quad (2)$$

where $NDVI_{max}$ and $NDVI_{min}$ are the values of maximum and minimum *NDVI*. The *NDVI* of growth season on July 1st was selected as the data source, ranging from 2000 to 2015.

Precipitation

The precipitation data is obtained from the Global Precipitation Climatology Project (GPCP) v1.3 daily data (mm/day) from 1948 through 2019 with spatial resolution of 0.5° over the study area. See Fig. 4.

Surface temperature

The surface temperature was acquired from NCEP datasets (National Weather Service National Centers for Environmental Prediction, https://www.ncep.noaa.gov/). The spatial resolution is 2.5°; the temporal resolution is daily. Statistics is conducted during the time period from 1948 and 2019.

Results

The variation of vegetation index

The *NDVI* monthly data from 2000 to 2015 July month were taken from MODND1D China of 500 m through cutting, unit conversion, and other processes. Figure 2 is a part of *NDVI* data (2000, 2005, 2010, and 2015). In Fig. 2, the color variation indicates corresponding minimum to maximum values. The positive value is the place with vegetation (the value closer to 1 means the better vegetation coverage), and negative value indicates the water body. The vegetation coverage in the eastern part of the TRH region is higher than that in the western. Table 1 illustrates the mean value of *NDVI* in the TRH region from 2000 to 2015. The maximum

Table 1 The mean *NDVI* of the TRH on July 1st from 2000 to 2015

Year	Mean	Year	Mean
2000.7.1	0.281	2008.7.1	0.267
2001.7.1	0.271	2009.7.1	0.285
2002.7.1	0.276	2010.7.1	0.306
2003.7.1	0.267	2011.7.1	0.281
2004.7.1	0.269	2012.7.1	0.286
2005.7.1	0.269	2013.7.1	0.290
2006.7.1	0.293	2014.71	0.278
2007.7.1	0.271	2015.7.1	0.290

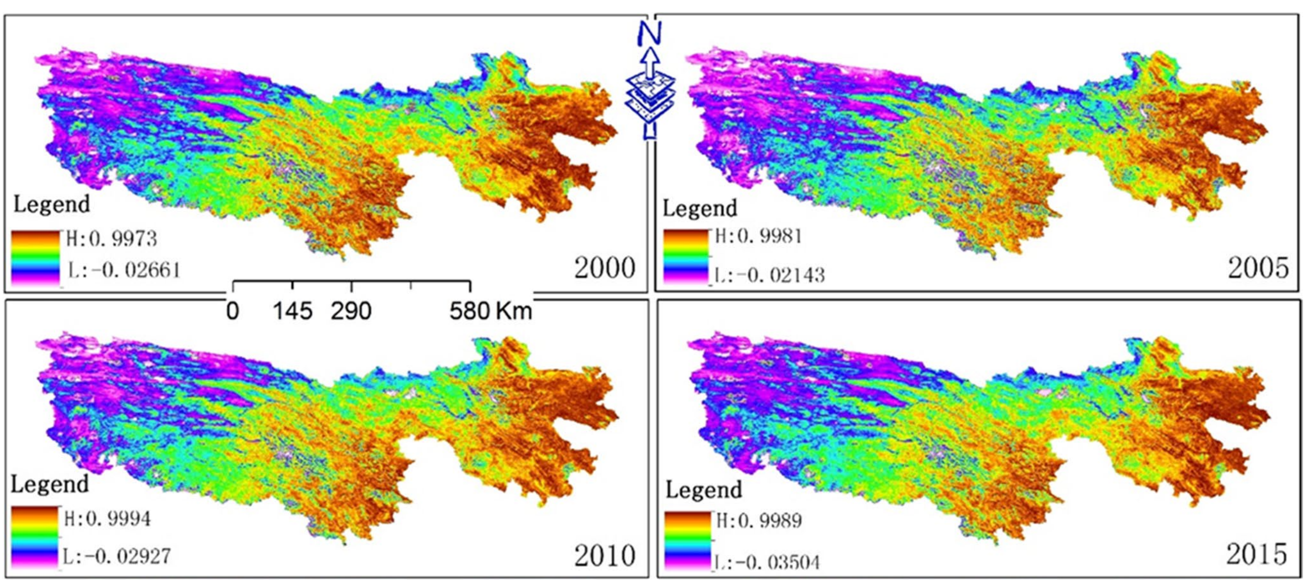

Fig. 2 MODIS NDVI in TRH from 2000 to 2015 on July 1st

Table 2 Mean vegetation coverage of the TRH on July 1st from 2000 to 2015 (%)

Year	Mean (%)	Year	Mean (%)
2000.7.1	30.1	2008.7.1	28.3
2001.7.1	28.7	2009.7.1	30.1
2002.7.1	28.9	2010.7.1	32.6
2003.7.1	28.3	2011.7.1	29.2
2004.7.1	29.0	2012.7.1	29.4
2005.7.1	28.5	2013.7.1	29.9
2006.7.1	30.7	2014.71	28.9
2007.7.1	28.6	2015.7.1	31.4

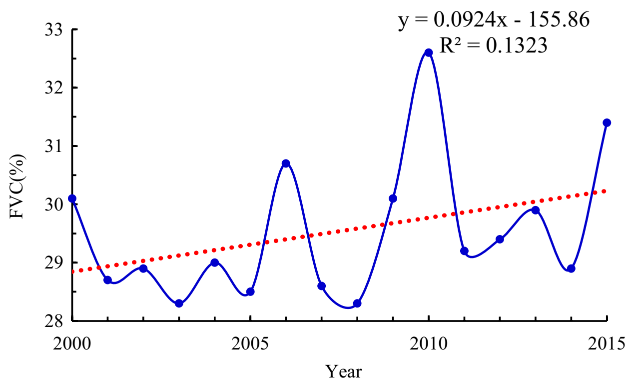

Fig. 3 The mean vegetation coverage from 2000 to 2015 on July 1st

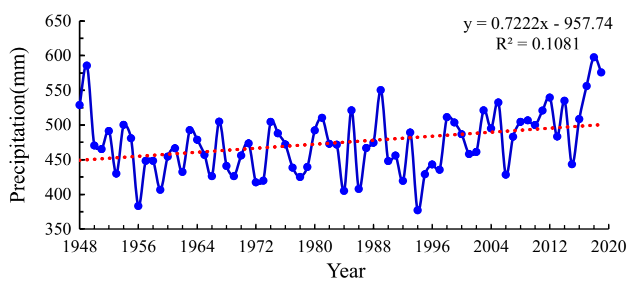

Fig. 4 The annual average precipitation from 1948 to 2019

(0.306) *NDVI* mean value is on 2010, the minimum (0.267) is on 2003 and 2008, and the value indicates increase in *NDVI* from 2000 to 2015.

Fractional vegetation coverage

Vegetation, including forest, grassland, farmland, bush, and orchard, is an important part of the ecological cycle and can maintain the ecological environment. Vegetation is the main index to measure the performance and status of ecological environment.

The vegetation coverage was calculated by MODIS NDVI from 2000 to 2015 on July 1st, using the ERDAS remote sensing image processing software. The FVC histogram of the TRH in the study period was obtained from the ERDAS software. The mean value of FVC can be seen as Table 2.

The maximum and minimum values of FVC can only represent individual values, and the mean value is used to analyze the annual change of FVC. In order to see the change of vegetation coverage more directly, we output the map, as shown in Fig. 3. Vegetation cover variations are given in the Fig. 3. As can be seen from Fig. 3, the FVC increased significantly, with the largest in 2010 and the minimum in 2003 and 2008; the values are 32.6% and 28.3%, respectively (See Table 2). Formula 3 is the regression equation obtained by regression analysis; the increasing rate of FVC is 0.92% per 10 years.

$$y = 0.0924x - 155.86 \quad R^2 = 0.1323 \tag{3}$$

Average annual precipitation

Figure 4 is the annual average precipitation from 1948 to 2019 in the TRH. It can be seen that the annual rainfall increases in volatility. Formula 4 was obtained by linear fitting the rainfall over the study period. The rainfall increases at a rate of 7.2 mm per 10 years.

$$y = 0.7222x - 957.74 \quad R^2 = 0.1081 \tag{4}$$

Figures 5 and 6 are the precipitation before and after 2000 in TRH. From Fig. 5, the annual rainfall decreases between 1948 and 2000. Formula 5 was obtained by linear fitting the rainfall from 1948 to 2000. The rainfall decreases at a rate of 2.3 mm per 10 years between 1948 and 2000.

$$y = 0.2307x + 918.25 \quad R^2 = 0.0076 \tag{5}$$

From Fig. 6, the annual rainfall increases between 2000 and 2019. Formula 6 was obtained by linear fitting the rainfall from 2000 to 2019. The rainfall increases at a rate of 41.2 mm per 10 years from 2000 and 2019. With the implementation of a series of ecological restoration policies, rainfall increased.

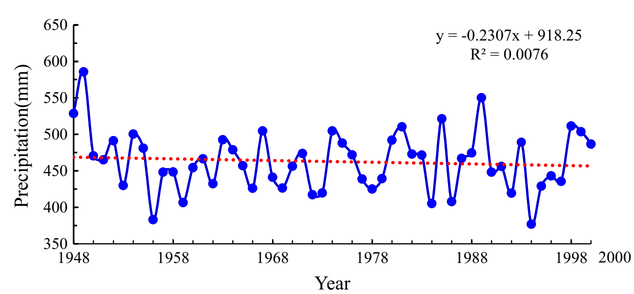

Fig. 5 The annual average precipitation from 1948 to 2000

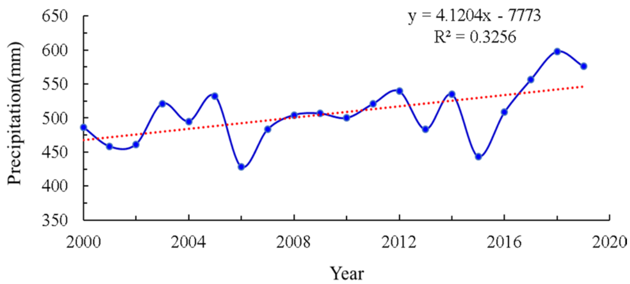

Fig. 6 The annual average precipitation from 2000 to 2019

$$y = 4.1204x - 7773 \ R^2 = 0.3256 \quad (6)$$

Seasonal average precipitation

The seasons are divided according to March to May as spring, June to August as summer, September to November as autumn, and December to February of the next year as winter. Before and after the implementation of the ecological restoration policy (before and after 2000), the seasonal rainfall variations are illustrated in Figs. 7, 8, 9, and 10. The linear fitting equations of rainfall in different seasons are given in Table 3.

From these equations, it can be seen that except for the summer and autumn of 1948 to 2000, the rainfall in the other seasons increased. From 2000 to 2019, the rainfall in four seasons shows an increasing trend; a higher precipitation is experienced in the summer.

Surface temperature

Figure 11 indicates the cumulative monthly average temperature between 1948 and 2019.

Figure 12 depicts the annual temperature variation in TRH region from 1948 to 2019. Temperature increased by 0.055 ℃ per 10 years between 1948 and 2019.

The summer mean temperature from 1948 to 2000 is given in Fig. 13, and there is a decreasing trend. It decreases with a trend of 0.069 ℃ per 10 years.

Figure 14 shows the summer mean temperature from 2000 to 2019. The mean temperature increased by 0.522℃ every 10 years, which is obvious.

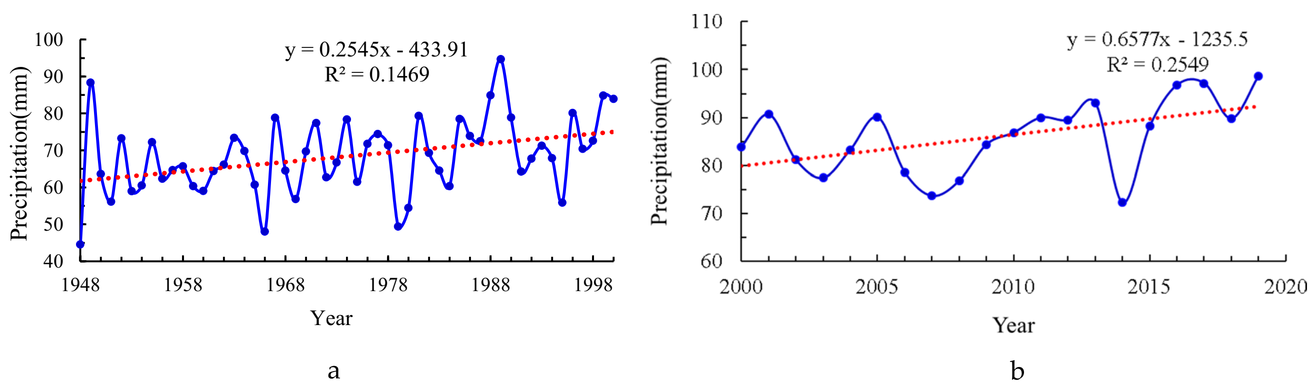

Fig. 7 Average precipitation in spring from 1948 to 2019

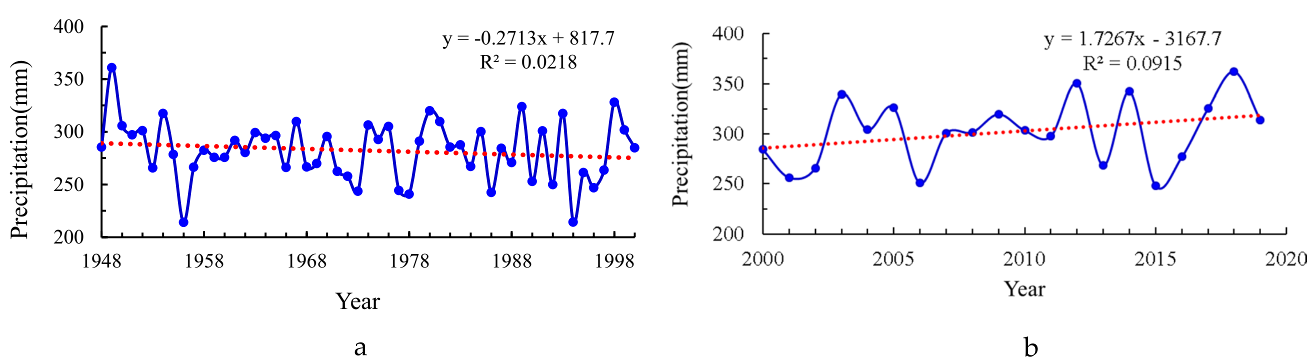

Fig. 8 The average precipitation in summer from 1948 to 2019

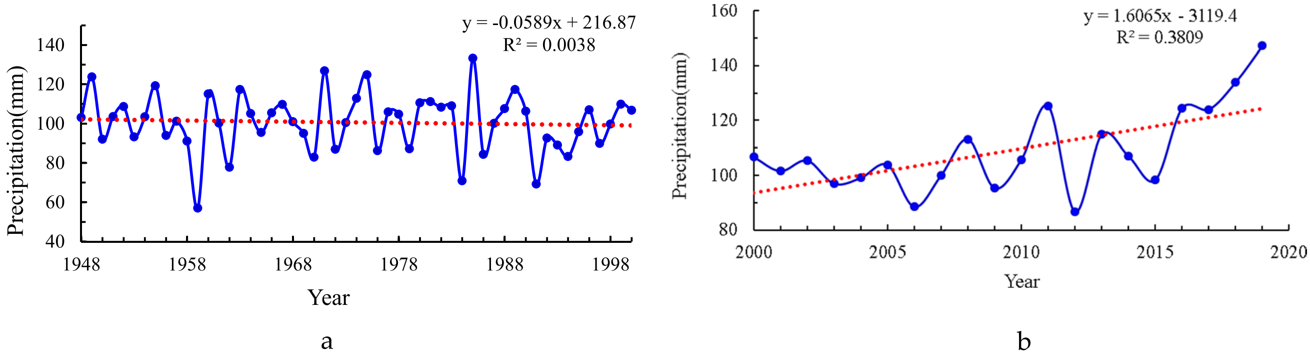

Fig. 9 The average precipitation in autumn from 1948 to 2019

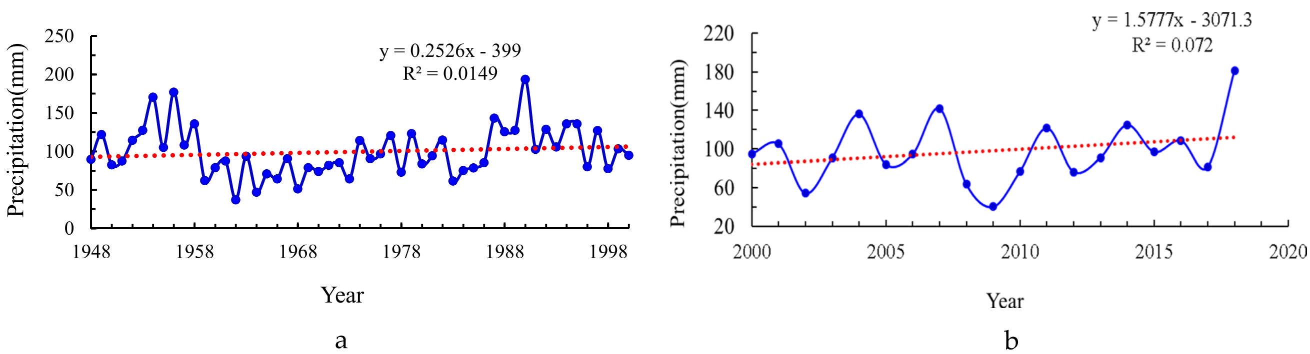

Fig. 10 The average precipitation in winter from 1948 to 2019

Table 3 The regression equation of rainfall in different seasons in TRH

Season	1948–2000		2000–2019	
	Formula	R^2	Formula	R^2
Spring	$y = 0.2545x - 433.91$	0.1469	$y = 0.6577x - 1235.5$	0.2549
Summer	$y = -0.2713x + 817.7$	0.0218	$y = 1.7267x - 3167.7$	0.0915
Autumn	$y = -0.0589x + 216.81$	0.0038	$y = 1.6065x - 3119.4$	0.3809
Winter	$y = 0.2526x - 399$	0.0149	$y = 1.5777x - 3071.3$	0.072

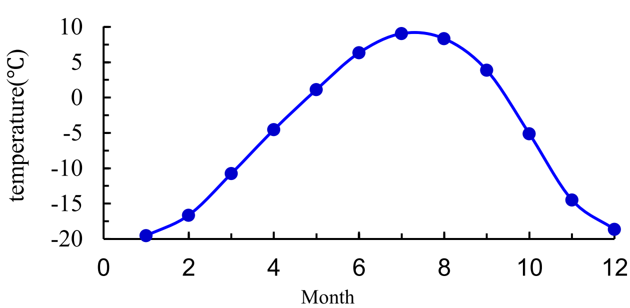

Fig. 11 The average monthly temperature

Discussion

Ecological protection policy in the TRH area

In the past few decades, the ecological of the TRH degraded obviously under the dual influences of global climate change and human activities, especially in grassland degradation, land desertification, and decline in agricultural and livestock production (Tang et al. 2006; Li et al. 2004; Xia et al. 2018). In this view, Qinghai Province established a provincial nature reserve in TRH in 2000 and established as a national nature reserve in 2003.

In January 2005, the State Council approved the "Master Plan for Ecological Protection and Construction of the Three-River Headwaters Nature Reserve in Qinghai" (hereinafter referred to as the "Plan"), investing 1.2 billion dollars to carry out ecological protection and construction projects (hereinafter referred to as the first-phase project). The first phase of the project was implemented from 2005 to 2013, lasting for 9 years, a total of 22 subprojects.

According to the "Plan," the environmental protection and restoration work of the Three-River Headwaters Nature Reserve is divided into three major items, namely, ecological protection and construction projects, farmers' production and living infrastructure construction projects,

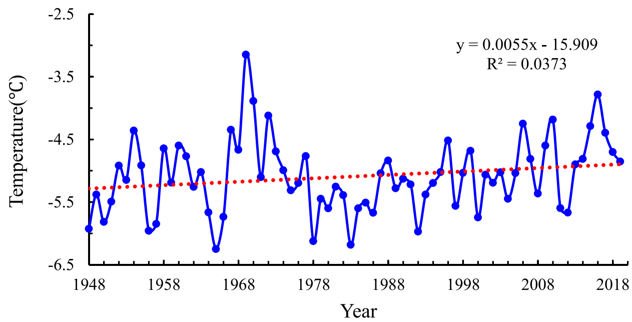

Fig. 12 The average temperature from 1948 to 2019

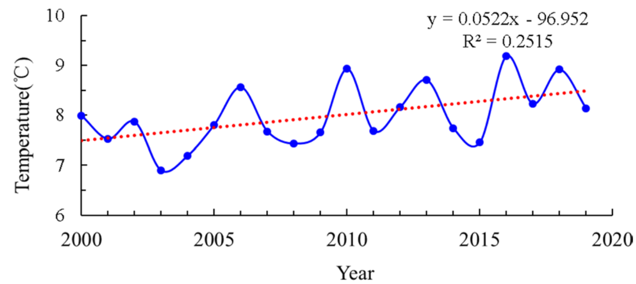

Fig. 14 The temperature in summer from 2000 to 2019

and supporting projects. This plan covered 69 townships (towns) in 16 counties. The eight projects of ecological protection and construction include reclamation of grasslands, protection facilities and capacity building, management of degraded land, grassland rodent control, returning farmland to forests, forest and grassland fire prevention, returning pastures to grasses, and soil and water conservation. The four projects for the construction of herdsmen's production and living infrastructure include human and livestock drinking water project, ecological immigration project, small town construction, and grassland protection supporting project. Two supporting projects include artificial rain enhancement project, and ecological monitoring and technological support. The project plans to complete the treatment of 372 thousand ha of black soil land, and increase the vegetation coverage from 20% to more than 80%. Meanwhile, the amount of water resources in the TRH Nature Reserve increases by 2.7 billion cubic meters, and the wetland area increases by 1.04 million square meters. The system's water conservation capacity increased by 174,000 tons, the closing of mountain land for forest (grass) of 371.3 thousand ha and 6.728 million ha of grazing land returned. The construction of 230,000 square meters of warm sheds can enable and 3.27 million sheep units to be moved from natural grasslands (Li et al. 2004; Hu et al. 2019).

In December 2015, the Chinese government adopted "Pilot Program of Three-River Headwaters National Park System in China." It is proposed to construct a pattern of "one park, three areas" with the typical representative area of the three major rivers as the main framework (Li et al. 2011; Xu 2017). Under this background, to accurate understanding of the vegetation trend and its main influencing factors of TRH is of great significance for the formulation of national ecological protection policies also to evaluate the effectiveness of ecological engineering undergoing since 2000. We select the year 2000 as the time division point to study the changes in vegetation and climate before and after the implementation of the ecological restoration policy.

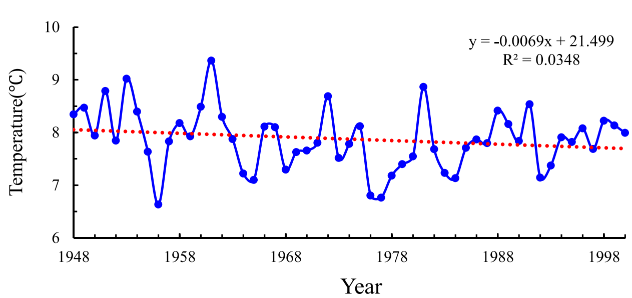

Fig. 13 The temperature in summer from 1948 to 2000

Vegetation cover change

Due to increase of grazing pressure, the grassland productivity decreased seriously in THR area. For example, in the early period of liberation in 1953, the average grassland per sheep unit in Zhiduo County (locate in TRH) was 2.3 hm^2, which dropped to 1.3 hm^2 by 1984, but only 1.1 hm^2 by 1994, a 50% reduction in 40 years (Wang 2003) . Since the Chinese government implemented a series of ecological protection policies for TRH, the vegetation coverage in this area has changed a lot and there is an increase in vegetation cover year by year.

The relationship between rainfall and vegetation change

The impact of climate change on vegetation has been widely recognized. TRH accounts for 43% of the total area of Qinghai Province. It is the wetland ecosystem with the highest altitude and largest area in the world. After grassland desertification, an increase of surface albedo causes the alteration of ground radiation balance. An increase in day and night temperature differences leads to a significant decrease in soil humidity. However, it is not conducive to the growth of existing vegetation. Precipitation is mainly concentrated in the plant growth season (May–September).

Figure 15 depicts FVC and summer rainfall over TRH from 2000 to 2015. The blue and orange lines are FVC and precipitation respectively. It can be seen that in most cases, FVC decreases with rainfall increases, except for 2001,

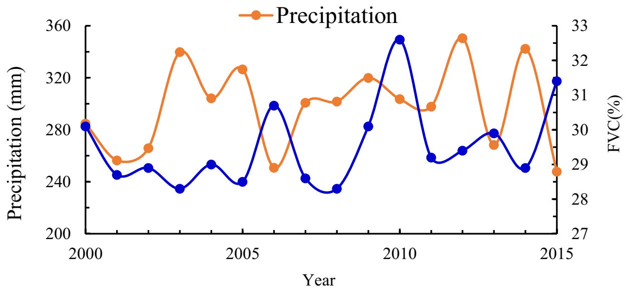

Fig. 15 The average precipitation and FVC in summer from 2000 to 2015

2003, 2008, and 2011. Combined with the summer temperature (Fig. 14), the summer temperature of these four years is lower at 7.5 ℃, 6.9 ℃, 7.4 ℃, and 7.6 ℃ respectively. Precipitation causes the temperature to drop; however, TRH is a cold area; low temperature in summer will have an adverse effect on the growth of vegetation. In most areas, moderate rainfall during the season will promote the vegetation growth, but in the TRH area, the rainy summer will impede the vegetation.

Effect of vegetation change on surface temperature

The latent heat and sensible heat are related to the surface temperature, which can reflect the change in soil moisture and vegetation coverage (Oke 1982). Vegetation can reduce the temperature and increase the humidity through photosynthesis, transpiration, and evapotranspiration, thus regulating the surface temperature. With the increase of vegetation coverage, the ability of the vegetation to convert the absorbed radiant energy into latent heat through transpiration is strengthened. The effect of sensible heat is relatively weakened, which reduces the surface temperature. At a given ground surface, the surface absorption of solar radiation and the supply of soil water are the two factors that control the surface temperature. If solar radiation absorbed by the ground surface does not change and the surface is arid and dehydrated, the transpiration of vegetation into latent heat energy decreases, the sensible heat exchange increases, and the surface temperature will increase accordingly (Yun and Shen 2010) .

On the time scale, as the land surface changes from forest to grassland or from grassland to cultivated land, the surface temperature increases constantly. This is due to the increase in sensible heat caused by vegetation degradation and dry land in this area. According to statistics, the areas with higher surface temperature are mainly with serious degradation of vegetation.

On the spatial scale, significant negative correlation between the surface temperature and the vegetation coverage, i.e., the surface temperature rises significantly in the areas with poor vegetation coverage, while the surface temperature in the area with high vegetation coverage changes little, or even appears cooling. Surface temperature is also sensitive to seasonal changes in vegetation. The difference in vegetation cover at different regions may lead to different surface temperature. It is necessary to consider the impact of vegetation cover and its dynamical changes to predict future climate.

The influence of surface temperature on vegetation change

Surface temperature is the result of material (water) and energy (thermal energy) exchange in the atmosphere-soil-vegetation system, which can reflect the change of topsoil moisture content, and then reveals the vegetation growth (Owen et al. 1998). Meanwhile, surface temperature can also be used to determine the status of surface evapotranspiration indirectly (Park et al. 2004). When the plant is under drought stress, in order to reduce the water loss caused by transpiration, the leaf stomata self-defensively closed, resulting in a reduction of latent heat flux. According to the principle of energy balance, the sensible heat flux will increase and the leaf temperature will rise. Surface temperature is very sensitive to this thermal response, and it decreases the vegetation coverage or changes the vegetation spectral index. Therefore, the surface temperature is a good indicator of plant growth.

Different vegetation types have different responses to surface temperature. For alpine meadow and coniferous forest, the increase of surface temperature can promote the photosynthesis of vegetation; for evergreen and deciduous mixed forest, agricultural vegetation, and evergreen and deciduous mixed shrub, the increase of surface temperature can prolong the growth season of deciduous vegetation. The lack of surface water in limestone area and the evaporation increase with the increase in surface temperature, thus limiting the growth of vegetation. Meanwhile, changes in land usage types will also have a strong impact on the surface vegetation (Carlson et al. 1990; Zhang et al. 2019a, b).

Evapotranspiration of the surface (soil or vegetation canopy) affects the surface temperature by controlling the surface energy balance. In the vegetation-covered area, the loss or gain of soil water affects the vegetation transpiration directly, which in turn leads to the change of canopy temperature. During the drought, plants have deficient in water, which effects their growth leading to decrease in *NDVI* and canopy temperature raises (Carlson et al. 1990, 1994).

The latitude determines the solar incident radiation. When the latitude span of the study area is wide, even if the soil temperature and vegetation cover are the same, the latitude difference will cause different surface temperature (Nemani and Running 1989) .

The effect of temperature on vegetation changes in the TRH

From 1906 to 2005, the global average surface temperature increased by 0.74 ℃, and from 1956 to 2005 by 0.65 ℃. Eleven of the 12 warmest years since 1850 appeared in the recent 1995–2006, and the rate of temperature rise in the past 50 years is almost twice than that in the last 100 years (IPCC 2007). Climate warming is an indisputable fact, and many natural systems are being affected by regional climate change, particularly by rising temperature. In the past 30 years, the temperature and precipitation of the TRH have increased, and the maximum potential evapotranspiration has decreased in most regions, but there are also areas where the maximum potential evapotranspiration increasing (Wu et al. 2005). TRH is located in the hinterland of the plateau, where the ecological environment is very fragile, and the natural ecosystem is sensitive to climate change (Tang et al. 2007). TRH has a unique and typical alpine vegetation system, which plays an important role in the study of global climate change and the response of vegetation to climate change (Zhao 2009) . The increase of temperature is beneficial to vegetation growth.

The study of *Haibei Research Station of Alpine Meadow Ecosystem of Chinese Academy of Sciences* shows that when the hydrothermal conditions of meadow grasslands are well coordinated, forage grass yields increase, and conversely, forage grass yields will be suppressed. In years with high rainfall and high temperature, the yield of grass is high (Pu et al. 2005). For example, in April–August of 1988 and 1989, the precipitation is 29% higher than the average of the same period for many years and the temperature is 0.6 ℃ higher, and grass yield is more than 8% higher than the average level in the same period. On the contrary, in the years with uncoordinated precipitation and temperature, forage yield is low. Such as April to August in 1985, although the monthly precipitation is 38% higher than the average of the same period for the multi-year average, the temperature is 0.1 ℃ lower, while the precipitation is 29% lower in 1991, and the temperature is 0.4 ℃ higher, and the forage yield is reduced by 10% and 12% respectively. In the years with significantly lower precipitation and temperature, the grass yield is lower, such as April to August 1980, the rainfall is 17% lower than the multi-year average, the temperature is 0.6 ℃ lower, and the forage yield decreased by 14%. This is confirmed by the long-term research results of the *Inner Mongolia Grassland Ecosystem Positioning Research Station of the Chinese Academy of Sciences* (Chen and Wang 2000) .

Table 2 and Fig. 3 describe the vegetation coverage changes in the TRH region from 2000 to 2015. It can be seen that the highest mean FVC is 32.6% in 2010, the lowest 28.3% in 2003 and 2008. Based on the analysis of summer surface

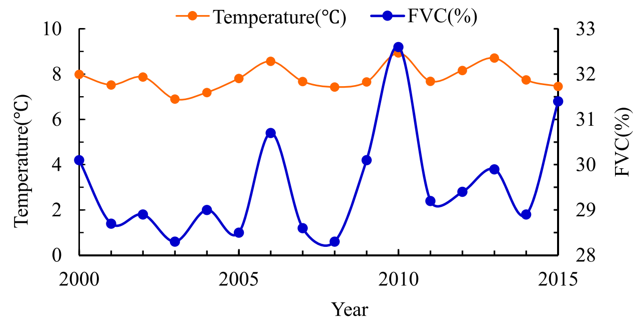

Fig. 16 The mean summer temperature and FVC from 2000 to 2015

temperature, it is found that the lowest temperature from 2000 to 2019 is in 2003, and the highest temperature in 2010. Temperature in 2008 is also lower. The temperature in summer has a great influence on the plant growth in TRH. In a certain range, the temperature in summer is high and the vegetation grows luxuriantly. TRH area belongs to the cold zone, and the period suitable for vegetation growth is relatively short.

Figure 16 indicates the effect of TRH summer temperature on vegetation change. From the figure, when the temperature increases, the vegetation grows better and the vegetation coverage increases. The trend of temperature change and vegetation coverage remained consistent. When the temperature reaches each peak, the vegetation coverage is also the peak, and vice versa.

In order to illustrate the correlation between summer temperature and vegetation coverage, regression analysis was performed out to obtain the regression equation (see Fig. 17, Eq. 7). Formula 7 demonstrates a positive correlation between them.

$$y = 1.422x + 18.4 \quad R^2 = 0.4084 \tag{7}$$

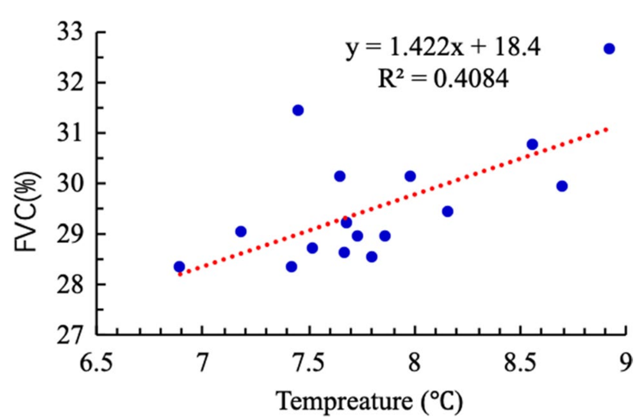

Fig. 17 Correlation analysis of vegetation and temperature changes from 2000 to 2015

A certain range of temperature increase in the TRH region will promote the growth of vegetation.

Conclusion

Water vapor in TRH area mainly comes from the Bay of Bengal. Affected by southwest monsoon and topography, the spatial distribution of annual precipitation gradually decreases from southeast to northwest. Natural precipitation is the main source of groundwater, soil water, and surface water in this area (Gang et al. 2011). Since the 1940s, the temperature in the TRH has increased significantly, and higher than that in the Qinghai Tibet Plateau. Although the precipitation has increased slightly, still shows periodic fluctuations in the long time scale. However, rainfall has increased significantly since 2000.

The increase of rainfall reduces the surface temperature and has a negative impact on the growth of vegetation in TRH in summer. Increase in temperature over the alpine zone can accelerate the plant growth, and the vegetation in TRH is more sensitive to temperature. The response of vegetation to temperature has the characteristics of sensitivity and dependence. The changes of temperature in summer have a key impact on plant growth. While vegetation growth mainly absorbs soil water, soil mainly obtains water through atmospheric precipitation, and vegetation has a lag response to precipitation.

This work includes the surface temperature and rainfall to validate the vegetation growth. However, the evapotranspiration, which occurred due to the vegetation, needs to study further to check the water balance (evaporation and precipitation) over the TRH. As the temperature increases in the summer season due to solar radiation, further studies need to focus on how the radiation budget (includes net radiation, latent heat and sensible heat fluxes) impact on the vegetation growth.

Author contribution Biyun Guo: conceptualization, methodology, software, data curation, writing—original draft preparation. Jushang Wang: data curation. Venkata Subrahmanyam Mantravadi: data curation, writing—reviewing and editing. Li Zhang: data curation. Guangzhe Liu: investigation.

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Data availability The normalized difference vegetation index (*NDVI*) we use is available for download from Geospatial Data Clouds, Computer Network Information Center, Chinese Academy of Sciences at http://www.gscloud.cn/. The precipitation daily data we use is available for download from the Global Precipitation Climatology Project (GPCP) at https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre. Hydrological data we use is obtained from the Yellow River Sediment Bulleting, Yellow River Conservancy Commission of Ministry of Water Resources. The surface temperature was acquired from NCEP datasets (National Weather Service National Centers for Environmental Prediction, https://www.ncep.noaa.gov/).

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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