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Analysis of Temporal and Spatial Variation Characteristics of NDVI in Siziwang Banner and Its Correlation with Meteorological Factors

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Abstract Based on the data of NDVI and meteorological factors in Siziwang Banner from 2000 to 2021, the temporal and spatial variation characteristics of NDVI in the grassland of Siziwang Banner and its responses to climate change were analyzed. The results show that the NDVI of grassland in Siziwang Banner tended to rise overall, with the average tendency rate of 0.05/10 a. The annual variation of NDVI was mainly driven by precipitation, and there was an extremely significant positive correlation between the two. During the growing season, temperature was positively correlated with NDVI in May, but then the correlation gradually turned negative. NDVI was generally positively correlated with precipitation, and there was a significant lag.

Key words NDVI; Satellite remote sensing; Temporal and spatial changes; Climate response

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In the course of human development and global change, the sustainable development of the environment has become a key challenge that humanity must confront. Ecosystems are an important natural environmental foundation that supports the continuation of human civilization. The degradation, restoration and evolution directions of ecosystems affect the survival and development of human society. Surface vegetation is an important component of terrestrial ecosystems, serving as the "bond" connecting natural elements and the foundation for the survival of other organisms[1]. The changes in vegetation can reflect the variations in local hydrology, climate, human activities and other aspects, and play a very important role in the monitoring of changes in regional ecological environment.

Among the existing vegetation indices, NDVI (Normalized Vegetation Index) is not only easy to calculate and obtain, but also can largely reflect surface vegetation conditions. It has a significant relationship with important vegetation characteristics such as total primary productivity of vegetation, photosynthetically active radiation, and leaf area index, and is currently the most commonly used vegetation index.

At present, research on the dynamic changes of NDVI and its response to climate change mainly focuses on provinces or river basins. Study areas are large and may have multiple ecological types. Due to the different responses and lag degrees of different vegetation to climate change, microscopic information is often masked. Siziwang Banner is mainly composed of desert steppe with relatively simple vegetation. It is highly representative among the semi-arid steppe in mid-latitude areas, and is of great significance for revealing the response characteristics of grassland vegetation to climate change.

Numerous studies have shown that the growth and change of vegetation are influenced by the combined effect of multiple factors, and precipitation and temperature are the main climatic factors affecting the growth and change of vegetation[2].

1 Data and methods

1.1 Overview of the study area Siziwang Banner (110°20′ – 113°00′ E, 41°10′ – 43°22′ N) is located in the center of Inner Mongolia Autonomous Region and the northwest of Ulanqab City, with a total area of 25 500 km^2. The terrain is rather complex, and there are undulating hills. It is mainly composed of two major landform units: low mountains and hills in the south and layered plateaus in the north. It borders Chayou Middle Banner and Chayou Back Banner of Ulanqab City and Sunite Right Banner of Xilingol League in the east, Zhuozhi County, Ulanqab City and Wuchuan County, Hohhot City in the south, Damu Banne, Baotou City in the west, and Mongolia in the north, respectively. The total length of its national border is 104 km. Siziwang Banner is the largest agricultural and pastoral integrated banner in Ulanqab City, where the pastoral area accounts for 82% of the total area. The banner has 2.14 million hm^2 of natural grassland, where the annual number of bred livestock is 1.44 million, and the annual number of slaughtered livestock for sale is 1.41 million.

1.2 Research data and methods The data of temperature and precipitation are the daily meteorological observation data of Siziwang Banner from 2000 to 2021. For NDVI, the MOD13A3 vegetation monitoring product provided by NASA from 2000 to 2021 was used, and the monthly data of MOD13A3 were generated through a time synthesis algorithm based on the weighted average

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method using the MOD13A2 product.

Trend line analysis means reflecting the spatial variation trend and speed of vegetation by calculating the tendency rate of linear changes in NDVI in each raster.

The correlation between NDVI and precipitation or temperature in Siziwang Banner was discussed by calculating and testing their correlation coefficient.

2 Results and analysis

2.1 Relationship between annual variation of vegetation and climate change

2.1.1 Spatial distribution of vegetation. Annual maximum NDVI, which is the maximum of NDVI obtained through satellite remote sensing technology within a single year, reflects the growth status and coverage of vegetation. The distribution of multi-year average means averaging annual maximum NDVI over many years to demonstrate the changing trends and distribution of coverage and growth conditions of vegetation over these years. Fig. 1 shows the multi-year average distribution of the maximum NDVI from 2000 to 2021. On the whole, NDVI decreased successively from south to north. The vegetation coverage in the south was relatively high, and annual maximum NDVI ranged from 0.4 to 0.6. The vegetation coverage in the middle was relatively low, with the annual maximum NDVI of 0.2 – 0.4. The vegetation coverage in the north was the lowest, and annual maximum NDVI was below 0.2.

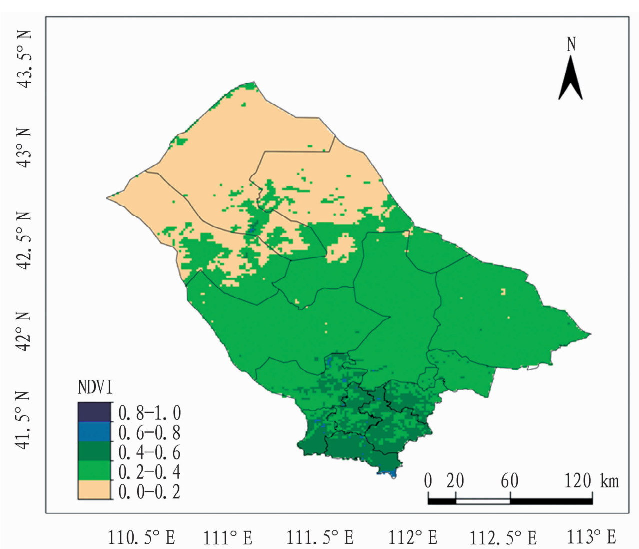

Fig. 1 Distribution of multi-year average of annual maximum NDVI in Siziwang Banner

2.1.2 Annual variation of vegetation. The trend line method was used to analyze the changes in the annual maximum NDVI of grassland in Siziwang Banner from 2000 to 2021, and the significance test of the linear trend was conducted. The results show that climate tendency rate was 0.06/10 a, and NDVI showed a significant increasing trend, which passed the significance test at 0.01 level. It indicates that the vegetation growth in this area had been continuously improved.

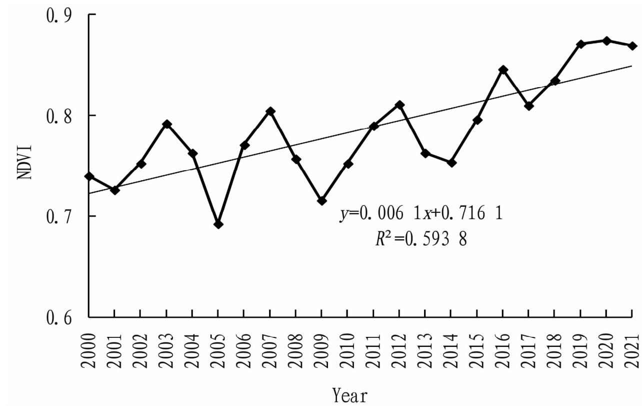

Fig. 2 Annual variation of annual maximum NDVI from 2000 to 2021

2.1.3 Annual variation of vegetation and meteorological elements. As shown in Fig. 3, NDVI showed an overall upward trend from 2000 to 2021, with the tendency rate of 0.05/10 a. Average temperature generally showed an upward trend, with the tendency rate of 0.09/10 a. Annual precipitation generally tended to decrease, with the tendency rate of 4.41/10 a. Annual average NDVI passed the significance test at 0.01 level, while annual average temperature and annual precipitation did not pass the significance test at 0.01 level.

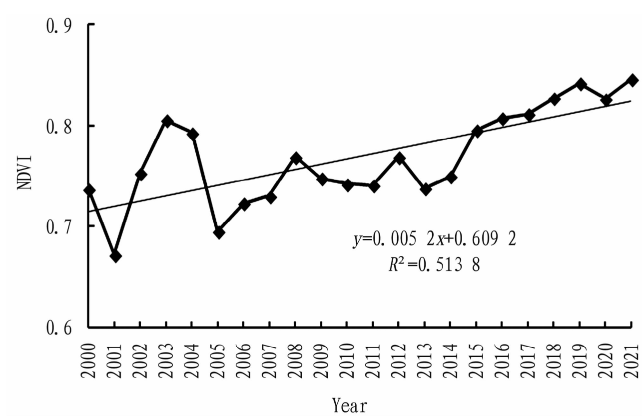

Fig. 3 Variation of annual average NDVI from 2000 to 2021

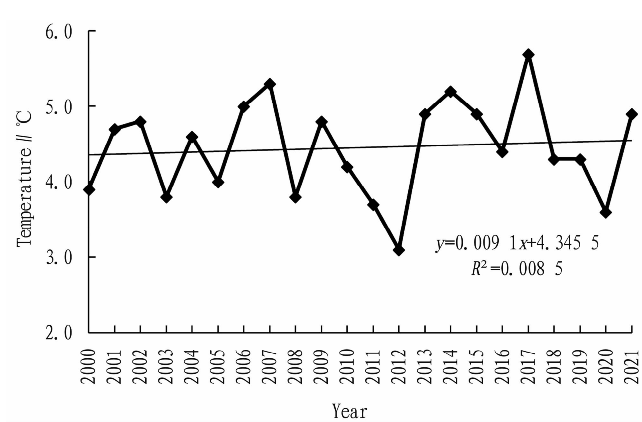

Fig. 4 Variation of annual average temperature during 2000 – 2021

2.1.4 Responses of vegetation to annual climate change. Correlation and partial correlation analyses were conducted between the regional annual average NDVI, temperature and precipitation from 2000 to 2021. The correlation coefficient between annual average NDVI and precipitation was 0.434, and their partial correlation coefficient was 0.468, both passing the significance test at 0.05 level. The correlation coefficient and partial correlation coefficient between annual average NDVI and temperature did not pass the significance test. It reveals that on the annual scale, precipitation played a decisive role for NDVI, and favorable water conditions enabled vegetation to grow more rapidly.

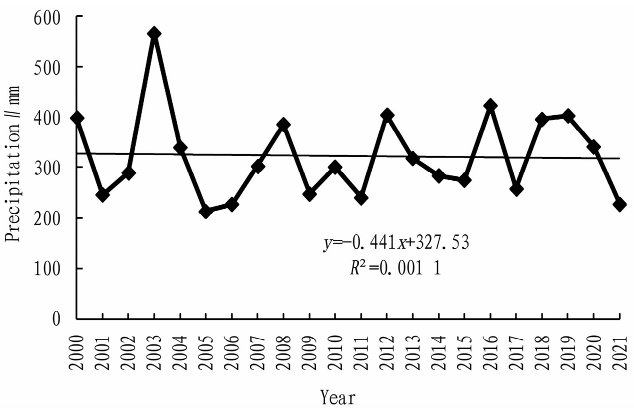

Fig. 5 Variation of annual average precipitation from 2000 to 2021

2.2 Relationship between vegetation changes and climate change during the growing season

2.2.1 Changes of vegetation and meteorological elements during the growing season. From Fig. 6, it can be seen that the multi-year average of NDVI maximum during the growing season in Siziwang Banner gradually increased in May, mainly because forage grass began to fully turn green in May and grew rapidly. In July, NDVI reached its peak of the year. As temperature dropped and precipitation decreased, grass gradually stopped growing, and quickly entered the yellowing and withering period.

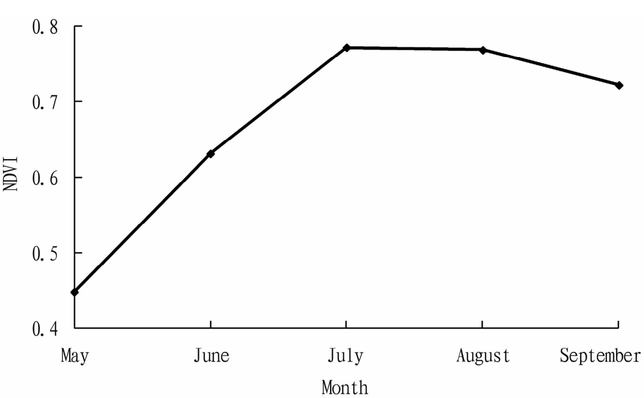

Fig. 6 Monthly variation of average maximum NDVI during the growing season

During the growing season, raining and hot happened during the same period in the grassland in Siziwang Banner. The average temperature in May was 13.5 ℃, and then roses slowly. Average temperature was above 18 ℃ from June to August, reached a peak of above 20 ℃ in July, and then began to drop. The precipitation in May was 31.8 mm, peaked in July (up to 79.0 mm), and then started to decline slowly.

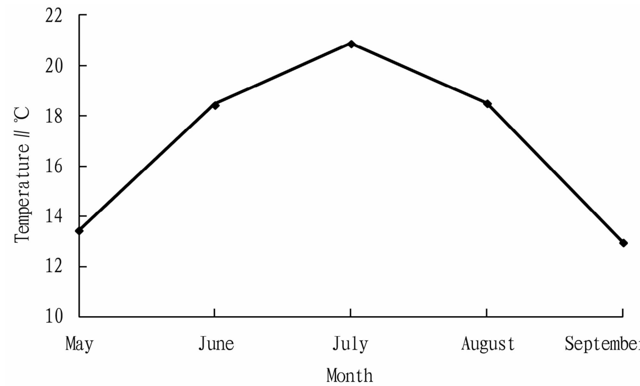

Fig. 7 Monthly variation of average temperature during the growing season

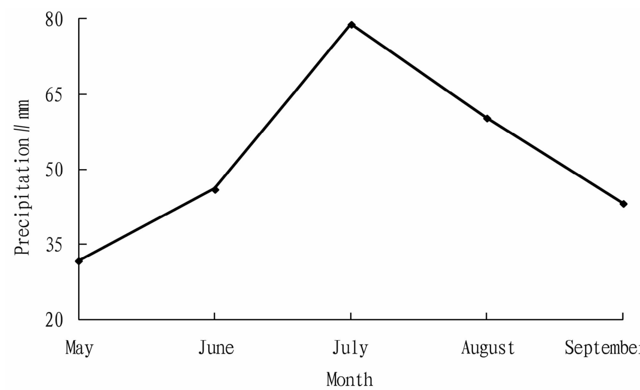

Fig. 8 Monthly variation of average precipitation during the growing season

2.2.2 Responses of vegetation to changes in meteorological elements. The influence of meteorological elements on vegetation growth is mainly reflected in the control of its seasonal rhythm. Analyzing the relationship between meteorological elements and vegetation growth can better explain which meteorological elements mainly affect vegetation at different growth stages.

In May, the NDVI of grassland in Siziwang Banner was correlated positively with temperature, and their correlation gradually became negative since June (the figure is omitted).

There was a positive correlation between NDVI and temperature mainly in the early stage of forage growth. The reason is that the heat conditions in the early stage of forage growth are generally insufficient, and the restrictive effect of temperature on forage growth is obvious. However, in the middle and later stages of forage growth, the heat conditions can meet their growth needs. Since precipitation was relatively less when temperature was higher, the correlation between NDVI and temperature became mainly negative.

The NDVI of grassland in Siziwang Banner was generally positively correlated with precipitation, and the correlation was signi-

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period of fruits, susceptibility to spring drought during the young fruit stage, and relatively low temperatures during the flowering and pollination period in some years are the main climatic factors affecting the formation of mango yield in Jingdong County and causing significant annual fluctuations. The insufficient light and heat intensity during the development and maturation period of fruits is the main reason for the late ripening of mangoes. At the same time, it indicates that in Jingdong County, medium and low altitude areas (< 1 400 m) are only suitable for growing mangoes.

(4) The results of this study have practical guiding significance. In the meteorological services for mango production, it is necessary to focus on light and heat intensity during the maturation period of fruits (from June to September), the impact of spring drought (rainfall at the beginning of the rainy season and from March to May), and light and heat intensity during the flowering and pollination period, which can great help improve the prediction level of mango yield in Jingdong County.

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ficant at 0.05 level in May and July. The significant positive correlation between NDVI and precipitation was mainly concentrated in the early stage. There was a significant lag in the response of vegetation to precipitation (the figure is omitted).

The snow on the grassland of Siziwang Banner in winter melts in spring, ensuring that the soil moisture can meet the needs of grass turning green again. Therefore, the impact of insufficient water on vegetation was mainly reflected in the middle and later stages of forage growth.

3 Conclusions

(1) From 2000 to 2021, the NDVI of grassland in Siziwang Banner showed an overall upward trend, with the average tendency rate of 0.05/10 a. The improvement of vegetation environment was quite obvious.

(2) The annual variation of NDVI in the grassland of Siziwang Banner was mainly driven by precipitation, and the correlation with temperature was relatively small.

(3) During the growing season, the temperature in May was positively correlated with NDVI. The heat conditions had certain restrictive effects during the greening period and the early stages of forage growth. Subsequently, the correlation between NDVI and temperature gradually became negative. NDVI was generally positively correlated with precipitation, but the response of NDVI to precipitation had a lag effect.

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