MONITORING VEGETATION DYNAMIC IN HORQIN SANDY LAND FROM SPOT VEGETATION TIME SERIES IMAGERY

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ABSTRACT:

The changes in the composition and distribution of vegetation represent one of the most main sources of systematic change on local, regional, or global scale. The temporal evolution of NDVI data strongly linked to changes in the state of the surface is regarded as an effective time window able to show the natural seasonal variations. This study investigated vegetation change between 1998 and 2006 in the Horqin region which is the east fringe of agro-pasture transitional zone in northern China. Time series of SPOT-VEGETATION Normalized Difference Vegetation Index (NDVI) data are adopted to monitor the vegetation cover change during last 9 years. We found that the yearly maximum value composite mean NDVI over the study area increased slightly from 0.327 in 1998 to 0.338 in 2006, which indicated the increasing trend of vegetation activity. The annual average NDVI in whole area was stable and its inter-annual change rate between 1999 and 2006 were -1.603%. Vegetation activity improved area reached 6366.4 km^2, taking up 5.09% of the whole study area while the degraded regions occupied about 3.84% of Horqin region. The increasing amplitude is more considerable than the decreasing amplitude on the whole. In spring, monthly maximum NDVI showed obvious decrease while increasing tendency in summer and autumn was found. Original land desertification has been basically controlled during past nine years. Rational human economic activities and vegetation restoration measures played a positive role in vegetation increases.

1. INTRODUCTION

Land vegetation distribution change influence land ecosystem changes in their structure and function, and vise versa. The issue of monitoring and evaluating the vegetation change of the earth which is desirable for modelling and predicting the interactions between land surface and atmosphere has caused worldwide growing concern in recent years. Quantitative analysis of vegetation change is not feasible by ground measurements alone. The characterization of land surface conditions and land surface variations can be efficiently approached by using satellite remotely sensed data because they provide wide spatial coverage and internal consistency of data sets. Vegetation Index (VI) is one of the techniques most frequently used in remote sensing to estimate the amount of vegetation. Normalized Difference Vegetation Index (NDVI) derived from infrared channel and near-infrared channel remote sensing data is a good indicator of the presence of green vegetation and its photosynthesis (vegetation activity). It has a high correlation at the local scale, with various plant parameters including leaf area index (LAI), biomass, production and per cent cover, which has been widely applied to monitor and evaluate terrestrial vegetation vigor at continental or global scales during past couple of decades. NDVI was found to suitably detect interannual variations in process occurring at the scale of the season (Lambin and Strahlers, 1994). Seasonal images have also been used in land cover classification with some success (Loveland, et.al., 1995; Lambin, 1996; Roberts et.al., 1997; Goetz et.al., 2004). The monitoring of NDVI time series can evidence the areas having seen increases or decreases in vegetation. Some previous studies have suggested that vegetation activity in China increased over the past two decades using different NDVI data sets (Piao and Fang, 2001; Fang et.al, 2003; Li et.al 2007). Other studies suggested that the vegetation degraded occurred in some arid regions (Guo and Huang, 2005; Song and Ma 2007).

Horqin sandy land locating in the transitional terrain between the Northeast Plain and Inner Mongolia in Northeast China is highly sensitive to global change. Horqin area has been occupied by agricultural and nomadic culture alternatively in history. Due to a combined effect of vulnerable physical basis i.e. arid climate (especially the strong wind and sparse precipitation in the spring), thick sandy soil and human activity such as increasing population, irrational and large scale land reclamation, excessive grazing, over-collection of fuel-wood, and abuse of water resource, the fine coverage of vegetation and soil has been destroyed and further destructed the fragile ecological environment of Horqin. This region has been suffering high risk of sandy desertification during the past century.

Horqin belongs to one of the key regions in the West development strategies implemented by the Chinese Government since 1999. Pervious efforts have been made to analyze the sandy desertification process and its driving forces at various spatial and temporal scales (Zhao et al, 2000; Wu

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2003; Wang et al, 2004; Chang et al, 2006). The sandy desertification expanded rapidly in the period of 1950s-late 1980s and gradually slowed down in the 1990s (Li et al, 2006).However, the vegetation cover change in Horqin since the late 1990s has not been adequately quantified. The main purpose of this paper is to explore the interannual change rules and their spatial distribution of a typical sandy land in a Chinese semi-arid region during past decade. The study also tries to give an example of the use of SPOT-VGT time series for environmental analyses performed on local scale.

2. STUDY AREA

This study is conducted at the Horqin Sandy Land, one of the seriously desertified sandy areas in the semi-arid agropastoral zone of northern China. The West Liaohe River in this area flows across about 14 counties affiliated with Inner Mongolia and Liaoning province respectively. Covering an area of $1.25\times10^5 km^2$, the Horqin Sandy Land is located in 41°36.73"-45°1'52.5"N,117°9'44.19" -123°15.16"E. The landform belongs to a transition zone between multiple geomorphologic units namely the Inner Mongolia Plateau, the Great Xingan Mountains and the West Liaohe River plain. Due to land desertification, the landscape comprises a mosaic of gently undulating and mobile sandy dune, semi-fixed dunes, stabilized dunes and interdune bottomlands. The study area experiences a temperate semi-humid and semi-arid monsoon climate, and is characterized by interannual dry and wet season and frequent sand-windy days. The dominant soil types include chestnut soil, chernozem soil, chestnut-cinnamon soil. Some soil has been degraded to aeolian soils and very susceptible to wind erosion. The natural vegetation is mainly composed of Stipa grandis, Leymus chinensis and Agropyron cristatum communities with sparsely scattered woods (mainly Ulmus pumila). During the past decades, the original vegetation has been greatly altered resulting from long-term overgrazing and over-cutting. Desertification usually experiences the following three stages: (1) conversion from the fixed sand dune to semi-fixed sand dunes due to removal of vegetation, (2) conversion from the semi-fixed dunes to semi-moving dunes, and (3) conversion from the semi-moving dune s to moving sand dunes. Vegetation in degraded sandy grassland is dominated by Artemisia halodendron communities. Main fuel wood species are Ulums pumila and Prunus sbirica (Li et al., 2003). Since the mid 1970s, some desertification controlling measures such as placing sand arresters (straw checkerboards), planting indigenous trees, shrubs and grasses adaptive to sandy land and fencing grassland have been implemented in parts of sandy land.

3. METHODOLOGY

3.1 Data source

This study was performed by using NDVI data derived from the VEGETATION sensor on board the SPOT4 (launched on April 1998) and VEGETATION2 on board SPOT5 (since February 2003). These data are available free of charge at the Vlaamse Instelling voor Technologisch Onderzock (VITO) Image Processing centre (Mol, Belgium) (http://www.vgt.vito.be). VEGETATION (VGT) is one of a new generation of space-borne optical sensors that were designed for observations of vegetation and land surfaces. These sensors offer a daily global coverage with a spatial resolution of about 1 km^2. Reflectance measurements are implemented within four spectral windows: B0 (blue, 430-470 nm), B2 (red, 610-680 nm), B3 (near infrared, 780-890 nm) and MIR (Medium Infra-Red, 1580-1750nm) with a high spectral (absolute calibration accuracy of about 5%) and geometric accuracy (less than 0.3 pixel). The spectral bands in the VGT-S1 (daily synthesis product) products are estimates of ground surface reflectance, as atmospheric corrections for ozone, aerosols and water vapor have been applied to the VGT-P images using the simplified method for atmospheric correction algorithm. VGT-S10 data (10-day synthesis product) is generated by selecting the VGT-S1 pixels that have the maximum NDVI values within a 10-day period.

In this study, 315 VGT-S10 images covering Southeast Asia between April 1998 and December 2006 were acquired and subset for the Horqin Sandy Land. The raw VGT data are in Plate carrée projection with a 0.0089285714-degree pixel resolution. Those temporal data were transformed and resampled using a nearest neighbor operator into the UTM projection based on WGS84 spheroid at 1-km resolution within ENVI 4.2 software. Besides, Landsat TM/ETM digital images in 2000 were also used to recognize vegetation.

3.2 MVC approach

Maximum Value Composites (MVC) technique retains the highest NDVI value for each pixel during a 14-day period producing images that are spatially continuous and relatively cloud-free, with temporal resolution sufficient for evaluating vegetation dynamics (Holben, 1986). It helps minimize the effects of cloud cover and variability of the scanning angle, sun angle, aerosols, and water vapor, which are the factors causing some residual noise(Hope et al.,2003;Stow et al., 2004).

The MNDVI is defined as the maximum NDVI for all time intervals of the MVC in a year or a month. The yearly MNDVI was found to be a reliable indicator of variations that can affect the state of vegetation cover. It was able to show the natural inter-annual variations, the consequences of extreme climatic events and the man-induced damage suffered by ecosystems (Cuomo et.al, 2001; Hope et al., 2003). In this investigation, 36 temporal series 1998-2006 made up of 10-days of NDVI were combined to produce one singular MVC of map for each year giving a total of nine NDVI maps. A simple formula, i.e. NDVI = DN×0.004-0.1 was constructed to relate DNs to NDVI value within those images. The MNDVI can be described by the following expression: $MNDVI_i = Max\ \{NDVI_{i1}, NDVI_{i2}, \ldots NDVI_{i36}\}$,in which $MNDVI_i$ is Maximum Normalized Difference Vegetation Index of year i, $NDVI_{i1}$ represents the first 10-day NDVI composites image, $NDVI_{i2}$ is the second 10-day NDVI composite data and so on. Note that there were 27 10-day NDVI composites image in 1998 because the acquisition of VGT-S10 data started from April. Yearly MVC image was calculated by comparing two temporally adjacent 10-day MVC images .The whole process was performed using an Interactive Data Language (IDL) program in this study. Likewise, monthly maximum NDVI for each year (NDVI_M) also obtained for the study period.

3.3 Time series NDVI analysis

The temporal evolution of decadal NDVI composition is regarded as an effective time window to show the natural seasonal variations, the consequences of extreme climatic events and the man-induced damage suffered by ecosystems. The change rate presents the relative variability of annual average NDVI value. The calculation can be performed using the following equations (Guo et.al, 2005):

$$\overline{NDVI_i} = \frac{1}{N} \bullet \sum_{j=1}^{N} NDVI_{ij} \quad (1)$$

$$V_s = \frac{\overline{NDVI_{i+1}} - \overline{NDVI_i}}{\overline{NDVI_i}} \times 100\% \quad (2)$$

where $\overline{NDVI_i}$ is NDVI mean for year *i*; $NDVI_{ij}$ is the *j-th* 10-day NDVI composites of year *i*; *n* is 36 (10-days periods from Jan 1 to Dec 21 in a year); V_s represents the change rate of annual average NDVI between two neighbor years. Another index was applied to reflect the change range of monthly maximum NDVI in the work. In the equation below, $NDVI\_M_{ij}$ is the *i-th* NDVI _M for year *j* ; $\overline{NDVI\_M_i}$ is the *i-th* NDVI _M mean over the study period then $NDVI\_M_j^i$ is the inter-month variation percent of *i-th* NDVI_M for year *j*.

$$NDVI\_M_j^i = \frac{NDVI\_M_{ij} - \overline{NDVI\_M_i}}{\overline{NDVI\_M_i}} \times 100\% \quad (3)$$

The greenness rate of change is defined as the slope of the least-squares line fitting the interannual variability of SINDVI values over some time period (e.g. decade) (Stow et.al., 2003).Similarly, the trend of annual maximal NDVI change can be derived from the slope of the linear time trend using OLS (Ordinary Least Squares) estimation:

$$SLOPE = \frac{n \times \sum_{i=1}^{n} i \times MNDVI_i - \left(\sum_{i=1}^{n} i\right)\left(\sum_{i=1}^{n} MNDVI_i\right)}{n \times \left(\sum_{i=1}^{n} i^2\right) - \left(\sum_{i=1}^{n} i\right)^2} \quad (4)$$

, in which n represents years range, i.e. 9 in this study, i is 1 for year 1998, 2 for the year 1999 and so on, MNDVI*i* is Maximum Normalized Difference Vegetation Index of year *i*. SLOPE is the slope of the linear regression of the one variable equation. It is the average annual increase (slope>0) or decrease (slope<0) in NDVI.

4. RESULT AND DISCUSSION

4.1 Spatial pattern of interannual maximum NDVI

NDVI describes the spectral response difference of the chlorophyll-loaded vegetal tissues between the red and infra-red channels. When NDVI is greater than 0.1, the land cover type is identified as vegetation cover, which is also used to confirm the growing season of the vegetation (Cuomo et.al. 2001; Lanfredi, et.al; 2003). Changes in vegetation cover can be inferred from NDVI. The higher the NDVI value, the higher the green vegetation density is. According to plant growing laws and NDVI variation characteristics, the yearly maximum NDVI reflects the best status of vegetation in a year. Spatial pattern of vegetation change in Horqin Sandy Land during past nine years is shown in Figure 1. In northern region covering forest and shrub, the average yearly maximal NDVI value ranged from 0.74 to 0.85. Agricultural vegetation with high biomass showed high maximal NDVI mean (0.64-0.74).The average MNDVI of the area dominated by medium density grassland was greater than 0.53. In central part of Horqin Sandy Land, relative low NDVI values were found. The inter-annual average maximum NDVI were between 0.11 and 0.21 occupied by very sparse grassland and sandy dune.

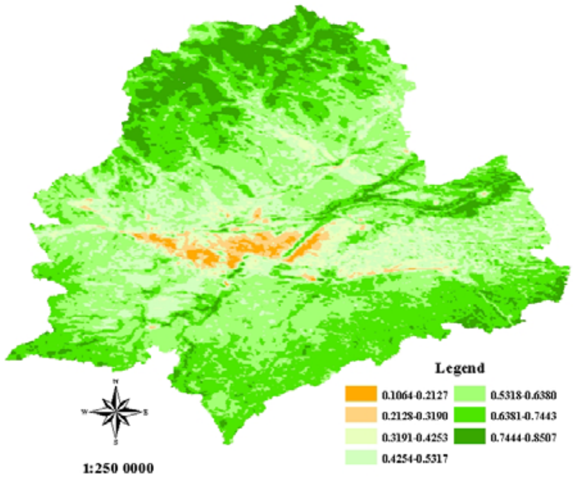
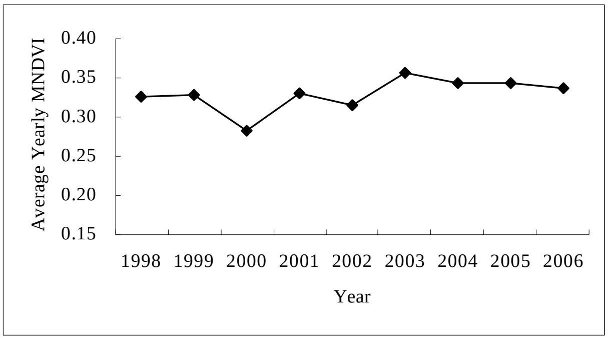


Figure 1. Average MNDVI pattern in Horqin Sandy Land

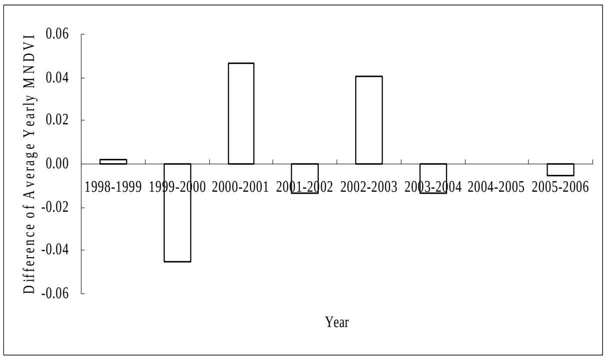
4.2 Yearly MNDVI and annual average NDVI changes

Vegetation cover in Horqin Sandy Land changed with an undulating trend in the period 1998-2006 (Figure 2a). Wave crests of the average yearly maximal NDVI values occurred in 1999, 2001 and 2003, while the wave troughs could be found in 2000 and 2002. In 2000, the annual maximum NDVI dropped to 0.284. The maximum NDVI in 2003 reached the highest 0.356 during past 9 years. The yearly maximal NDVI values mean over the study area increased slightly from 0.327 in 1998 to 0.338 in 2006, indicating the increasing trend of vegetation activity. Figure 2b illustrates MNDVI difference between two neighbor years. The inter-annual average yearly maximal NDVI value differences from 1999 to 2000, 2001 to 2002, 2003 to 2004 and 2005 to 2006 were negative, which showed the degradation of vegetation cover during these periods. Yet those values from 1998 to 1999, 2000 to 2001, 2002 to 2003 and 2004 to 2005 were greater than zero and the vegetation activity tended to increase gradually.

Annual NDVI mean value represents the average level of vegetation growth within this year. The acquisition of VGT-S10 data started from April in 1998, therefore, the yearly average NDVI of this year was not taken into account in this study. The yearly NDVI mean and its variation rate are shown in Figure 3. During the period of 1999-2006, the annual average NDVI value in whole area slightly dropped by 0.00168. Inter-annual change rate of annual average NDVI between 1999 and 2006 were -1.603%. From 1999 to 2000, the annual change rate reached the highest value -22.15%. However it increased by 13.77%, 2.29% and 10.21% respectively during the successive three periods, which showed improvement in vegetation cover. From 2003 to 2004 the annual change rate was -6.77%. After that, vegetation increased again by 6.66% from 2004 to 2005. During 2005-2006, annual average NDVI in Horqin Sandy Land decreased by 0.91%.



(a)



(b)

Figure 2. Average yearly MNDVI (a) and its differences (b) in Horqin Sandy Land

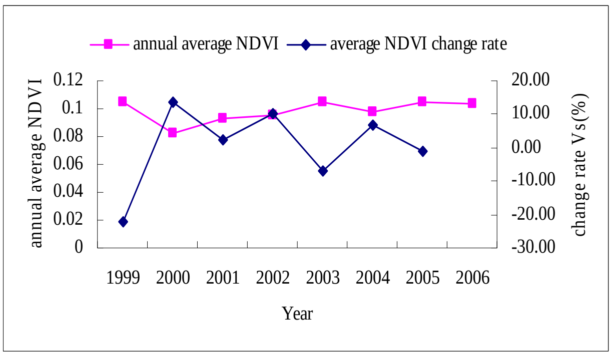


Figure 3. Annual average NDVI and multi-year change rate in Horqin Sandy Land

4.3 Yearly MNDVI change trend

To simulate the change trend of the yearly maximum NDVI change, we employed the OLS linear regression method. The area statistics for different degrees of MNDVI change in past 9 years is shown in Table 1. Vegetation activity in the Horqin Sandy Land tended to increase. The unchanged area accounted for 91.07% of the whole area. Slight improved area reached 6214.96 km^2, taking up 4.97% of the whole study area. About 0.105% and 0.012% of the total area were improved in medium and high degree. The degraded regions occupied about 3.84% of the study area, of which slight degraded area accounted for 3.769%.

The vegetation cover increased significantly in the boundary area between Horqin Right Wing Middle Banner, Zhalute Banner, Horqin Left Wing Middle Banner and Kailu County for the period of 1998-2006 (Figure 4). The slope of the linear regression of annual maximum NDVI was greater than zero, and original land desertification has been improved. There was considerable decrease trend of yearly maximum NDVI in the northern Horqin Left Wing Rear Banner, south part of Horqin Left Wing Middle Banner, the southern Tuquan County and eastern Horqin Right Wing Middle Banner. In the boundary region between Aerqin Banner, Balin Left Banner and Right Banner, vegetation tended to eliminate. Some non-desertified land in these area were transforming to desertifed land, the land desertification deteriorated. The landscape evolution in Horqin Sandy Land was characterized by two opposite processes, namely vegetation restoration (returning cropland for farming to grassland and close grazing) and land desertification. The increasing amplitude is larger than the decreasing amplitude between 1998 and 2006 on the whole.

Description	Slope	Area/km^2	Area percent%
severely degraded	-0.0543--0.0371	47.53	0.038
moderate degraded	-0.0370--0.0198	46.80	0.037
slight degraded	-0.0197--0.0025	4713.08	3.769
slight improved	0.0148-0.0320	6214.96	4.970
moderate improved	0.0321-0.0493	131.18	0.105
high improved	0.0494-0.0666	15.48	0.012
very high improved	0.0667-0.0839	4.79	0.004

Table 1 Area statistics of the average MNDVI change between 1998 and 2006

4.4 Monthly maximum NDVI change

Figure 5 illustrates the dynamic of monthly maximum NDVI in Horqin Sandy Land in 1998 and 2006. With maximum NDVI values correspond to the greenness peaks of the growing seasons (July and August), while the minimum values correspond to the dormant seasons. The monthly maximum NDVI of spring (April, May and June) in 1998 was apparently greater than that in 2006. Compared to 1998, the vegetation activity in July and August increased in the whole area. There was almost no difference between autumn.

A trend change can be calculated for a certain period by the method of linear regression of one variable, Y = aX + b. The slopes of the linear regression between the monthly MNDVI and year for the period of 1998-2006 are shown in Figure 7. It is the average annual increase (slope>0) or decrease (slope<0) in monthly MNDVI. The higher or lower the slope value for a specific month is, the more significant increase or decrease in

NDVI for this month is. Because there are no data available before April 1998, the slopes for the corresponding month were calculated from the year of 1999. The monthly MNDVI in spring months has a decreasing tend, while there is a considerable rising of monthly MNDVI in summer and autumn indicating an increasing vegetation activity during this period.

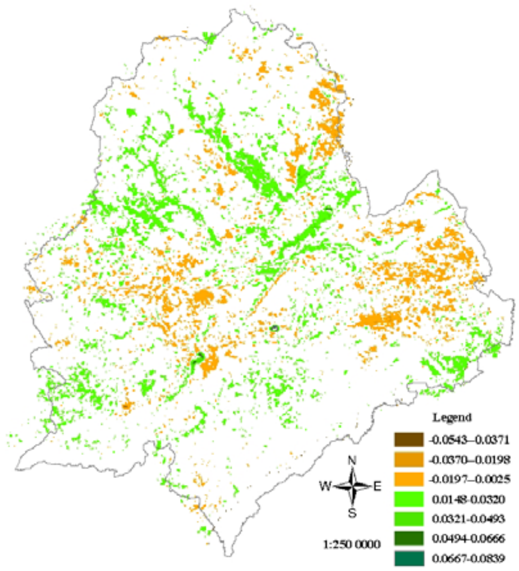


Figure 4. Yearly MNDVI change pattern in Horqin Sandy Land

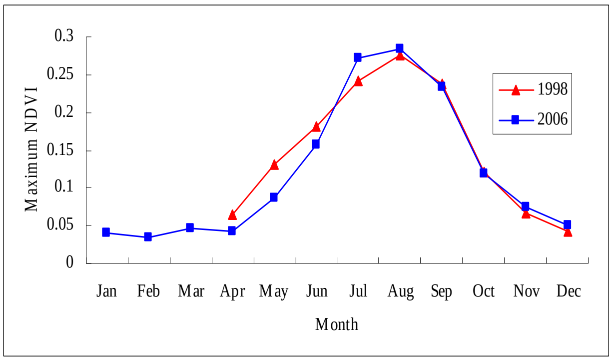


Figure 5. Monthly maximum NDVI in 1998 and 2006

Climate change is one of the main drivers of the interannual variation in vegetation activity. Figure 7 shows the variation of annual precipitation and annual average temperature in the Horqin Sandy region. During the last decades, temperature in the Northeast China including the study area has shown an overall warming trend. However, the precipitation in Horqin Sandy Land has oscillated throughout the past decades. Generally, this warming and drying climate may accelerate land desertification, for instance, in some non-desertified land has been transforming to desertifed land. Note that vegetation cover in Horqin Sandy land slightly increased and original land desertification has been basically controlled during past nine years. Rational human economic activities and vegetation restoration measures played a positive role in vegetation increases.

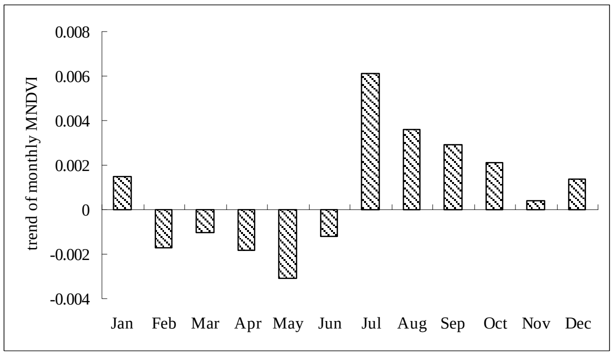


Figure 6. Monthly MNDVI change trend during 1998-2006

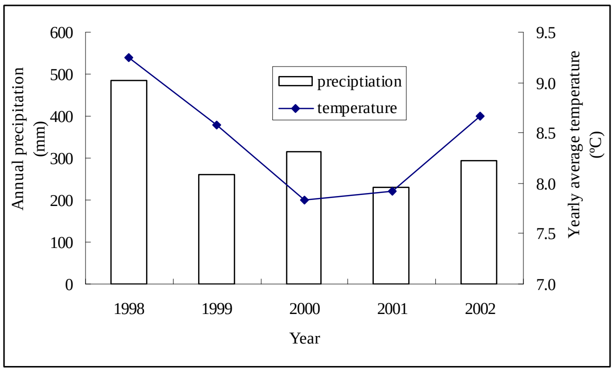


Figure 7. Temperature and precipitation variation in Horqin Sandy Land during 1998-2002

5. CONCLUSION

We used time series of SPOT-VEGETATION NDVI data to monitor temporal dynamics of vegetation in Horqin Sandy Land, Northeast China. During 1998-2006, vegetation cover in this region slightly increased with an undulating trend. The yearly average maximum NDVI increased by 0.011. It suggested that vegetation activity in Horqin region gradually increased. There was a significant decrease of monthly maximum NDVI in spring months. The increase of monthly MNDVI in summer and autumn could be contributed to the increase of yearly NDVI. The landscape evolution in Horqin Sandy Land was characterized by two opposite processes, namely vegetation restoration and desertification. Some original land desertification has been controlled, while some non-desertified land were transforming to desertifed land. The increasing amplitude is larger than the decreasing amplitude on the whole. Though the obvious warming and drying climate throughout the past decades may accelerate land desertification, in conjunction with rational human economic activities and vegetation restoration, original land desertification has been basically controlled during past nine years.

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