

Article

Spatiotemporal Variation of Vegetation Coverage and Its Response to Climate Factors and Human Activities in Arid and Semi-Arid Areas: Case Study of the Otindag Sandy Land in China

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Abstract: Vegetation coverage is a key variable in terrestrial ecosystem monitoring and climate change research and is closely related to soil erosion and land desertification. In this article, we aimed to resolve two key scientific issues: (1) quantifying the spatial-temporal vegetation dynamics in the Otindag Sandy Land (OSL); and (2) identifying the relative importance of climate factors and human activities in impacting vegetation dynamics. Based on correlation analysis, simple regression analysis, and the partial derivative formula method, we examined the spatiotemporal variation of vegetation coverage in the OSL, belonging to the arid and semiarid region of northern China, and their interaction with climate-human factors. The results showed that the vegetation coverage of the area showed a downward trend with a rate of $-0.0006/a$ during 2001–2017, and gradually decreased from east to west. Precipitation was the main climate factor controlling the overall distribution pattern of vegetation coverage, while the human factors had a more severe impact on the vegetation coverage than the climate factors in such a short period, and the overall impact was negative. Among the human factors, population pressure, urbanization, industrialization, pastoral production activities, and residents' lifestyles had a negative impact. However, ecological restoration policies alleviated the contradiction between human development and vegetation deterioration. The results of this article provide a scientific basis for restoring grassland systems in arid and semi-arid areas

Keywords: fractional vegetation cover (FVC); human activities; climate factors; spatiotemporal patterns; otindag sandy land (OSL)

1. Introduction

Global climate change and the response of terrestrial ecosystems have been increasingly attracting academic attention [1]. As an active part of the Earth system, vegetation is deeply affected by changes in the type, quantity, or quality of terrestrial ecosystems [2]. The terrestrial ecosystem is affected by both climate factors and human activities, reflecting the process of climate change and human activities [3]. Especially in arid and semi-arid area, the vegetation provides vital products and services for local ecosystem, which combats the desertification process there [4]. Therefore, monitoring the dynamics of vegetation cover in arid and semi-arid areas and studying the impact mechanisms of its changes are critical when assessing the environmental quality of ecosystems and maintaining optimal ecosystem function.

In arid and semi-arid areas, the plant species are mostly deep-rooted vegetation, which can adapt to special desert habitats, maintain the energy and material circulation process of desert ecosystems, and play the roles of preventing wind erosion, fixing quicksand, maintaining land productivity, improving microclimate, and protecting biodiversity [5]. The changes in vegetation cover are influenced by the interaction between climate factors and human activities [3]. It is believed that it is important to distinguish these influences [6]. One line of literature considers that climate factors may be equally or more important in promoting vegetation dynamics compared with human activities [7,8]. In other words, vegetation coverage is more sensitive to climate factors, but human activity reduces its sensitivity [9]. Studies have shown that climate affects vegetation dynamics mainly through precipitation and temperature changes [10]. In arid regions, due to the scarcity of precipitation and large evaporation, vegetation growth is extremely sensitive to precipitation, and the correlation between vegetation coverage and precipitation is higher [11]; however, temperature has no significant effect on the normalized difference vegetation index (NDVI) [12]. Another line of literature argues that the impact of human activities on changes in vegetation cover is increasingly significant [13], which may be the main driving force of vegetation dynamics [14–16]. Recent studies have contrived to identify these specific human activities that affect regional vegetation coverage variation, and preliminary results show that human activities are much more complicated and effects on the vegetation dynamics vary from one region to another. For example, the vegetation degradation in agricultural areas of the Otindag Sandy Land (OSL) of China is related to incorrect farming behavior, while that in pastoral areas is mainly caused by overgrazing and rapid industrialization process [17]. Moreover, human activities have two-way effects on vegetation cover. The development of urbanization leads to a reduction in vegetation coverage in the suburbs on the one hand, and it also increases the urban green area in the city center on the other hand [18,19]. In addition, policy intervention, such as the “Grain for Green Project” and “Grass-livestock Balance Program” in China, with the purpose to increase vegetation coverage by planting trees for afforestation and convert cultivated land or bare land into forests and grasslands [20,21], has been used to suppress the negative impact of human activities and promote vegetation restoration in arid and semi-arid regions. Therefore, human factors are worth further examination in detail.

Overall, the extant literature has not reached consensus about the relative importance of climate factors and human activities in affecting the vegetation dynamics in arid and semiarid regions. It is necessary to quantitatively distinguish the relative importance between climate factors and human activities in terms of how each affects vegetation dynamics within a short-term scale. In addition, there are few existing studies on the quantitative impact analysis of specific human factors, which can provide a more scientific basis for the sustainable development of arid and semi-arid regions. Therefore, the study area is the OSL, which is located in the arid and semiarid region of northern China. The ecological environment is very fragile there. With the frequent occurrence of sandstorms in the early 21st century, the OSL, where desertification is severe, has received wide attention [22]. It is located in an area which is highly sensitive to the influence of climate factors. Since the 21st century, with the advancement of urbanization, human activities (including population growth, economic development, and a series of ecological restoration policies) have had larger impacts on vegetation dynamics [23,24]. The objectives of this article are (1) to quantify the spatial-temporal vegetation dynamics in the OSL; and (2) to identify the relative importance of climate factors and human activities in impacting vegetation dynamics. We hope that this article can provide a scientific basis for the sustainable development of arid and semiarid regions.

2. Data and Methods

2.1. Study Area

The main part of the OSL is located at the southern end of the Xilinguole grassland in central Inner Mongolia. It traverses the East-West direction in the central and eastern part of the Mongolian Plateau,

close to the northern foothills of the Yanshan Hills, eastward from Darinol, which is the western foothills of the southern section of the Daxinganling Mountains, and extends westward along the Ji'er Railway of Sonid Right Banner. It ranks seventh among the deserts/sandy land in China. The total area is 32,553.1 km². Among them, there is grassland in 49.4% of the area, thicket in 21.7%, broad-leaved forest in 14.2%, meadow in 11.0%, cultivated vegetation in 2.6%, desert in 1.0%, and coniferous forest in 0.1 % (as shown in the Figure 1).

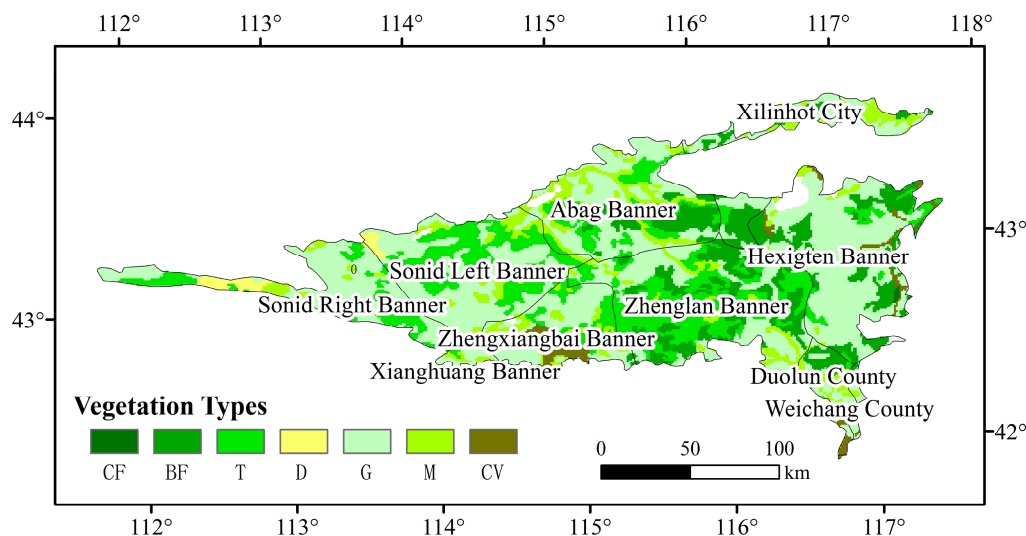


Figure 1. The vegetation types in the study area. **Note:** CF = coniferous forest, BF = broad-leaved forest, T = thicket, D = desert, G = grassland, M = meadow, CV = cultivated vegetation.

2.2. Data Source and Pretreatment

We downloaded the MODIS (Moderate Resolution Imaging Spectroradiometer)-derived 16-day composite vegetation indices (MODISQ1L3) of atmospherically corrected maximal values at a 250 m resolution from NASA's MODIS Web (<https://modis.gsfc.nasa.gov>) from 2001 to 2017. We used the mask extraction tool to obtain the NDVI raster image of the study area and calculated the average NDVI data of the 24 periods within a year to generate an annual average NDVI dataset [25]. The fractional vegetation cover (FVC) is defined to be the ground vegetation vertical projected area as a percentage of the total area [26]. The pixel binary model method used in this article was proposed by Gutman et al. (1998), which is suitable for collecting vegetation coverage information [27]. At the same time, the vegetation coverage was divided into five grades (Table 1) based on the Soil Erosion Classification Standards issued by the Ministry of Water Resources (SL190–1996) and the numerical distribution in the study area: extremely low coverage vegetation ($FVC \leq 20\%$), low coverage vegetation ($20\% < FVC \leq 40\%$), medium coverage vegetation ($40\% < FVC \leq 60\%$), high coverage vegetation ($60\% < FVC \leq 80\%$), extremely high coverage vegetation ($FVC > 80\%$).

The meteorological data came from the China Meteorological Science Data Sharing Service Network (<http://cdc.cma.gov.cn>). According to the latitude and longitude information of each meteorological site, the Kriging method of the ArcGIS tool was used for spatial interpolation to obtain the raster image of annual cumulative precipitation and annual average temperature from 2001 to 2016. Kriging has been proven to be a useful linear interpolation procedure that provides an optimal, unbiased, and minimal variance estimation in a limited region through the semi-variance function [28,29]. Therefore, we adopted the kriging interpolation method to obtain the annual meteorological raster data in this article. The human factor data were derived from the remote sensing monitoring data of Chinese land-use status (2000, 2005, 2010, and 2015) published by the Data Registration and Publishing System of the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn/>), as well as the statistics from the China County Statistical Yearbook,

Inner Mongolia Statistical Yearbook, Hebei Economic Yearbook, and Chengde Statistical Yearbook (2002–2012). In addition, during the period from November 3 to November 9, 2018, a household survey was conducted in Zhenglan Banner. It is located in the hinterland of the OSL as the largest county there, accounting for about 21% of the total area, which is representative for the survey. The investigations were taken place in three Sumus, including 33 Gachas (the Inner Mongolia Autonomous Region is a national autonomous region, a provincial-level Mongolian agglomeration area. A Banner under its jurisdiction is a county-level administrative region, a Sumu is a township-level administrative region, and a Gacha is a village-level administrative region). The herdsmen were interviewed to collect information related to the implementation of local policies and the production-living conditions, with a goal to conduct an in-depth exploration and analysis of the influencing factors.

2.3. Research Methods

2.3.1. Trend Analysis of Vegetation Coverage

A simple linear regression method was used to study the overall change trend and spatial distribution pattern of vegetation coverage in the study area from 2001 to 2017. The vegetation coverage raster image was processed by ArcGIS's raster calculator tool to obtain the regression slope of a single pixel, that is, the annual variation rate, to analyze the distribution pattern of the change trend. If the regression slope was negative ($b < 0$), it indicates that the vegetation coverage was decreasing; otherwise, the vegetation coverage was increasing ($b > 0$) [30]. The Mann-Kendall test statistic was adopted to detect the statistical significance of the spatially averaged FVC. Furthermore, based on a confidence level of 0.05 in the Mann-Kendall test, if $|Z| \geq 1.96$, the trend was significant. Recommended by the World Meteorological Organization (WMO), the Mann-Kendall test has the advantages of assuming no special form in the distribution functions of the data [31], and vegetation changes from one steady state to another and these conditions can often be met in time series analysis [6]. By calculating the coefficient of variation of the annual average vegetation coverage, the overall situation of the relative fluctuation degree of vegetation coverage in the study area could be determined [30].

2.3.2. Correlation Analysis between Vegetation Coverage and Climate Factors

The MODIS-NDVI and meteorological data were used, and the correlation coefficient was calculated on the annual scale to express the spatial distribution pattern of the correlation between the vegetation cover and the climate factors [30].

2.3.3. Contribution of Each Driving Factor to the Inter-Annual Variability of FVC

Extant literature has attributed vegetation dynamics in China based on residual analysis using coarse resolution vegetation index time series [32,33]. However, the residual analysis method usually just makes a distinction between different driving factors, and is limited in quantifying the contribution of climate factors and human activities to vegetation changes, particularly in distinguishing and comparing the effects of individual climate factors on vegetation dynamics [34]. To detect and attribute vegetation changes, we adopted the method based on partial derivatives adopted to estimate the contribution of each driver factor to the inter-annual change rate of FVC for each pixel over 15 years [35,36]. FVC variations are a function of climate variables (air temperature, precipitation) and other variables (dominated by human activities) [37]. As described by some articles, the contributions of climate variability and human activities to vegetation change can be estimated as the following procedures [38]:

$$\begin{aligned} \frac{dFVC}{dt} &= \varepsilon_1 \frac{dTEM}{dt} + \varepsilon_2 \frac{dPRE}{dt} + HA, \\ &= TEM^* + PRE^* + HA, \end{aligned} \quad (1)$$

where TEM^* and PRE^* represent the contributions of temperature and precipitation to FVC change rate at pixel scale, respectively. $\frac{dFVC}{dt}$ is the annual variation rate of FVC in time variable t . $\frac{dTEM}{dt}$ and $\frac{dPRE}{dt}$ can be considered as slopes of the linear regressions for climate variables temperature and precipitation

against time t at pixel scale. The coefficients ε_1 and ε_2 can be estimated as $\varepsilon_1 = \frac{\partial FVC}{\partial TEM}$ and $\varepsilon_2 = \frac{\partial FVC}{\partial PRE}$, respectively, which is the slope of the linear regression line between FVC and climate variables. HA is the residual between FVC variation rates and climate factor contribution. Considering the intense human activities, we assumed that HA represents the variation rate of the contribution of human activities to FVC. Similar methods are now widely used in studies of climate impact on hydrological dynamics [35,38].

As for the contribution of individual human factors to the annual change of FVC, it can be calculated by the following formula:

$$X_i = \frac{\partial FVC}{\partial X_i} \times \frac{dX_i}{dt}, \quad (2)$$

where X_i represents the i -th human factor, $\frac{\partial FVC}{\partial X_i}$ is the slope of the linear regression line between FVC and the human factor, $\frac{dX_i}{dt}$ can be regarded as the slope of the linear regression of the human factor with time t .

3. Results

3.1. Temporal and Spatial Changes in Vegetation Coverage in the OSL from 2001 to 2017

In terms of temporal change, the vegetation coverage of the OSL showed a fluctuating trend from 2001 to 2017. The overall vegetation coverage was low ($20\% < FVC \leq 40\%$), and the vegetation coverage was basically stable between 29% and 45%. Different levels of vegetation coverage had different variation trends, and there was a process of mutual conversion among them (Figure 2). The average annual vegetation coverage of the study area was 36.83%. The area with low coverage (20–40%) accounted for 45.36% and was concentrated in the mid-west of the study area. The area with medium coverage (40–60%) accounted for 30.07% and was concentrated in the mid-east. The area with very low coverage (0–20%) accounted for 15.28% and was concentrated in the western fringe. The area with high coverage (60–80%) accounted for 8.26% and was mostly located in the eastern fringe. Finally, the area with extremely high coverage ($> 80\%$) accounted for 1.03% (Figure 3a); The overall vegetation coverage in the study area showed a downward trend with an annual decline rate of $-0.0006/a$ (Figure 3b); there was a downward trend of FVC accounting for 61.88% of the total area, as well as an upward trend accounting for 38.12%. However, the change trend was not significant (Figure 3c, $|Z| < 1.96$).

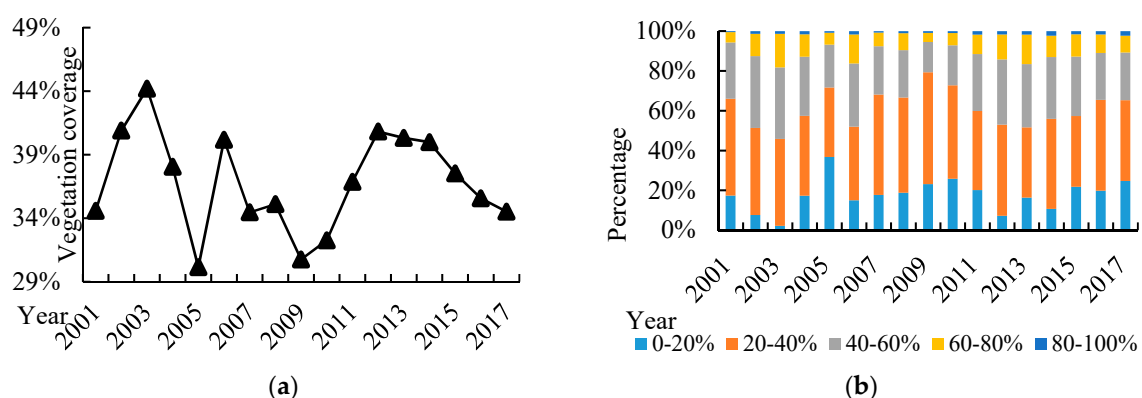


Figure 2. Changes in vegetation coverage from 2001 to 2017 (a) trends; (b) the proportion of area covered by different grades of vegetation coverage.

In terms of spatial distribution, the multi-year average vegetation coverage conformed to the spatial characteristics of zonal differentiation, showing a decreasing trend from East to West. There was a relatively slight decrease trend in 60.73% of the total area, and a slight increase trend in another 38.71% area. The area where FVC showed a significant decrease trend accounted for 3.67%, and the area where FVC showed a severe significant decrease trend accounted for 1.42%, concentrating in

the western Sonid Left Banner and Hexigten Banner. The vegetation coverage was low or extremely low in the western marginal areas, which showed a tendency to extend towards the middle areas. The area of high vegetation coverage fluctuated, mainly located in the eastern margin and scattered parts of the central area, which is consistent with the conclusions of related studies [30]. We found that the vegetation coverage in the eastern and southern part of the OSL showed a slight upward trend, while there was a slight downward trend in the western and northern part. The vegetation variation coefficient was low in most areas, and the vegetation coverage was relatively stable on the whole. The vegetation coverage variation coefficient in the western margin was higher than that in the central and eastern regions, indicating that the low vegetation coverage in the western area was more likely to be affected by climate change and human activities. The sensitivity and vulnerability there were more obvious (Figure 3d).

3.2. The Impact of Climate-Human Factors on FVC

Quantitative determination of driving factors to FVC is essential for optimizing the subsequent management of vegetation ecosystems. Figure 4 illustrates the distribution of the contribution of climate factors and human activities to the inter-annual change of FVC. From 2001 to 2016, the inter-annual change rate of FVC was $-0.0006/a$. The contribution of climate factors was $0.0021/a$ and that of human activities was $-0.0027/a$.

Climate factors had a positive effect on the inter-annual change of FVC in 92.09% of the region, and a negative effect in 7.91% of the region. Compared with climate factors, human activities were the main factors causing inter-annual changes of FVC, and their impact was negative (Figure 4) in 77.99% of the OSL, most of which was located in the northern and western region. While the positive effects of climate factors in the northern region offset some portion of negative effects of human activities, negative impacts of both climate factors and human activities in the western marginal area were shown to be associated with the highest variation coefficient of FVC there. Human factors had a positive impact only in 22.01% of the OSL, mainly distributed in the southeast counties, such as Weichang County and Duolun County.

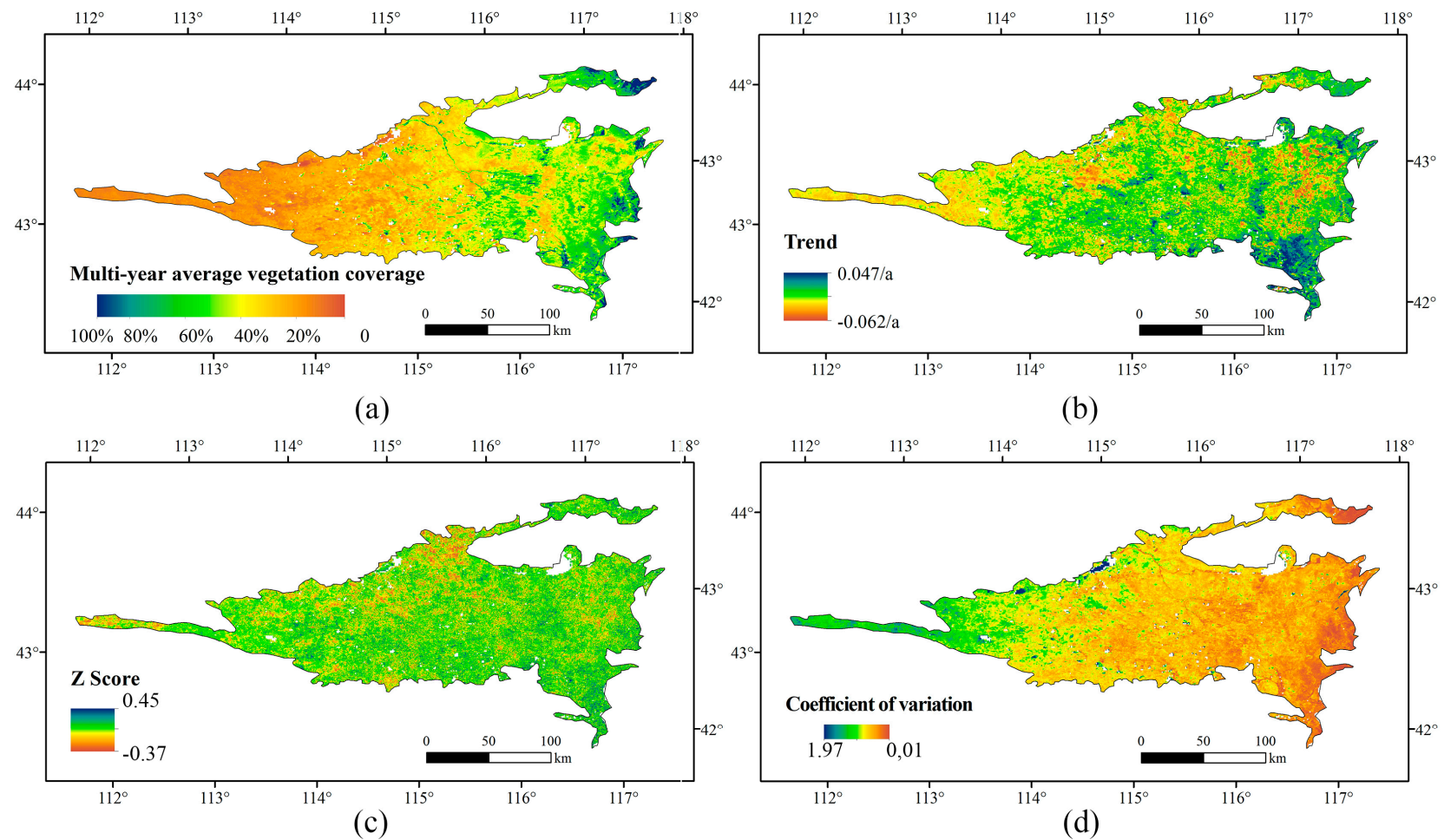


Figure 3. Spatiotemporal variation in vegetation coverage from 2001 to 2017: (a) multiyear average vegetation coverage; (b) distribution of changing trend; (c) significance test; (d) coefficient of variation.

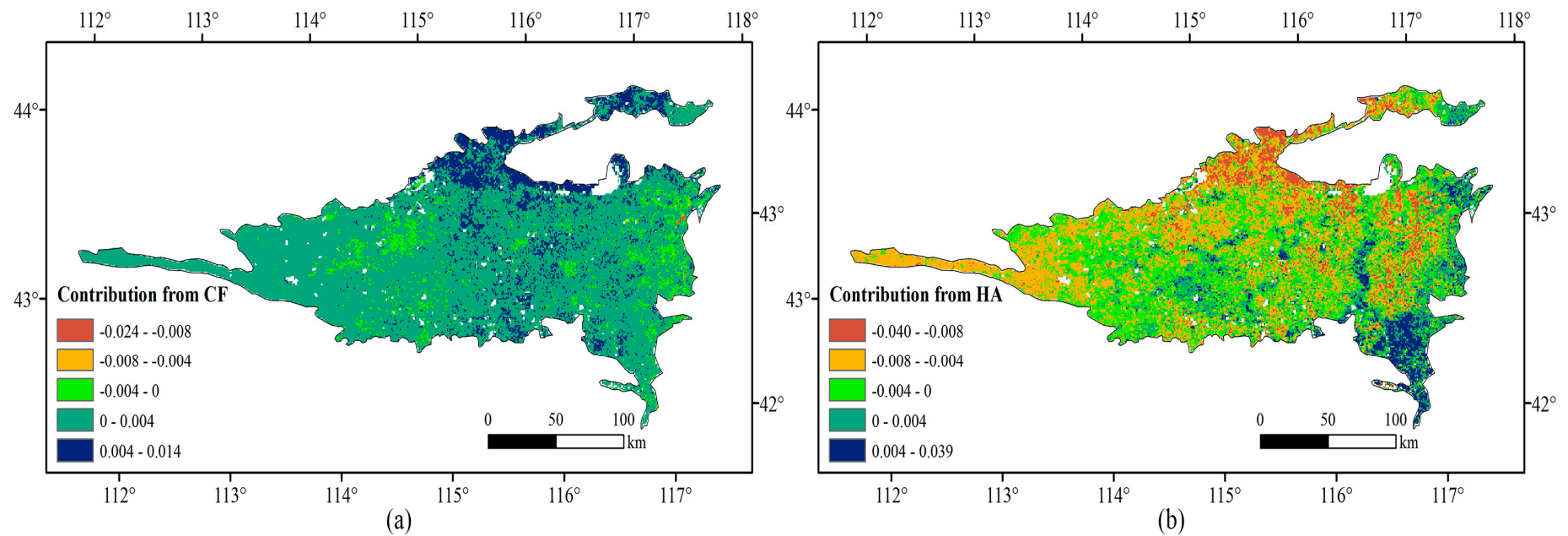


Figure 4. Spatial distribution of the contribution of climate factors and human activities to the interannual change of fractional vegetation cover (FVC): (a) “CF” = climate factors; (b) “HA” = human activities.

3.2.1. Contribution of Climate Factors to the Inter-Annual Change of Vegetation Coverage

The atmospheric circulation of temperature and precipitation through evapotranspiration has an important impact on vegetation growth and distribution and changes the dynamics of vegetation coverage through periodic changes.

The correlation between vegetation growth and precipitation was larger. In the context of global climate change, the increase in precipitation and the relative decline in temperature have a significant effect on the vegetation growth in the OSL. By calculating the correlation between vegetation coverage and temperature and precipitation in each unit, it was found that the vegetation coverage in this area was significantly positively correlated with the annual precipitation in the whole region, and the correlation with annual average temperature was not significant (Figure 5). The correlation between vegetation coverage and precipitation was higher, and the significance was stronger. A region of 19.93% passed the significance test of $p = 0.05$. The correlation between vegetation coverage and temperature was lower, and a region of 97.67% did not pass the significance test of $p = 0.05$ (Figure 5). The correlation coefficient described the possible relationship between FVC and climate variables, but failed to quantify the contribution of individual climate factor to the change of FVC [36]. So, we further analyzed the contribution of climate factors by the means of calculating partial derivatives, which is shown in Figure 6.

Precipitation was the most important climate factor affecting FVC. From 2001 to 2016, the average contributions of temperature and precipitation to FVC changes were 0.0001/a and 0.0020/a. Overall, the contribution rate of precipitation to the inter-annual change of FVC was a positive effect in about 96.03% of the area. However, the influence of temperature on FVC had two sides. There was a positive effect in 59.06% of the area, mainly located in the central and western marginal regions, as well as negative effects the remaining 40.94%, mainly located in the eastern and central parts.

The contribution of temperature and precipitation showed significant spatial heterogeneity in terms of distribution (Figure 6). Precipitation showed an upward trend from northwest to southeast, which is more consistent with the distribution pattern of vegetation coverage variation. There was abundant rainfall in the southeastern fringe, such as Weichang County and Duolun County, so the vegetation coverage there was increasing. In addition, due to the lack of precipitation in the western region, the vegetation coverage showed a downward trend, which was more severely affected by external disturbances. However, in desert steppe areas where precipitation was relatively scarce, the effects of high temperatures on vegetation growth were more pronounced [39].

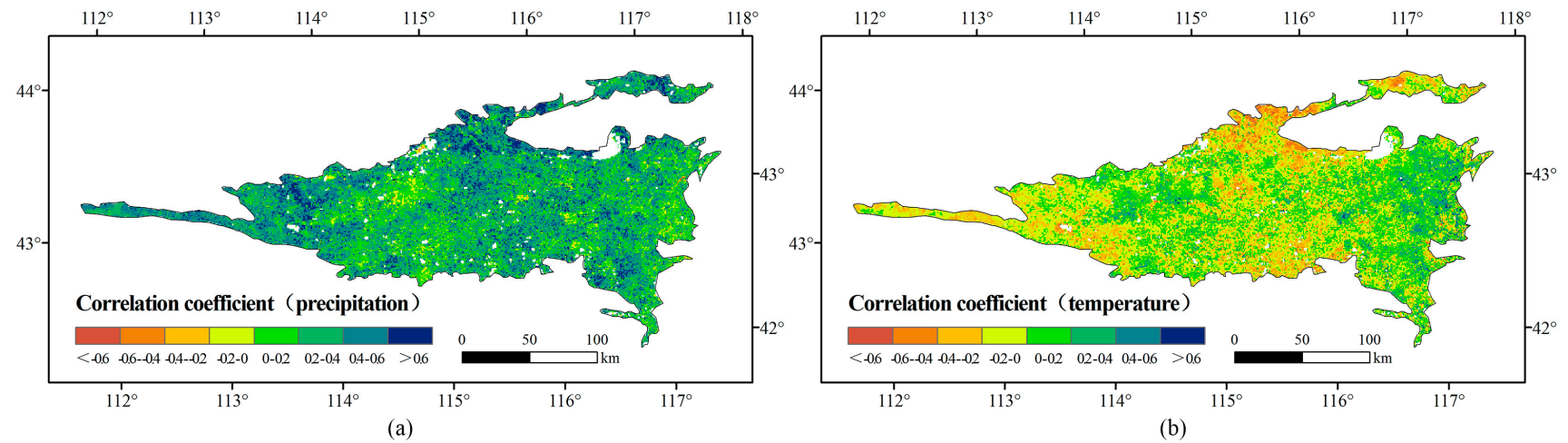


Figure 5. Spatial distribution of the correlation coefficient from 2001 to 2016: (a) between vegetation coverage and annual precipitation; (b) between vegetation coverage and annual average temperature.

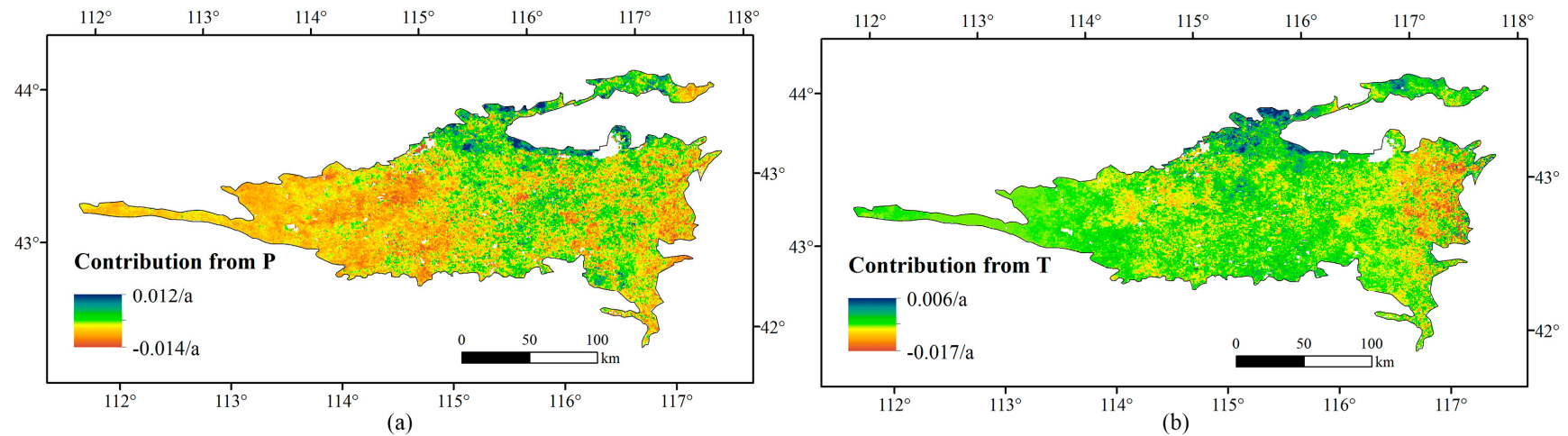


Figure 6. Spatial distribution of the contribution of climate factors to the inter-annual change of FVC from 2001 to 2016: (a) “P” = precipitation; (b) “T” = temperature.

3.2.2. Contribution of Human Activities to the Inter-Annual Change of Vegetation Coverage

In order to further analyze the contribution of specific human factors to the inter-annual change of FVC, a partial derivative calculation was performed on the socioeconomic statistics from 2002 to 2012 to compare the relative importance of different human factors on FVC. The results showed that the influence of population density, economic scale, industrial structure, and animal husbandry structure were all negative (Table 1).

Table 1. The contribution of individual human factor to the inter-annual change of FVC.

Human Factors	Index	Contribution
Population pressure [39]	Population density	−0.0040/a
Economic development level [39]	GDP	−0.0026/a
	per unit area GDP	−0.0029/a
	Number of employees in the secondary industry	−0.0054/a
Industrial structure [16]	Number of employees in the tertiary industry	−0.0039/a
	Industrial added value	−0.0060/a
	Number of large livestock	−0.0059/a
Pastoral structure [16]	Number of sheep	−0.0042/a

Among them, the contribution rate of population density to FVC was −0.0040/a. Cai et al. (2014) found that if the population pressure exceeded vegetation carrying capacity, it would become one of the important factors leading to vegetation degradation [40]. With the increase of population density, humans' demand for living land would also increase, and part of the vegetation cover area would be converted into construction land and facility land, thus affecting the ecological environment of vegetation restoration. The contribution rate of economic scale was −0.0026/a. Economic development will increase the consumption of resources and produce a certain negative externality to the ecological environment. When the gross national product (GDP) of per unit area (GDP/area) exceeds a certain threshold, the vegetation coverage remains low [41]. The multi-year average per unit area GDP in the study area was 200,000 yuan/km² during 2002–2012, and the contribution rate to FVC was −0.0029/a. What is more, the industrial structure can also have a certain impact on vegetation coverage. The impact of the current industrial structure was negative, but the impact of the tertiary industry was smaller than that of the secondary industry. The industry development intensity had the largest contribution rate of −0.0060/a, indicating that the development was rapid and its damage to FVC was the greatest. Last but not least, the study area is a grassland pastoral area, and animal husbandry is the main industry. The current animal husbandry structure had a negative impact on FVC, but the impact of large livestock was greater than that of sheep.

According to the survey, the main production activity in the study area is pastoral production, but the grazing level varies from region to region. The number of livestock (mainly cattle and sheep) increased significantly during 2001 and 2015, from 500,000 to 883,000, especially in the northwestern marginal area, where the overgrazing was serious. The increasing grazing rate exhibited a relationship with vegetation degradation there. Furthermore, increasing industrial and mining activities had a negative effect on the ecological environment and the vegetation cover. A case in point is, the coefficient of variation in the western area was high (Figure 3d), while a large number of mining sites had been constructed there, observed from remote sensing images. Besides, burgeoning industrial production brought about the increasing consumption of water resource and the compression of ecological resources for vegetation restoration. In particular, mining activities did severe damage to the underlying surface and increased the difficulty in vegetation restoration as well.

3.3. Characteristics of Land-Use Change and its Impacts on Vegetation Coverage

In general, the study area was covered mostly by grassland and unutilized land, followed by cultivated land, water area, and forestland; in contrast, the industrial, mining warehouse land, and

residential land occupied the smallest area of OSL. The land-use type changes happened in 1.13% of OSL from 2000 to 2015. The area of cultivated land, forestland, and water area decreased significantly. However, the industrial, mining warehouse land, and residential land increased slightly. The area of water area and unutilized land changed quickly. We found that the change trend of sandy land was an inverted “U” type, while that of grassland was a positive “U” type, which showed opposite trends between them.

Land use change has been considered as the direct impact of human activities on the ecological environment [42]. There was a relatively complex interaction between land-use type changes and vegetation coverage variation. The area of grassland at different coverage levels changed obviously. Among them, the high coverage grassland declined obviously, which happened in 59.29% of OSL. The area of lakes also decreased quickly, which happened in 27.87% of OSL. The most obvious increase in area was found for medium and low coverage grassland, accounting for 64.21% of OSL. In addition, the area of sandy land, beaches, and cultivated land decreased by 16.94%, 10.11%, and 6.83%. This indicates that although the total area of grassland increased from 2000 to 2015, the high coverage grassland was converted to low or medium coverage grassland, resulting in a decline in overall coverage. The area of sandy land increased significantly, and shrub land and sparse woodland decreased rapidly, which indicates that the degree of desertification was increasing. Rapid urbanization has increased the demand for construction land such as residential land. The area of lakes decreased by 27.87% from 2000 to 2010 (Table 2), most of which were converted into beaches and swamps. The amount of water resources decreased, which further increased the pressure of vegetation restoration, but the reservoirs and ponds increased. Our investigation found that local government has adopted ecological measures for water storage projects, such as building reservoirs, to cope with the water resources guarantee for vegetation restoration in the region. These changes indicate that although the policies such as “Grain for Green Project” had a positive impact on FVC, the water resources reduction and deforestation influenced by human activities still existed. On one hand, some cultivated and saline-alkali land was transferred to grassland and forestland. On the other hand, a large amount of water area and forestland were converted to sandy land, beaches, wetlands, and even construction land, which exhibited a close relationship with the overall decreasing vegetation coverage.

Table 2. Proportion of changes in the area of different land use types from 2000 to 2015.

Primary Classes	Secondary Classes	Area Change Ratio from 2000 to 2015	
Cultivated Land	Dry land	−6.83%	−6.83%
	Woodland	0.27%	
Forestland	Shrub land	−2.73%	−2.73%
	Sparse woodland	−0.27%	
	High coverage grass	−59.29%	
Grassland	Medium coverage grass	28.69%	4.92%
	Low coverage grass	35.52%	
	River channel	0.00%	
Water area	Lake	−27.87%	
	Reservoir pit	0.27%	−17.49%
	Beach	10.11%	
Industrial and mining warehouse land, residential land	Townhouse	0.82%	
	House-site in the countryside	0.55%	3.28%
	Other construction land	1.91%	
	Sandy land	16.94%	
	Saline-alkali land	−3.01%	
Unutilized	Wetlands	4.92%	18.85%
	Bare land	0.00%	
	Bare rock texture	0.00%	

4. Discussion and Conclusions

4.1. Discussion: Impact of Human Factors on FVC

We conducted a quantitative analysis on FVC changes by human factors. However, FVC changes are also affected by some human factors that are difficult to quantify. As these factors are important for vegetation restoration, we need further discussion and analysis. Human activities, including production activities and lifestyles [43], were the main factors that had a negative impact on vegetation coverage and led to a decrease in the sensitivity of FVC to climate factors [9]. Urbanization [44], population growth [45], resource consumption [46], and other human factors have put pressure on the ecological environment. Local urbanization and lifestyle changes also had a negative impact on vegetation coverage. With the development of urbanization, the herdsmen have gradually changed their lifestyle from a nomadic state to a settled one and built large-scale settlements, which converted a certain amount of the grasslands into the construction land. According to the interview, some herdsmen ride motorcycles or even drive cars for grazing instead of following their horse-riding grazing tradition, which means the livestock activities are more random than before and have much more negative impacts on the vegetation restoration.

However, human factors also had a positive effect on FVC. Human factors had been confirmed, especially afforestation projects, to be the key factor related to restoration of Chinese vegetation coverage [47]. Recently, the central government of China adopted a series of ecological protection policies and measures, such as Beijing-Tianjin Sandstorm Source Control and Grain for Green Project [48]. Such policies promote vegetation restoration, especially in Weichang County and Duolun County, which are located in the Chinese ecotone between farming and animal husbandry. Local people there use modern sprinkler irrigation circle technology to develop irrigated agriculture (Figure 7). They have also returned farmland to forests and grasslands on slopes, which brought about the increasing variety of the cultivation types there, thus increasing FVC and improving the ecological environment. The local government in Duolun County has implemented a forestry ecological construction project based on the afforestation of *Pinus sylvestris* var. *mongolica* since 2010. Through ten years of ecological construction, the forest area there has increased dramatically from 90,000 acres in 2000 to 500,000 acres, accounting for 51% of the total land. Accordingly, FVC has increased from 6.8% in 2000 to the current 37.9%. Moreover, with the German government's free assistance afforestation ecological project in 2003, 20,000 acres of afforestation tasks have been completed in Weichang County. In addition, the ever-increasing grazing pressure was an important factor influencing vegetation coverage [9]. As a response to the national ecological policies such as "Forbidding Grazing, Rotation Grazing and Pausing Grazing Program" and "Grass-Livestock Balance Program", local government implemented the policy of "increasing cattle and reducing sheep" as a measurement to make pastoral structure adjustment, which had a positive impact on vegetation coverage, because the destruction of grasslands eaten by sheep is far greater than that by cattle in arid and semi-arid areas. Meanwhile, grass production capability was evaluated to determine the number of livestock, and subsidies and incentives were provided as encouragement for such adjustment for local herdsmen. Consequently, the number of sheep has decreased from more than 5 million in 2002 to about 4 million, which controls local desertification efficiently. However, we failed to quantify the contribution of these policies, which deserves further attention.



Figure 7. The sprinkler irrigation circle method in June of 2011: (a) in Duolun County; (b) in Weichang County.

4.2. Conclusions

According to Ma et al. (2017), it is necessary to consider the impacts of climate and human factors on FVC separately [17]. Moreover, for a specific region, it is valuable to identify the key factors through quantitative comparison of their impacts [49]. As a response to these perspectives, we took OSL as a study area, and used the partial derivative method to quantitatively analyze the impact of the main climate factors and human factors. Besides this, we identified the key human factors especially, which contributed to understanding the changing process of FVC in arid and semi-arid areas. We drew the conclusions as follows.

1. The vegetation changes are the results of the integrating effects of climate and human factors. In terms of the case of OSL, climate-human factors had a negative effect on FVC overall, so the vegetation coverage tended to decline slightly. The climate factors individually had a positive impact on FVC, while human activities had a negative impact, which was greater than that of the climate factors, indicating that the changes of FVC were more susceptible affected by and more sensitive to human factors.
2. There were differences in the impacts on FVC inside the climate and human factors. Precipitation was the main climate factor with a significantly positive impact, but the impact of temperature was relatively slight. The impacts of human factors had two sides, that is, the positive one and negative one. Industrialization (especially mining activities), urbanization, and lifestyle changes had a negative impact, effecting vegetation recovery, while ecological policies promoted the vegetation restoration, prevented FVC from further degradation, and made up for the negative impacts of other human factors mentioned above.
3. The differences in the combination of specific climate and human factors influenced the spatial patterns of FVC. In the region with abundant precipitation and ecological restoration projects, the positive impact of human factors was more likely to be observed, so FVC there showed an upward trend. However, in the region with scarce precipitation, great evapotranspiration, and few ecological measures, FVC was more fragile and sensitive to production and other economic activities impacts.

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