Bangladesh J. Bot. **48**(3): 789-798, 2019 (September) Special

DYNAMICS OF VEGETATION INDEX IN ARID DESERT REGION OF NORTHWEST CHINA USING ON MODIS DATA

HU LIU, CHUNYAN YIN[1*], RUIQIANG ZHANG, WEIGANG HAO*, ZHANMIN WEI[2], TIANMING GAO, JIAN WANG AND HENGLU MIAO

Institute of Water Resources for Pastoral Area, Ministry of Water Resources, Hohhot, Inner Mongolia, 010018 China

Keywords: MODIS data, Arid desert, Vegetation index, Climatic factor, Vegetation coverage, Spatial and temporal change

Abstract

Arid desert grassland in Northwest China is an important ecological barrier and animal husbandry production base in the western frontier regions of China. Analysis of the temporal and spatial dynamics of vegetation growth under certain climatic conditions is of great significance for the analysis of regional ecological changes and vegetation succession processes. In order to analyze the spatial and temporal dynamic processes of different vegetation growth and the main factors of vegetation growth in the arid desert areas of China, the 250-meter resolution vegetation index MOD13A1 data product obtained by medium resolution imaging spectrometer (MODIS) was used to study the temporal and spatial variations of NDVI from 2000 to 2016 in typical arid desert in Northwest China. The results showed that seasonal and interannual variations in vegetation growth can cause seasonal and interannual synchronized changes in NDVI. Overall, the typical desert steppe vegetation showed a degraded trend in the past 17 years. The most important climatic factors affecting NDVI changes within each year were precipitation and temperature. Precipitation conditions were the main factors affecting the interannual volatility of NDVI. Precipitation and mean temperature were more correlated with NDVI during the whole growth period (May to September) than during other growth periods. The comprehensive analysis of meteorological data such as temperature and precipitation show that the climate change in the region was relatively small in the past 17 years, but it was generally becoming colder and drier, which were not conducive to vegetation growth and ecological environment improvement. It was necessary to strengthen the management and protection of desert grassland in this area and formulate a scientific and efficient Water-grass-livestock utilization system.

Introduction

The arid desert region in the north western region in China was an extremely important natural ecological barrier in the northwest, and had an important strategic position in maintaining social stability, national unity and national defence security. The area is mostly located in arid and semi-arid areas, with rare rainfall, strong evaporation, shortage of water resources, serious soil erosion, and very fragile ecological environment (Wang *et al*. 2004). The climatic conditions are the direct driving force of vegetation distribution and change. At the same time, the vegetation also has a feedback effect on the climate, which can slow or aggravate the extent of climate change to a certain degree. Vegetation is an indicator of the environment, and the change of vegetation index can reveal the evolution of the environment. The Normalized Difference Vegetation Index (NDVI) accurately reflects the changes in vegetation photosynthesis intensity, greenness, vegetation metabolism, as well as annual and seasonal variations. Therefore, vegetation types, vegetation dynamic monitoring, land cover/utilization classification and its changes, natural disasters such as flood and draught monitoring, vegetation phenology monitoring, and crop growth monitoring have been widely used at regional, continental, and even global levels. MODIS data

*Author for correspondence: <455252435@qq.com>. [1]Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences, Hohhot 010020, China. [2]Inner Mongolia Agricultural University, Hohhot 010020, China.

has been acquired since 2000, and its spatial resolution (250 m) is relatively poorer than SPOT-VG, TAVHRR, TM remote sensing data, etc., but its time series is complete (Liu *et al.* 2012, Cao *et al.* 2016, Ge *et al.* 2017,). Furthermore, supporting data other than MODIS/NDVI are also becoming more and more abundant, and it has broad application prospects in terms of vegetation dynamics, real-time monitoring, and agricultural production monitoring.

At present, domestic and foreign scholars have used the long sequence NDVI resources in MODIS data to complete a large amount of vegetation dynamics research. Pei *et al.* (2014) introduced the MODIS MOD13Q1 vegetation products, and analyzed the data preprocessing process through computational examples. Li *et al.* (2011), Ge *et al.* (2017), Xu *et al.* (2017), Xia *et al.* (2018) used MODIS to analyze the temporal and spatial changes of grassland coverage rates and vegetation cover in the main river source areas of China based on results from the eastern part of the Yellow River source area, Liaohe source area, Sanjiang source area and Hanjiang Zhongyou river source area, and analyzed the process of vegetation growth in response to climate using the coupling relationship between time and space changes of vegetation and climate factors. Du *et al.* (2015), Chen *et al.* (2016), Lin *et al.* (2016), conducted long sequence analysis study on vegetation NDTV in Xinjiang, including the Tarim River Basin in southern Xinjiang and the Yili River Basin in Xinjiang. In the lower reaches of the rivers in the eastern part of China and in the delta areas, An *et al.* (2012), He *et al.* (2012), Zhu *et al.* (2013) also carried out research on NDVI dynamics and their climate response. At present, the use of MODIS data to carry out vegetation dynamic research is limited to China's major river sources, perennial river basins and river discharges (Yang *et al.* 2015, Zhang *et al.* 2018). It is not enough to grasp the changes of vegetation in the arid desert areas of northern China, especially after ecological construction. The present study was undertaken to select the representative Inner Mongolia Autonomous Region Dalham Mingan Union Banner (hereinafter referred to as Damao Banner) as the research area, and used the 16 days maximum synthetic vegetation index MOD13A1 data product in the MODIS data from 2000-2016. The changes in vegetation cover and its response to major climatic factors during the growth period and throughout the year of the studied area in the past 17 years were analyzed to study the temporal and spatial dynamics of vegetation in the area, and to provide rationale for repair and development and for future climate change management and ecological recovery for the arid desert areas in the northwest.

Materials and Methods

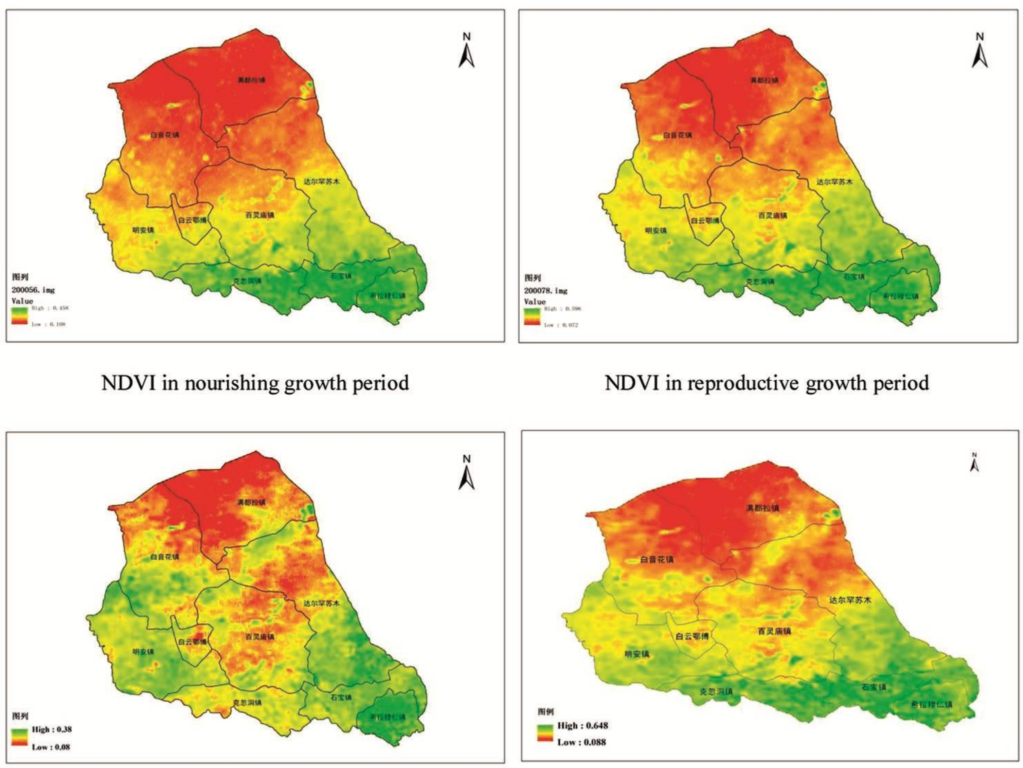
Normalized Difference Vegetation Index (NDVI) was a concept first introduced in 1973 (Pei *et al.* 2014) . Because vegetation more strongly absorbs chlorophyll under red light, the internal structure reflections of plants will be stronger under near-infrared, the NDVI can express valid information of vegetation. Currently, NDVI is the most widely used vegetation index. NDVI is a simple and effective means to measure surface vegetation coverage. It is the most commonly used vegetation index. It is the difference between the near-infrared and visible-light reflections divided by the sum of the two, ranging from −1 to 1. When NDVI > 0, larger its value, the greater the vegetation coverage; NDVI < 0 indicates cloud, water, snow and other ground coverings; NDVI = 0 indicates that the ground covering is bare land and other surface features. Therefore, the NDVI can distinguish between vegetation and non-vegetation to some extent. The calculation formula of NDVI is as follows (Eq.1):

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_R}{\rho_{\mathrm{NIR}} + \rho_R} \qquad \text{(Eq. 1)}$$

where ρ_{NIR} is near-infrared reflectance; ρ_{R} is red band reflectance. ρ_{NIR} and ρ_{R} correspond to band 2 and band 1 in MOD09Q1 data, respectively.

The MODIS data are derived from the 16 days maximum composite vegetation index MOD13A1 data product in the MODIS data of the US Land Process Distributed Active Archive Center (LPDAAC). The spatial resolution is 250 m and the time is from May to September in 2000-2016. According to the data, the vegetation growth period is divided into three stages: nourishing growth period (May and June), reproductive growth period (July and August) and withering period (September).

Using the MRT software provided by MODLAND, the MODIS data are processed by subset extraction, image mosaic, data format conversion, projection conversion, etc., to obtain a more reliable NDVI data set (Pei *et al.* 2014). The MVC method is then used for maximum synthesis of the ten sets of NDVI data from May to September each year. The maximum NDVI is obtained during the period to represent the best vegetation growth in the year. The reason is that the study area is cold in winter, and there is often snow residual on the surface. There is considerable difference in winter NDVI and actual vegetation conditions. Conventional use of the average



NDVI in nourishing growth period

NDVI in reproductive growth period

NDVI in withering period

NDVI in whole year

Fig. 1. NDVI during different periods in 2000 in the study area.

NDVI of 12 months in the year as the NDVI value representing the year will have large error. The annual maximum NDVI overcomes this problem on one hand, and on the other hand, the MVC method can further eliminate some interferences such as clouds, atmosphere and solar elevation angle. A total of 33 average indices and 11 annual average indices were extracted from the study area (Figs 1 to 4).

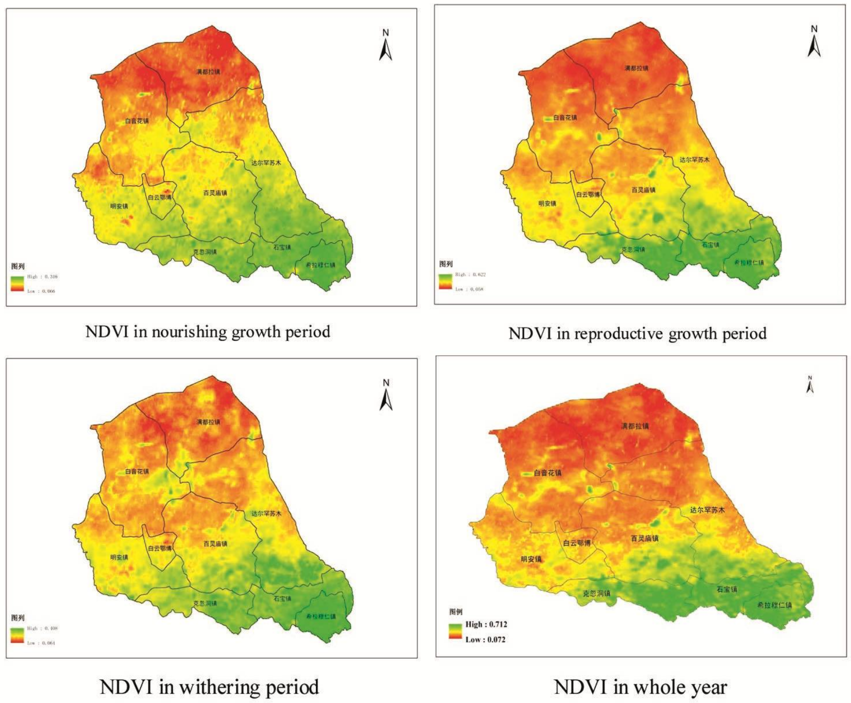


Fig. 2. NDVI during different periods in 2005 in the study area.

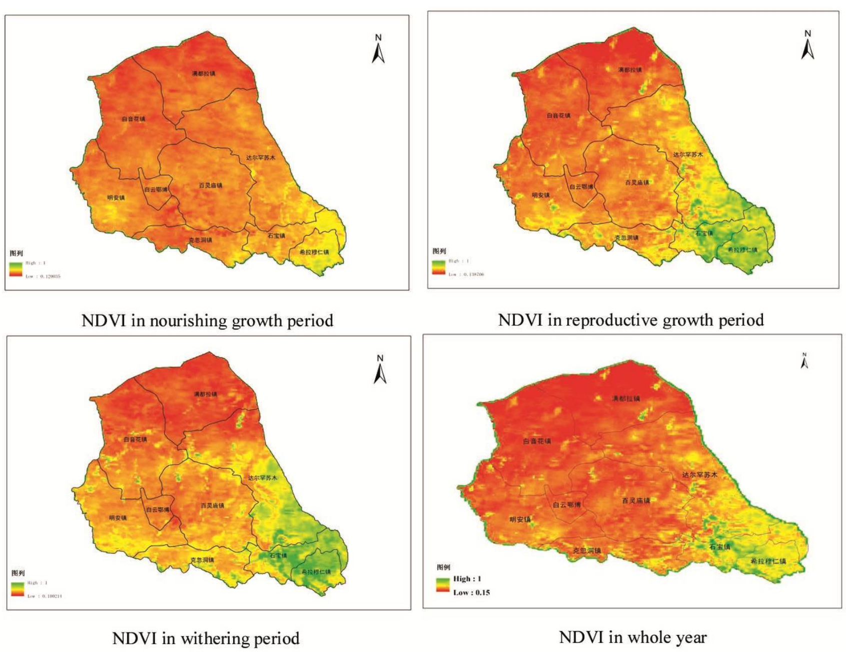


Fig. 3. NDVI during different periods in 2010 in the study area.

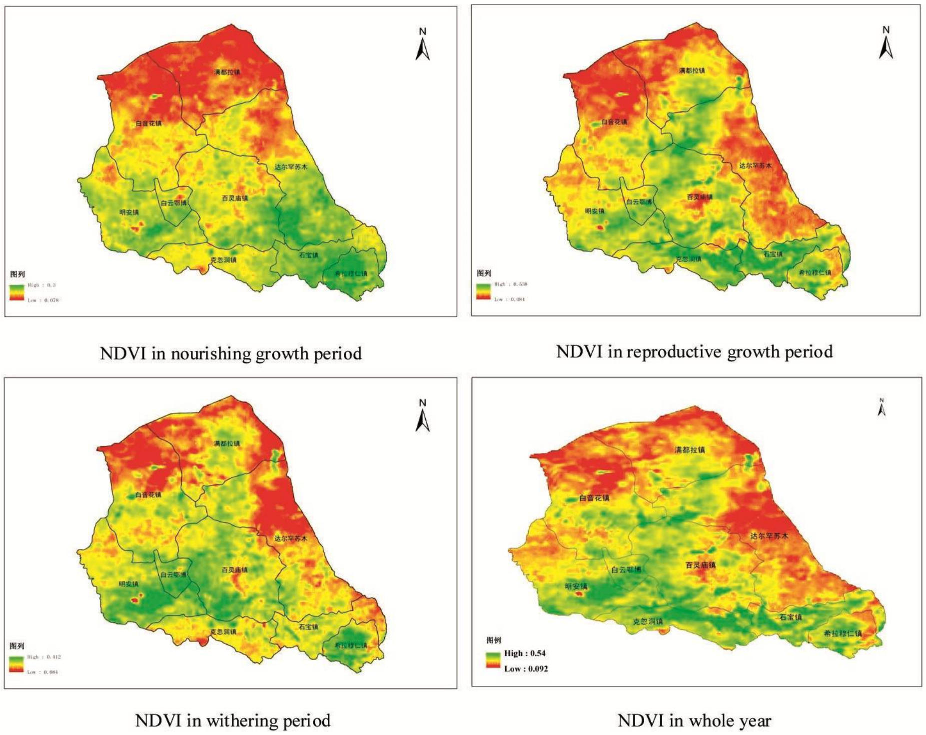


Fig. 4. NDVI during different periods in 2015 in the study area.

Results and Discussion

Trend analysis method is used to analyze the trend of NDVI from May to September in typical arid desert steppe from 2000 to 2016. As Eq. 1, which is a regression analysis of NDVI with time as the independent variable. The positive regression coefficient indicated that the variable had an upward trend during the study period, and the negative regression coefficient indicated that the variable had a downward trend. The regression coefficient being zero indicated that the variable had not changed. A 0.05 significance level test was done on the trend analysis. The test coefficient was $p < 0.05$. Passing the testing showed that the trend of NDVI in the study area was found significant in the past 17 years, otherwise the change was not significant.

$$Slope = \frac{n\sum_{i=1}^{n} iX_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} iX_i}{n\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \qquad \text{(Eq. 2)}$$

where n is the number of years in the study period, $n = 17$, X_i is NDVI.

The interannual variation of NDVI in typical desert steppe from 2000 to 2016 is shown in Fig. 5. The average NDVI of the study area from May to June in 2000 - 2016 was 0.169, the highest occurring in 2013, which was 0.23, and the lowest occurring in 2006, which was 0.122. The NDVI showed a trend of 0.0001/a decline from May to June. The average NDVI of July-August was 0.231, the highest occurring in 2003, which was 0.33, the lowest occurring in 2013, which was 0.16, and the NDVI showed a trend of 0.0001/a decline in May-June. The average NDVI in

September was 0.191. The highest occurred in 2012, which was 0.254, and the lowest appeared in 2013, which was 0.144, and the NDVI in September showed a trend of rise of 0.002/a. Overall, the average NDVI for May-September was 0.198, with the highest occurring in 2012 at 0.267, the lowest occurring in 2013 at 0.153, and the NDVI showed a trend of decline of 0.0004/a, but the trend of increase and decrease was not significant. NDVI showed no obvious linear correlation with the interannual variation.

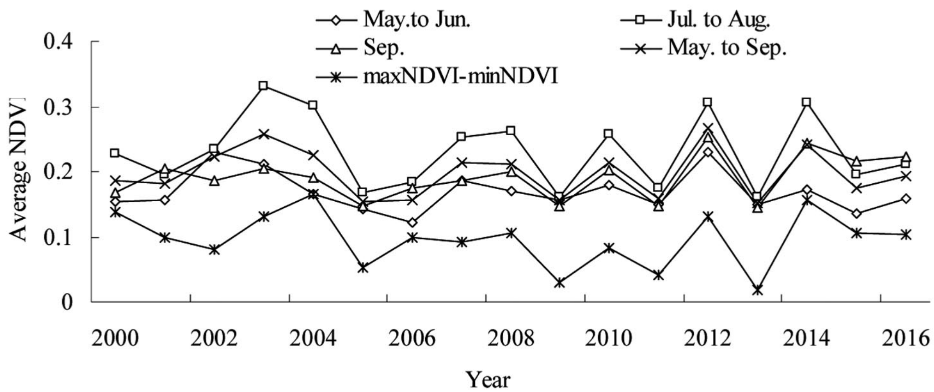


Fig.5. Interannual variation of NDVI in arid desert area.

From a spatial perspective, the vegetation in the study area is mainly distributed in the southern and southeastern parts of the Banner, including Xilamuren town, Shibao town, the south of Bailingmiao town and the southern part of Darhan Sumu. Among them, the NDVI in the south of Dalhan Sumu and Bailingmiao town improved significantly; the Mandula town and Baiyinhua town in the north declined slightly; the other areas remained basically unchanged. The areas where NDVI significantly increased mainly surrounding the Aibuhe River, the Tartu river and the Zhaohe river Basin; the areas where the NDVI decreased considerably were the southwest of Mandula town and the northeast of Baiyinhua town. Based on the annual NDVI volatility analysis, the minimum and maximum values of NDVI fluctuations from May to September ranged from 0.019 to 0.165, with the minimum and maximum fluctuation appearing in 2013 and 2004, respectively.

The average NDVI of the typical desert grassland vegetation from 2000 to 2016 are from 0.163, 0.175, 0.222, 0.241 and 0.191 for each month during the growth periods from May to September. It can be seen from Fig. 6 that the annual variation of NDVI in typical desert grassland vegetation was unimodal during the growth period of the plants. The annual maximum value appeared in July or August according to the temperature and rainfall of the year (Du *et al.* 2015). Overall, the NDVI in the study area increasd significantly from early May to early June, then rapidly increased to a higher value in late July, and then slowly increases to the peak in early August. Then the vegetation started to wither and the NDVI decreased. From the NDVI volatility analysis from May to September of 2000 - 2016, the minimum and maximum values of NDVI fluctuations ranged from 0.163 to 0.241, and the minimum and maximum values of variation fluctuations appeared in May and August, respectively (An *et al.* 2018).

From a spatial perspective, as the precipitation in the study area gradually decreased from south to north, the climate gradually becomes dry and hot, and the land use types were found different, resulting in different NDVI trends in different regions of the study area. In the southern and southeastern part of the study area, the area of farming and animal husbandry in the north of the Yinshan Mountains and the warm typical grassland, from May to June, with the increase of temperature and precipitation, the NDVI rising trend was significant, and the NDVI peaks in this area from July to August. Due to the high degree of development and utilization, the NDVI reduction was more obvious in September, while in the central and northern warm desert areas turning into grassland, the NDVI was generally at a lower level, and the NDVI in each month was in a relatively stable state. There was no significant change in May and June.

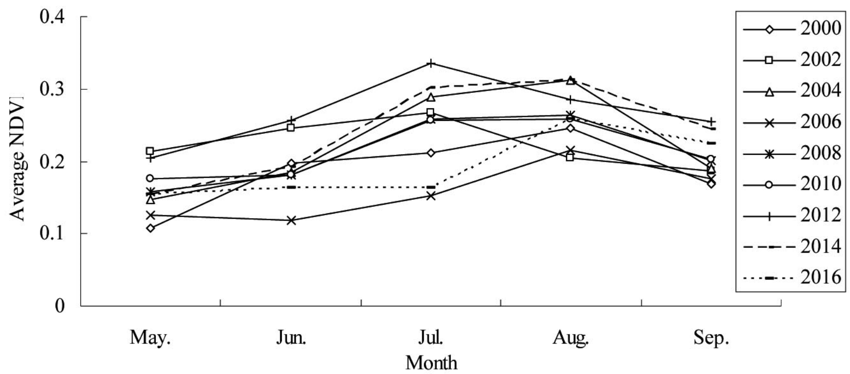


Fig. 6. Annual variation of NDVI in typical arid desert steppe area.

The precipitation and temperature data of Damao Banner from 2000 to 2016 was downloaded from the China Meteorological Data Network (http://cdc.cma.gov.cn). The precipitation and temperature data have been tested with 95% confidence. Fig. 7 showed a map of precipitation and temperature changes in the study area. As can be seen from Fig. 7, the precipitation in May, June, July, August and September accounted for 5.98, 22.1, 28.4, 16.3 and 17.1%, respectively of the total annual precipitation. The precipitation from May to September accounted for 89.9% of the total annual precipitation. In terms of monthly mean temperature, the average temperatures in May, June, July, August and September were 10.94, 15.91, 19.12, 17.45 and 10.65°C respectively.

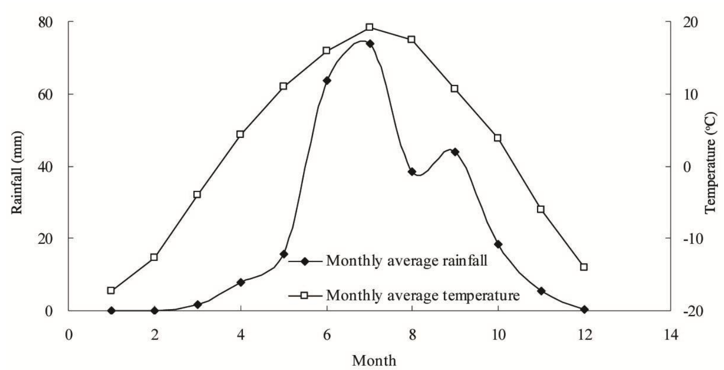


Fig. 7. Annual variation of average temperature and precipitation in typical desert steppe area from 2000 to 2016.

Fig. 8 shows the annual average temperature and the annual average precipitation as functions of year. It can be seen from the time series from 2000 to 2016 that the maximum annual precipitation was 450 mm in 2003, and the minimum 2006 at 165 mm. The precipitation showed a decreasing trend with the reduction extent of 2.2 mm/a and a correlation coefficient of 0.158. The downward trend was not significant. The maximum and minimum annual average temperatures were 4.24 and 1.75°C, which appeared in 2003 and 2012, respectively. The data shows that the annual average temperature was decreasing year by year. The decline was 0.053°C/a with correlation coefficient 0.433. The decline trend was not obvious, and the annual average temperature fluctuated greatly (Chen *et al.* 2016).

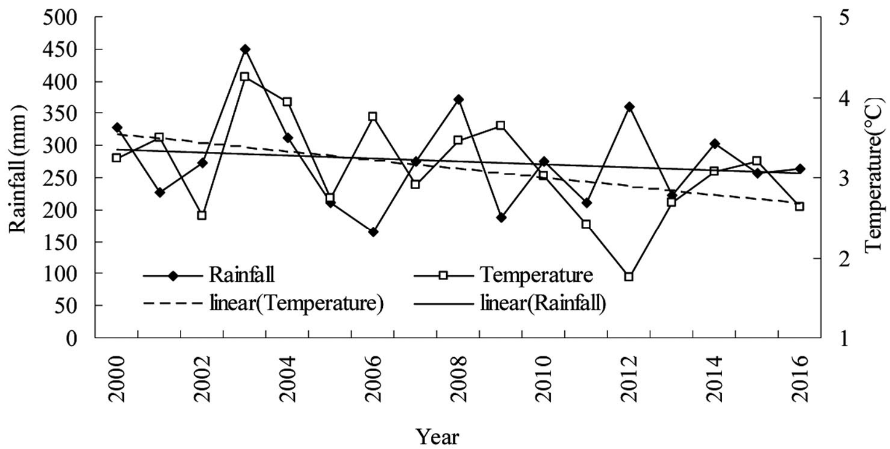


Fig. 8. Interannual variations of annual mean temperature and annual precipitation from 2000 to 2016.

It can be seen from Fig. 9 that the correlation coefficient between average NDVI and precipitation from May to September in 2000-2016 was 0.848. NDVI increased significantly with the increase of precipitation, and the correlation was considerable. The increase of precipitation increased the water content in soil, and improved the regional microclimate, conducive to the growth and development of vegetation (Zhu *et al.* 2013). The correlation coefficient between the average NDVI and the average temperature from May to September in 2000 - 2016 was −0.741, and the NDVI decreased with the increase of the average temperature. The high temperature and good light and heat conditions were conducive to grassland growth, but if the rainfall is not synchronized, there will have an adverse effect on grassland growth due to increased evapotranspiration and increased temperature (He *et al.* 2012).

It is revealed from Fig. 10 that, the correlation coefficients between average NDVI and precipitation and average temperature from July to August were 0.803 and −0.649, indicating that the precipitation and average temperature of the vegetation during the whole growth period (May to September) in the study area were more related to NDVI than the reproductive growth period (July to August) and other growth periods. Using the precipitation from May to September and the average temperature can be calculated more accurate NDVI (Zhang *et al.* 2018). At the same time, the correlation coefficient between precipitation and normalized difference vegetation index NDVI was greater than the correlation coefficient between average temperature and NDVI, indicating that the impact of precipitation on vegetation cover was greater than temperature (Xia *et al.* 2018).

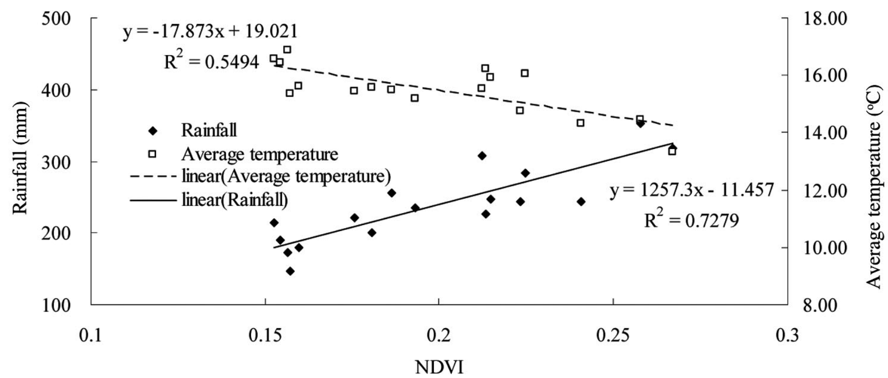


Fig. 9. Relevant maps of mean NDVI and climate factors in May-September.

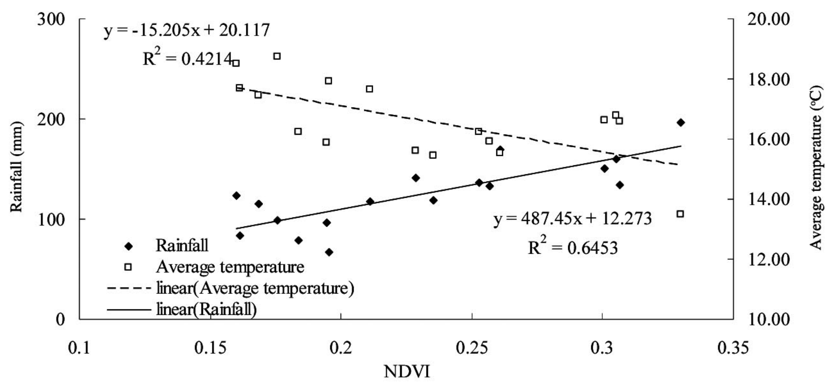


Fig. 10. Relevant map of mean NDVI and climate factors from July to August.

The annual maximum value of NDVI in the study area appeared in July or August, and the minimum value was in May. The NDVI rise and fall trend in the area of the farming-pastoral ecotone in the northern foot of Yinshan Mountain was significant. And the overall NDVI in the warm desert area turning into grassland was at a lower level and the changes were more stable. From the NDVI over 17 years, the trend showed a downward trend from May to August, and an upward trend in September, but the trend of increase and decrease was not significant. There was no obvious linear correlation between NDVI and yearly variation.

The precipitation in the grassland growth period of the study area accounted for 89.9% of the total annual precipitation. The temperature and precipitation decrease with a trend of 2.2 mm/a and 0.053°C/a, respectively. The correlation coefficients were 0.158 and 0.433, respectively. Overall, the climate was moving towards colder and more arid conditions.

The most significant climatic factors affecting the vegetation index of NDVI were rainfall and average temperature. The correlation coefficients between average NDVI and precipitation and average temperature were, 0.848 and −0.649 respectively. The increase of precipitation significantly contributed to vegetation growth, but temperature rise inhibited the growth of vegetation, causing the decline of NDVI. The process also was found to be related to the amount of precipitation. When the rain and temperature were synchronized, it was more conducive to vegetation growth.

Acknowledgements

This research was supported by the Special funds projects of China Institute of Water Resources and Hydropower Research (MK2018J07, MK2017J05, MK2016J10), Inner Mongolia Science and Technology Project (201701024), National Natural Science Foundation of China (51469024), National key research and development program (2018YFD0300400).

References

An YZ, Liu CS, Shi RH, Gao W and Yin J 2012. Spatio-temporal analysis of the vegetation changes based on MODIS time-series data in the Yangtze River Delta region. Ecol. Envir. Sci. **21**(12): 1923-1927.

Cao X, Chen XH and Zhang WW, Liao AP, Chen LJ, Chen ZG and Chen J 2016. Global cultivated land mapping at 30 m spatial resolution. Science China Earth Sci. **11**: 1426-1435.

Chen AJ, Xiao JD and Cao ML 2016. Research on change of vegetation index and response to climate in Yili River Valley based on MODIS data. Pratacultural Sci. **33**(8): 1502-1508.

Du JQ, Jiaerheng A and Zhao CX 2015. Dynamic changes in vegetation NDVI from 1982 to 2012 and its responses to climate change and human activities in Xinjiang, China. Chin. J. Appl. Ecol. **26**(12): 3567-3578.

Ge J, Meng BP, Yang SX, and Gao JL 2017. Dynamic monitoring of alpine grassland coverage based on UAV technology and MODIS remote sensing data-A case study in the headwaters of the Yellow River. Acta Prataculturae Sinica **26**(3): 1-12.

He Y, Fan GF and Zhang XW 2012. Variation of vegetation NDVI and its response to climate change in Zhejiang Province. Acta Ecologica Sinica **32**(14): 4352-4362.

Li HX, Liu GH and Fu BJ 2011. Response of vegetation to climate change and human activity based on NDVI in the Three-River Headwaters region. Acta Ecologica Sinica (19): 5495-504.

Lin X, Guo F, Huang CC and Yang X 2016. The applicability of VIs from MODIS in estimating vegetation cover in the middle and lower reaches of the Tarim River. Pratacultural Sci. **33**(12): 2434-2441.

Liu LL, Liu LY and Hu Y 2012. Comparative analysis of global vegetation phenology based on AVHRR and MODIS. Remote Sensing Tech. Appl. **27**(5): 754-762.

Pei XY, Zang SY and Na XD 2014. The Introductions and rapid pretreatment of MODIS MOD13Q1 vegetation product. Natural Science J. Harbin Normal Univ. **30**(02): 65-77.

Wang Q and Tenhunen JD 2004. Vegetation mapping with multitemporal NDVI in north-eastern China Transect (NECT). International J. Applied Earth Observ. Geoinfo. **6**(1): 17-31.

Xia HJ, Kong WJ, Sun JX and Hou LP 2018. Spatial-temporal dynamics of vegetation cover before and after establishment of Liaohe River Reserve based on MODIS NDVI. Acta Ecologica Sinica **38**(15): 5434-5442.

Xu JE, Xiao F and Liao W 2017. Spatial-temporal changes of vegetation and its geomorphic differentiation in the middle reaches of the Hanjiang River based on MODIS NDVI data. Resour. Envir. Yangtze Basin **26**(11): 1895-1901.

Yang YJ, Zhan YL, and Tian QJ. 2015. Crop classification based on GF-1/WFV NDVI time series. Transac. Chinese Society Agricul. Engin. **31**(24): 155-161.

Zhang Z, Zhang M, Xiao W, Wang W, Xiao QT, Wang Y and Li X 2018. Analysis of temporal and spatial variations in NDVI of aquatic vegetation in Lake Taihu. J. Remote Sensing **22**(2): 324-33.

Zhu MM, Hou XY and Wu T 2013. Spatio-temporal characters of vegetation cover in the Eastern China from 2001 to 2010 based on MODIS NDVI. Remote Sensing Tech. Appl. **28**(6): 1027-1032.

(Manuscript received on 17 July, 2019; revised on 18 September, 2019)