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Change of surface cover greenness in China between 2000 and 2010

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Surface greenness reflects the situation of vegetation cover. Vegetation index calculated from the Red and Near Infrared bands of remote sensing images, whose values indicate the level of photosynthetic activity, is monotonically related to surface greenness when vegetation canopy does not fully cover the background soil. Especially for desert regions, vegetation index is positively correlated with vegetation coverage. Therefore, vegetation index can be used to study the change in greenness of desert areas. This study collected MODIS Normalized Difference Vegetation Index (NDVI) data from 2000 to 2010 and analyzed their change over China in this period. The results showed that an increasing trend of NDVI occurred over 66.84% (OLS fitting) or 64.27% (LAD fitting) of China, indicating that China's greenness is increasing overall. Meanwhile, desertification of China decreased. Areas showing large increase in greenness are found in Shaanxi, Shanxi, Ningxia, Henan, Shandong, Qinghai, and Gansu while regions with large decrease in greenness are found in Northeast Inner Mongolia, South Tibet, Jiangsu, and Shanghai. Changes of Qinghai, Gansu, Xinjiang and South Tibet could probably be driven by climate factors. Decrease of greenness in Northeast Inner Mongolia was related to agricultural reclamation. Decrease of greenness in Jiangsu and Shanghai was related to rapid urbanization. Climate factors did not exhibit obvious correspondence to the large increase in greenness in Shaanxi, Shanxi, Ningxia and Gansu, indicating that the changes might have been caused by human factors. The reduction of desert areas in China could probably have been caused by human management and protection at the national scale.

desertification, greenness, MODIS, NDVI, trend

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Surface greenness correlates closely to the situation of vegetation cover. Remote sensing has been used to study vegetation cover through Vegetation Index (VI) [1]. Especially for desert regions, Normalized Difference Vegetation Index (NDVI) is positively correlated with vegetation coverage [2].

As one of the biggest environmental problems, desertification is also an important content of global change studies, bringing great pressure to the sustainability of human society. According to the definition of the "United Nations convention to combat desertification" (hereafter "convention" for short), desertification means land degradation in arid, semiarid and dry sub-humid areas resulting from various factors, including climatic variations and human activities [3]. Long-time loss of natural vegetation, low vegetation coverage, and desolation of land, are salient features of land degradation and important basis of desertification monitoring. Therefore, we can use the value of vegetation coverage to evaluate the level of desertification. Vegetation index is thus a practical and feasible measure for desertification monitoring and evaluation.

China is one of the countries with serious desertification in the world. Since 2000, rapid expansion of urbanization and increasing material demand of the population have made land use/land cover of China change dramatically, with increasing intensification of land degradation led by

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the expansion of built-up area, excessive reclamation, and over-grazing activities. On the other hand, people have gradually realized that we are facing with huge challenges of the global environmental change and sustainable development. Governmental agencies at various levels are also trying to enhance vegetation growth through such means as afforestation, increased irrigation, wetland restoration and returning cropland to forest land, in order to prevent further development of desertification [4]. The State Forestry Administration (SFA) published the fourth *Chinese Desertification and Sandy Land Bulletin* on January 4, 2011, revealing the situation of China's desertification from 2005 to 2009. It pointed out that, by the end of 2009, the area of national desertification was 2.6237 million square kilometers, occupying 27.33% of China's total land territory. The national desertification area reduced by about 2491 square kilometers annually on average through the 5-year periods. The bulletin also pointed out the situation of desertification and sandy land in China had been under preliminary control and declined at the national scale [5]. Desertification monitoring and evaluation by SFA were mainly based on field investigation using long-term ground observation sites [6], which is labor intensive and time consuming at the national scale. A large portion of desertification occurs mostly in remote and undeveloped areas, which makes it hard to do long-time onsite survey and dynamic monitoring, and the subsequent accuracy of survey data can also be difficult to evaluate.

Visual interpretation, image classification and analysis of vegetation index are often used for dynamic monitoring and evaluation of desertification and for the study of its driving factors [7,8]. Hot spots such as Inner Mongolia, Horqin grassland, Hulunbuir, Ordos, Qinghai-Tibet Plateau, Minqin, and the three north shelter forests, are major focal areas of previous remote sensing research [9–22], and there is no desertification analysis about the whole territory of China. Time series data used in existing research are mostly before 2000, incomplete since 2000 to nowadays [9–22], and there is still no report for the time period of 2000 and 2010. Therefore, in this paper we aim to map China's desertification between 2000 and 2010 based on international standard and definition of desertification, and the capability of remote sensing technology, in order to lay a foundation for China's long-term remote sensing monitoring of desertification.

1 Data and method

1.1 Data and pre-processing

NDVI is the most widely used vegetation index in desertification monitoring at present, whose value is positively correlated with vegetation coverage, making it appropriate as the first choice for monitoring and evaluation of desertification [23]. Some study suggests that Net Primary Productivity (NPP) is a preferred index [7], while others argue that Enhanced Vegetation Index (EVI) could be used as an index [23]. Although these two kinds of index has great denotative meaning in quantitative studies, NPP obtained from remote sensing are usually derived from NDVI while EVI primarily based on spectral information in the red and near infrared bands functions similarly to NVDI. So for the purpose of this study, that is to qualitatively assess the trend of greenness in China, there are no fundamental differences among the three indices. They can basically achieve the same effect. We also did some experiments using EVI and achieved consistent results with NDVI in trend analysis. Therefore, in this study NDVI was chosen as the indicator of vegetation status. NDVI from NOAA satellite series has the longest time series in 15-day composites since 1981, but they are more affected by water vapor for the satellite observation time is in the afternoon. Since the data were obtained by several satellites with different local overpass times and orbit drifts, application of this long-time series of NOAA data has certain limitations [23]. The Moderate Resolution Imaging Spectrometer (MODIS) NDVI data product has improved sensitivity to vegetation and reduced the influence of external factors (such as atmosphere, observation angle, the sun angle, and cloud, etc.), and thus is more applicable at the global scale [24].

In this study, we used MOD13A1 vegetation index product obtained from the Earth Observation System (EOS) with a spatial resolution of 500 m. It is calculated from two-way atmospherically corrected surface reflectivity that reduced the effect of water, clouds, and heavy aerosol. It comes with cloud shadow mask. A 16-d composite was used in order to further improve data quality. The value range of the MODIS NDVI data set is between −2000 to 10000, with a scale conversion factor of 10000. The time range of the data set is from 2000 to 2010, in the growing season (May to August). We used 88 different time phases for China in the primary growing season.

The data was stitched and cut off from 19 scenes of MODIS images, covering the entire mainland of China and Taiwan. We transferred the Sinusoidal Projection generally used in MODIS products to Albers Equal Area Projection, and did the Maximum Value Composites (MVC) processing by month, in order to further eliminate interference of cloud, atmosphere, and solar altitude angles. After these preprocessing, we have prepared 44 cloudless NDVI images for China with minimum deviation.

1.2 Method

Our focus here was on the variation and range of desertification. Therefore we carried out trend analysis and greenness classification.

(1) Trend analysis. In order to analyze changes in NDVI, we used a Linear Regression Model to obtain the change trend of every pixel, by fitting a linear equation of

NDVI as a function of the variable of YEAR, to get an image of changing slope in the 11 years. For every pixel, using the Ordinary Least Squares (OLS) method and the Least Absolute Deviations (LAD) method, we built the linear relation between NDVI and YEAR:

$$\text{NDVI} = \text{SLOPE} \times \text{YEAR} + b. \tag{1}$$

The two methods can both obtain a SLOPE, following different criteria. The OLS method requests that the fitted trend produce the minimum of $\sum_{i=1}^{n}(y_i - a - bx_i)^2$, while the LAD method requests for the minimum of $\sum_{i=1}^{n}|y_i - a - bx_i|$. The OLS method, which is one of the commonly used methods in trend analysis of this type of data [25–27], has a simple formula of its extreme-value problem. The LAD method has a more complicated process in solving its extreme-value problem. In consideration of the absolute deviation rather than square of deviation, the LAD method has a better robustness with a capability of reducing the influence of outlier data [28].

SLOPE represents the trend in NDVI, which is used as the value in the output image. If there is an increasing trend of NDVI from 2000 to 2010, the SLOPE is > 0. Conversely, if there is a reducing trend, the SLOPE is < 0.

(2) Greenness classification. We divided NDVI values into different levels using the following categories: NDVI values less than a preset threshold in all 4 months of the growing season in a year; NDVI values less than the preset threshold in 3 months of the growing season in a year; NDVI values less than the preset threshold in 2 months of the growing season in a year; NDVI values less than the preset threshold in 1 month of the growing season in a year. NDVI values greater than the preset threshold in all 4 months of the growing season in a year. In order to avoid the influence of water bodies we have deleted pixels whose values are below 200, with the remaining pixels all classified into one of the 5 categories. Thus, we obtained annual greenness distribution of China from 2000 to 2010. Using the desertification distribution map of Northern China in the Atlas of Population and Environment Change of People's Republic of China as a reference [29], we experimented with 500, 1500, 2500, 3500, and 4500, as the threshold value to avoid the fortuity of a single threshold by taking the advantage of analyzing changes with different thresholds.

2 Results

2.1 Change trend

Grayscale images of linearly fitted NDVI slopes are shown in Figure 1, with the range of SLOPE from −1144.3 to 1507.5 for the OLS fitting and from −1460.4 to 1574.0 for the LAD fitting. Using the same stretching method, we can see from Figure 1 that the 2 images are very similar.

We divided the SLOPE image into 2 levels above or below 0. The region with SLOPE<0 occupies 33.16% of China, leaving 66.82% of China having an increasing trend in NDVI as determined with the OLS fitting results. For the LAD method, the region with SLOPE<0 occupies 35.73% of China, leaving 64.27% of China having a trend of becoming greener. The areas with SLOPE<0 concentrate mainly in northern Xinjiang, most areas of Tibetan Plateau, northeast of Inner Mongolia, and part of the three northeast administrative areas. These indicate that the surface greenness of approximately 2/3 of China increased but reduced in some regions through the 11-year period.

By taking 100 as an interval, a histogram of SLOPE is generated (Table 1). It is nearly a normal distribution with points having lower absolute value of slope occupying the central part, but the distribution is obviously drifted to the positive side.

Most slope values are in the range of (−100, 100), taking up 90% and 89% of the total area with OLS and LAD fitting methods, respectively, while more than 99% are between −350 and 350 for both methods. Clearly, the smaller the absolute value of the SLOPE, the less likely the trend is significant. We excluded areas whose SLOPE falls within the range of (−100, 100) and we found that 7.3% of China

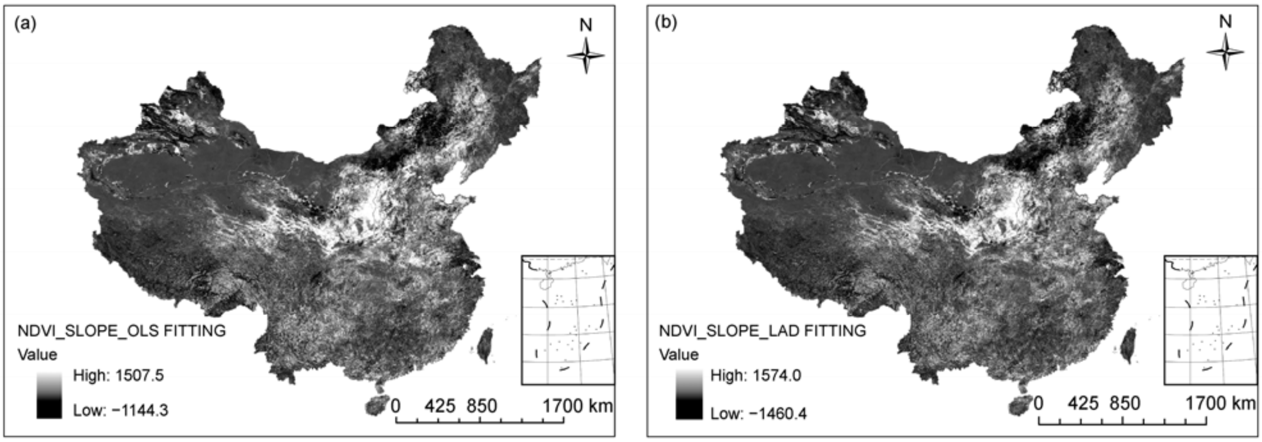

Figure 1 Image of surface cover greenness change in China 2000–2010. (a) OLS fitting; (b) LAD fitting.

Table 1 Statistics of slope classification

Threshold	Pixel numbers		Percentage		Cumulative percentage	
	OLS	LAD	OLS	LAD	OLS	LAD
Unclassified	353	939	0.00	0.00	0.00	0.00
−850 to −500	4555	6508	0.01	0.02	0.01	0.02
−500 to −400	6914	8925	0.02	0.02	0.03	0.04
−400 to −300	21951	31220	0.06	0.08	0.09	0.13
−300 to −200	101010	149463	0.27	0.40	0.36	0.52
−200 to −100	757612	976295	2.00	2.58	2.36	3.10
−100–0	11644462	12333942	30.80	32.62	33.16	35.73
0–100	22507964	21364877	59.53	56.51	92.69	92.24
100–200	2335383	2443837	6.17	6.46	98.87	98.70
200–300	339309	387939	0.90	1.03	99.77	99.73
300–400	58194	67518	0.15	0.18	99.92	99.90
400–500	17574	20513	0.05	0.05	99.97	99.96
500–850	12467	15772	0.03	0.04	100	100

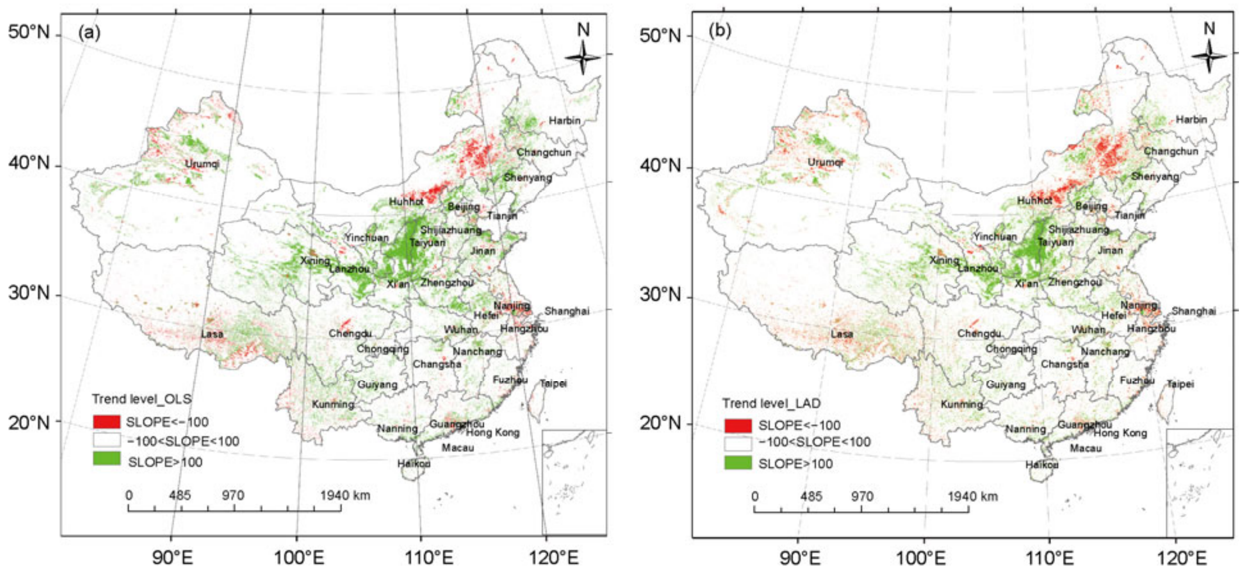

Figure 2 Key areas in surface cover greenness change in China 2000–2010. Green: NDVI trend slopes greater than 100; red: NDVI trend slopes smaller than −100. (a) OLS fitting method; (b) LAD fitting method.

had slopes greater than 100 and only 2.4% had slopes smaller than −100 from the OLS method of trend fitting (Figure 2(a)). From the LAD trend fitting results, we found that 7.8% of China had slopes greater than 100 and 3.1% smaller than −100 (Figure 2(b)).

Tables 2 and 3 show the statistics of changes of average greenness at the provincial level for OLS and LAD, respectively. By taking the LAD result as examples with the zooming in over 4 parts of the significant regions of change in China, we can see that surface cover greenness of China increased most significantly in central Shaanxi and Shanxi, part of Qinghai, Gansu, and Ningxia (Figure 3(a)). In contrast, the most significant regions of greenness decrease appeared in northern Inner Mongolia (Figure 3(b)), and most parts of southern Tibet (Figure 3(c)), parts of Jiangsu Province (Figure 3(d)), and Chengdu Plain of central Sichuan. Within the five primary administrative areas of desertification in China, Gansu and Qinghai had a markedly increasing trend in surface cover greenness from 2000 to 2010. In Xinjiang, Inner Mongolia and Tibet, surface cover greenness changed differently in different areas. Thus the overall statistics of greenness remained stable. The 4 administrative areas whose greenness changed at the fastest rate in China are Shaanxi, Shanxi, Ningxia, and Henan which are all in the north. The changing trend in southern China is not obvious. The 4 administrative areas with negative changes are Shanghai, Jiangsu, Taiwan, and Tibet.

Shanghai, Jiangsu and Zhejiang at the Yangtze River Delta experienced the fastest urbanization in the past 10 years. The decrease in greenness of Chengdu is closely related to the urbanization centering around Chengdu. According to results of urban expansion mapping in China for 1990, 2000, and 2010, Jiangsu Province has a total urbanized area of over 4500 km^2 in 2010 leaping from 1500 km^2

Table 2 Greenness change of the administrative areas of China-OLS fitting

Administrative area	NDVI slope	Administrative area	NDVI slope	Administrative area	NDVI slope
Shanghai	−44.70	Macau	15.32	Qinghai	32.00
Jiangsu	−4.76	Guangdong	16.34	Gansu	36.07
Taiwan	−4.38	Yunnan	16.82	Anhui	36.79
Xizang	−2.14	Jilin	17.60	Hebei	37.50
Zhejiang	2.16	Sichuan	17.87	Liaoning	40.57
Inner Mongolia	3.63	Hainan	18.47	Shandong	41.42
Tibet	6.76	Beijing	20.86	Henan	47.13
Hong Kong	7.16	Jiangxi	24.83	Ningxia	57.63
Heilongjiang	9.80	Chongqing	28.31	Shanxi	76.78
Hunan	11.93	Tianjin	29.94	Shaanxi	85.56
Fujian	12.94	Hubei	30.70		
Guangxi	13.65	Guizhou	31.63		

Table 3 Greenness change of the administrative areas of China-LAD fitting

Administrative area	NDVI slope	Administrative area	NDVI slope	Administrative area	NDVI slope
Shanghai	−63.10	Tianjin	15.32	Shandong	35.44
Taiwan	−5.85	Sichuan	15.57	Anhui	35.53
Jiangsu	−5.52	Guangdong	16.66	Macau	35.91
Tibet	−2.63	Hainan	16.68	Hong Kong	36.13
Zhejiang	−2.14	Yunnan	16.88	Liaoning	36.81
Inner Mongolia	−0.27	Beijing	18.15	Hebei	37.17
Xinjiang	5.20	Jiangxi	24.07	Henan	41.50
Heilongjiang	8.35	Chongqing	25.06	Ningxia	58.59
Fujian	9.82	Guizhou	28.90	Shanxi	68.62
Hunan	10.18	Hubei	29.96	Shaanxi	83.19
Guangxi	12.69	Qinghai	31.05		
Jilin	14.78	Gansu	35.06		

in 2000, becoming the province with the greatest urban area. Chengdu, as the metropolitan city on the Sichuan Plain, had only 228 km^2 urban area in 2000, soared to 498 km^2 by 2010 [30].

Between 2000 and 2010, another study on the changing trend of forest leaf area index over China reported an obvious reduction trend of forest in parts of Jiangsu and Zhejiang and significant increase in Shaanxi and Shanxi [31]. Between 1980 and 2000, other studies suggested that, in southwest of Ordos Plateau in Inner Mongolia, the desertification had a trend of decline [9,10]. Desertification of Hulunbuir prairie, in China bordering with Russia and Mongolia shrank from 4053.9 km^2 in 2000 to 3859.6 km^2 in 2006 [11]. Desertification area of Minfeng was also reduced during 1992–2001, which is located at southwest Xinjiang [12]. Between 1996 and 2001, land degradation in Qinghai-Tibet Plateau turned to be serious, with increased desertification at an annual rate of about 1.8% [13]. Tongyu is located in northwest of Jilin Province, whose desertification area expanded to 4214 km^2 by 2400 km^2 from 1992 to 2002 [14]. Desertification area in Horqin grassland, the border area between Inner Mongolia and Liaoning Province, changed from 22423.1 to 22422.4 km^2 between 2000 and 2005, which was quite stable, but their work analyzed desert land area only, leaving the overall change of greenness in that region unevaluated [15]. For the same region, another study using the method of change comparison after image classification indicated sandy land of the region was reduced from 1999 to 2007, at the same time forest, grassland, and wetland area were also reduced, but farmland area increased, which are also evidences of land degradation in that region [16]. These research results are subsets of our study in spatial range. The temporal ranges of these works are mainly before the time series we chose, or overlap the earlier part of our temporal range. Therefore, these research results can be used as reference and basis for our study, and their conclusions are consistent with ours.

The results of the two different linear fitting methods show quite high consistency, and more than 70% of the total points pass the α=0.05 significance test. The results from both methods are reasonable as can be validated using relatively homogeneous areas in China. We can find no apparent

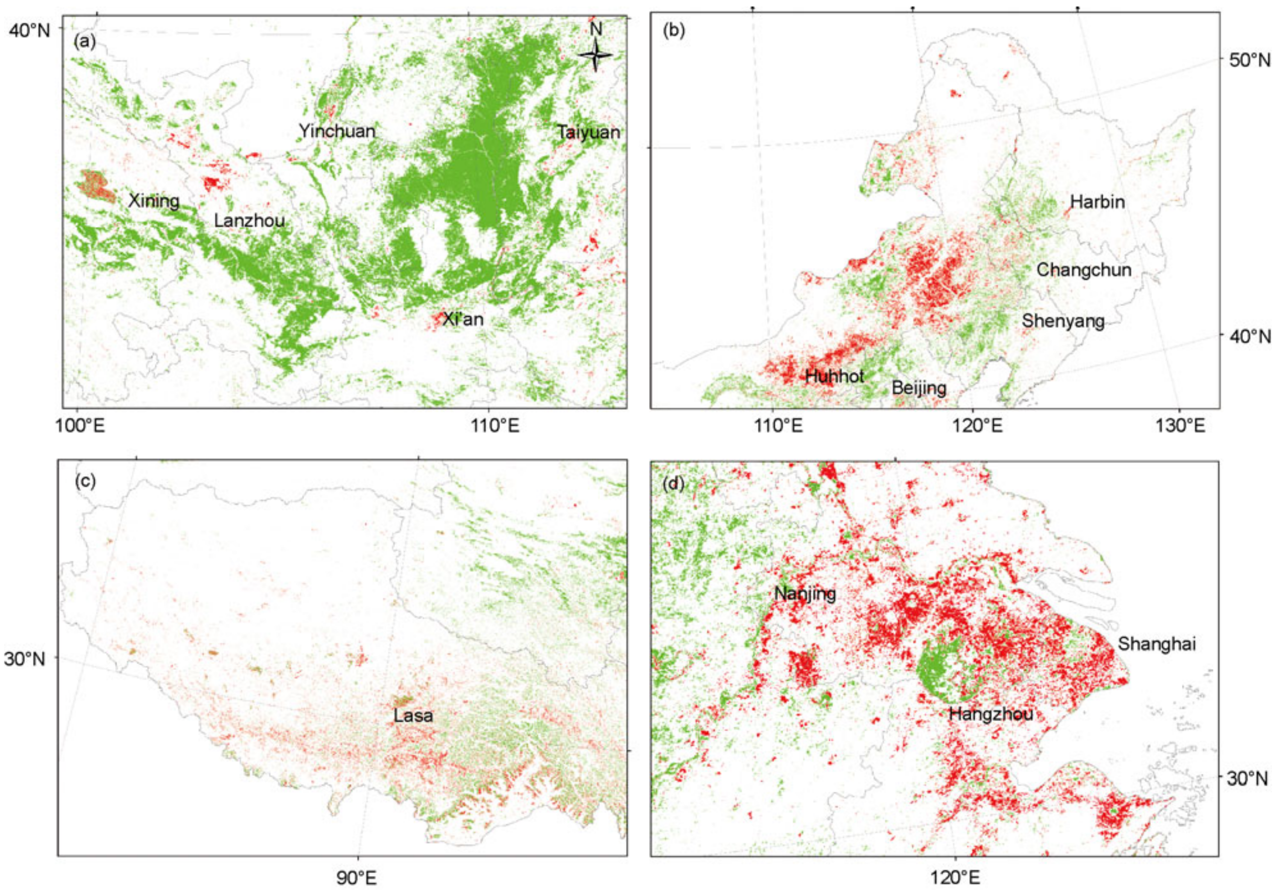

Figure 3 Regions in China with greater rates of changes in NDVI. (a) Shanxi, Shaanxi, Qinghai, Gansu; (b) eastern Inner Mongolia; (c) Tibet; (d) Jiangsu.

noise at those extremely dry desert regions in southern Xinjiang, whose vegetation coverage is in consistently low condition during the entire 11-year period with a uniformly low value of changing trend closed to zero in this study. The result of our study in key desertification research areas of China (such as eastern Inner Mongolia) shows good consistency with conclusions obtained by many previous researchers. Therefore in large scale trend analysis, the results of this study are reliable.

2.2 Greenness classification

In comparison with the desert map in the *Atlas of Population and Environmental Change in China*, the desert map with 1500 as the threshold is in the greatest agreement, but the eastern Inner Mongolia region is not included in the atlas. This area has exhibited an obvious reduction in surface cover greenness especially for 2000–2010. The map with 3500 as a threshold is generally consistent with the desert map in the Atlas in northern China, but a large part of Tibet is included in our map that does not exist in the Atlas. The leading factor of low value of greenness in Tibet is not desiccation, but controlled by low temperature.

NDVI classification images of different thresholds for 2000 and 2010 are shown in Figure 4. Along with the increase of threshold, the red area spreads from southeast to northwest, indicating an increasing distribution of NDVI value in China from northwest to southeast. The lowest surface greenness appears in southern Xinjiang. Most land of Xinjiang and Qinghai-Tibet Plateau, eastern and central Inner Mongolia, are areas with low NDVI values.

Within all the 4 levels we set in greenness classification whose values are below a preset threshold, distribution of low value in all 4 months during the growing season in a year occupies a majority of the areas, indicating a stable trend of NDVI value in all 4 months during the growing season. It means in those areas with low surface greenness, NDVI level remains from the beginning of the growing season, without much change. Distribution of the remaining 3 levels which respectively has values lower than the threshold in 3 months, 2 months, and 1 month of the growing season takes quite small proportions, and they are located at the southeast border of the areas with the lowest NDVI values, which is a sign of transition from relatively wet areas to dry areas.

Table 4 shows changes of desert areas between 2010 and 2000. The threshold of 1500 has indicated the greatest area reduction of 293077 km^2, and the threshold of 500 has resulted in the greatest rate of reduction at about 22.9%.

An area of 2623700 km^2 of deserts was reported in the

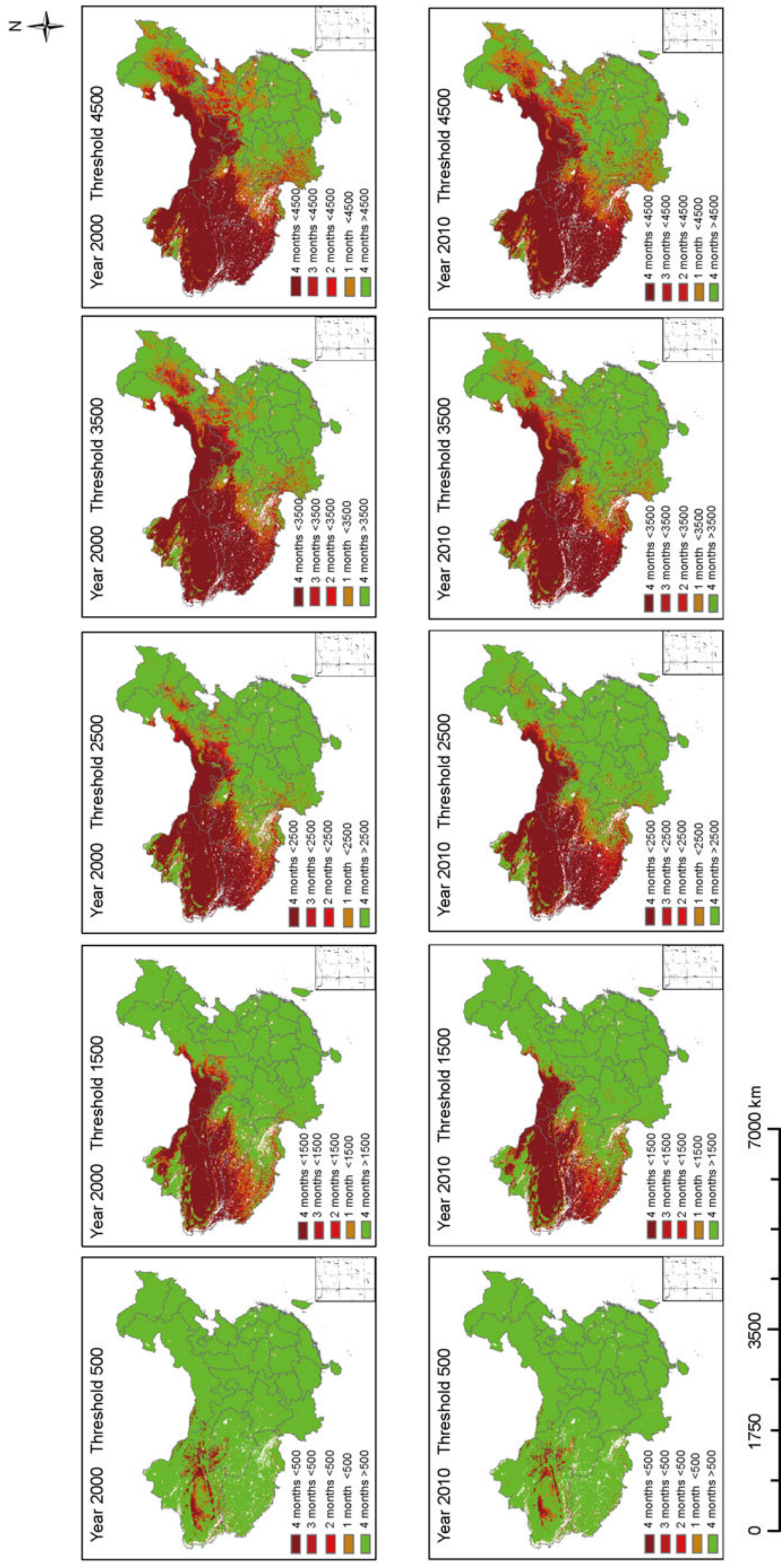

Figure 4 Image of greenness classification series 2000–2010.

fourth desertification survey of China for 2009. It is most consistent with the results derived with the threshold of 1500 in our analysis (Table 5). In that report, an annual reduction rate of 2491 km^2 was obtained for 2004 and 2009. In the same period, our results showed desertification area of 2788800 km^2 in 2009, with an average annual reduction of 3902 km^2. In summary, it seems to us that the threshold value of 1500 could be used for desert area classification in China.

Table 6 shows percentages of NDVI values below different thresholds from 2000 to 2010, and for every threshold, it gives a linear fitting slope of area changes through the 11 years. It is noted that as long as there is 1 month for the NDVI value below the threshold, we determine the pixel to be a desert one. Fit slopes of all 5 preset thresholds turn out to be all negative, indicating a reduction trend in area whose value is lower than the given threshold. This implies an increase in greenness through the 11 years. Threshold range reduced from 4500 to 500, with the slope of linear fitting increasing in a certain range. Overally speaking, the lower the NDVI values, the greater will be the reduction in area of deserts. That is, the regions with low vegetation coverage improved more obviously in the past 11 years, and for obtaining the greatest shrinkage in desert areas the threshold of 1500 was used.

Figure 5 shows greenness classification results of north west China on an annual basis using the 1500 threshold as an example. Although areas in red are not reduced consecutively on a year by year basis, a consistent trend of reduction through the 11 years can be observed. The boundary located in middle Inner Mongolia varies a lot. Desert areas in Gansu and Qinghai show a clearly reducing trend, while in southern Xinjiang they remain stable.

Table 4 Statistics of desertification area change compared between 2010 and 2000

Threshold	2010 (km^2)	2000 (km^2)	Reducing (km^2)	Reducing rate (%)
500	414282	537508	123225	22.9
1500	2718486	3011563	293077	9.73
2500	3759064	4021385	262321	6.52
3500	4743689	5006777	263088	5.25
4500	5631516	5889116	257600	4.37

Table 5 Results from greenness classification and ref. [5]

Desert area (10^4 km^2)	From [5]	2004–2009 NDVI classification
2009	262.37	278.88
2004	263.62	280.83
2004–2009	1.25	1.95
Average annual reduce	0.25	0.39

3 Discussion

3.1 Determination of an index for desertification monitoring

The word "greenness" used as an index in this paper reflects only the level of vegetation coverage [1], which is not identical to the definition of desert given in the "convention". The definition of desert in the "convention" describes desert from a climate perspective, and it points out in the extension of the definition "arid, semiarid and dry sub-humid areas" meaning that regions in polar and subpolar regions with the wetness index (ratio of annual precipitation and potential evapotranspiration) of 0.05–0.65 to be excluded [3]. So wetness index can be used as a quantitative indicator of desert classification. However, there is no further description about vegetation coverage in the definition of desert. It is difficult to set a standard threshold of vegetation coverage for different geographic landscapes and ecological characteristics, which is why we selected a series of thresholds in greenness in this research. In fact, regions of low greenness in this study are not limited to areas defined by desert in the "convention", but it can reflect the vegetation change of desert areas well [17–20,31].

In comparison with the fourth desertification survey of China, an NDVI value of less than 1500 can be used as an evaluation standard of desert. But the "convention" points out "desertification" with wetness index between 0.05 and 0.65 meaning that extremely arid area with a wetness index of less than 0.05 belongs to "desert", but not "desertification". Such areas are out of the United Nations Desertification Prevention Plan. Such regions would correspond to areas lower than 500 NDVI value. Except for desiccation, temperature is also an important factor restricting plant growth. So compared with the traditional definition, the "desert" in our study includes both cold regions and dry regions. For example, the Tibetan Plateau is beyond the

Table 6 Area statistics and linearly fit slopes from 2000–2010

Threshold	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Slope
500	5.69%	6.68%	5.48%	4.77%	3.85%	4.37%	4.01%	3.50%	4.54%	5.02%	4.38%	−0.17
1500	31.9%	31.6%	29.0%	29.9%	29.8%	29.4%	30.1%	29.3%	29.7%	29.5%	28.8%	−0.21
2500	42.6%	42.6%	40.1%	41.6%	41.3%	39.0%	41.6%	41.0%	41.2%	40.4%	39.8%	−0.18
3500	53.0%	51.6%	49.3%	51.6%	50.9%	49.2%	51.8%	50.5%	51.0%	50.4%	50.2%	−0.14
4500	62.3%	59.9%	57.2%	59.7%	59.1%	58.3%	60.7%	58.7%	59.6%	58.8%	59.6%	−0.10

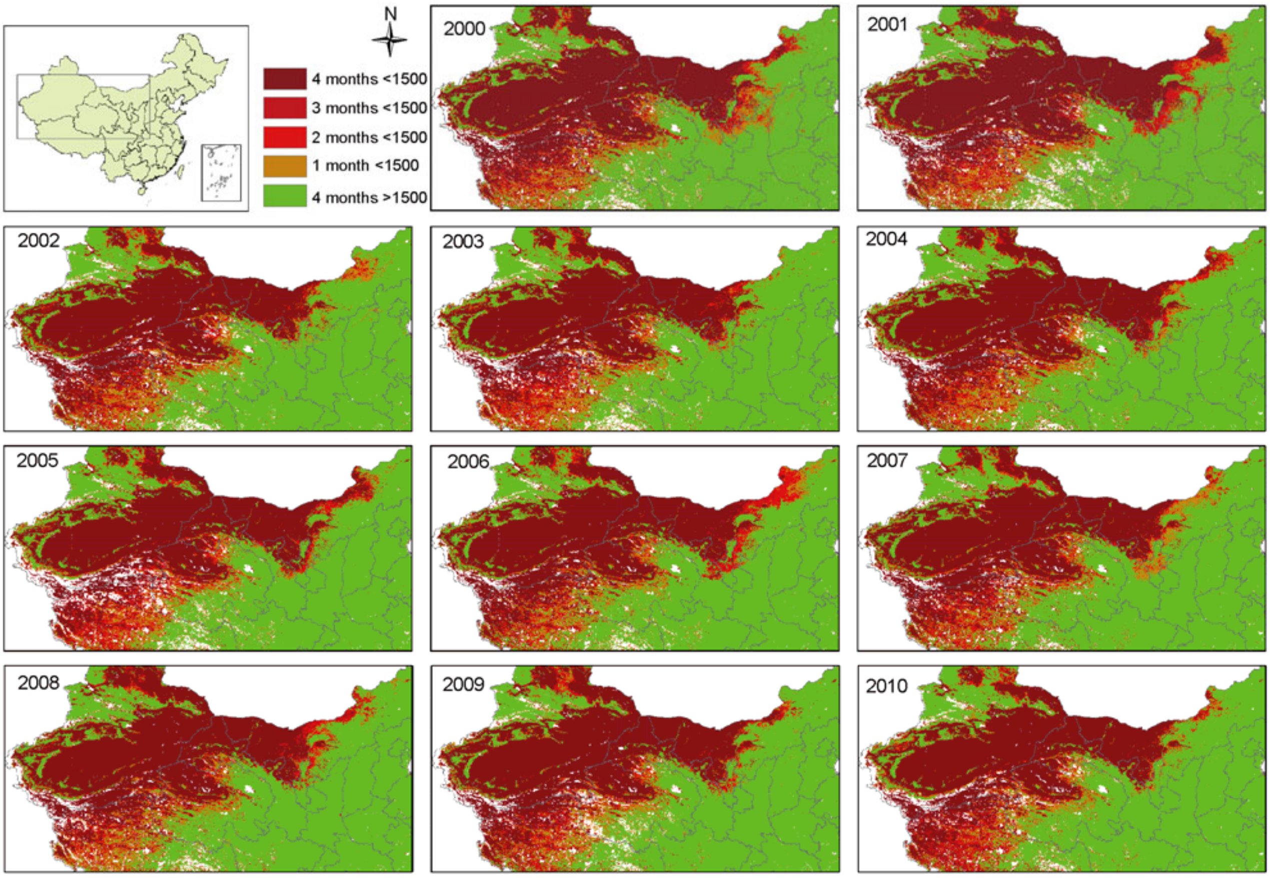

Figure 5 NDVI change in Northwest China from 2000 to 2010 (threshold 1500).

scope of the "convention" definition.

Therefore, using greenness as a monitoring index can not only reflect changes of desertification, but also contain description of vegetation cover change in extremely high altitude and cold regions or dry areas. The desertification bulletin achieved by the SFA adopts the desertification definition from the "convention", which can explain the reason that our research results are greater than that in the bulletin. In this research we focused on desertification land with long-time loss of vegetation and low coverage of vegetation, mostly found in Xinjiang, Tibet, Inner Mongolia, Gansu, and Qinghai of China.

3.2 Driving force analysis

Desertification land is an important land cover type in China, occupying nearly 30% of the total area. China turns out to become greener in the 21st century, but why did the desertification situation improve? Is this the result of natural factors or human intervention? Is this trend stable? Can this trend situation in the next 10 years? All these questions are worth studying. Here we try to answer part of these questions.

Natural factors and human intervention can both lead to land cover change and cause vegetation change. Regions located in the east which have large population can have more serious situation of desertification due to frequent human activities including urbanization, excessive reclamation, farming, grazing and deforestation [9,10,14], which makes human intervention the main factor. At the same time, human intervention could also become driving force to restrain desertification, such as the construction of the three north shelter forests and the grain for green policy in China. Although studies have pointed out that the effect of the three north shelter forests could have been overestimated [17,18], it has positive significance in reducing the situation of desertification. Climate has huge effect on vegetation growth [32]. In the wild, dry, and poor land of west China, without much human activities, natural factors might become the primary driving factor of desertification [13].

There are studies analyzing the role of temperature and precipitation in China in causing NDVI changes, by considering obvious regional differentiation of climate factors. For example, in Greater Khingan and northern Lesser Khingan area, more precipitation indicated lower temperature and less sun light, which is detrimental to vegetation growth; and in semiarid northern China, moisture is the main inhibiting factor for vegetation growth, so the increasing precipitation can promote vegetation growth [31]. Most desertification lands are found to be driven by reduction in precipitation. Only the Tarim Basin and east Tianshan are driven by a synergy of temperature and precipitation [33]. Clearly precipitation can directly influence the situation of vegetation cover. In addition, temperature can also play some important roles. Therefore, in this study we analyzed data downloaded from the Meteorological Data Sharing Service System of China, including temperature and rainfall data of 732 weather stations from 2000 to 2009.

Here we use the OLS results for analysis. Among these sites, 340 sites had increasing precipitation through the 10 year period (Figure 6). These sites are mainly located in eastern and central China and western administrative areas such as Qinghai, Gansu and Inner Mongolia. The 392 sites had decreasing precipitation through the 10 years, such as Xinjiang and south Tibet. Thus, from 2000 to 2009, precipitation in China has not shown a consistent trend of increase or decrease. Therefore, we could not confirm that the improvement of China's desertification situation during the same period was due to precipitation. Overlaying the climate trend data with those in Figure 2, we found that among the 158 sites falling into the region with sharp decrease in NDVI, 98 of which experienced a decrease trend in precipitation while 60 of which had an increase trend in precipitation. On the other hand, among the 152 sites falling into the region with obvious NDVI increase, 88 of them had an increase in precipitation, while 65 of them had a decrease trend in precipitation. The decrease of precipitation in Qinghai, Gansu, southern Xinjiang corresponded well with the NDVI change trend.

As shown in Figure 7, there were 585 sites whose annual average temperature increased through the 10 years, and only 147 sites had a decreasing trend of temperature. An increase in temperature increases the evaporation capacity in arid and semiarid regions making the water scarcity situation more serious. Therefore, temperature is not the primary factor that can explain the increase trend of greenness in desert areas.

We list the slope values for NDVI, precipitation, and temperature for the 5 administrative areas with the greatest desert area in western China in Figure 8. The greenness in Qinghai increased along with the precipitation increase through the 11 years, while the greenness in Tibet decreased along with the precipitation decrease and temperature increase through the 11 years. Natural factors, especially precipitation, may be the leading driving force of the desertification process in these two regions. And in Gansu, Xinjiang, and Inner Mongolia, the corresponding relationship of natural factors and the change in greenness is not obvious. Human intervention may be the dominant factors in these areas. Protection and management turn out to be effective in Gansu province, and for Xinjiang and Inner Mongolia, the effect of protection effect by the three north shelter forests is not apparent, with agriculture, husbandry, and urbanization developing rapidly in these areas, which are all possible factors important to aggravate the situation of desertification. A study using subsection regression analysis and residue analysis in Xilin Gole Grassland from 1983 to 1999 evaluated the influence of human intervention in land degradation, and it showed a growing land degradation caused by human intervention [34].

In summary, changes of natural factors (mainly precipitation here) are corresponding to changes of NDVI in some local areas, but not obvious across the whole country. The increasing trend of temperature has a tendency to aggravate the situation of desertification. In such conditions, reduction in desertification may be relevant with human management and protection.

4 Conclusion

Between 2000 and 2010, NDVI presents an overall increasing trend in China, indicating the growth of surface greenness and the alleviation of desertification. Decreasing trends are shown in local regions, indicating a trend of expansion in desertification of some areas. This coincided with the result of the desertification survey achieved by the State

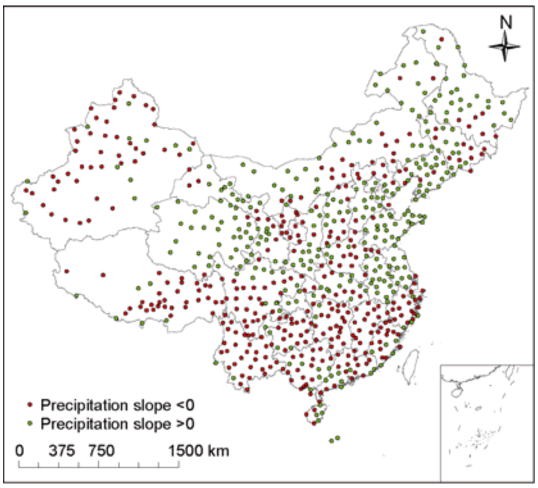

Figure 6 Slope image of precipitation changes from 2000–2009.

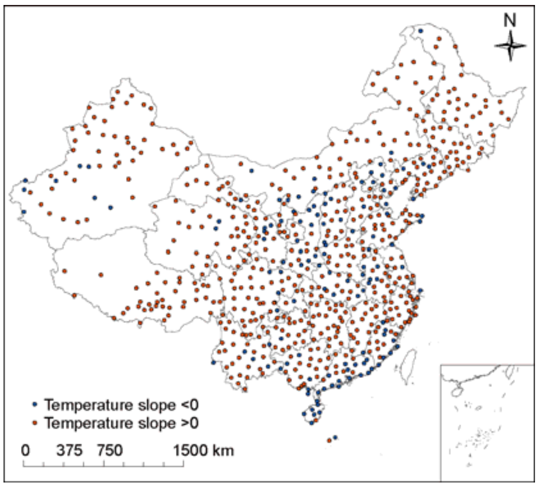

Figure 7 Temperature changes as measured by slope from 2000–2009.

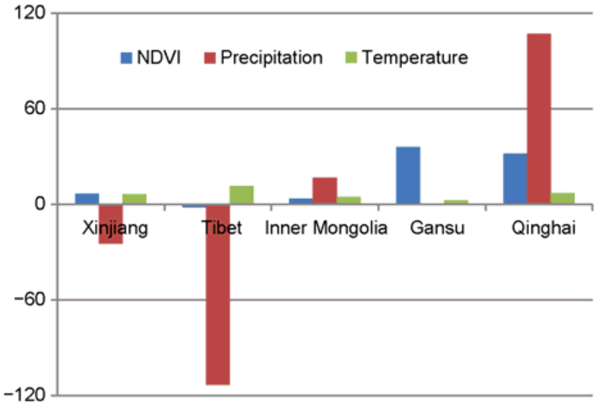

Figure 8 NDVI, precipitation, and temperature slope of Xinjiang, Tibet, Inner Mongolia, Gansu, and Qinghai.

Forest Administration. In some areas, due to dry climate, acceleration of urbanization and excessive development and use of land, the desertification situation intensified. However, the overall situation of desertification in China improved, which means that China had become greener. The change in greenness and the signal of climate change or influence of human activities in correspondence to the greening process needs further study.

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