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ANALYSIS OF VEGETATION COVERS CHANGE AND ITS INFLUENCING FACTORS IN ORDOS SINCE THE 21ST CENTURY

Bao Xiuyan, Bao Yuhai*, Tong Siqin

© **Xiuyan Bao**
Chifeng University
Chifeng 024000, China
E-mail: bxy9119@163.com

© **Bao Yuhai**
PhD, Prof. College of Geographical Science,
Inner Mongolia Normal University
Hohhot 010022, China
E-mail: baoyuhai@imnu.edu.cn

© **Siqin Tong**
Inner Mongolia Normal University
Hohhot 010022, China
E-mail: baoyuhai@imnu.edu.cn

Taking MODIS NDVI as the main data sources, combing with precipitation and temperature, using trend analysis and correlation analysis methods to study the vegetation cover changes and its influencing factors in Ordos during 2000 to 2013. The results showed that, the average annual growing season NDVI has a significant increasing trend in Ordos over the past 14 years, the relative change rate was up to 28.40% and there was 61.1% of the total area NDVI significantly increased. At the inter-annual scale, the rainfall controls the growth of vegetation in Ordos and the NDVI and precipitation has markedly positive correlated (R^2=0.64, $P<0.05$), while has a weak positive correlation to the temperature. During the 2000–2013, the increase of residual NDVI was larger than that of decreasing area, which indicated that vegetation construction was stronger than the destruction in Ordos in recent years due to human activity.
Keywords: Vegetation covers change; Correlation analysis; Climatic factors; Human activities; Ordos.

1. Introduction

Vegetation is the natural link between soil, water and environment, and acts as an «indicator» in the global change [1], so the vegetation change can be a sensitive index of climate and human factors to the environment. Monitoring the dynamic changes of vegetation and its relationship with climate change and human activities has important practical value to determine the reasonable methods with vegetation protection and management.

Ordos is a typical ecological fragile area of China, located in the upper reaches of the Yellow River region with serious soil erosion and a main sand source of Northwest and North China, along with arid conditions and long-term unreasonable land use have restrict the sustainable development of the local economy and society [2]. And there has a large area of sandy land, i.e. the southeast Maowusu Desert and northwestern Kubuqi Desert, about 43000 square kilometers, and occupied the 48% of total area [3]. In recent decades, climate change, over grazing, and mining activities led to the decline in the rate of vegetation cover in Ordos, expansion of sandy land, and then it became one of the most serious desertification in China [4]. In order to curb the further development of desertification, the implementation of large-scale ecological engineering construction in Ordos, including banning grazing, rotation grazing, ecological migrants, returning farmland to forest (grass) and other measures to increase surface coverage, so as to improve the regional ecological environment [2], and has achieved obvious benefits since the policy implementation [5]. In recent years, many scholars have studied the related characteristics of vegetation in different time scales Ordos NDVI and the variation of temperature and precipitation, and made a series of research results in the classification of vegetation, vegetation change monitoring, relationship between vegetation and climate [6, 7]. However, the relationship between vegetation changes and human activity reports are rare to see, and the use of residual method to quantify human impact on vegetation NDVI changes in the literature is even more rare [8, 9], and the existing literature does not have a systematic description of the change trend and speed of the NDVI residual, because of human activities become more and more frequent, with a comprehensive and systematic description of the two major climatic factors under the influence of temperature and precipitation, the residual analysis is of great significance to regional research.

The previous literatures have used the NOAA NDVI data to study the vegetation changes, which has the deficiency of low spatial resolution. With the launch of Terra satellite, which equipped with the Moderate Resolution Imaging Spectroradiometer has solved the problem of resolution very well [10], and also improved on chlorophyll sensitivity and reduced by narrow band effect of atmospheric water vapor in the red band and near infrared band, improve the monitoring capacity of vegetation index. Therefore, this paper is based on the MODIS NDVI data and meteorological data, using regression analysis, correlation analysis and residual analysis to study the Ordos vegetation covers change and its relationship with climate change and human activity, understand the spatial and temporal change trend of vegetation in Ordos, explore the driving factors of vegetation cover changes, so as to provide a theoretical basis for the rational organization of the orderly human activities.

2. Data and methods

2.1. Study area

Ordos is located in the southwest of the Inner Mongolia (106°42′40″ —111°27′20″E, 37°35′24″ — 40°51′40″N), with a total area of 86752 km², its west, north, East three adjacent to the Yellow River, next to the

Loess Plateau in the South, bordering Shaanxi Province, Shanxi province and the Ningxia Hui Autonomous Region (Figure 1). Temperate semiarid to arid continental climate, the annual sunshine duration was 2716–3194h, the annual evaporation in 2000–3000 mm, the annual average temperature of 5–8 degrees, more than 10 DEG C for the accumulated temperature of 2600–3200 DEG C [11]. The annual precipitation is 160–400 mm, influenced by the Ocean monsoon, the annual precipitation decreased gradually from east to west, from the east to the west of the dry climate gradually increased. Altitude range between 794 to 1777 m, the west is higher than the east. The zonal distribution of vegetation is obvious, affected by climate change and human activities, temperate grassland in the East, temperate deciduous scrub in the southeast, desert grassland in the southwest, desert in the north, irrigated farmland in the Yellow River, and desert in the northwest.

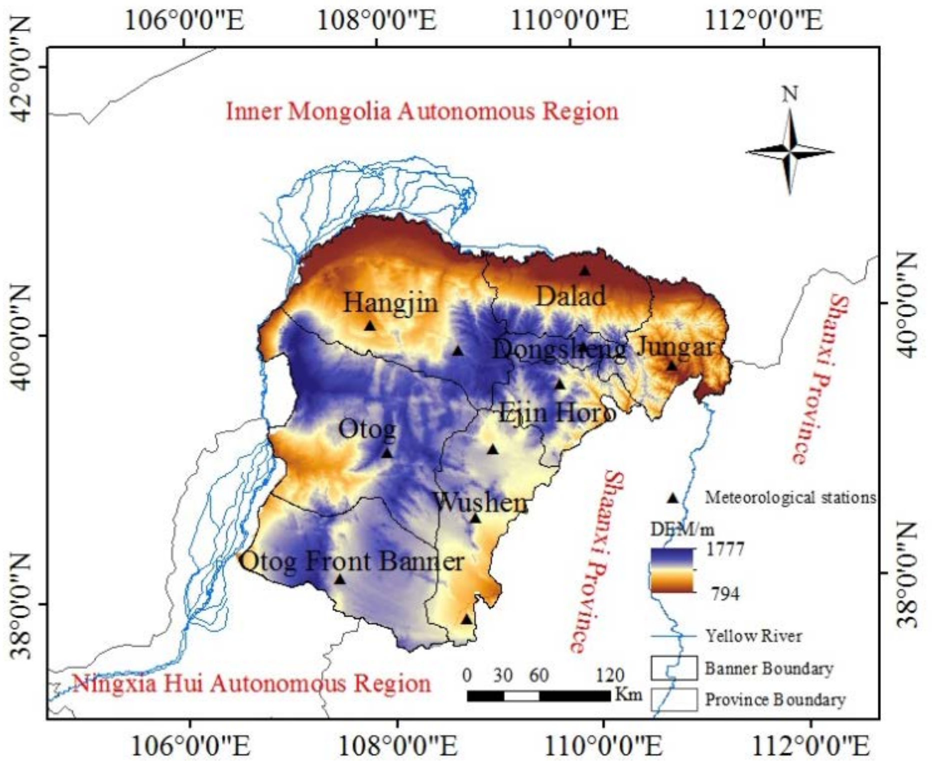

Fig. 1. The geographical location of Ordos and the distribution of meteorological stations

2.2. Data

In this paper, take the MOD13A3 (https://ladsweb.nascom.nasa.gov/data) as the NDVI data source to analyze the vegetation change in Ordos. Due to the vegetation in the Ordos region was almost stopped growing or covered with snow in winter, this paper studies the time period of 4–10 months of the growing season, the time series for 2000–2013 years. The original MODIS products is the use of hierarchical data format and sinusoidal projection, so we first need to use MRT software covert the HDF file into WGS-1984 latitude coordinate system with GeoTiff file format, and then preprocess the data such as project transformation and extract by study area.

Meteorological data were downloaded from China Meteorological Data Service Sharing network, including the monthly average temperature and monthly precipitation data of 10 stations in the Ordos Basin (Fig. 1). Then we used GIS kriging interpolation to get the raster image of temperature and precipitation. The average growing season temperature was obtained by weighted average temperature of each month in the growing season, and the growing season precipitation data were the total of each month in the growing season.

2.3. Method

2.3.1 Linear Regression Analysis

In this paper, the linear regression method was used to analyze the temporal trends of vegetation dynamics for each pixel, the calculating formula is described as follows (Equation 1):

$$y = a + bx \qquad (1)$$

Where y is the NDVI value of each year from 2000 to 2013, x is the year from 2000 to 2013, a is the intercept and b is the slope of annual NDVI, which is calculated by the least square method (Equation 2):

$$Slope = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} NDVI_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i \right)^2} \qquad (2)$$

Where n is the number of years (equal to 14 in this study), denotes the year (=1, 2, 3,…, 32), $NDVI_i$ represents the annual mean NDVI value in the i th year. When Slope>i 0 means an increasing trend in NDVI and vice versa [12, 13]. The spatiotemporal variations of the climate factors are also derived from the algorithm above.

2.3.2 Relative Changing Rate

Using the Relative Change Rate (RCR) [14] to show the variation characteristics of vegetation in different counties (increase or decrease), the calculation formula is as follows:

RCR= (Slope / Mean) ×N×100% (3)

Where, the slope is derived from the equation 2; Mean is average of NDVI during 2000–2013; N is year, and in this paper it is equal 14.

2.3.3 Correlation Analysis

To assess the effects of climate variables on vegetation dynamics, the Pearson correlation coefficients (Equation 4) are calculated for the growing season NDVI, temperature and precipitation on a per pixel basis [15]. If the correlation coefficient is larger than 0, the two variables are positive correlated, and the two variables are consistent with the tendency of increasing or decreasing. However, if the correlation coefficient is less than 0, it indicates that the negative correlation between the two variables and the changing tendency are at the reverse direction.

$$r_{xy} = \frac{\sum_{i=1}^{n}\left[(x_i - \bar{x})(y_i - \bar{y})\right]}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (4)$$

Where r_{xy} is the correlation coefficient between two variables x and y, whose value is ranges from -1 to 1, the larger absolute value indicates the stronger correlation; i is the order of year from 1 to 32 in the study period; n for the period of time, namely 14 years in this study. x_i is the growing season NDVI of i th year; y_i is the growing season temperature or precipitation of i th year; $\bar{x}$ and $\bar{y}$ are the mean NDVI, mean temperature or mean precipitation in the growing season from 2000 to 2013.

2.3.4 Residual Analysis

By establishing the regression model between NDVI and air temperature and precipitation, to predict the NDVI value based on existing temperature and precipitation. And then subtract the predicted NDVI value from the remote sensing NDVI value to get the residual value. This is the quantitative results of effect of human activities on vegetation [16].

3. Results

3.1 Characteristics of climatic variation in Ordos

Figure 2 shows the time variation curves of precipitation and temperature in vegetation growing season. It can be seen from the figure that the precipitation has an increasing tendency with a rate of 3.43 mm /a and the minimum and maximum values occurred in 2005 and 2012, the relative changing rate was 17.9%. The annual mean growing season temperature has a slight upward trend, the lowest value and the highest value reach in 2010 and 2012, with a 3.6 ^{o}C difference. In general, during the study period the annual growing season precipitation and temperature increased, and the increasing rate of precipitation is greater than that of temperature, which showed that there is no obvious tendency of drought in the climate and this phenomenon will be beneficial to the growth of vegetation.

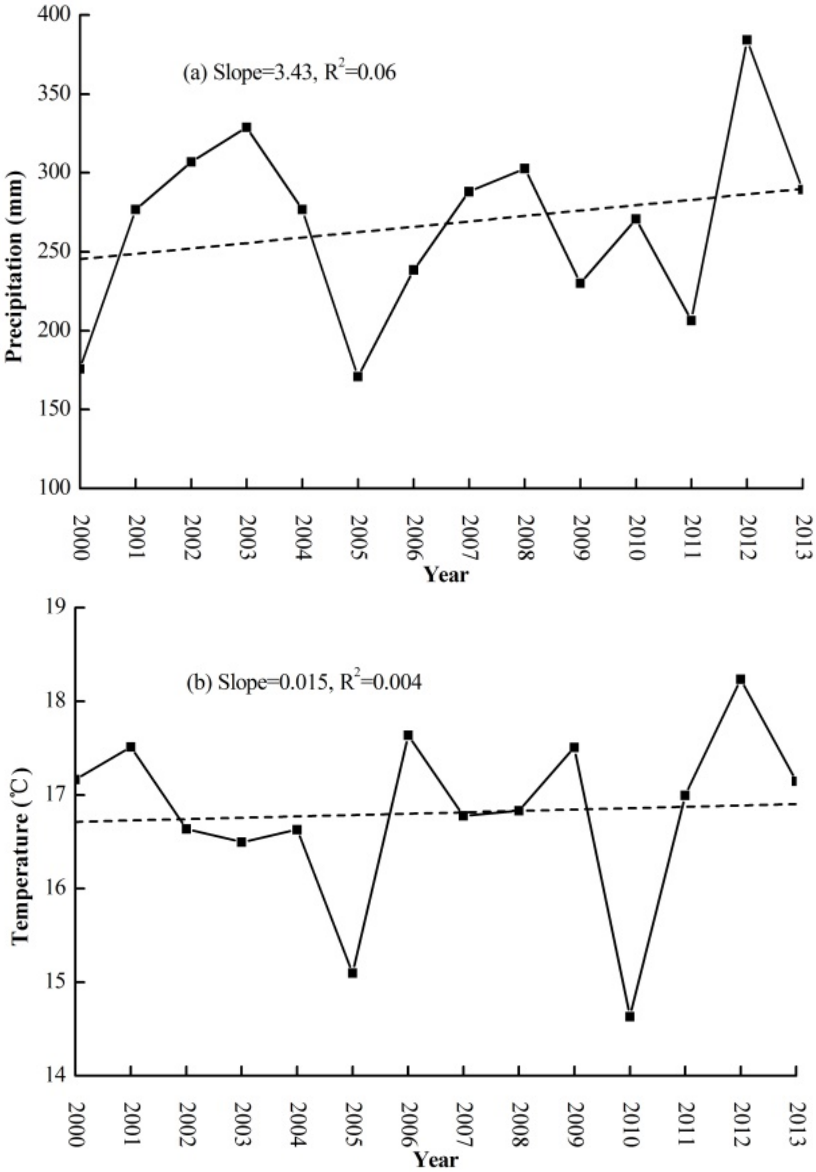

Fig. 2. Temporal variation characteristics of precipitation and temperature in growing season during 2000 to 2013

3.2 Characteristics of temporal and spatial variation of NDVI in Ordos

In order to analyze the change of NDVI in the Ordos region, the average value of 14a in the growing season NDVI was obtained and the time series of annual average growing season NDVI was illustrated in Figure 3.It can be seen from the figure that, the average growing season NDVI value has a significant upward trend (R^2=0.587, P<0.05) with a rate of 0.004/a. The NDVI value increased from 0.162 in 2000 to 0.229 in 2013; the minimum value appeared in 2001, while the maximum value appeared in 2012; the average NDVI value was 0.197 and relative changing rate was 28.40%. From the statistical data of each county of vegetation changes (Table 1), we can see that the vegetation NDVI of each county has increased with different degree. Among them, the Ejin Horo's NDVI value was largest, followed by Jungar and higher than the region's average NDVI value and Hangjin's was the minimum. The linear change trend slope showed that in addition to Hangjin and Otog, other counties' NDVI slope were larger than the region's slope, and the change trend of Hangjin was largest and reached 0.0074/a. Has the characteristic of relative change rate was maximum in Jungar and minimum in Hangjin, up to 41.17% and 22.98%, respectively. In general, the vegetation growth was the best in Jungar and the worst in Hangjin over the past 14 years.

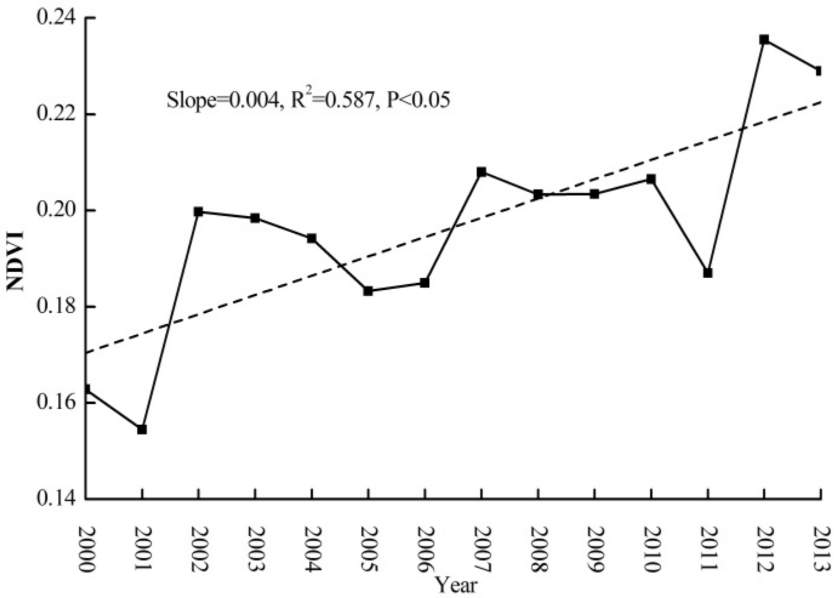

Fig. 3. Temporal variation trend of annual mean growing season NDVI in Ordos during 2000 to 2013

The spatial distribution of NDVI in Ordos was shown in Figure 4a, the NDVI value distributed between 0–0.4, mainly in 0.1–0.2, accounting for 48.6% of the total area, specifically distributed in most areas of Hangjin, Otog and Wushenqi; Followed by NDVI value in 0.2-0.3, accounting for 42.7%, the pixel distributed in Jungar, Ejin Horo, Dongsheng and Otog Front Banner; The pixel value less than 0.1 were in northern of Hangjin, where the big area distributes Kubuqi desert; larger than value 0.3 occurred in northern tip of Dalad, accounted for only 3.6% of total area. On the space, there are only 4.9% area decreased and other regions have increased, in which significantly increased area accounted or 61.1%, mainly in the eastern part of study area (Figure 4b).

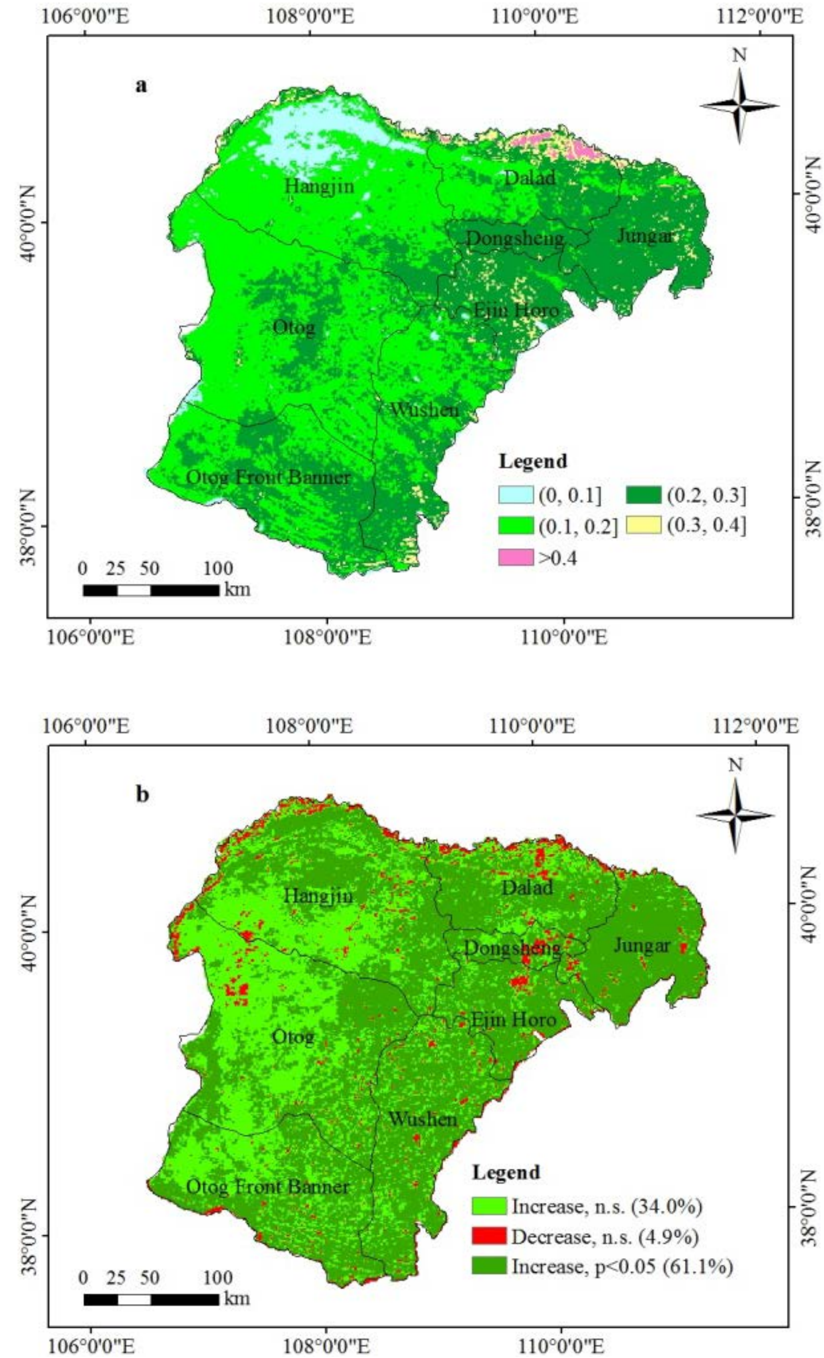

Fig. 4. Spatial distribution and significance test results for NDVI l inear trend of each pixel in Ordos during 2000 to 2013

Table 1

The average of annual growing season NDVI,
slope and the relative change rate of NDVI in Ordos

Counties	Mean NDVI	Slope	RCR
Dalad	0.229	0.0041	25.10
Dongsheng	0.240	0.0047	27.39
Otog	0.176	0.0035	27.90
Otog Front Banner	0.198	0.0041	29.04
Hangjin	0.152	0.0025	22.98
Wushen	0.206	0.0042	28.53
Ejin Horo	0.256	0.0053	28.99
Jungar	0.252	0.0074	41.17
Whole area	0.197	0.0040	28.40

3.3 Analysis of vegetation influencing factors in Ordos

3.3.1 Correlation between NDVI and climatic factors

It can be seen from the figure 2 and figure 3 that NDVI coupling relationship with precipitation and temperature, and reached the peak in 2012, respectively. Through Pearson correlation analysis, we found that NDVI has strong positive correlation with precipitation (R2=0.64, P<0.05), and has a weak positive correlation with temperature (R2=0.07). Which indicate that the vegetation growth in Ordos was mainly controlled by precipitation at the annual scale, the response of vegetation growth to precipitation was more sensitive than that of temperature. Spatial correlation analysis showed that (Figure 5), the positively correlated area between NDVI and precipitation (96.1%) was far greater than the negative correlation area (3.9%), where the significantly positive correlated area was 38.6%, mainly distributed in northern part of Hangjin, Otog, western of Otog Front Banner, Dongsheng, southern of Dalad and Jungar (Figure 5a). The correlation between NDVI and temperature also has the same phenomenon that the positive correlated area was larger than the negative correlated area, accounted for 63.4% and 36.6%, respectively; and the negative correlation area were occurred in southern of Jungar, Ejin Horo, northeast of Wushenqi and east of Otog (Figure 5b).

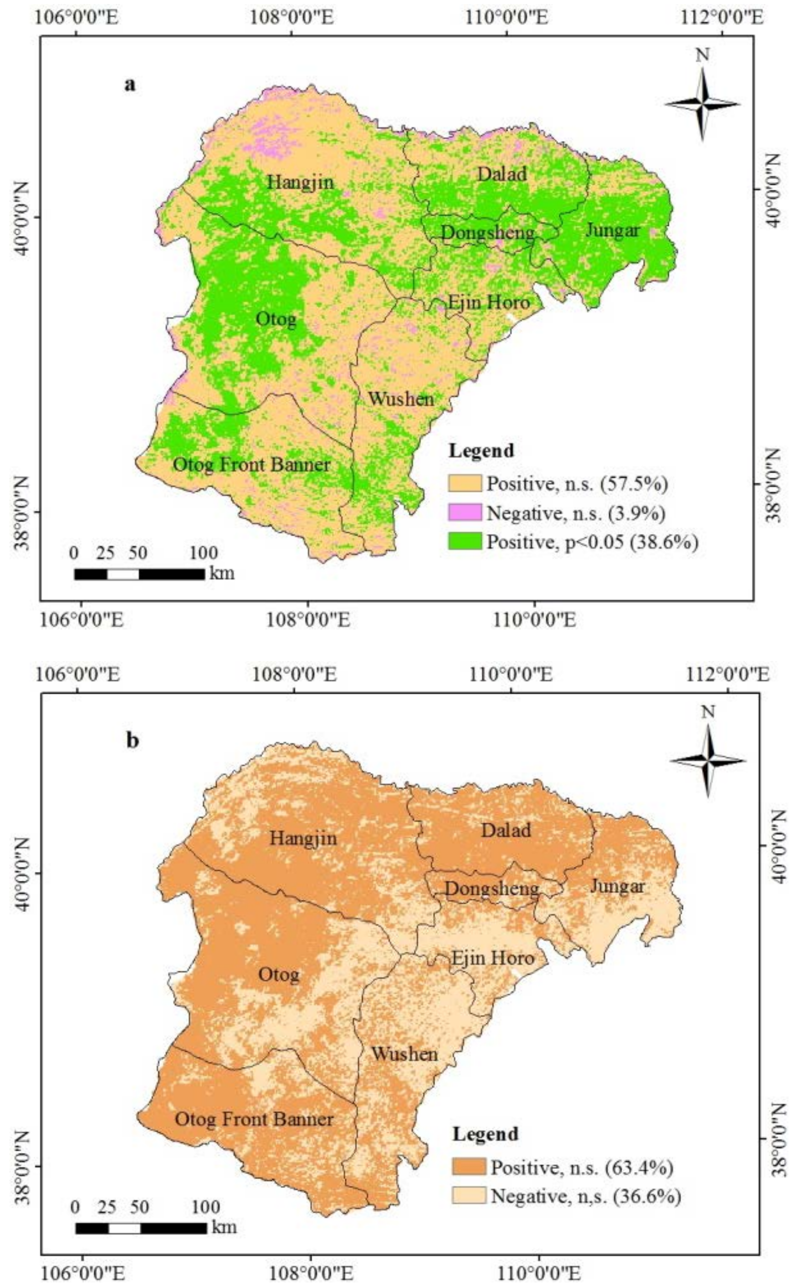

Fig. 5. Significance test results for correlation coefficient between NDVI and precipitation (a) and temperature (b) of each pixel in Ordos

3.3.2 Analysis of the relationship between the vegetation cover and human activity in Ordos

Climate change is an important factor that causes the change of vegetation cover in Ordos, but human activity is also a driving factor that cannot be ignored. The identification of human activity in the process of vegetation cover change can be realized by means of NDVI residual analysis, and quantify it. Through the regression analysis of NDVI, temperature and precipitation, we can establish a regression model of NDVI, temperature and precipitation. Set the temperature and precipitation as explanatory variables, the model can predict NDVI value by using temperature and precipitation data at each pixel, and then subtract the predicted NDVI value from the remote sensing observation NDVI [16] to obtain the residual NDVI value year by year. Then the NDVI residual series is calculated by using linear regression method. Then we can get the spatial distribution map of the variation trend of NDVI residual in Ordos, as illustrated in Figure 6.

In recent 14 years, the change of annual average temperature and annual precipitation trend in Ordos were not significant, therefore, the spatial distribution maps of change trend in residual NDVI and NDVI are generally consistent. We can see from the figure 6 that the area of increasing was larger than the decreasing in residual NDVI, which indicate that vegetation restoration was more than its destruction in Ordos over the past 14 years. The significantly increased of residual NDVI accounted for 61.5% of the total area and mainly in the typical grassland and shrub grassland area, indicating that the growth of vegetation in these areas is not only affected by climate, but also affected by human activities. Some of the relevant literatures indicate that human activities are frequent in the southeastern part of Ordos. In 2000, Dalad and Jungar have been included in the national first batch of pilot counties of returning farmland to forest, then carry out a series of measures and have significance effect on afforestation and return farmland to forest, played a positive role on recovery of grassland ecological [17–20].

The significantly decrease of residual NDVI trend accounted for 0.4% in Ordos, mainly in the northern part of study area, little in Dongsheng and Ejin Horo. It shows that the vegetation growth in these areas is lagging behind the vegetation growth status of predicted by climate. And this situation is caused by a variety of factors, such as sand storms, wind and other extreme weather events' impact on vegetation cover change; there is also has a hypothesis that human activities lead to land degradation, such as excessive grazing resulting in the deterioration of the ecological environment of grassland, land desertification and so on, led to the reduction in vegetation NDVI.

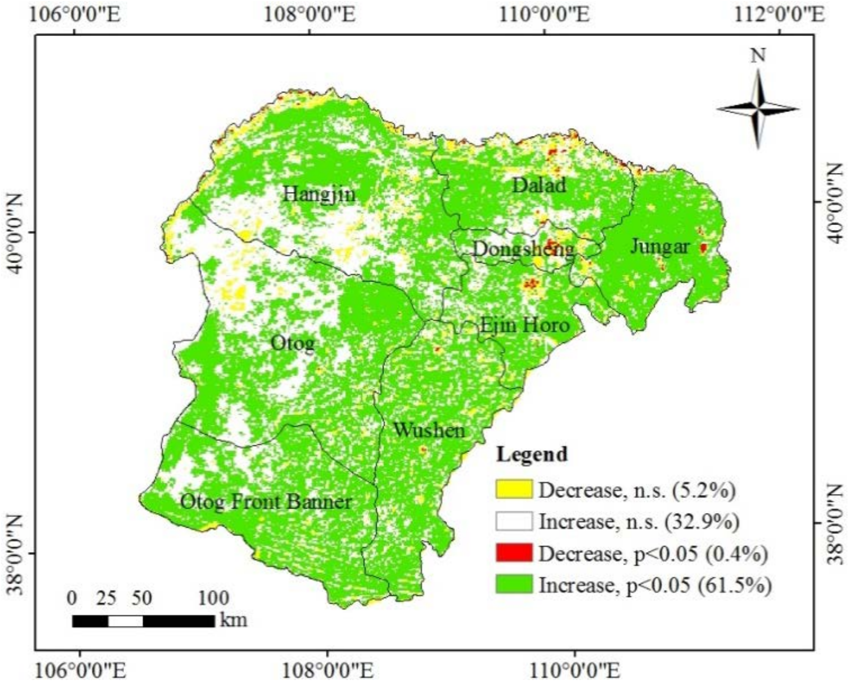

Fig. 6 Significance test results for linear trend of NDVI residual in Ordos during 2000–2013

3.3.3 Other influencing factors analysis

For a region, human activities, which make an impact on ecological environment with mutuality, continuity, bi-directional and proactivity, have complexity and uncertainty [21]. Differences of human activities are consequent on the main nature factors and differences between active mode, size and strength also. In order to prevent the emergence of negative outcomes, however, people may take some necessary measures to improve the environment, such as controlling the number of livestock, increased resource utilization, implementing ecological engineering. Due to the limitations of data acquisition, this paper discusses the grazing intensity and policy effecting on vegetation cover based on the existing information.

Livestock pressure is an important indicator represented the grazing intensity. Grazing capacity in a certain area is limited, and if grazing livestock once more than this limit there will result in different intensity of bare surface [22]. Using livestock number (large animals and sheep combined) represent the livestock pressure in this paper. The larger the livestock pressure is, the larger grazing intensity and risk of vegetation deterioration will become. As shown in Figure 7b the number of livestock shown an extremely significant upward trend ($p<0.001$) in Ordos during 2000–2013, from 550.09 million head in 2000 to 917.17 million head in 2013. At this period, NDVI has presented a fluctuating increasing trend. It was indicated, to some extent, that increasing of livestock pressure has not posed bad effects on vegetation cover. For this phenomenon, firstly, a possible reason was that the Inner Mongolia government carried out ecological construction and environmental protection in Ordos city from 2000. These measures achieved good results that afforested areas gradually increased (Figure 7a) resulting the upwards of NDVI [23].

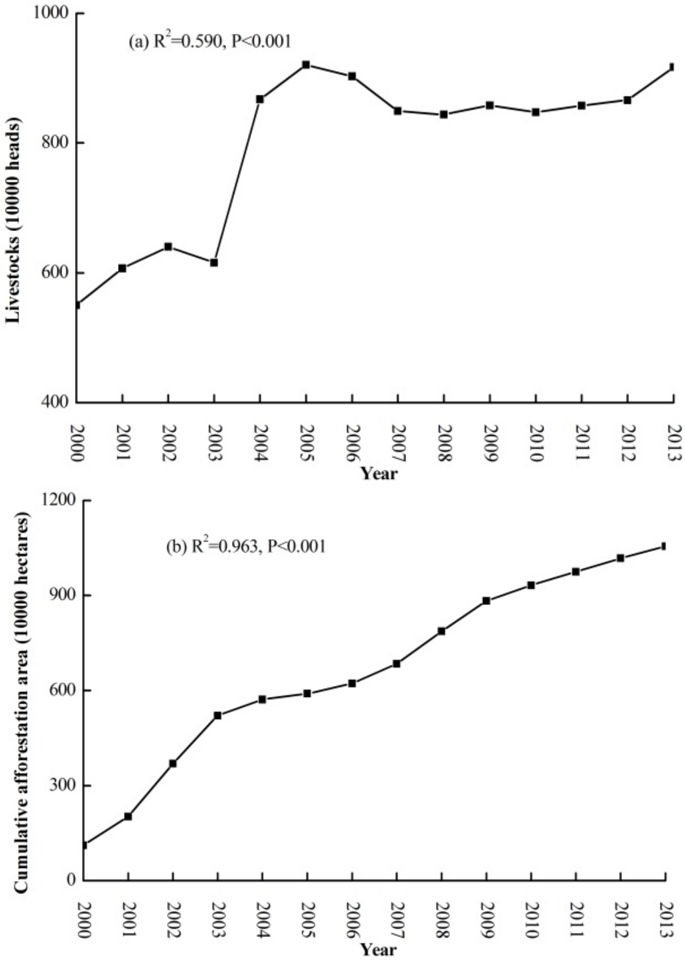

Fig. 7. Changes of cumulative afforested area and number of livestock in Ordos during 2000 to 2013

Secondly, the Inner Mongolia government had changed the way of grazing and implemented rest grazing, rotation grazing and prohibiting grazing project (three-grazing project). Also, the government introduced the strategy of feed-animal balance, based on self-healing capacity of the ecosystem to promote natural recovery of vegetation. The strategy is the inherent requirement of sustainable development in grassland animal husbandry, which is beneficial to protect the grass at returning green stage and grassland protection and restoration. At returning green stage, grassland is carrying out the policy of «rest grazing in spring», rest in 45 to 60 days; rotational grazing is carrying out in area of better grassland vegetation; and, the key is carrying out the surrounding prohibiting grazing in area where is eco-environmental fragility and distributed of grassland degradation and desertification, leading people and livestock to move so as to restore the grassland vegetation [24]. Therefore, further study will take into account that how much area will implement the three-grazing project in each county, and carry out field survey to further getting variations and driving factors of vegetation restoration in Ordos. It can provide the efficient data support for government working.

4. Conclusions and discussions

This paper constructed the annual NDVI sequences of Ordos covering 2000-2013 using the per-pixel linear regression model based on AVHRR dataset. The data were comprehensively used in the analyses of the spatial-temporal change trend of NDVI and correlation between NDVI and climatic factors. And we come to conclusions as follows:

The annual growing season NDVI has significantly increased in Ordos during 2000–2013 and the relative change rate was 28.40%; and there are 95.1% area is increased at the space and among them the significantly increased area was 61.1%, mainly distributed in eastern of Ordos. Each county have different rate of increase in NDVI, of which Jungar was maximum and Hangjin was minimum.

The NDVI was significantly positively correlated with precipitation (R^2=0.64, $P<0.05$), while slightly correlated with temperature. Which indicate that the precipitation is the main climate factor to determine the growth of vegetation in Ordos.

The area of increasing in residual NDVI was larger than the decreasing area over the past 14 years. This indicated that the positive effect of human activities on vegetation is greater than its destruction. Also shows that the relevant government policies have a good effect on vegetation restoration.

Because of the limitation of MODIS data lead to the climate factors had no significant change in a short study period, the residual NDVI and remote sensing NDVI have similar change trend in the space, but the residual analysis can accurately quantify the impact of human activity on vegetation NDVI, which will play a guiding role on the effect of human activity on region under the different climate background. The vegetation cover change is not only closely related to climate, but also have strong relation with human activity, it can be said that the vegetation cover change is the joint product of climate and human activities. According to the residual NDVI analysis, the ecological condition of Ordos is in the stage of «overall containment and partial improvement», provide a theoretical basis for construction of ecological environment and agricultural management.

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АНАЛИЗ ИЗМЕНЕНИЙ РАСТИТЕЛЬНОГО ПОКРОВА В ОРДОСЕ И ВОЗДЕЙСТВУЮЩИЕ НА НЕГО ФАКТОРЫ В XXI в.

Бао Сюйян, Бао Юхай, Тонг Сицинь

© **Бао Сюйян**
Университет Чифэна
Китай, 024000, г. Чифэн
E-mail: bxy9119@163.com

© **Бао Юхай**
доктор наук, профессор,
Педагогический университет Внутренней Монголии
Китай, 010022, г. Хух-Хото
E-mail: baoyuhai@imnu.edu.cn

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Педагогический университет Внутренней Монголии
Китай, 010022, г. Хух-Хото
E-mail: baoyuhai@imnu.edu.cn

Для изучения изменений растительного покрова и влияющих на него факторов в Ордосе в период с 2000 по 2013 г. в качестве основного источника данных мы использовали нормализованный относительный индекс растительности (NVDI), полученный дистанционным зондом MODIS, в сочетании с методами корреляционного анализа осадков и температуры. Результаты показали, что в Ордосе наблюдается значительный рост среднегодовых темпов роста NVDI за последние 14 лет, относительный коэффициент изменений возрос до 28,40%, что 61,1% общего показателя NVDI. В межгодовом масштабе осадки влияют на рост растительного покрова в Ордосе, NDVI имеет выраженную положительную корреляцию с осадками (R^2 =

0,64, P <0,05), в то время как с температурой наблюдается слабая положительная корреляция. В течение 2000–2013 гг. увеличение остаточного NDVI свидетельствовало, что усилия по озеленению в Ордосе минимизировали ущерб от разрушающей деятельности человека.
Ключевые слова: изменение растительности; корреляционный анализ; климатические факторы; деятельность человека; Ордос.