

Vegetation change based on SPOT-VGT data from 1998–2007, northern China

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Abstract Dynamic change of vegetation in northern China from 1998–2007 was explored, based on SPOT-VGT data. The results showed that the NDVI can effectively monitor vegetation change, but also the mean multi-year NDVI maximum of 0.10 basically can be considered as the threshold of vegetation cover in northern China, and those places with smaller than or equal to the threshold value mainly were covered by deserts, Gobi and lakes, salinization lands, glaciers, snow patches and bare mountains, etc. The change trends of vegetation where sub-region C and D were affected by east-Asia monsoon were similar with the characteristics of first decreasing, later increasing and finally slowly decreasing; the difference lies in that sub-region C maintained a lower vegetation state, and sub-region D reached a higher state. The vegetation change of sub-region A was anomalous with smaller fluctuation. The change trend of vegetation of sub-region B was not only extremely unstable, but also the change extent was huge. As far as the whole of northern China is concerned, vegetation has not demonstrated obvious improvement since these ecological construction and protection projects, and the area of vegetation degradation still is much larger than that of vegetation improvement from 1998 to 2007, but there was a bigger spatial difference.

Field investigation and remote sensing monitoring reveal that vegetation has obviously been improved in the agro-grazing mixing zone and to the south, as well as many oases in the northwestern arid zone, while vegetation still has worsened in the steppes, especially the Ulanqab steppe, Hunshandake Sandy Land, the region along the Sino–Mongolia border within Xilingol Meng, Hulunbeir Sandy Land and the northern Tianshan mountain region in Xinjiang. Human activities only obviously showed success in local regions. The compelling challenges of restoring the eco-environment are still immense, especially in the northern grazing zone of China.

Keywords Northern China · Vegetation change · NDVI · SPOT data

Introduction

Vegetation is an important component of the global land surface system, and it has a significant role in stabilizing and improving the regional ecological environment. A negative correlation between vegetation coverage and the occurrence of dust storms in northern China in spring for the 1982–2001 period was demonstrated (Zou and Zhai 2004). Vegetation has often been considered an indication sign of the state of the environment. Multi-temporal remote sensing data recording the vegetation change process are of great significance for revealing global or regional environmental change (Shabanov et al. 2002; Fuller 1998; Zhou et al. 2001; Stow et al. 2003). Because the vegetation index (VI) can be sensitive to and can reflect the vegetation growth state, it is often used for monitoring vegetation change. The NDVI (normal difference vegetation index) is not only very sensitive to the physical characteristics of

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vegetation, but also is able to effectively lower the impact from the sensor observation angle, solar radiation and different soil backgrounds. Using the NDVI has become an important means for monitoring the changes in global vegetation cover (Ma et al. 2006).

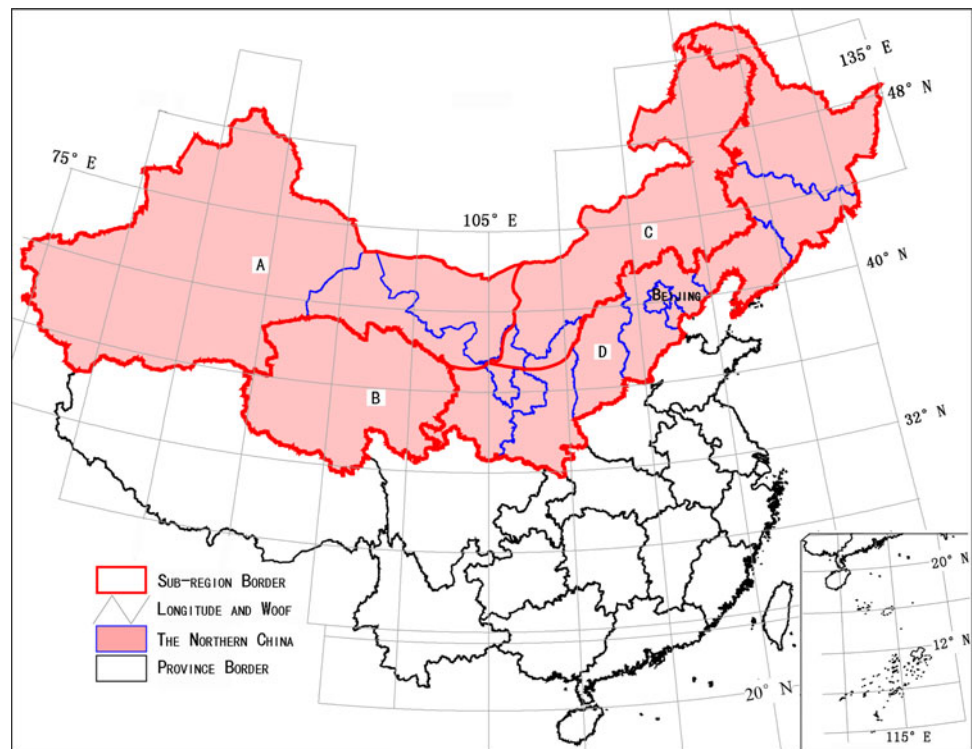
The study area covered the whole of northern China, including 13 provinces (cities or municipalities) of Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Shanxi, Shaanxi, Ningxia, Gansu, Qinghai and Xinjiang, the People's Republic of China (Fig. 1). The study area is a major area of aeolian desertification development in China, which is mainly covered by arid and semi-arid areas with sparse vegetation cover. Aeolian desertification in northern China has been going on for the last 50 years and is still spreading at an accelerated rate of development, though there is reversion in local regions (Wang et al. 2004). Because of the serious aeolian desertification situation and the frequent sand and dust storms, in the early twenty-first century, the state and governments at all levels in northern China implemented many ecological construction and protection projects aiming at controlling the aeolian disaster, such as the Returning Slope Farmland to Woodland or Grassland project (experimental test since 1999, full implementation in 2002) covering the whole study area, the Wind and Sand Source Area Control project around the Beijing–Tianjin regions (experimental test since 2000, implementation in

2002) and the Eco-water Transfer projects in the inland river basins, etc. The effect of these projects since the implementation is an important problem being considered by many people.

For ease in discussion, the whole study area was divided into four further sub-regions, referring to Wang's research results (2005). Sub-region A is to the west of the Wusholing Mountains and Helan Mountains, mainly covered by deserts, gobis and oases, etc., including Xinjiang, the west of Gansu Province and the west of Inner Mongolia; sub-region C is to the east of the Helan Mountains, mainly covered by sandy lands, grasslands and partly farmlands, etc., including the north of Ningxia, the north of Shaanxi, and the middle and east of Inner Mongolia; sub-region B is the whole Qinghai Province; sub-region D is other places in northern China with good vegetation conditions and scattered aeolian desertified lands.

Because there are obvious differences among current research results, such as evident increasing NDVI trends in almost all regions in China from 1982 to 1999 (Fang et al. 2004) and the popular vegetation degradation in most regions of northwest China from 1998 to 2004 (Song and Ma 2007), and lack of further monitoring of dynamic changes in vegetation in northern China since the various projects implemented, it is not clear how the projects were implemented and where further combating and protecting should be carried out. In this paper, vegetation change in

Fig. 1 The Northern China and sub-regions distribution map



northern China during the last 10 years will be analyzed using SPOT VGT data, aiming at providing a scientific basis for assessing the effect of the projects and further desertification control.

Methodologies

Data and processing

The SPOT-4 VEGETATION (VGT) sensor (launched on April 1998) is one of a new generation of space-borne optical sensors providing measures of land surface reflectance in the visible and in the infra-red domains. This sensor offers a daily global coverage with a spatial resolution of about 1 km². Reflectance measurements are performed within four spectral windows: blue (B0: 0.43–0.47 μm), red (B2: 0.61–0.68 μm), near infra-red (NIR: 0.78–0.89 μm) and medium infra-red (MIR: 1.58–1.75 μm) with a high spectral (absolute calibration accuracy of about 5%) and geometric accuracy (less than 0.3 pixels). The data used in this paper are a series of 10-day composite images (S10 products) of the VGT sensor. These S10 products are operationally generated based on a pixel selection by the maximum normalized difference vegetation index (NDVI), and they are radiometrically calibrated, precisely geo-located and corrected for atmospheric effects. Atmospheric corrections were performed using the simplified method for atmospheric corrections (SMAC) (Rahman and Dedieu 1994). Multi-temporal geo-location accuracy of the VGT data is particularly good (absolute location <0.8 km, multi-spectral registration <0.2 km and multi-temporal registration for 1 year <0.5 km), and thus the data are well suited to change detection applications. For more information on the VGT instrument, see the VEGETATION User Guide (<http://www.spot-vegetation.com>). All SPOT VEGETATION 1-km 10-day images were downloaded free of charge from the following URL: <http://free.vgt.vito.be>, and 351 S10 products of VEGETATION over the period of 1 April 1998–31 November, 2007 were acquired and analyzed in this paper.

Each 10-day synthesis file in Hdf format was read and saved as the files of a uniform Tiff format with projection information in ENVI software. Due to the presence of noise stripes in some data, they were processed through the destripping method first. All newly produced data were transformed into those with the same Albers Equal Area Conic Krassovsky projection. The original VGT-S10 (10-day synthesis) products are composit (maximum-value) products. All the segments of this period are compared to select the maximum ground reflectance values. Because the maximum NDVI value composite (MVC) (Holben 1986) (a maximum daily NDVI value in each 10 days) minimizes

atmospheric effects, scan angle effects, cloud contamination and solar zenith angle effects (Hope et al. 2003; Stow et al. 2003); following this concept, all three 10-day-synthesis products in every month were combined into monthly NDVI datasets for the best vegetation state in those months, adopting the former MVC method. The yearly NDVI datasets were produced with the monthly NDVI datasets from May to October each year using the same method, sequentially, because the maximum was always produced from May to October every year in northern China, but this also can avoid many stochastic errors caused by the lower NDVI values in the winter and spring seasons in northern China. Thus, the newly produced yearly NDVI products will be the best vegetation state pixel by pixel each year from 1998 to 2007. For spatial statistical analysis, all images were converted into grid-type raster files.

The valid range of the eight-bit (raw) data values is 3–255. A RAW value of zero denotes a land pixel with no NDVI calculated because of quality control flagging (i.e., clouds, snow or ice). A RAW value of 1 is not used in the binary files (this is reserved for the graphics plane). A RAW value of 2 denotes a water pixel. NDVI can be converted from those RAW values using the following formulation:

$$\text{NDVI} = (\text{DN} \times 0.004) - 0.1.$$

We can easily determine that the NDVI values smaller than –0.092 are not for vegetation, according to the information above. In fact, those areas with multi-year maximum NDVI values smaller than 0.10 also were proved for bare deserts, gobis and non-vegetated areas, according to existing knowledge (Wang et al. 2005; Wang and Hui 2005) and our preliminary results in this paper. The areas with NDVI <0.1 were defined as “sparsely vegetated areas,” while the areas with NDVI ≥0.1 were defined as “vegetated areas” (Fang et al. 2004). To reduce the impact resulting from these vast areas in northern China on spatial statistical analysis, those grids with multi-year maximum NDVI values equal to or smaller than 0.1 over the past 10 years were considered as non-change regions and are given a new value of zero in all later analysis in this paper.

Key methods

Difference method

Because all images were corrected accurately by the Flemish Institute for Technological Research, Vito, the vegetation change of the whole study area during 1998–2007 was detected in this paper by adopting the mean maximum NDVI values of the latter 5 years (2003–2007) subtracting those of the former 5 years (1998–2002).

Regression analysis method

Linear regression analysis can be used to simulate the change trend of each grid. Stow et al. (2003) adopted this method to simulate the greenness rate of change. For each pixel, the linear trend of annual maximum NDVI over the study period was estimated using ordinary least-squares regression. Slope is the slope coefficient of the fitted regression line at each pixel. Slope > 0 is better for vegetation, while slope < 0 is worse for vegetation

$$\text{Slope} = \frac{\sum_{i=1}^n (Y_i - \bar{Y})(Y_{\text{NDVI}_i} - \overline{Y_{\text{NDVI}}})}{\sum_{i=1}^n (Y_i - \bar{Y})^2} \quad (1)$$

where n is 10 (because it is 10 years from 1998 to 2007), and i is 1, 2, 3, till 10. Y_{NDVI_i} is for the yearly maximum NDVI value from the first year of 1998.

Results

Spatial distribution patterns of the multi-year NDVI maximum during 1998–2007

Figure 2 clearly shows that spatial distribution of the multi-year NDVI maximum of northern China is basically consistent with the main types of land cover. Those places with NDVI values of less than 0.1 were mainly concentrated in arid regions to the west of the Helan Mountains and overlapped with the distribution patterns of the Chinese deserts and gobis. This result shows that NDVI can be used for dynamic monitoring and quantitative research of vegetation changes, and the NDVI value equal to 0.1 basically

can be an important threshold of vegetation cover in the sandy regions of northern China. According to statistical analysis, these non-change regions where the NDVI value is equal to or smaller than 0.1 occupied about 28.9% of the total study area.

Vegetation dynamic change in the northern China during 1998–2007

Vegetation states of 1998, 2003 and 2005 were obviously better than those of other years from 1998–2007 according to Fig. 3 of the yearly NDVI maximum distance from average. The worst vegetation state occurred from 1999–2001.

The vegetation change trend of the four different sub-regions is obviously different. Sub-regions C and D are strongly affected by the East Asian monsoon, but at the same time basically has had the same change mode for the last 10 years, and present the mode of “first decreasing, later increasing and finally slowly decreasing.” However, the difference is that vegetation of sub-region D recovered to a better state, while that of sub-region C was only maintained at a worse state. The vegetation change of sub-region A was anomalous with smaller fluctuation, but it was similar to the mode of sub-region C and D at a certain extent. The vegetation change trend of the sub-region B is completely opposite to those of sub-regions A, C and D (Fig. 4).

In order to reveal the effectiveness of ecological construction projects for the past 10 years, the mean NDVI maximum of the first 5 years (1998–2002) as the basis and that of the second 5 years (2003–2007) as output were taken. The dispersion of the latter and the former was considered as vegetation change (Fig. 5).

Fig. 2 Comparison between the multi-year NDVI maximum distribution patterns and the distribution of deserts, gobis and sandy lands in northern China

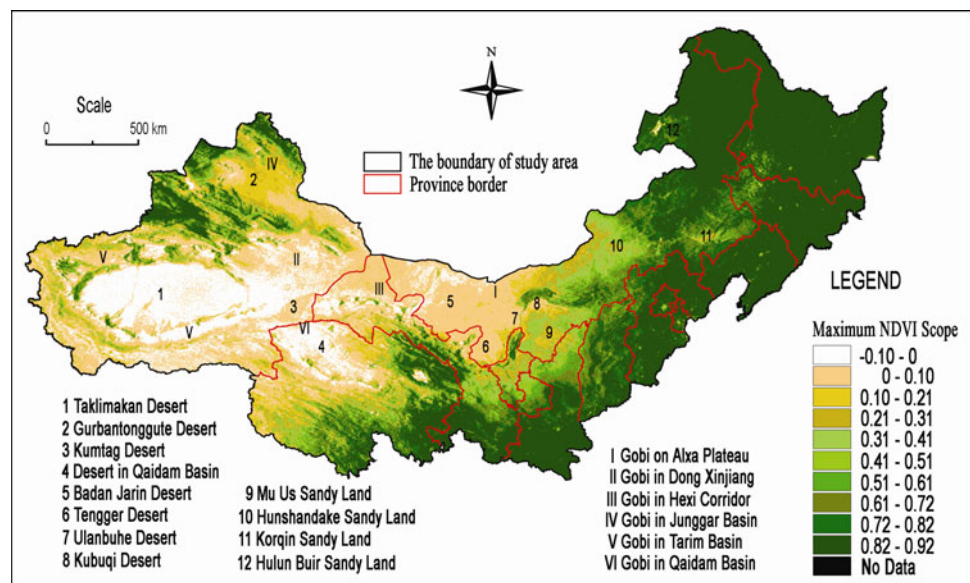


Fig. 3 Dynamic change of the yearly NDVI maximum distance from the average in different sub-regions of northern China from 1998–2007

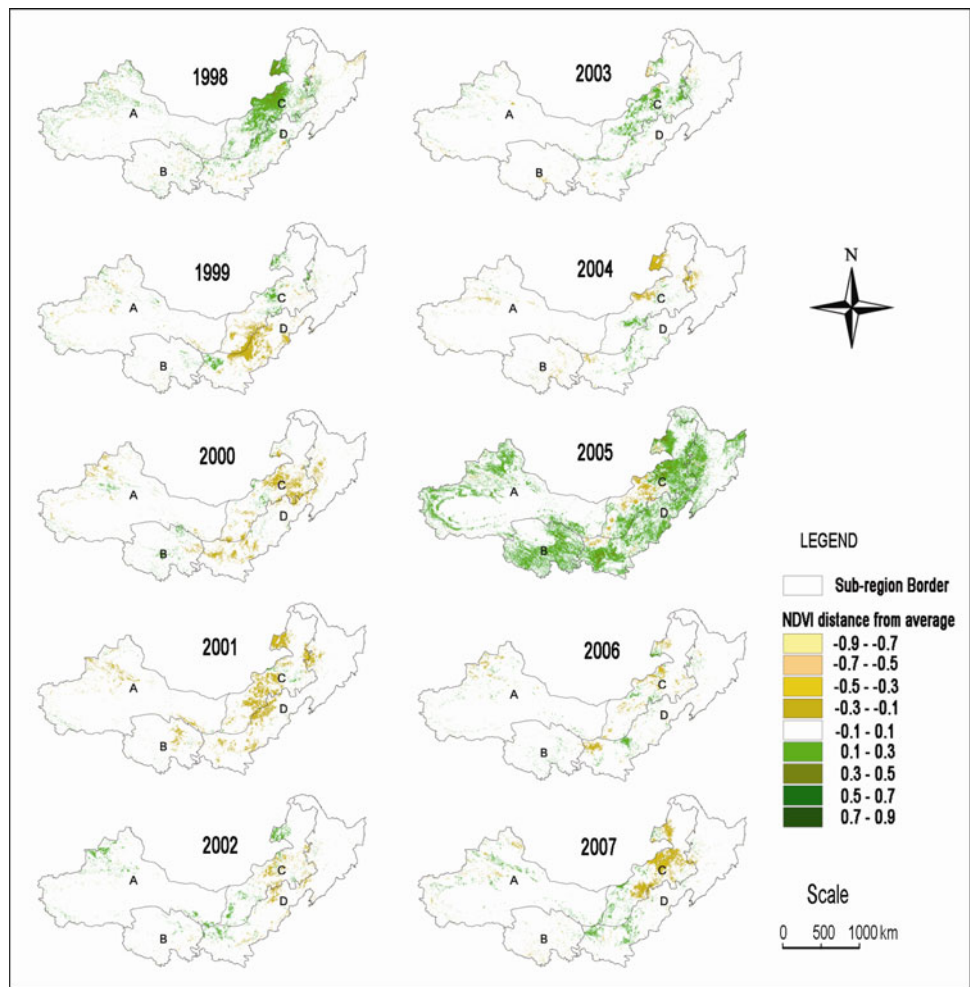


Fig. 4 Change modes of the yearly NDVI maximum distance from average in different sub-regions of northern China from 1998–2007

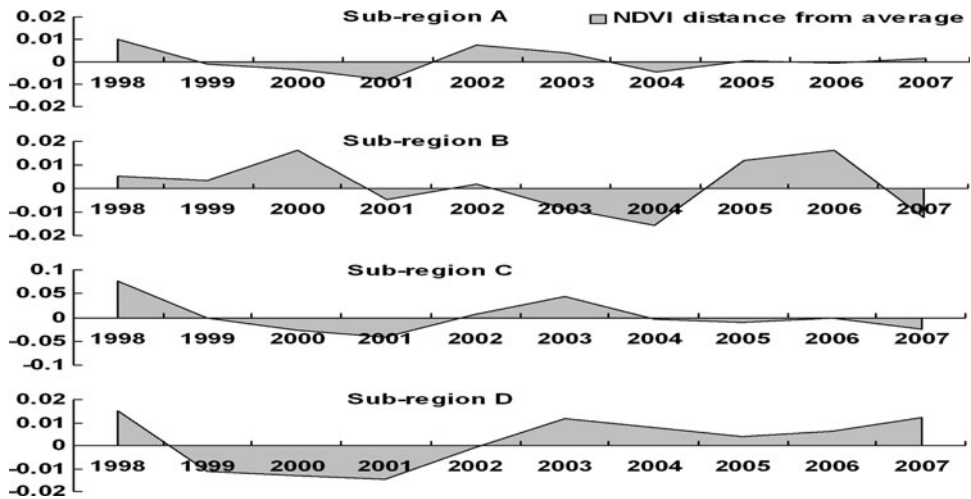


Figure 5 clearly shows that vegetation improvement mainly occurred in the north-piedmont oases of the Tianshan Mountains, north oases, west oases and southwest oases around Tarim Basin, part oases of the Hexi Corridor, Pingliang, Tianshui and Qingyang region in the eastern part

of Gansu Province, north-central Shaanxi, Shanxi’s major basins, the Erdos Plateau, the Hetao district, the Horqin region of Inner Mongolia and the Bashang Region of Hebei Province. Vegetation deterioration mainly occurred in the Tianshan Mountains, Altai Mountains, the northwest

Fig. 5 Change of mean NDVI maximum from the period of 1998–2002 to that of 2003–2007

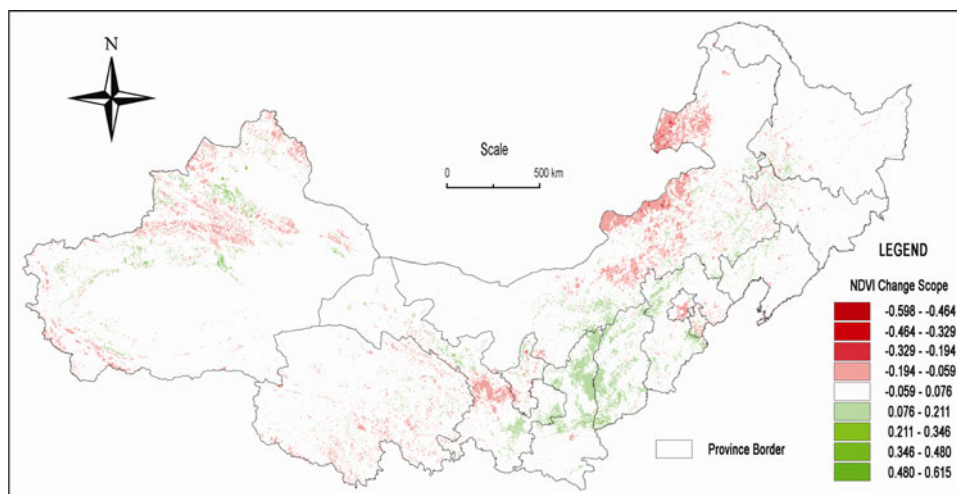


Table 1 The multi-year mean NDVI maximum change from the period 1998–2002 to 2003–2007 in northern China

Change scope of multi-year mean NDVI maximum	State	Number of pixels	Area percentage
−0.598 to −0.464	Very serious degradation	23	0.001
−0.464 to −0.329	Serious degradation	237	0.015
−0.329 to −0.194	Moderate degradation	6232	0.387
−0.194 to −0.059	Slight degradation	361,268	22.434
−0.059 to 0.076	Basically stable	944,417	58.645
0.076 to 0.211	Slight improvement	292,237	18.147
0.211 to 0.346	Moderate improvement	5,219	0.324
0.346 to 0.480	Obvious improvement	638	0.040
0.480 to 0.615	Very obvious improvement	123	0.008

Kunlun Mountains, the source regions of the Yellow River in Qinghai, Longzhong Plateau in Gansu, Ulanqab Plateau, Xilingol Plateau along the Sino–Mongolia border, Hunshandake Sandy Land and Hulun Buir Sandy Land of Inner Mongolia, as well as Beijing, etc.

According to the difference results between 2003–2007 and 1998–2002, vegetation change types with different NDVI change scope were classified into nine types by the equal interval classification method and are recorded in Table 1. For the whole study area, 58.645% of the vegetation coverage basically remained stable. Vegetation coverage improved in about 18.52% of the land; vegetation coverage declined in another approximately 22.84% of the land (Table 1).

Figure 6 shows that the NDVI trend was spatially heterogeneous. In this figure, it can be clearly seen that vegetation degraded on the Tianshan Mountains and Altai Mountains, while the vegetation at the piedmont of mountains and oases obviously improved in the sub-region. Vegetation improvement and degradation coexisted in the Hexi Corridor. Vegetation degradation occurred in most areas of sub-region B. In sub-region C, the vegetation obviously improved in Horqin Sandy Land, Mu Us Sandy

Land, Hetao Plain and Ordos Plateau, while the vegetation in other places stayed unchanged or there was degradation formation, especially in Ulanqab Steppe, Xilingol Steppe along the border of Sino–Mongolia and Hulun Buir Sandy Land. In sub-region D, vegetation improved in most places, and vegetation degradation occurred only in the Beijing District and other cities mainly because of rapid urbanization.

According to the yearly NDVI maximum from 1998 to 2007, the area with a different scope of slope change was classified and is recorded in Table 2. The vegetation coverage on 97.56% of the total land remained unchanged. Vegetation coverage improved on about 0.54% of the land; vegetation coverage degraded on another about 1.90% of the land, mainly due to moderate and slight degradation (Table 2).

Conclusion

The NDVI can effectively monitor vegetation change, but also the mean multi-year NDVI maximum of 0.10 basically can be considered as the threshold of vegetation cover in

Fig. 6 Change trend spatial distribution of yearly NDVI maximum from 1998–2007 ($P > 0.05$)

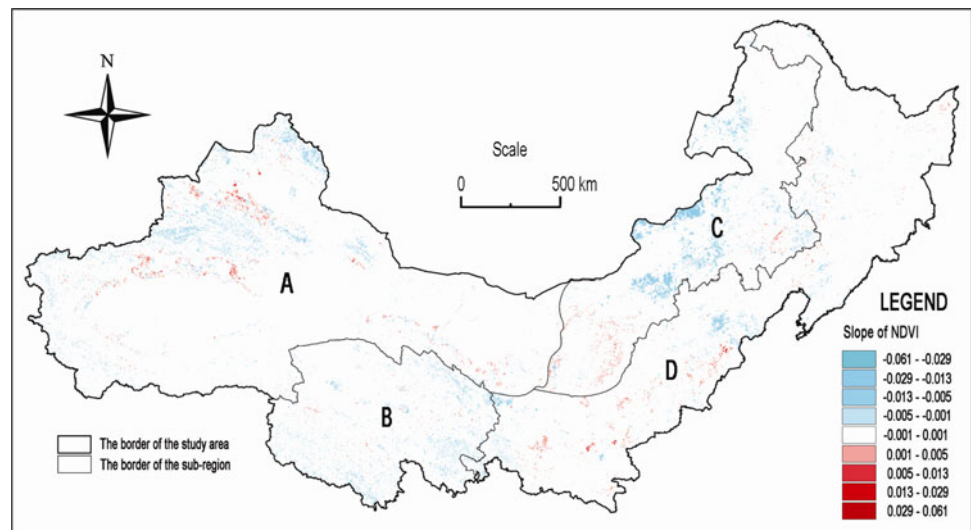


Table 2 The slope statistics of the yearly MVC NDVI change trend in the northern China from 1998–2007 ($P > 0.05$)

Scope of slope value	State	Number of pixels	Area percentage
-0.061 to -0.029	Very serious degradation	225	0.002
-0.029 to -0.013	Serious degradation	21,186	0.179
-0.013 to -0.005	Moderate degradation	96,890	0.818
-0.005 to -0.001	Slight degradation	106,764	0.902
-0.001 to 0.001	Basically stable	11,842,359	97.560
0.001 to 0.005	Slight improvement	47,428	0.400
0.005 to 0.013	Moderate improvement	15,938	0.135
0.013 to 0.029	Obvious improvement	605	0.005
0.029 to 0.061	Very obvious improvement	0	0

sandy regions of northern China, and those places with smaller than or equal to the threshold value mainly were covered by deserts, Gobi and lakes, salinization lands, glaciers, snow patches and bare mountains, etc.

Vegetation state change has been quite huge for the last 10 years in northern China. The change trend of vegetation where sub-regions C and D were affected by the east-Asia monsoon were similar to the characteristics of first decreasing, later increasing and finally slowly decreasing; the difference lies in that sub-region C maintains a lower vegetation level, and sub-region D reaches a higher level. The vegetation change of sub-region A was anomalous with smaller fluctuation. The change trend of vegetation for sub-region B was not only extremely unstable, but also the change extent was huge.

As far as the whole of northern China is concerned, vegetation has not undergone obvious improvement since the ecological construction and protection projects, and the area of vegetation degradation is still much more than that of vegetation improvement from 1998 to 2007. According to the comparison of mean multi-year NDVIs between

2003–2007 and 1998–2002, vegetation coverage improved on about 18.52% of the land; vegetation coverage declined on another approximately 22.84% of the land. At the same time, there was a larger spatial difference concerning the effect of restoration. The field investigation and remote sensing monitoring reveal vegetation obviously has improved in the agro-grazing mixing zone and to the south of it, and many oases in the northwestern arid zone, while vegetation still has worsened in the steppes, including most grasslands of Qinghai Province, Altai Mountains and northern Tianshan mountains region in Xinjiang, especially Ulanqab steppe, Hunshandake Sandy Land, the region along the Sino–Mongolia border within Xilingol Meng and Hulunbeir Sandy Land.

This research of dynamic vegetation change in northern China during 1998–2007 based on SPOT-VGT data clearly revealed that human activities have only had obviously success in local regions at present, mainly in the agro-grazing mixing zone and to the south of that, as well as in part of those oases. This may mainly benefit from the Returning Slope Farmland to Woodland or Grassland

project and the Eco-water Transfer project in the inland river basins. Vast grasslands still were not improved. The compelling challenges from the eco-environment restoration in northern China are still very large, especially in the northern grazing zone of China. More effective countermeasures and grazing management for improving grasslands need to be further explored.

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References

- Fang J, Piao S, He J, Ma W (2004) Increasing terrestrial vegetation activity in China, 1982–1999. *Sci China Ser C* 47(3):229–240
- Fuller DO (1998) Trends in NDVI time series and their relation to rangeland and crop production in Senegal, 1987–1993. *Int J Remote Sens* 19(10):2013–2018
- Holben BN (1986) Characteristics of maximum-value composite images from temporal AVHRR data. *Int J Remote Sens* 7(11):1417–1434
- Hope AS, Boynton WL, Stow DA, Douglas DC (2003) Inter-annual growth dynamics of vegetation in the Kuparuk River watershed based on the normalized difference vegetation index. *Int J Remote Sens* 24(17):3413–3425
- Ma M, Wang J, Wang X (2006) Advance in the inter-annual variability of vegetation and its relation to climate based on remote sensing. *J Remote Sens* 10(3):421–431 (in Chinese)
- Rahman H, Dedieu G (1994) SMAC: a simplified method for the atmospheric correction of satellite measurements in the solar spectrum. *Int J Remote Sens* 15(1):123–143
- Shabanov NV, Zhou LM, Knyazikhin Y, Mynemi RB, Tucker CJ (2002) Analysis of interannual changes in northern vegetation activity observed in AVHRR data from 1981 to 1994. *IEEE Trans Geosci Remote Sens* 40(1):115–130
- Song Y, Ma M (2007) Study on the vegetation cover change in Northwest China based on SPOT VEGETATION data. *J Desert Res* 27(1):89–93 (in Chinese)
- Stow D, Daeschner S, Hope A, Douglas D, Petersen A, Mynemi R, Zhou L, Oechel W (2003) Variability of the seasonally integrated normalized difference vegetation index across the north slope of Alaska in the 1990s. *Int J Remote Sens* 24(5):1111–1117
- Wang C, Hui X (2005) Borderline variations of desertification and Grassland over China viewed from NDVI 0.12. *J Desert Res* 25(1):88–92 (in Chinese)
- Wang T, Wu W, Xue X, Sun Q, Chen G (2004) Study of spatial distribution of sandy desertification in North China in recent 10 years. *Sci China Ser D* 47(z1):78–88
- Wang T, Xue X, Wu W, Sun Q (2005) Regionalization of desertification Lands in North of China—a program. *J Desert Res* 25(6):816–822 (in Chinese)
- Zhou LM, Tucker CJ, Kaufmann RK, Slayback D, Shabanov NV, Mynemi RB (2001) Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *J Geophys Res* 106(16):20069–20083
- Zou X, Zhai P (2004) Relationship between vegetation coverage and spring dust storms over northern China. *J Geophys Res* 109: D03104. doi:[10.1029/2003JD003913](https://doi.org/10.1029/2003JD003913)