

Article

Responses of Vegetation NDVI to Climate Change and Land Use in Ordos City, North China

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Abstract: Ordos City lies in a semiarid-arid farm pastoral region in north China. In recent years, as an ecological security barrier and ecological vulnerable and sensitive region, the intensification of human activities and climate change in the foreseeable future have aroused people's attention to ecological security issues. Based on the meteorological data of MOD13Q1 and the socioeconomic activity data in the same period, the variation characteristics of annual and seasonal vegetation NDVI, the response of vegetation NDVI to climate change, and the impact of human activities on vegetation NDVI in Ordos City from 2000 to 2020 were obtained by using trend analysis, sustainability analysis, and path analysis. The results showed that: (1) Ordos City vegetation NDVI showed an obvious growth trend, except for the interannual growth rate (0.0075/a), the growth rate in autumn increased faster than in other seasons (0.0067/a); (2) the future trend of vegetation NDVI in Ordos City is mainly anti-continuous improvement. If no effective measures are taken, the vegetation NDVI will degrade in the future; (3) precipitation was the main climate factor in the vegetation growth compared with temperature. An increase in precipitation promoted vegetation growth directly, while an increase in temperature showed a negative effect by reducing precipitation in the whole growing season; (4) the utilization pattern greatly affects the spatial distribution of vegetation NDVI, and stable land use can improve the utilization of vegetation.

Keywords: vegetation NDVI; path analysis; land use; Ordos City



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1. Introduction

The terrestrial ecosystem plays a key role in climate change, and life support systems for human survival and development depend on it [1]. Due to the unrestricted exploitation and utilization, China's ecosystem shows a development tendency from structural damage to functional disorder [2], especially the vulnerable ecosystem in arid and semi-arid areas. The terrestrial vegetation, the primary producer in the ecosystem, refers to a vitally essential component of the terrestrial ecosystem [3]. Change in vegetation is sensitive to climate change and human activities as an indicator [3,4]. It is of great ecological significance to study the impacts of climate change and human activities on terrestrial ecosystems through vegetation [5].

Precipitation and temperature act as critical factors in controlling vegetation growth [6,7]. The growth period of vegetation and the composition and morphology of vegetation itself will be affected by climate change [8–10]. Studies have shown that the driving factors of climate on vegetation have gradually shifted to precipitation and temperature [11,12]. Therefore, precipitation and temperature, as the two most direct and significant factors, are usually selected to study the influence of climate factors on vegetation change [13]. Shang et al. [14] showed that precipitation and temperature were the main factors affecting NDVI changes in northwest China. Wang et al. [15] showed that precipitation had a more obvious effect on vegetation growth in arid areas of northwest China, and the influence of precipitation on grassland was much greater than that on the forest. Li et al. [16] showed that under the influence of climate change, vegetation in the Loess Plateau, North China

Plain, Qinghai, Inner Mongolia, and Liaoning border areas became green. Precipitation and temperature promoted vegetation growth, while wind speed inhibited it.

In addition, the change of vegetation is also affected by human activities [17]. Human activities often show duality to vegetation growth, with vegetation changes more obvious in areas where human activities are more frequent and to a lesser extent in uninhabited areas and areas where human activities are less frequent [18]. The urban vegetation cover is often negatively affected by urbanization to a certain extent [19], but major ecological engineering projects will make vegetation cover develop in a positive direction [20]. Land use change is also often used as a means to examine the impact of human activities on vegetation change [21], and the impact trends of different land use situations on vegetation are different [22]. Land use change can have a positive effect through afforestation and grass planting [23] or negative effects through unsustainable agricultural practices and expansion of built-up areas [24]. Wang et al. [25] found that the land use change induced by afforestation was the main factor in vegetation dynamics in semi-arid areas of northern China. Liu et al. [26] studied the influence of human activities on vegetation in the Qinba Mountains through the change of afforestation area, and the results showed that land use change was an important factor leading to NDVI changes.

Ordos City lies in a semiarid-arid farm pastoral region in north China. As an ecological security barrier and ecological vulnerable and sensitive region, desertification, induced by overgrazing, reclamation, mining, climatic change, and so on, has been a serious problem. In the past several decades, many ecological conservation and restoration programs have been put into effect [12]. Revealing the change of vegetation and terrestrial ecosystem further, and recognizing the attribution of influencing factors, including climate factors and human activities, are of great consequences to assessing the effect of the ecological programs. As one of the best indicators of vegetation growth state and coverage, the time series normalized difference vegetation index (NDVI), derived from remote sensing images, is widely applied in vegetation change monitoring in arid areas [27,28]. So, in this context, the vegetation dynamic in the period from 2000 to 2020 and the role of climate change, especially precipitation and temperature, and human activities, especially land use change, in the vegetation dynamics were analyzed and revealed based on remote sensing data NDVI, meteorological data, and land use/coverage change data.

2. Research Methods

2.1. Overview of the Study Area

Ordos City is located in the Ordos Plateau, north China, between 37°35'24" N~40°51'40" N, 106°42'40" E~111°27'20" E (Figure 1). It is located in the hinterland of the Yellow River bay, surrounded by the Yellow River in the west, north, and east. The area of Ordos City is 86,752 km², with a 400 km length from west to east and a 340 km width from north to south. The terrain is uneven with high northwest and low southeast and has an elevation from 1000 m to 1500 m. The area is dominated by a semi-arid continental climate, with a multi-year average precipitation of 295.3 mm, and evaporation of 2506.3 mm. The precipitation mainly occurs from July to September and diminishes from southeast to northwest. There are big seasonal temperature differences. The mean temperature is 21 °C in summer, while the mean temperature is −6.6 °C in winter.

The grassland area accounts for more than 60% of the territory. From east to west, the vegetation zone is typical grassland dominated by *Stipa binata* and *thymus mongolicus* communities, desertification grassland dominated by short-flowered needlegrass, narrow-leaved brome-short-flowered needlegrass scrub, Tibetan brome scrub and other communities, and grassland desertification zones based on red sand shrubs, *tetraena-pearl* shrubs, *hemiday* flower community, and *ammopiathanthus*—king scrubs, respectively [29].

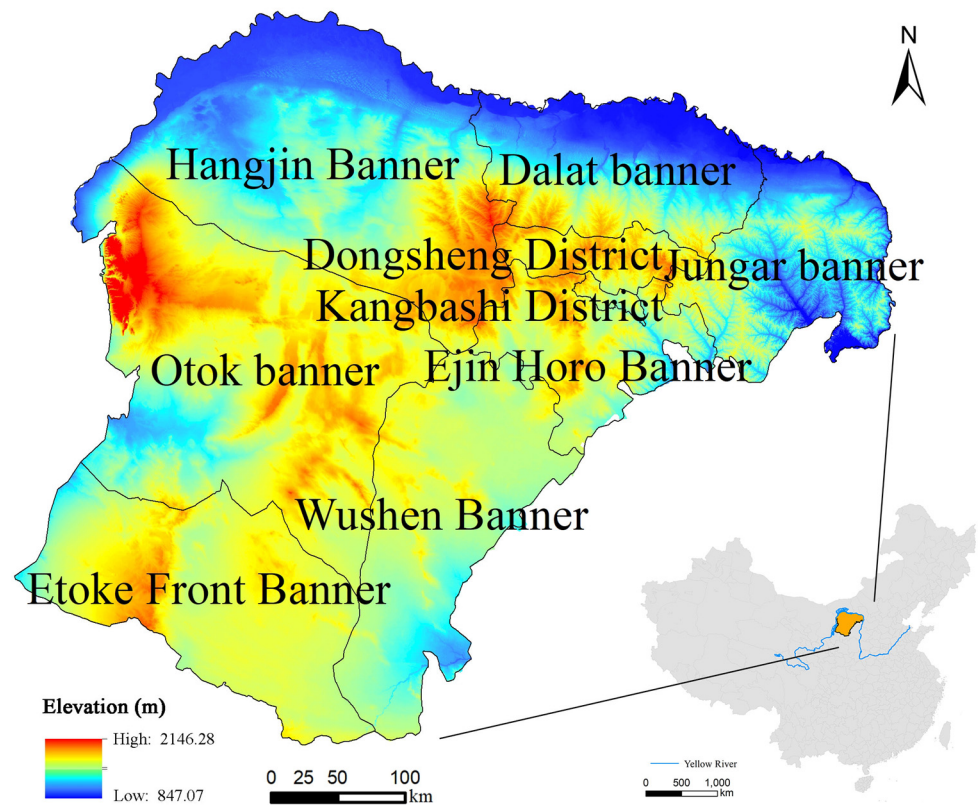


Figure 1. Geographical location of Ordos City.

2.2. Data Sources and Processing

The precipitation and temperature data were obtained from the “China Surface Climate Data Diurnal Data Set (V3.0)” of the China Meteorological Data Sharing Network (<http://data.cma.cn/>, accessed on 20 May 2022). The precipitation and temperature data of 17 weather stations in Ordos City and its surrounding areas were selected, and the raster data with the same resolution as NDVI was obtained by the Kriging interpolation method. MOD13Q1 NDVI data were obtained from NASA’s official website network (<https://ladsweb.modaps.eosdis.nasa.gov/>, accessed on 20 May 2022). Its spatial resolution is 250 m. The MRT tool was used to splice the images and convert the projection (equal area projection). The annual NDVI data set was synthesized by the maximum synthesis method. Land use data were obtained from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn/>, accessed on 20 May 2022).

3. Data Analysis

(1) Trend Analysis

Trend analysis takes each pixel as the research unit. Analyzing the pixel changes in different periods reflects the vegetation dynamics of the whole study area under a certain time series [30], which can eliminate the influence of abnormal factors so as to more accurately reflect the trend of vegetation evolution.

$$Slope = \frac{n \times \sum_{k=1}^n k \times x_k - \sum_{k=1}^n k \times \sum_{k=1}^n x_k}{n \times \sum_{k=1}^n k^2 - (\sum_{k=1}^n k)^2} \quad (1)$$

where *Slope* is the changing trend of NDVI; *n* is the length of time series, which is 21 in this study; x_k is the *k*-year NDVI value, $k = 1, 2, 3 \dots 21$; when *Slope* is positive, it indicates that the vegetation index increases with time; otherwise, it shows a degradation trend. The significance test was carried out by using the *F* test method, and the *p*-value was taken as 0.01 and 0.05.

(2) Sustainability Analysis

The Hurst index, based on (R/S) analysis, can predict the future development trend by judging the dependence of time series [4,31,32]. The principle is as follows:

Define the NDVI of time series within the research years as $x(i)$ ($i = 1, 2, \dots, 19$) for any number of years t , then:

The mean value is:

$$\bar{x}(i) = \frac{\sum_{i=1}^t x_i}{t}, t = 1, 2, 3 \dots, 19 \tag{2}$$

The cumulative deviation is:

$$X(i, t) = \sum_{u=1}^i (x(u) - \bar{x}(i)), 1 \leq i \leq t \tag{3}$$

The extreme difference is defined as:

$$R(t) = \max_{1 \leq t \leq i} X(i, t) - \min_{1 \leq t \leq i} X(i, t) \tag{4}$$

The standard deviation is:

$$S(t) = \left[\left(\frac{\sum_{i=1}^t (x(i) - \bar{x}(t))^2}{t} \right)^{\frac{1}{2}} \right], t = 1, 2, 3 \dots, 19 \tag{5}$$

Taking $\ln(t/2)$ as the horizontal axis and $\ln(R(t)/S(t))$ as the vertical axis, a double logarithmic coordinate system was built. The data of 19 points were linearly fitted by the least square method, and the slope obtained was the Hurst index (H).

$$\ln \frac{R(t)}{S(t)} = H \cdot \ln \frac{t}{2} + \ln C, t = 1, 2, 3 \dots, 19 \tag{6}$$

The Hurst index has the characteristic that the change trend of the future is similar to that of the past when the index value is greater than 0.5, and the change trend is contrary to the past when the index value is between 0 and 0.5 (Table 1). Therefore, the Hurst index was used to forecast and analyze the future change of the vegetation NDVI in Ordos City.

Table 1. Hurst variation characteristics based on trend analysis.

Hurst	Trends	Results of Future Change	Meaning
>0.5	>0	Continuous Improvement	Future changes are the same as in the past, showing an increasing trend
<0.5	>0	Anti-Continuous Improvement	Future changes are contrary to the past, showing a downward trend
>0.5	<0	Continuous Degradation	Future changes are the same as in the past, showing a downward trend
<0.5	<0	Anti-Continuous Degradation	Future changes are contrary to the past, showing an increasing trend
=0.5	<0 or >0	Random Variation	Change trends of the future are not obvious

(3) Path Analysis

Path analysis is a multivariate statistical technique to study the direct and indirect relationship between independent variables and dependent variables through the decomposition of the surface direct correlation between independent variables and dependent variables [33]. The principle is as follows:

If the correlation coefficient between independent variables and independent variables is $r_{x_i x_j}$, the correlation coefficient between independent variables and dependent variables is $R_{x_n y}$

$$\begin{bmatrix} 1 & r_{x_1 x_1} & \cdots & r_{x_n x_n} \\ r_{x_2 x_1} & 1 & \cdots & r_{x_2 x_n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{x_n x_1} & r_{x_n x_2} & \cdots & 1 \end{bmatrix} \begin{bmatrix} A_{1y} \\ A_{2y} \\ \vdots \\ A_{ny} \end{bmatrix} = \begin{bmatrix} R_{x_1 y} \\ R_{x_2 y} \\ \vdots \\ R_{x_n y} \end{bmatrix} \tag{7}$$

The path coefficient A_{ny} can be solved by a matrix, which reflects the direct effect of independent variable x_n on dependent variable y , $r_{x_n x_j y} A_{jy}$ is the indirect path coefficient, reflecting the indirect effect of the independent variable x_n on the dependent variable y through the independent variable x_j .

4. Analysis of Results

4.1. Vegetation NDVI Trend Analysis

The interannual variation trend of vegetation NDVI in Ordos City is shown in Figure 2, which is obtained by the trend analysis method. Vegetation NDVI shows an overall improvement trend (97.97% of the region shows a positive trend), but there are significant spatial differences. The average NDVI of Ordos City over 21 years is 0.324, with an average annual increase rate of 0.0075/a. The area of extremely significant improvement account for a large proportion, about 51.92% (Table 2), and it is distributed in all banners, among which the proportion of area with extremely significant improvement is larger in Ejin Horo Banner, Dongsheng District, Kangbashi District, and Jungar Banner in the east, especially in Ejin Horo Banner and Jungar Banner. The area with a significant increase account for about 16.74%, mainly distributed in the central and western parts of Erdo City. The area with no obvious change is 31.02%, mainly distributed in Hangjin Banner, Otok Banner, and Etoke Front Banner. The area of significant degradation and extremely significant degradation is relatively small, accounting for 0.13% and 0.19% of the total area, respectively, mainly distributed in the urban area of Ordos City and the northern Yellow River.

Table 2. Variation trend and significance of vegetation NDVI in Ordos City.

Trends	Annual	Spring	Summer	Autumn
Extremely significant improvement	51.92	52.94	39.16	58.94
Significant improvement	16.74	16.56	15.02	17.78
No significant change	31.02	30.34	45.47	23.21
Significant degradation	0.13	0.10	0.16	0.04
Extremely significant degradation	0.19	0.06	0.19	0.03

In order to further analyze the vegetation change in Ordos City, the trend analysis of vegetation NDVI in spring, summer, and autumn for 21 years was carried out separately. In spring, the mean value of vegetation NDVI in Ordos City is 0.182, and the average annual increase rate is 0.0041/a, the slope of vegetation NDVI in 97.46% of Ordos City (Figure 2b) is positive, and 52.94% of the area is extremely significantly improved. It mainly appears in Jungar Banner, Dalat Banner, Dongsheng District, Kangbashi District, Ejin Horo Banner, and other areas; the area of significantly improved area is 16.56%, which is widely distributed and scattered throughout the region; the area of significant degradation and highly significant degradation are 0.1% and 0.06%, respectively, which are mainly found along the Yellow River and some areas in the north of Dalat Banner.

In summer, the mean value of vegetation NDVI in Ordos City is 0.319, with a small difference from the interannual mean value, the average annual increase rate is 0.0063/a, and the slope of vegetation NDVI in 94.52% of Ordos City (Figure 2c) is positive, the area where the improving trend is greater than 0.02 is much larger than that in spring. A total of 39.16% of the area is extremely significantly improved, mainly concentrated in the east of Ordos City; the area of significantly improved area is 15.02%, which is more concentrated in Wushen Banner, Dalat Banner, and Etoke Front Banner; the percentage of significant degradation and highly significant degradation is 0.16% and 0.19%, respectively.

In autumn, the mean value of vegetation NDVI in Ordos City is 0.254, which is greater than it in spring but less than the value of summer, and it is consistent with the characteristics that vegetation starts to grow in spring, grows in summer, and gradually dies in autumn. The average annual increase rate is 0.0067/a, the slope of vegetation NDVI in 98.47% of Ordos City (Figure 2d) is positive, the area where the improving trend

is greater than 0.02 is larger than spring but smaller than summer, 58.94% of the area is extremely significantly improved, the area occupied by areas with significant improvement is 17.78%, and the area occupied by areas with significant degradation and very significant degradation is at least 0.04% and 0.03%, respectively.

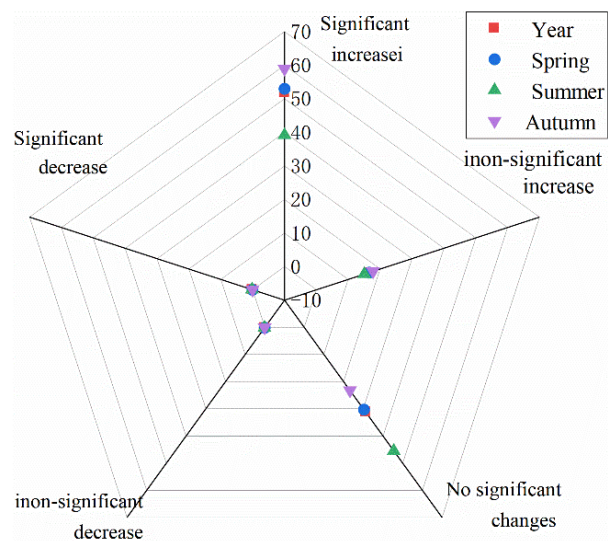
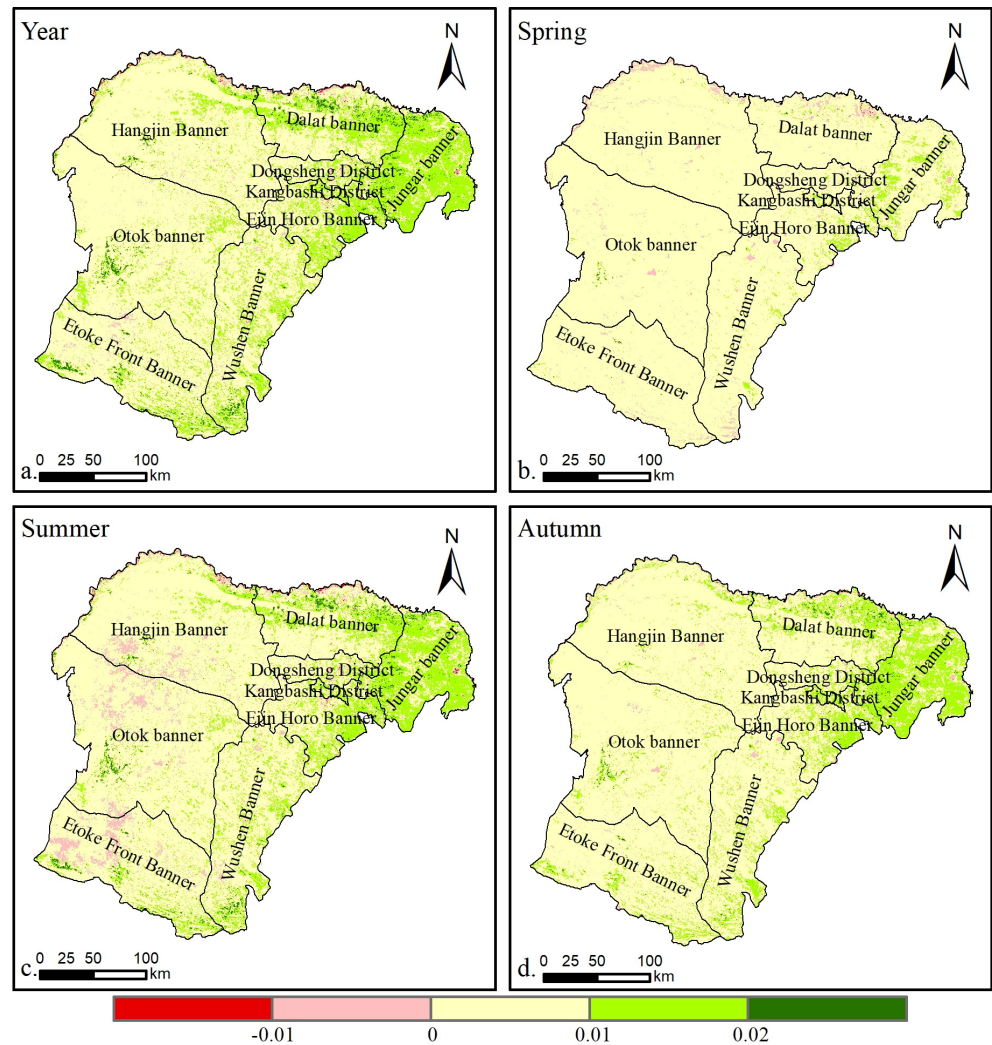


Figure 2. Variation trend and significance of vegetation NDVI in Ordos City.

The comparative analysis of the interannual seasons shows that the interannual growth trend is larger, followed by autumn and the least in spring. The areas with a more obvious growth trend are mainly located in the eastern part of Ordos City, and the proportion of extremely significant growth in autumn is the largest.

4.2. Spatial Persistence Analysis of Vegetation NDVI

The Hurst value of 80.94% of the area in Ordos City is in a range of 0.3–0.5 (Figure 3), and the mean value of the index is 0.43, showing an opposite development trend from the past, the area in which the index is greater than 0.5 are mainly distributed in the northern part of Ordos City as well as the eastern and southeastern areas. Combined with trend analysis, the Hurst index is classified in Table 1. The results show that only 0.03% of the vegetation in Ordos City shows random changes in the future and is spatially scattered; 1.65% of the vegetation in the area shows anti-continuous degradation, mainly distributed in the north along the Yellow River, Dongsheng District, Kangbashi District, Etoke Front Banner, and parts of the southern part of Hangjin Banner and northern part of Etoke Banner; the area with continuous degradation only accounts for 0.45%, mainly distributed in Dalat Banner and parts of northern Hangjin, and scattered in Ejin Horo Banner; in the future, it is worth noting that the area with anti-continuous improvement accounts for the larger partition, about 82.88%, and it is almost distributed in all Ordos City; the area with continuous improvement accounts for 14.99%, scattered in the whole city, mainly in the eastern region.

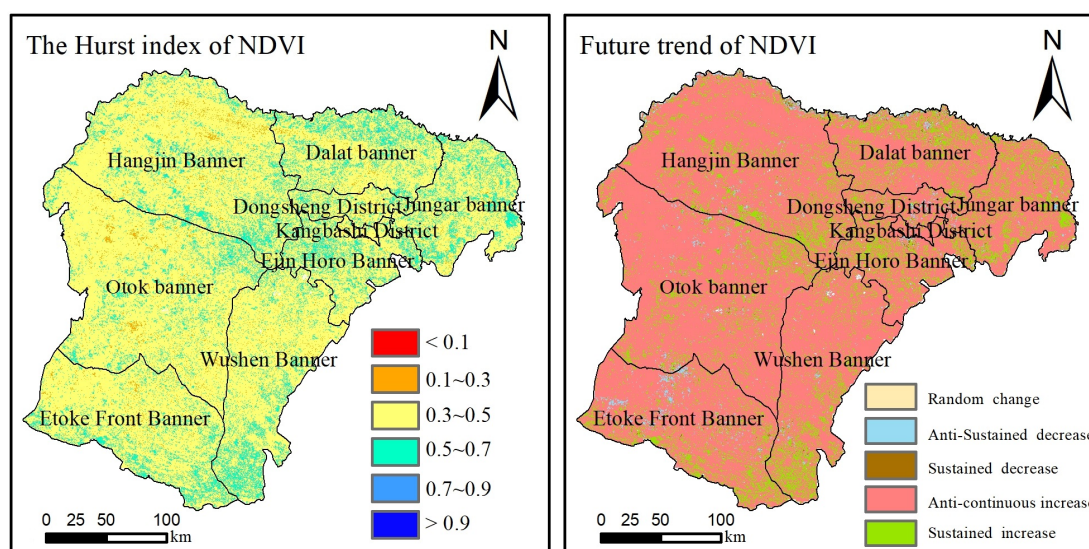


Figure 3. Spatial distribution and future evolution trend of vegetation NDVI Hurst index in Ordos City.

In order to further analyze the future vegetation NDVI in Ordos City, three seasons of spring, summer and autumn were analyzed, respectively, as shown in Figure 4. The average Hurst index value is 0.41 in spring, 0.42 in summer, and 0.43 in autumn. The anti-continuous improvement phenomenon accounts for 88.94% in spring, 79.14% in summer, and 82.84% in autumn, the future change of each season is dominated by the anti-continuous improvement phenomenon. Among the three seasons of spring, summer, and autumn, the relative proportion of stochastic changes that occurred in spring is greater than that in summer and autumn; the relative proportion of anti-continuous degradation phenomenon occurred in summer is greater than that in spring and autumn, the relative proportion of continuous degradation phenomenon occurred in summer is also greater than that in other two seasons; the relative proportion of continuous improvement phenomenon occurred in spring is lower than that in other two seasons. Compared with the interannual data,

the proportion of areas where continuous improvement occurred in spring and autumn is larger.

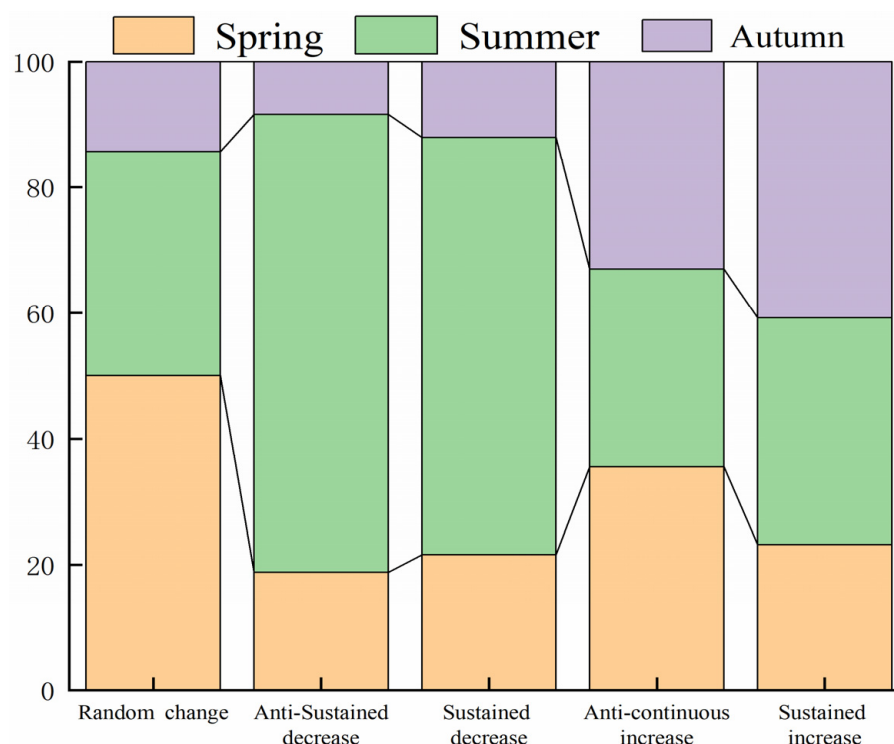


Figure 4. Proportion of future variation trend of vegetation NDVI in different seasons.

4.3. Climate Effects on Interannual Vegetation NDVI

In order to analyze the influence of climatic factors on vegetation NDVI, path analysis was introduced to analyze the interrelationship between precipitation, temperature, and vegetation NDVI. Figure 5 shows the spatial distribution of the influence of precipitation and temperature on the vegetation NDVI, including direct effect, indirect effect, and comprehensive effect. Direct effect means the direct influence on vegetation growth of precipitation or temperature change. The indirect effect was used to indicate the indirect influence on vegetation growth of precipitation change deduced from temperature variation or temperature change deduced from precipitation variation. Because the increase in precipitation can turn down the temperature, and the increase in temperature will reduce precipitation. In contrast, comprehensive effect equals the grand sum between the direct and indirect effect of precipitation or temperature change, respectively.

The increase in precipitation showed a positive effect on vegetation growth in the northern part of Hangjin Banner, the western part of Etoke Banner, and the western part of Etoke Front Banner (shown in Figure 5a), which covers 78.83% of the whole city. The mean direct influence of precipitation is 0.542 (shown in Table 3) in the whole city, which indicates that an increase in precipitation promoted the growth of vegetation directly. The increase in temperature showed an active influence on the growth of vegetation in Dongsheng District, Kangbashi District, and other eastern parts (shown in Figure 5b), which covers 35.46% of the whole city. The mean direct effect of temperature on vegetation NDVI is -0.043 (shown in Table 3) in the whole city, which indicates that the increase in temperature has no direct effect on vegetation growth.

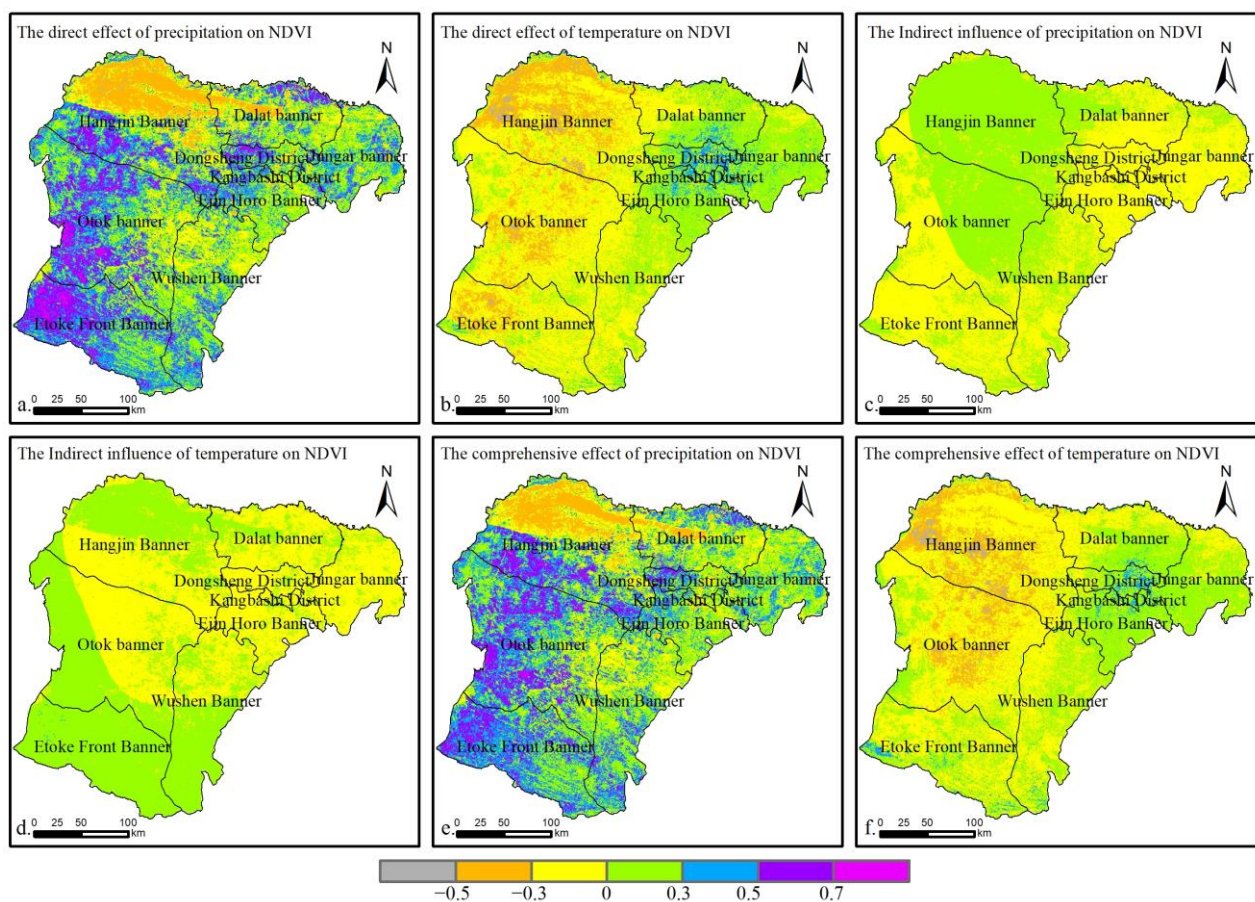


Figure 5. Spatial distribution of effects of precipitation and air temperature on vegetation NDVI.

Table 3. Influence of multi-year mean climate on vegetation NDVI.

Climate Factors	Direct Effect	Indirect Effect	Comprehensive Effect
Precipitation	0.542	0.014	0.556
Temperatures	−0.043	−0.158	−0.205

Because the increase in precipitation will reduce the temperature, thus precipitation has an indirect effect on vegetation growth. The indirect effect of precipitation on vegetation NDVI is 0.014 (shown in Table 3), which could be ignored (shown in Figure 5c). In contrast, the increase could reduce the precipitation; thus, temperature also has an indirect effect on vegetation growth. The indirect effect of temperature on vegetation NDVI is -0.158 (shown in Table 3), which indicates that the increase in temperature inhibited vegetation growth by reducing the precipitation. The indirect effect, mainly distributed in the central part of Hangjin Banner, most of the former banner of Etoke Banner, the western part of Etoke Banner, and the southern part of the Wushen Banner (shown in Figure 5d), is larger than the direct effect.

The comprehensive effect of precipitation on vegetation NDVI is 0.556 (shown in Table 3), which showed that precipitation promoted the growth of vegetation. In contrast, the comprehensive effect of temperature on vegetation NDVI is −0.205 (shown in Table 3), which indicates that temperature increase had an inhibitory effect on the growth of vegetation.

In spring, the direct effect of precipitation and temperature on vegetation NDVI are both positive, which means both temperature increase and precipitation increase could promote vegetation growth. The direct effect of precipitation on vegetation NDVI is 0.645, while the direct effect of temperature on vegetation NDVI is 0.184 (shown in Figure 6).

It could be considered that the direct promotion effect of precipitation on vegetation growth is greater than temperature. The indirect effect of precipitation on vegetation is -0.119 ; thus, the increase in precipitation inhibited the growth of vegetation by reducing the temperature in spring. The indirect effect of temperature on vegetation is -0.419 , indicating that the increase in temperature inhibited the growth of vegetation by reducing precipitation. Moreover, the indirect negative effect caused by the increase in temperature is greater than the direct promotion effect of temperature increase. The comprehensive effect of precipitation on vegetation NDVI is 0.526 , meaning positive promotion. The comprehensive effect of temperature on vegetation NDVI is -0.235 , which indicates that warming was unfavorable to vegetation growth in spring. It is concluded that the effect of precipitation on vegetation growth in Ordos City was greater than temperature, and precipitation was the key factor affecting vegetation growth in spring.

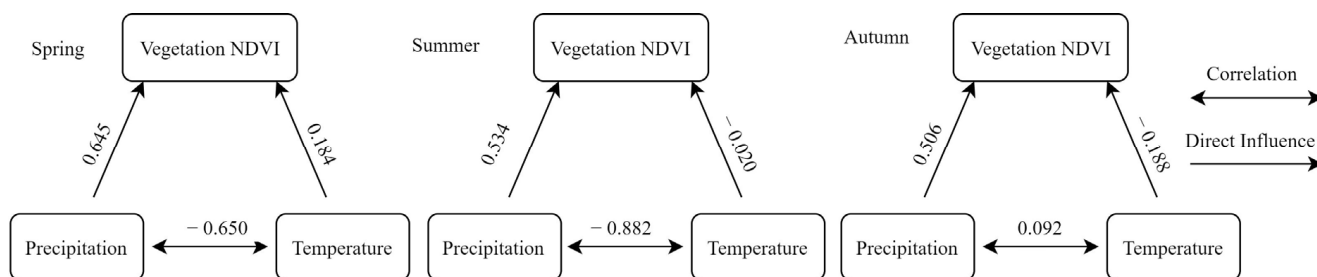


Figure 6. Path analysis of the effects of precipitation and temperature on vegetation NDVI.

In summer, the direct effect of precipitation on vegetation NDVI is 0.534 (shown in Figure 6), which indicates that the increase in precipitation promoted vegetation growth. The direct effect of temperature on vegetation NDVI is -0.020 , which was basically negligible. The indirect effect of precipitation on vegetation is 0.018 ; thus, precipitation promotes the growth of vegetation by reducing the high temperature. The indirect effect of temperature is -0.471 , which indicates that temperature inhibits the growth of vegetation by reducing precipitation in summer. The comprehensive effect of precipitation on vegetation NDVI is 0.552 , which means positive promotion. The comprehensive effect of temperature on vegetation NDVI is -0.471 , which indicates that the increase in temperature inhibited vegetation growth. It is concluded that the effect of precipitation on vegetation growth in Ordos City was greater than temperature, and precipitation was the key factor affecting vegetation growth in summer.

In autumn, the direct effect of precipitation on vegetation NDVI is 0.506 (shown in Figure 6), which indicates that the increase in precipitation promoted vegetation growth. The direct effect of temperature on vegetation NDVI is -0.188 , meaning an increase in temperature inhibited vegetation growth. The indirect effect of precipitation and temperature on vegetation NDVI are -0.017 and 0.046 , which are basically negligible. The comprehensive effect of precipitation on vegetation NDVI is 0.489 , which showed a positive promotion effect. The comprehensive effect of temperature on vegetation NDVI is -0.142 , which indicates that the increase in temperature inhibited vegetation growth. It is concluded that the effect of precipitation on vegetation growth in Ordos City in autumn was greater than temperature, and precipitation was the key factor affecting vegetation growth.

Generally, precipitation was the main climate factor in the vegetation growth compared with the temperature in Ordos City. The increase in precipitation promoted vegetation growth directly, while an increase in temperature showed a negative effect by reducing precipitation in the whole growing season. However, there were seasonal differences in the inhibition influence of temperature increase. In spring and summer, the indirect effect of temperature increase leads to the inhibition influence. The direct effect of temperature increase induced the inhibition influence in autumn.

4.4. Impact of Land Use Change on Vegetation NDVI

Based on the map of land use change in Ordos City and combined with the five image types (extremely significant degradation, significant degradation, no obvious change, significant improvement, and extremely significant improvement), the significance test of the NDVI trend of vegetation from 2000 to 2020, the land use types corresponding to the significance of different trends of change are derived. Combined with Table 4, it can be seen that the conversion of some grassland to grassland and the conversion of cultivated land to cultivated land are important reasons for the extremely obvious degradation trend of NDVI. The conversion of grassland mainly occurs in the central part of Etoke Banner and the northern part of Dalat Banner. The conversion of partly cultivated land to cultivated land and the conversion of grassland to grassland are important reasons for the significant improvement; the conversion of cultivated land mainly occurs in the eastern part of Ordos City, and the conversion of grassland mainly occurs in Etoke Front Banner and Etoke Banner. The conversion of partly grassland to grassland and the conversion of unutilized land to unutilized land are important reasons for the extremely significant improvement. The improvement of vegetation NDVI (significant improvement, very significant improvement) mainly occurs in the areas where the land use types, such as grassland and unutilized land, are basically unchanged, and the improvement of vegetation NDVI tends to occur in the areas where the land use is not changed.

Table 4. Land use types and proportions corresponding to the significance of different trends. A: Extremely significant degradation; B: Significant degradation; C: No significant change; D: Significant improvement; E: Extremely significant improvement.

		2020									
Projects		Cultivated Land					Woodland				
		A	B	C	D	E	A	B	C	D	E
2000	Cultivatedland	0.028	0.025	1.343	0.566	2.483	0.002	0.002	0.051	0.021	0.057
	Woodland	0.000	0.000	0.009	0.004	0.019	0.002	0.002	0.380	0.182	0.991
	Grassland	0.001	0.001	0.070	0.051	0.332	0.001	0.001	0.126	0.058	0.291
	Waters	0.002	0.001	0.011	0.005	0.019	0.000	0.000	0.004	0.002	0.017
	ConstructionLand	0.000	0.000	0.007	0.002	0.007	0.000	0.000	0.001	0.000	0.001
	Unutilizedland	0.000	0.000	0.013	0.008	0.036	0.000	0.000	0.061	0.053	0.183
		2020									
Projects		Grassland					Waters				
		A	B	C	D	E	A	B	C	D	E
2000	Cultivatedland	0.001	0.001	0.064	0.037	0.202	0.013	0.005	0.023	0.005	0.014
	Woodland	0.001	0.000	0.029	0.025	0.158	0.003	0.001	0.004	0.001	0.004
	Grassland	0.041	0.023	16.895	9.906	30.685	0.008	0.003	0.037	0.015	0.051
	Waters	0.000	0.003	0.057	0.023	0.068	0.103	0.017	0.588	0.274	0.946
	ConstructionLand	0.000	0.000	0.006	0.003	0.017	0.000	0.000	0.001	0.000	0.001
	Unutilizedland	0.000	0.002	0.240	0.242	0.860	0.019	0.003	0.044	0.010	0.020
		2020									
Projects		Construction Land					Unutilized Land				
		A	B	C	D	E	A	B	C	D	E
2000	Cultivated land	0.003	0.004	0.081	0.015	0.035	0.000	0.001	0.013	0.006	0.022
	Woodland	0.001	0.001	0.031	0.007	0.029	0.000	0.000	0.024	0.003	0.016
	Grassland	0.004	0.007	0.368	0.104	0.326	0.001	0.001	0.430	0.337	1.023
	Waters	0.000	0.000	0.006	0.004	0.020	0.006	0.001	0.070	0.016	0.032
	Construction land	0.005	0.004	0.302	0.123	0.436	0.000	0.000	0.002	0.001	0.004
	Unutilized land	0.000	0.000	0.093	0.024	0.085	0.022	0.008	9.039	4.627	12.478

5. Discussion

The vegetation NDVI of Ordos City has changed significantly in the past 21 years, and the increase in NDVI of vegetation in both interannual and seasonal seasons is inseparable from the national project of returning farmland to forest and grass. According to the relevant data, in recent years, the sand desertification land and desertification land area in Ordos City continued to decrease, and the control rates of Kubuqi Desert and Mu Us sand reached 25% and 70%, respectively. The Kubuqi Desert basically tends to be stable, and the sand damage in Mu Us sandy land basically disappeared. Xie [34] analyzed the vegetation cover of the Loess Plateau in the past 30 years based on the LTDR NDVI and concluded that the change trend of vegetation NDVI was relatively larger in summer and autumn and the smallest in spring. This is basically similar to the conclusion of this paper, but there is a significant difference between the growth trend in summer and autumn, which may be related to the difference between the study area and the data set. In summer and autumn in Ordos City, the change of vegetation NDVI may be related to the implementation of rotational grazing in recent years and the local climate environment. In spring, because the vegetation has just entered the growth period, the NDVI value of the vegetation is low, so the growth trend is not obvious. The analysis of future trends shows that the vegetation NDVI in Ordos City will be mostly in a state of anti-continuous improvement in the future. This is basically similar to the conclusion of Sun et al. [35] that the vegetation NDVI changes in the Loess Plateau from 2000 to 2016 show an increasing trend of anti-continuous improvement, which is mainly distributed in southwestern Inner Mongolia and other regions. Most of the land use in Ordos City is dominated by grassland. Although the growth trend of grassland has been improving in recent years, it is generally believed that the interference of factors is large; due to the poor ecological environment, grassland sensitivity is strong. In addition, Ordos City has vigorously developed forestry relying on the national Three-North Shelterbelt Project in recent years, but Ordos City is in the transition zone between semi-arid and drought, which is not suitable for large-scale implementation of forestry development. Taking the afforestation field in Ordos City as an example, the ratio of pure forest to mixed forest is 9:1. In the forest farm, *Salix psammophila*, *Caragana korshinskii*, and other shrub forests accounted for more than 60%. Most of the arbor forests are poplars, which have a simple stand structure, dilapidated forest phase, and low protection capacity.

The path analysis between vegetation and climate factors showed that precipitation was the main factor, and an increase in precipitation basically promoted the growth of vegetation, while the increase in temperature inhibited the growth of vegetation in Ordos City. The effect of precipitation increase on vegetation growth is the response of water shortage climate conditions with extremely insufficient annual precipitation and very high potential evapotranspiration. An increase in temperature showed a negative effect on vegetation. In spring, vegetation was in the early growing season. With a small amount of precipitation and low temperature, there was a mutual negative interaction between precipitation and temperature. This had a negative indirect effect on vegetation growth. In summer, quick increases and high temperature showed negative effects on vegetation growth for the reason that high temperature enhanced the potential evapotranspiration and reduced soil water content. In autumn, an increase in temperature accelerated the wilting of vegetation in the late growing season. Research on the desertification of the Ordos Plateau showed similar results that the greening mainly depended on the increase in precipitation [36]. Ma Q M et al. also figured out that precipitation played a leading role compared with temperature [37]. Zhao, M. S., et al. [38] showed that high temperature could inhibit vegetation growth. When sunshine hours are 835.79~1106.16 h and the temperatures are 6.24~14.07 °C, the vegetation will grow well in the Loess Plateau [39]. The sunshine hours are 2700~3000 h in Ordos City. Heat increase based on lengthy sunshine may be the reason for the negative effect of temperature increase.

The analysis of the effect of land use change on vegetation NDVI shows that the improvement of vegetation NDVI tends to occur more in the areas where land use has

not changed, and the proportion of the conversion type of grassland to grassland is much larger than in other types. The reason for this is that Ordos City has protected the development of grassland well through various means, such as perfecting the system (grassland household contract responsibility system, agriculture and animal husbandry development 'three districts' planning, delimitation of no grazing and no grazing area) and innovate technical means (aircraft reseeded forage, no-repose rotational grazing, grassland reseeded improvement, artificial grassland, and shrub grassland construction).

6. Conclusions

- (1) The vegetation NDVI in Ordos City shows an obvious increasing trend, and the vegetation growth has been greatly improved in 21 years. The interannual growth trend of vegetation NDVI is the largest (0.0075/a), and the growth trend in autumn is (0.0067/a). The area of improving vegetation NDVI in autumn is 72.76%, that in summer is 54.18%, and that in spring is 69.50%. The areas of unstable vegetation NDVI are mainly distributed in the central part of Hangjin Banner and Wushen Banner.
- (2) A total of 80.94% of the regional Hurst index in Ordos is between 0.3 and 0.5, and the average index value is 0.43, showing an opposite development trend of that in the past. The future change of vegetation NDVI is divided by the change trend, and the trend of future change of vegetation NDVI is mainly anti-continuous improvement, and the area of the anti-continuous improvement accounts for 82.88% of the interannual change. Among three seasons, the percentage of anti-continuous improvement in summer is relatively small, but it also reaches 79.14%. If no effective measures are taken in Ordos City, the vegetation NDVI will be degraded extensively in the future.
- (3) As a typical arid and semi-arid region, the vegetation growth in Ordos City is mainly influenced by precipitation. Precipitation plays a dominant role in promoting the growth of vegetation, and, generally, it is mostly a direct effect. The comprehensive effect of precipitation on vegetation NDVI in spring, summer, autumn, and the whole season was 0.526, 0.552, 0.489, and 0.556, respectively. Temperature plays an inhibitory effect on the growth of vegetation. In spring and summer, the inhibitory effect is deduced from the indirect effect. In contrast, in autumn, the inhibitory effect was produced through direct effect. The comprehensive effect of temperature on vegetation NDVI in spring, summer, autumn, and the whole season was -0.235 , -0.471 , -0.142 , and -0.205 , respectively.
- (4) The spatial distribution pattern of vegetation NDVI in Ordos City is inseparable from the land use pattern, and the land use pattern largely determines the spatial distribution of vegetation NDVI. The improvement of vegetation NDVI is obvious in land use types such as grassland and unutilized land. The improvement of vegetation mostly occurs in the areas where the land use type has not changed; therefore, stable land use is favorable to the improvement of vegetation.

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