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ORIGINAL ARTICLE

# Trends and variation in vegetation greenness related to geographic controls in middle and eastern Inner Mongolia, China

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**Abstract** Extensive studies have investigated the relationships between climate change and vegetation dynamics. However, the geographic controls on vegetation dynamics are rarely studied. In this study, the geographic controls on the trends and variation of vegetation greenness in middle and eastern Inner Mongolia, China (mid-eastern Inner Mongolia) were investigated. The SPOT VEGETATION 10-day period synthesis archive of normalized difference vegetation index (NDVI) from 1999 to 2007 was used for this study. First, the maximum value compositing (MVC) method was applied to derive monthly maximum NDVI (MNDVI), and then yearly mean NDVI (YMNDVI) was calculated by averaging the MNDVIs. The greenness rate of change (GRC) and the coefficient of variation (CV) were used to monitor the trends and variation in YMNDVI at each raster grid for different vegetation types, which were determined from a land use dataset at a scale of 1:100,000, interpreted from Landsat TM images in 2000. The possible effects of geographic factors including elevation, slope and aspect on GRC and CV for three main vegetation types (cropland, forest and steppe) were analyzed. The results indicate that the average NDVI values during the 9-year study period for steppe, forest and cropland were 0.26, 0.41 and 0.32, respectively; while the GRC was 0.008, 0.042 and 0.033 per decade, respectively; and CVs were 10.2, 4.8 and 7.1%, respectively. Cropland and steppe shared a similar trend in NDVI variation, with both decreasing initially and then increasing over the study period. The forest YMNDVI increased throughout the study period. The GRCs of the forest also increased, although GRCs for cropland and steppe decreased with increasing elevation. The GRCs of cropland and steppe increased with increasing slope, but the forest GRCs were not as closely related to slope. All three vegetation types exhibited the same effects in that the GRC was larger on north-facing (shady) slopes than south-facing slopes due to differences in water conditions. The CVs of the three vegetation types showed different features to the GRC. The CVs for all three vegetation types were not affected by aspect. The CVs for forest and cropland showed minor effects with changes in elevation and slope, but the CV for steppe decreased with increasing slope, and increased with increasing elevations to 1,200 m, before decreasing at higher elevations. Our findings suggest that the role of geographic factors in controlling GRC should also be considered alongside climate factors.

**Keywords** Agro-pastoral ecotone · Degradation · Elevation · Geographical controls · Vegetation dynamic · Slope

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## Introduction

Since the “Opening and Reform Policy” was implemented in China 30 years ago, dramatic changes have occurred. Land use patterns in China have undergone major changes due to high rates of population growth and economic development. Large areas of land were occupied for expansion of urbanization in traditional agricultural regions while steppe and forest was reclaimed into cropland for agricultural production in fragile ecological ecotones such as in northeastern and northwestern China (Liu et al. 2003, 2005a). This occurred particularly in the agro-pastoral ecotone of northern China (Zou and Zhang 2005; Zhou et al. 2007). Studies on land use/land cover change will have a high level of significance for regional ecological and environmental security. The middle and eastern part of Inner Mongolia (hereafter referred to as mid-eastern Inner Mongolia) is a typical agro-pastoral ecotone located on the transition from plateaus to plains and basins in terrain, from arid to sub-humid areas in climate, and also from pastoral production to agricultural production in land use style. Consequently, the ecosystem in this area is highly vulnerable with vegetation dynamics subject to both natural and human factors.

Monitoring of variations in vegetation greenness in a region is an effective method of ecological and environmental assessment. Extensive studies have shown that mid-eastern Inner Mongolia is an area undergoing obvious climate change (Tao et al. 2005a, b, 2008). The warming rate was higher than the average level of the warming across the rest of the country over the past 50 years and particularly since 1988, while at the same time, annual precipitation has varied substantially (Qin et al. 2005; Ding et al. 2006; Hou et al. 2008; Yiu et al. 2008). Some studies indicated the spatial heterogeneity of vegetation in the region (Song et al. 2008), while other studies have focused on the relationship between vegetation and climate change, especially precipitation and temperature (Li and Shi 2000; Zhang et al. 2001; Chen and Zheng 2008; Tao et al. 2008). However, few studies have investigated the possible controls of geographic factors such as elevation, slope and aspect on vegetation pattern and greenness trend and variation (e.g., restoration or degradation of vegetation and the sensitivity of vegetation) which has been proved important (Pickup and Chewings 1996) especially in mid-eastern Inner Mongolia where geographic and climatic transitions are typical.

The aim of vegetation monitoring in mid-eastern Inner Mongolia was to answer several questions, including: what is the overall change trend and variation in vegetation from 1999 to 2007 across the region using a fine spatial resolution dataset? Are vegetation greenness changes different among different vegetation types? Is there a significant geographic characteristic (elevation, aspect and slope) that controls vegetation changes? What is the mechanism of that characteristic change?

Remote sensing has become an effective and principal tool for large-scale ecological and environmental monitoring, especially for monitoring land cover changes. The normalized difference vegetation index (NDVI) is a common and essential parameter for monitoring, and has been proved to be an effective and important indicator for characterizing variations in vegetation cover, productivity, biomass and eco-environmental quality from local to global scales. NDVI is commonly used in vegetation canopy monitoring (Carlson and Ripley 1997; Myneni et al. 1997), ecological monitoring and assessment and biomass assessment (Wessels et al. 2006), productivity monitoring (Chen et al. 2004), agricultural production estimation (Zhang et al. 2003; Tao et al. 2005b), land degradation (Pei et al. 2008), and other monitoring activities. In the study area, some vegetation monitoring studies have been carried out which have proven that vegetation productivity has increased (Runnstrom 2000). He et al. (2008) studied the relationship of terrain–climate–vegetation patterns on the southeastern margin of the Inner Mongolia Plateau at different scales. However, the trend and variation in vegetation dynamics and geographic controls in different land cover types have not yet been explored.

In this study monthly maximum normalized difference vegetation indexes (MNDVI), based on the SPOT VGT 10-day period synthesis archive were generated. Then, yearly average normalized difference vegetation indexes (YMNDVI) were generated by averaging the MNDVI values. The trend and variation of vegetation patterns in mid-eastern Inner Mongolia was analyzed based on YMNDVIs (1999–2007) with a greenness rate of change (GRC) calculated using the least squares method, and a coefficient of variation (CV) was also calculated. Finally, the dynamics of different vegetation types, as well as the effects of geographic factors such as elevation, slope and aspect were investigated.

## Materials and methods

### Study area

Mid-eastern Inner Mongolia is located in the northeast of China (Fig. 1), and includes five administration regions: Hulun Buir, Xing'an, Tongliao, Chifeng and Xilin Gol, with total area of 66.58 $\times$ $10^4$ $km^2$. Daxinganling Mountains with an elevation of 700–1,700 m crosses the region from northeast to southwest, and provides a distinct boundary of terrain, climate, and cropping system. The Nenjiang and West Liaohe plains are located to the east of the mountain, at an elevation of about 200–500 m and are important areas for both food and cash crop production. The Hulun Buir and Xilin Gol steppes are located to the west of the mountain with an elevation of 550–1,000 m and are mainly for stockbreeding. Finally, the Hunshandake Sand is located in the southwest of the study area with an

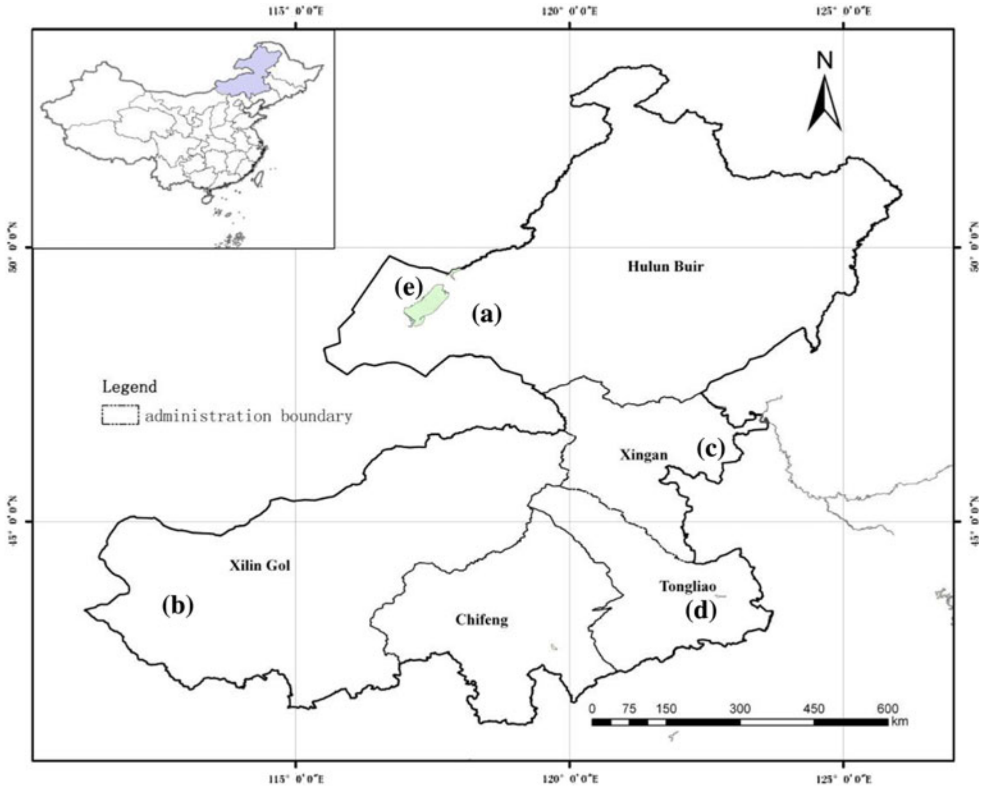



**Fig. 1** Location of study area and main physiognomies: **a** Hulun Buir Steppe, **b** Xilin Gol Steppe, **c** Nenjiang Plain, **d** West Liaohe River Plain, and **e** Hulun Lake

elevation of 800–1,200 m. The climate to the east of the mountain is semi-humid with an annual precipitation of 500–800 mm, while to the west, it is semi-arid with an annual precipitation of 300–500 mm.

## Data

### *Vegetation data and DEM data*

Extensive studies have investigated land use and land cover monitoring, and various methods have been used including NDVI time series (Sheng et al. 1995; Geerken et al. 2005), principal component analysis (Lasponara 2006) and clustering methods for vegetation identification and classification (Li and Shi 1999; Yamano et al. 2003; Bagan et al. 2007). Considering the inherent error in auto-classification, Liu et al. (2005a) developed a classification method with high accuracy based on Landsat TM/ETM satellite data (Liu et al. 2005a, b) and have established spatial dataset for China covering for four time periods (the late 1980s, the mid-1990s, 2000 and 2005). In this paper, the land use classification data from 2000 (at a scale of 1:100,000) was used for identification of vegetation types, in which land use was divided into six major categories (cropland, forest, steppe, water body, built-up land, and unused land). The maximum area raster–vector conversion method was adopted to generate the 1 by 1 km vegetation type data (Fig. 2a). The shuttle radar topography mission (SRTM) digital elevation data (at a scale of 90 by 90 m) provided by the CGIAR consortium for spatial information (CGIAR-CSI) GeoPortal (Reuter et al. 2007) were used to investigate the effects of elevation, slope and aspect (Fig. 2b).

### *SPOT VGT NDVI (1999–2007)*

The SPOT VGT-S10 products with a spatial resolution of 1 by 1 km, from 1998 to 2008, were used and were compiled by merging segments (data strips) for 10-day periods using the maximum value compositing (MVC) method (Holben 1986) which can alleviate some of the limitations of optical satellite imagery, such as cloud cover and large solar zenith angles (Stow et al. 2007).

The data were stored in a digital number format (0–250) for convenient storage. Real NDVI values were calculated using the following formula developed by the image processing and archiving center, VITO, Belgium (http://www.vgt.vito.be/):

$$NDVI = 0.004 \times DN - 0.1 \quad (1)$$

where DN is the digital number used for storage.

Because of problems with the data from 1998 and 2008, only the data from 1999 to 2007 were used. Monthly maximum NDVI (MNDVI) was calculated using the MVC method shown below:

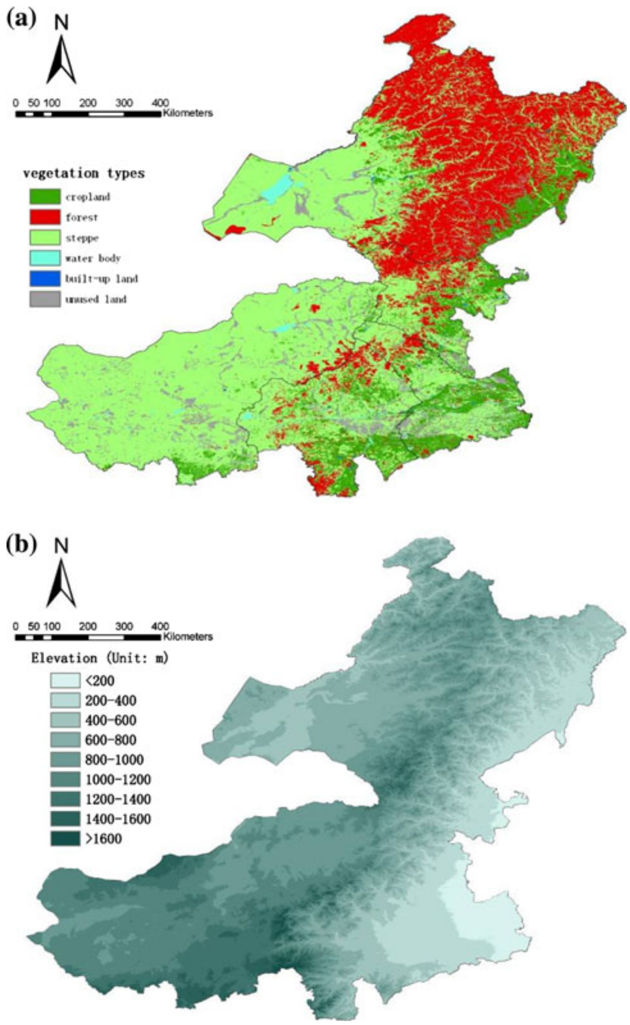



**Fig. 2** **a** Land use pattern and **b** the elevation of study area

$$\text{MNDVI} = \text{Max}(\text{NDVI}_1, \text{NDVI}_2, \text{NDVI}_3) \quad (2)$$

where $NDVI_1$, $NDVI_2$, $NDVI_3$ are the maximum NDVI during three 10-day periods in every month. The MNDVI is the maximum of the three values. The yearly mean NDVI (YMNDVI) was derived from *MNDVI* as shown below.

$$\text{YMNDVI} = \frac{\sum_{i=1}^{12} \text{MNDVI}_i}{12}. \quad (3)$$

Elaboration of the data

Spatiotemporal variation patterns in vegetation greenness and production from 1999 to 2007 can be reflected by the trend of NDVI values. The greenness rate of change (GRC), defined as the slope of the linear least squares regression line fit to the interannual pattern of SINDVI values (Stow et al. 2003), is an effective method to indicate above-ground biomass and land cover changes (Stow et al. 2007), which has been also used in other fields (e.g., monitoring of climate change) (Stow et al. 2003; Ma et al. 2007; Stow et al. 2007; Du and Li 2008; Olthof et al. 2008). Here, the GRC was taken as an indicator from the trend of YMNDVI values from 1999 to 2007. GRC was generated by the formula:

$$\text{GRC} = \frac{n \times \sum_{i=1}^{n} i \times \text{YMNDVI}_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} \text{YMNDVI}_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \quad (4)$$

where $i$ was the year, ordered from 1 to 9, and $n$ was equal to 9.

The sensitivity and variability of the YMNDVI from 1999 to 2007 can be evaluated by the coefficient of variation (CV), with a larger CV indicating greater instability.

$$\text{CV} = \frac{\sigma}{\bar{x}} \quad (5)$$

where $\sigma$ is the standard deviation of YMNDVI from 1999 to 2007; and $\bar{x}$ is the mean of YMNDVI.

The greenness trend and variation were analyzed for several spatial extents: (1) the study area as a whole; (2) the three major vegetation types including steppe, cropland and forest; and (3) physiographic units according to elevation, slope and aspect.

## Results

### Spatial patterns of vegetation types and mean YMNDVI

*Vegetation types and NDVI pattern*

Significant spatial heterogeneity was found in the study area, with the three main vegetation types dominating the area, and displaying an obvious spatial succession. Forests were distributed in the north, steppes in the west and cropland in the east (Fig. 2a). The steppe area was the largest, accounting for 55% of the total land area, followed by forest covering 25% of the area, while cropland covered 12%. These three vegetation types together accounted for 92% of the overall area, and consequently the following analysis focused on these three main vegetation types.

There were obvious differences among the vegetation types. The mean YMNDVI of the forest was highest followed by cropland and steppe. Because of greenbelts in cities, built-up land had a higher NDVI than steppe in the study area (Fig. 6a). The mean YMNDVI for 1999–2007 decreased from the northeast to the southwest (Fig. 3), and the average NDVI values for steppe, forest and cropland were 0.26, 0.41 and 0.32, respectively.

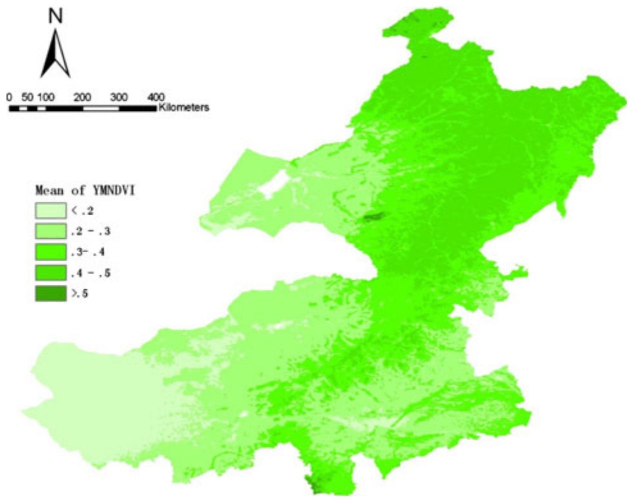



**Fig. 3** Mean YMNDVI (MYMNDVI) image from 1999 to 2007

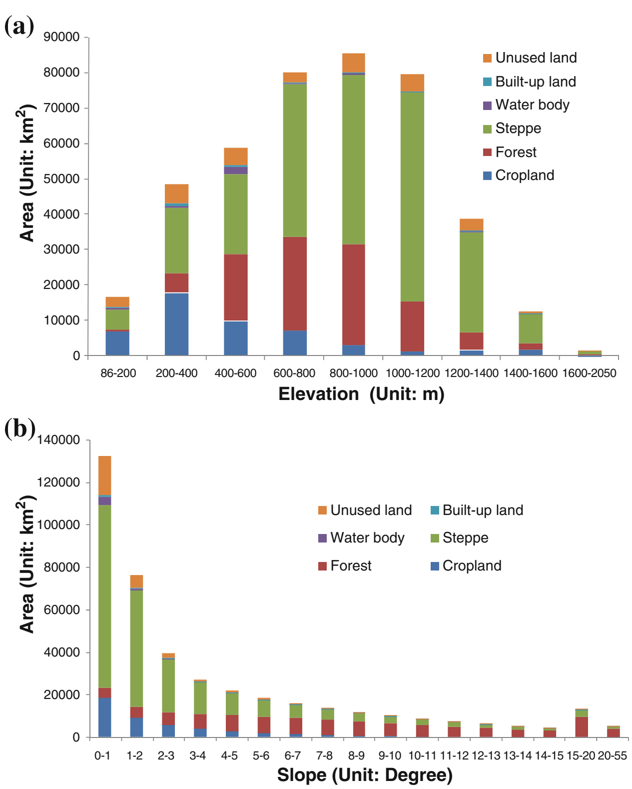



**Fig. 4** Areas of different vegetation types with different levels of elevation and slope

*Effects of elevation and slope on vegetation types and NDVI pattern*

As shown in Fig. 4a, 69.50% of the cropland is located below 600 m, and is the dominant land use kind below 400 m, but is seldom found above 800 m. Forest is mainly located in the areas between 400 and 1,200 m, and is seldom found above 1,400 m. Steppe is located in the areas between 200 and 1,400 m, and is the dominant land use kind in the areas between 600 and 1,400 m. The vegetation distribution exhibits obvious changes with elevation.

The composition of vegetation types on different levels of slope was also different (Fig. 4b). There was 31.41% of the total vegetation area had slopes of 0°–1°, and a further 18.09% had 1°–2° slopes, so the area with slopes of less than 2° accounted for nearly half of the total area. Conversely, the area with slopes over 10° was small, comprising only 12.5% of the total. Cropland was mainly distributed in the region with small slopes, with 68.41% of cropland having a slope of less than 3°. Forests were evenly distributed on various degrees of slope and were the dominant land use kind for slopes above 15°. There was a decreasing trend in the proportion of steppe with increasing slope (Fig. 4b).

The 9-year mean YMNDVI (MYMNDVI) for 1999–2007 did not show any obvious characteristics (Fig. 6b) with elevation. At elevations below 800 m, MYMNDVI increased with increasing elevation, but then declined at elevations between 800 and 1,600 m, indicating that there was no obvious relationship between MYMNDVI and elevation.

NDVI trend and variation for different vegetation types from 1999–2007

A trend analysis of the YMNDVI from 1999 to 2007 showed that the vegetation in most of the study area was improving (Fig. 5a; Table 1). Approximately 71.40% of area showed improved vegetation (GRC > 0), while the area with deteriorating vegetation (GRC < 0) accounted for 28.60% of the area. According to the criteria of land cover degradation (Table 1), the area showing mild improvement accounted for 40.62%, moderate improvement was 20.12%, and significant improvement was seen on 1.41% of the area; the area with mild degradation accounted for 16.82, 3.55% was moderately degraded and 0.27% was significantly degraded. The mean GRC for the whole study area was 0.020 per decade, indicating that vegetation was improving in general, especially in the south of Chifeng and Tongliao where tree planting and ecological restoration projects have been implemented effectively. Similar effects were also seen in the middle and north of Hulun Buir where forest is the main vegetation type and this has been affected by climatic warming instead of precipitation. However, parts of Xilin Gol and the west of Hulun Buir, two of the main rangelands in China, showed a trend of decreasing YMNDVI, especially in the northern region of Xilin Gol (Fig. 5a) due to increased grazing intensity and decreased precipitation. These findings agree with the results from Chen and Wang (2009). The stability of the YMNDVI in this area declined as well

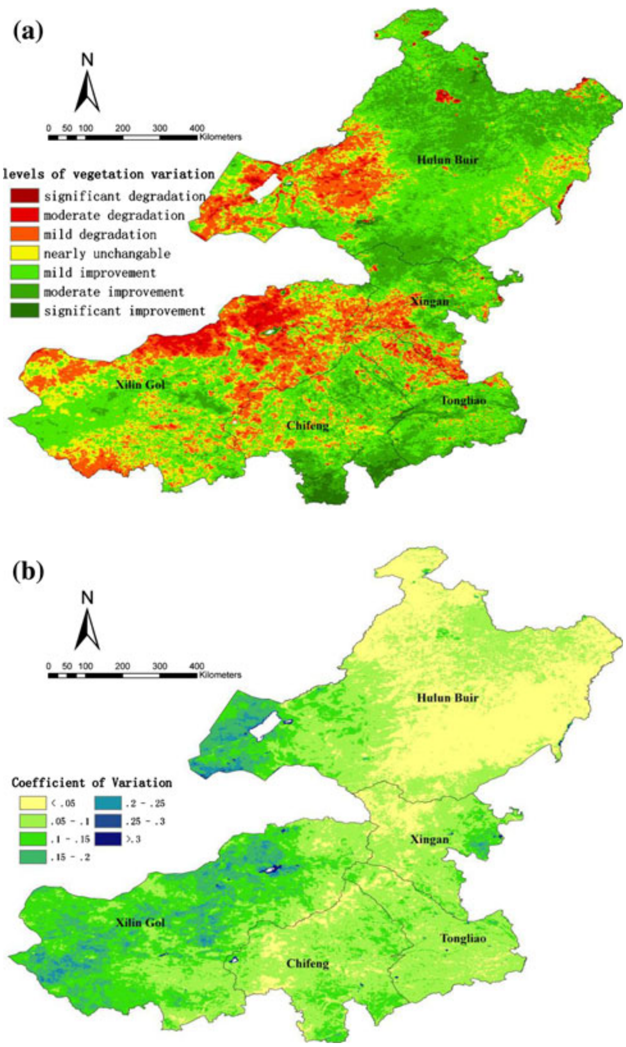



**Fig. 5** **a** GRC image of YMNDVI from 1999 to 2007, and **b** CV image of YMNDVI from 1999 to 2007

**Table 1** Criteria and area percentage of vegetation trend

| GRC | State of vegetation trend | Area percentage (%) |
|---|---|---|
| −0.037 to −0.010 | Significant degradation | 0.3 |
| −0.010 to −0.005 | Moderate degradation | 3.6 |
| −0.005 to −0.001 | Mild degradation | 16.8 |
| −0.001 to 0.001 | Nearly unchangeable | 17.2 |
| 0.001 to 0.005 | Mild improvement | 40.6 |
| 0.005 to 0.010 | Moderate improvement | 20.1 |
| 0.010 to 0.038 | Significant improvement | 1.4 |

(Fig. 5b). The mean CV value across the study area was 8.46%. The area with a CV <5% accounted for 26.43% of the total, and the area with a CV between 5 and 10% accounted for a further 43.16%. The CV across the majority (89.61%) of the region was less than 15% (Table 2).

The NDVI trend across all vegetation types increased over the past decade, which can be seen in the mean GRCs

**Table 2** Area percentage of different CV levels of vegetation

| CV (%) | <5 | 5–10 | 10–15 | 15–20 | 20–25 | 25–30 | >30 |
|---|---|---|---|---|---|---|---|
| Area percentage (%) | 26.43 | 43.16 | 20.02 | 8.77 | 1.35 | 0.09 | 0.17 |

which were all greater than zero. However, the rates of change varied for the different vegetation types and geographical environments. As shown in Fig. 6a, the GRC of the forest was the largest at 0.042 per decade, with a CV of 4.8%, followed by cropland with a GRC of 0.033 per decade, and CV of 7.1%. The GRC value for steppe was only 0.008 per decade, indicating that the steppe has begun to mitigate the degradation but only slowly, as the trend for steppe was low in comparison with the other two vegetation types. The interannual variation in steppe GRC was obvious, with a CV of 10.2%.

Further trend and variation analysis of the three major vegetation types (Fig. 7) identified the following results:

The increasing trend in forest YMNDVI was the most obvious in the past decade with a significant greenness improvement shown with a GRC value of 0.042 per decade. However, the process of forest NDVI change was not consistent with other vegetation types. The forest NDVI value was relatively high in 2002 and decreased in 2003 while the other vegetation types had increasing NDVI values at the same time (Fig. 7a–c). Other vegetation covers began to decline after 2006, but the forest NDVI increased continually with some fluctuations. These were primarily due to human activities and changes in precipitation and temperature. In addition, forest fires could also work. The overall increase in steppe NDVI was slight, but there were notable fluctuations shown by the largest CV of 10.2%, consistent with previous studies by Tao et al. (2008). The YMNDVI of steppe declined significantly from 1999 to 2001 due to decreasing precipitation and then increased to maximum value in 2004 (Fig. 7c). Cropland had a similar trend in YMNDVI. So, steppe and cropland were sensitive to precipitation, while the trend of forest YMNDVI was similar to steppe and cropland to some extent, however, the forest was less sensitive to precipitation than steppe and cropland (Fig. 7b). The increase of forest YMNDVI after 2005 may be related to the temperature to some extent (Fig. 7e). These can be examined by comparing the five trend-fit lines on Fig. 7.

## Geographical factors controlling trend and variation of YMNDVI for cropland, steppe and forest

### *Geographical factors controlling trend and variation for overall vegetation*

It can be seen from Fig. 6b that effects of elevation on vegetation variation were not obvious, but GRC and

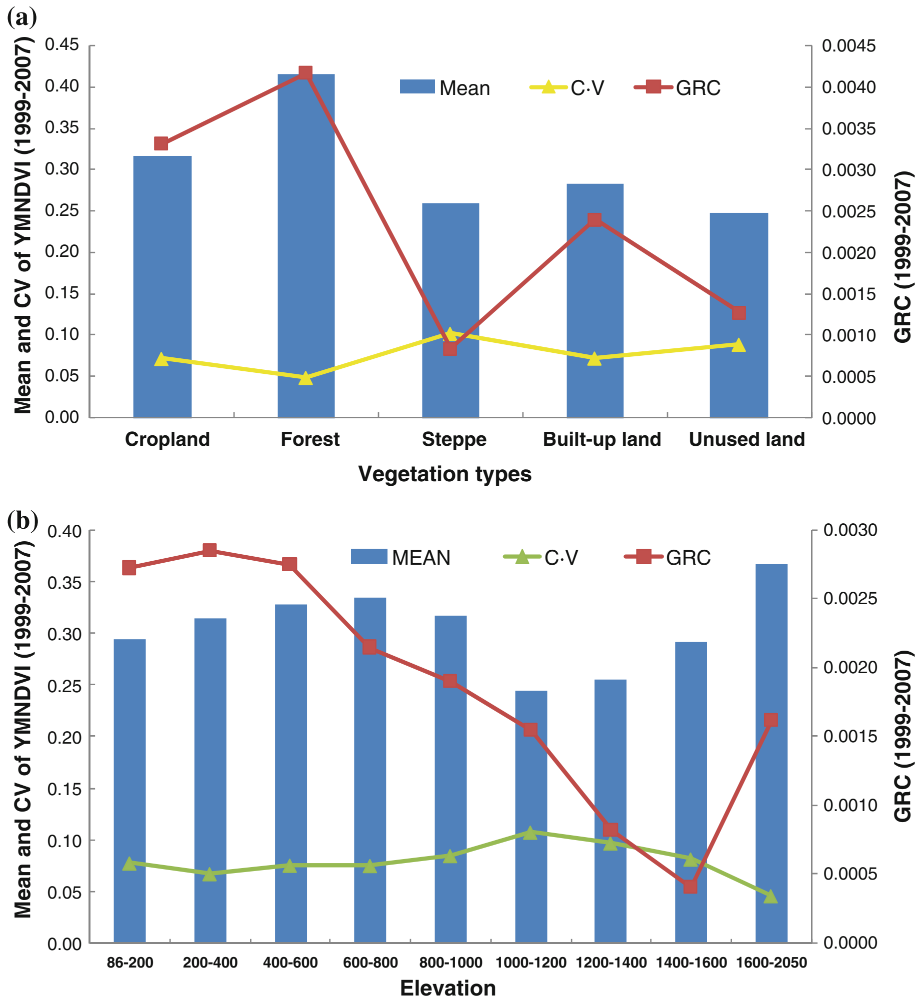



**Fig. 6** MYMNDVI, GRC and CV for different vegetation types (**a**) and elevations (**b**) from 1999 to 2007

elevation were negatively correlated in regions lower than 1,600 m. The 9-year mean YMNDVI was not well controlled by elevation. The terrain in the study area was relatively symmetrical but vegetation coverage was different on the two sides of Daxinganling Mountains, so taking the overall mean values of different vegetation types from two sides of the mountains may have obscured any possible effects of elevation. More effective results were seen when the individual vegetation types were analyzed separately.

With increasing elevation, the MYMNDVI increased initially, then decreased and finally increased again (Fig. 6b). The NDVI value at elevations of 1,000–1,600 m became smaller because of the increased distribution of steppe.

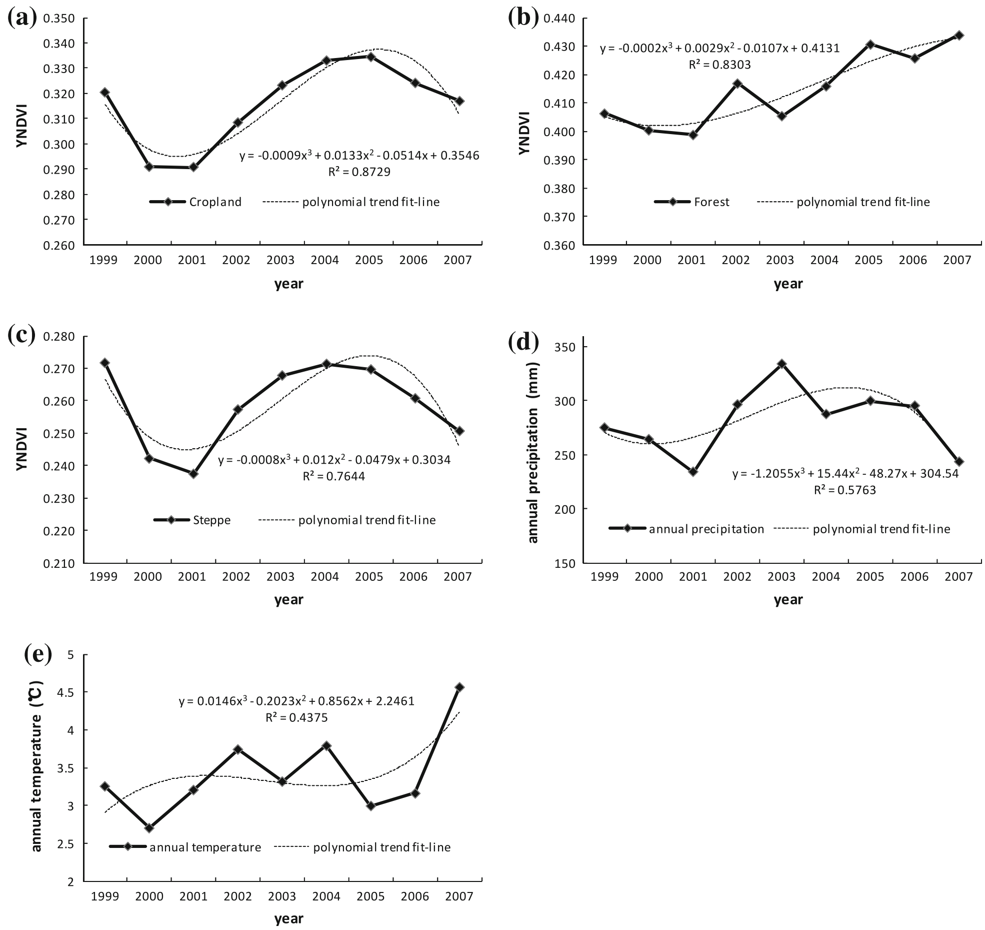
## Elevation controls on GRC

The GRC of cropland changed with elevation (Fig. 8a) while CV of cropland was moderate (Fig. 8b). Generally, the GRC of cropland decreased with increasing elevation. On the low plains (less than 200 m above sea level) and the high plains (200–400 m above sea level), GRC declined with the increase in elevation. Then there was an increase in GRC through the 400–600 m hilly region, with GRC values decreasing gradually above 600 m. The improvement in cropland greenness had two main reasons: climatic variation and human activities. Temperature and precipitation conditions vary at different elevations, with typically better natural conditions at lower elevations. The anthropogenic influences on cropland also decreased with increasing elevation.

The GRC for steppe declined with increasing elevation due to the decrease in temperature and precipitation (Fig. 8a). However, there was a rapid increase in GRC above 1,600 m and the possible reason was reduced human disturbance. The CV for steppe showed an obvious change with elevation, as the CV increased until the elevation reached 1,200 m, and then decreased (Fig. 8b).

The forests showed a distinct trend with GRC increasing slightly with increased elevation, but over 1,600 m GRC begun to decline. The CV of forest was almost unchanged with elevation (Fig. 8a, b).

**Fig. 7** Interannual variation of YMNDVI for different vegetation types: **a** cropland, **b** forest, **c** steppe; interannual variation of climate: **d** annual precipitation, and **e** annual mean temperature



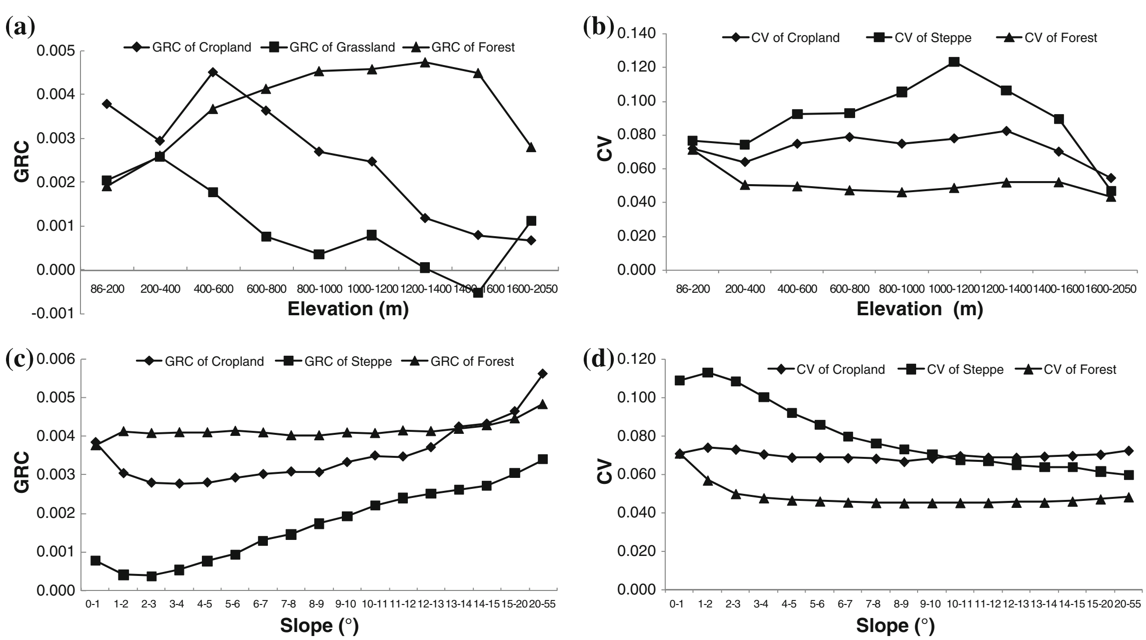




**Fig. 8** GRC and CV in different elevations and slopes for three vegetation types (cropland, steppe and forest): **a** GRC in different elevations, **b** CV in different elevations, **c** GRC in different slopes, **d** CV in different slopes

### Slope controls on GRC

The effects of slope on GRC were not as significant as elevation (Fig. 8c). However, steppe showed a significant increase in GRC with increasing slope. This is probably due to reduced human disturbance (e.g., grazing) at higher slopes, leading to better vegetation growth for the same temperature and precipitation conditions. Although steppe greenness increased steadily with increasing slope (Fig. 8d), the CV for steppe decreased when slope increased.

The GRC of cropland reduced with increasing slope below 3° and then increased at higher slopes above 3° (Fig. 8c). Possible reasons were ascribed to human effects. The GRC of forest was not sensitive to slope. The CVs for forest and cropland remained largely unchanged with slope (Fig. 8d).

### Aspect controls on GRC

All three vegetation types showed the same pattern of GRC with aspect, in that higher GRC values were seen on the entropic slope compared with the shady slope, while there was very little difference in GRCs between the eastern and western slopes (Fig. 9a). The CV was largely unchanged for all aspects (Fig. 9b).

The mean GRC for cropland on southern slopes was 0.028 per decade, while the mean GRC was 0.038 per decade on northern slopes, an increase of 33.1% over the southern slopes. The mean GRC for forests on southern slopes was 0.038 per decade, and 0.045 per decade on northern slopes, an increase of 17.4%. The mean GRC of steppe was 0.005 per decade on southern slopes, and 0.012 per decade on northern slopes. The main reason for this variation may be the lower evaporation on the shady slopes leading to better moisture conditions there, and consequently, the vegetation had a higher GRC.

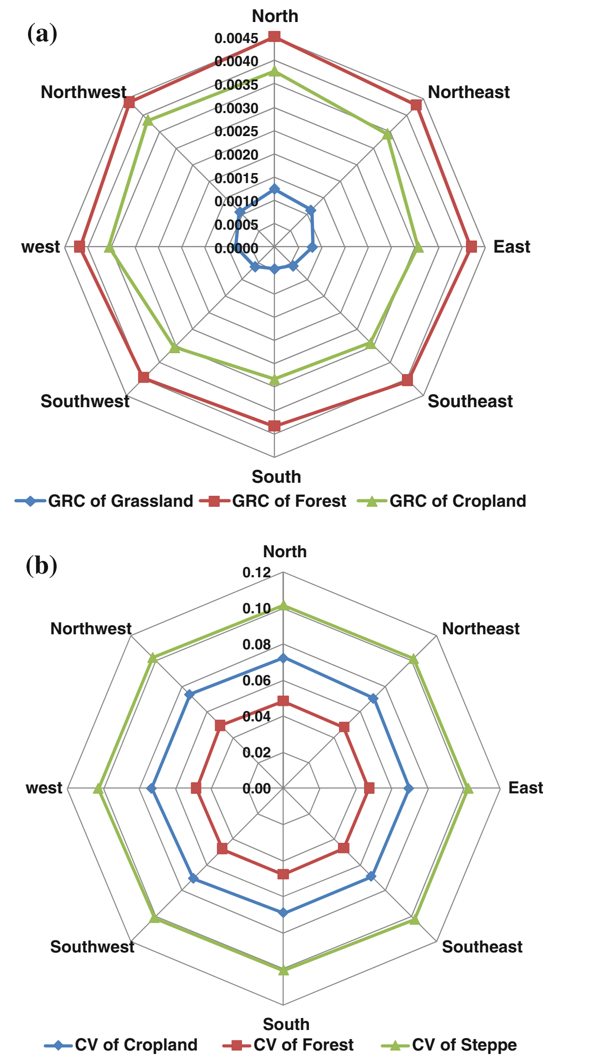



**Fig. 9** **a** GRC and **b** CV in different aspects for three vegetation types (cropland, steppe and forest)

## Discussion

### The significances of geographical factors on vegetation dynamics

Vegetation changes resulted from a combination of hydrothermal conditions and human activities (Tao et al. 2008). Extensive researches were currently focused on correlation analyses between vegetation changes, temperature and precipitation (Schultz and Halpert 1993; Di et al. 1994; Wang et al. 2003; Ding et al. 2007; Propastin and Kappas 2008) due to the public attention on climate change. The controlling effects of geographical factors have been ignored to some extent. However, a regional ecological system is an integrated system including elements of climate, soil, topography, hydrology, and human activities and other factors. All of the elements are interrelated and interact to form an integrated system. In addition to climate, geographical factors such as elevation, slope and aspect also play an important role in vegetation growth (Pickup and Chewings 1996; Matsushita et al. 2007) especially in our study area. These factors are indispensable for understanding the drivers of vegetation variation. This paper found that the control of topography on the trend and variation of vegetation YMNDVI in study area was significant. The findings suggest that the role of geographic factors in addition to climate factors in controlling GRC should be noted.

### Implications of geographical controls

The above results imply that different land use measurements and policies should be applied in different topographical regions. Considering the effects of elevation (Fig. 8a), stricter laws for ecological protection should be used in higher elevation areas, especially for farming and grazing.

Areas with lower slopes are important for steppe and cropland because of the smaller greenness increase at lower slopes (Fig. 8c) especially for steppe, and grazing in flatter areas should be reduced. Thus, the study results can provide important information for land use planning and management.

### Uncertainty analysis

The analysis of vegetation dynamics was based on a hypothesis that vegetation distribution was largely unchanged in the study period, so land cover data in 2000 was used. However, as a typical agro-pastoral ecotone, the transition of cropland and steppe may be frequent especially for the conversion of steppe to cropland.

In this study, three dominant vegetation types, cropland, forest and steppe, were investigated. However, further studies should be done for the subclasses of vegetation in steppe, cropland and forest. For example, there are several kinds of steppes (e.g., desert steppe and typical steppe) with different characteristics. Further studies should be considered for the subclasses of vegetation.

## Conclusions

In this paper, the trend and variation of YMNDVI for the main vegetation types in the study area was analyzed by using the indicators of GRC and CV based on SPOT VGT NDVI dataset (1999–2007), to evaluate the effects of geographical factors on the different types of vegetation in study area. The main findings of this study were as follows:

1. There were three main vegetation types of steppe, forest and cropland which accounted for 92% of the study area. Forests were located to the north of Daxinganling Mountains, steppe was located to the west of the mountain and cropland was found in the southeast. Vertically, cropland was mainly distributed in the region below 600 m, forest mainly distributed in the area between 400 and 1,200 m, and steppe had the widest distribution from 200 to 1,400 m. The mean YMNDVI values for steppe, forest, and cropland were distinctly different at 0.26, 0.41 and 0.32, respectively.
2. The vegetation greenness in mid-eastern Inner Mongolia generally improved from 1999 to 2007 with a variation of 8.46%. The proportion of the study area with GRC >0 was 71.40%, and the proportion with GRC <0 was only 28.60%. However, there were different characteristics between the three main vegetation types. The GRC in steppe was the least (0.008 per decade), while the forest GRC was largest (0.042 per decade), and the GRC was 0.033 per decade in cropland. Cropland and steppe had a similar trend of initially decreasing then increasing and finally decreasing GRC during 1999–2007, while the GRC of the forest increased throughout the study period, although with fluctuations similar to the trends of steppe and cropland to some extent. The variation of forest greenness was small with a CV of 4.8%, while the CV for steppe was 10.2%.
3. With statistical analysis of GRC and CV for the different geographical factors and different vegetation types, possible effects of elevation, slope and aspect were found. The GRC of cropland and steppe decreased with the increase in elevation, but the GRC of forest increased with elevation. The CVs for forest and cropland were unchanged by elevations while the CV for steppe exhibited obvious fluctuations. The GRC of cropland and steppe increased while the forest showed no significant change with increasing slope, however, the CV for steppe decreased when slope increased, while forest and cropland exhibited no change in CV with slope. Vegetation on northern slopes had a larger increasing trend than that on southern slopes for all the three types of vegetation because of better moisture conditions due to less evaporation. However, the variation in vegetation greenness was unchanged at different aspects.

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