

Regulation factors driving vegetation changes in China during the past 20 years

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Abstract: Vegetation change is of significant concern because it plays a crucial role in the global carbon cycle and climate. Many studies have examined recent changes in vegetation growth and the associated drivers. These drivers include both natural and human activities, but few studies have identified the regulation factors. By employing normalized difference vegetation index (NDVI) data, we analyzed the spatiotemporal pattern of vegetation change in China and then explored the driving factors. It was found that the overall greening of China has improved significantly, especially in the Loess Plateau and southwest China. The Yangtze River Delta and Bohai Rim, however, have not seen as much growth. Natural conditions are conducive to vegetation growth. Although socioeconomic development will be more beneficial for vegetation restoration, the current level and speed of development have a negative effect on vegetation. The regulation factors are considered separately since they affect both directly and indirectly. Regulation factors have accelerated vegetation growth. By understanding the factors affecting the current vegetation growth, we can provide a guide for future vegetation recovery in China and other similar countries.

Keywords: vegetation change; NDVI; regulation factors; climate change; China

1 Introduction

Vegetation is a vital component that maintains the stability of terrestrial ecosystems linking the atmosphere, water, and soil (Fu *et al.*, 2017; Zhao *et al.*, 2018). Vegetation is viewed as a sensitive indicator of climate change (Smith *et al.*, 1997); therefore, monitoring vegetation change is valuable for studying global climate change and even terrestrial ecosystem health (Beerling *et al.*, 2010). Vegetation disturbances and their subsequent recovery are shifting with global changes in climate and land use. Changes in ecological factors, land use, and

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environmental degradation regimes are replacing old-growth forests with younger, shorter stands (McDowell *et al.*, 2020). Therefore, researchers and government officials need to closely monitor and investigate the influencing factors of vegetation change.

The link between vegetation change and climate change has been extensively studied (Wu *et al.*, 2015; Pan *et al.*, 2018). Previous studies that were based on factorial simulations with multiple global ecosystem models have revealed that the atmosphere and climate change are the dominant factors affecting vegetation change (Keenan *et al.*, 2016; Zhu *et al.*, 2016). On a regional scale, many studies have focused on the relationship between vegetation and local climatic factors. In addition, vegetation change is also related to other factors, such as urbanization (Zhao *et al.*, 2016), the excessive exploitation of water resources, oil and natural gas extraction (Jiang *et al.*, 2017), and human population (Brant *et al.*, 2017), as well as the geographical location of different regions. For example, tundra vegetation exhibits strong regional change in response to warming, especially in vulnerable regions (Elmendorf *et al.*, 2012), and in wet and cold regions, vegetation cover is positively correlated with maximum air temperature and negatively correlated with minimum air temperature. In hot and dry regions, vegetation cover is negatively correlated with maximum air temperature, and the relationship between vegetation cover and minimum air temperature is complex (Peng *et al.*, 2013). Chen *et al.* (2019) found that northern temperate forests account for 16% of the global net greening, which indicates the value of large-scale afforestation in previously low-productive areas of China and tree plantation practices in developed countries and highlights the role of national policies and regulation factors.

China has a vast area with variable terrain, vegetation, and meteorological conditions; therefore, it is of critical significance to research China's vegetation changes and their driving factors. According to relevant studies, the vegetation cover in China has increased significantly since 1982, but since the beginning of the 21st century, the growth rate of vegetation cover in China has slowed, and there are spatial and seasonal differences in vegetation cover (Peng *et al.*, 2011). China accounts for nearly 25% of the global net increase in vegetation area and has the highest growth rate in the world (Chen *et al.*, 2019). To contend with and control soil erosion, desertification, and sandstorms, which are critical problems in many regions of China, the Chinese government has launched a series of policies and land conservation programs from the perspective of the social economy and ecological environment (Yang, 2004). China has invested a substantial amount of human, material, and financial resources to promote vegetation growth and restoration. China has eight existing forestry programs, including the Three-North Shelterbelt Program, afforestation program for the Taihang Mountain, shelterbelt programs for the Liaohe River, middle reaches of the Yellow River, Huaihe River and Taihu Lake, and upper and middle reaches of the Yangtze River, Pearl River, and the coastal shelterbelt program. These forestry programs were unprecedented in world history in terms of their geographic and spatial extent, government input budget, and magnitude of the mobilization of social factors (Dai, 2010).

In the existing studies on vegetation change, scholars have focused on the impact of climate factors on vegetation change (Afuye *et al.*, 2021), ignoring the potential impact of factors related to human activity on vegetation cover. Although many studies have explored the effects of natural and socioeconomic factors on vegetation growth in China, the majority have ignored the effects of regulation factors on vegetation growth and changes (Li *et al.*,

2020; Mu *et al.*, 2021). Anthropogenic factors, including regulation factors that directly or indirectly affected the total vegetation cover, were still largely absent in recent research. There is a need to study what large-scale regulation factors influence vegetation cover change and how to influence positive or negative changes in vegetation cover. The Chinese government has adopted policies for mining and reclamation, land abandonment and consolidation, and regional nature conservation, which have a special impact on vegetation change (Feng *et al.*, 2021). China has gradually paid attention to the ecological environment and allocated money to increase vegetation cover in recent years. Afforestation-oriented greening in China has been observed based on remote sensing datasets (Piao *et al.*, 2021). Moreover, regulation factors cannot change basic natural conditions, but they can indirectly affect climate change and socioeconomic activities, affecting natural factors and socioeconomic factors. The disturbance and effect of regulation factors on vegetation cover should be deeply understood to clarify the impact of regulation-driven activities on the environment.

China's natural conditions are complex and diverse, and due to its high population density, human activities have a significant impact on vegetation (Wang *et al.*, 2019). Therefore, the differentiation characteristics and driving factors of vegetation change in China are extremely complex. Taking the provincial administrative regions of China as the research unit, we employed normalized difference vegetation index (NDVI) data, combined with temperature, precipitation, GDP, construction land, and other relevant data, to explore the following three aspects: (1) spatiotemporal changes in vegetation cover in China over the past two decades; (2) the driving factors of vegetation change in China, including natural, socioeconomic development, and regulation factors; and (3) the critical role and influence of regulation factors on vegetation change and growth in China.

2 Data and methods

2.1 Vegetation changes

2.1.1 Data source

The NDVI is a valuable index that indicates changes in vegetation (Wang *et al.*, 2013; He *et al.*, 2017). It is the ratio of the difference between the near-infrared reflectance and red reflectance to the sum of the two. The NDVI is considered useful in temperate environments and in areas with little vegetation (Pettorelli *et al.*, 2011). Based on the SPOT/VEGETATION and MODIS data, the long-term NDVI series has been widely used to monitor dynamic vegetation changes in different regions, detect land cover changes, and estimate net primary productivity. In this study, we used NDVI data during the growing season from the Resource and Environment Science and Data Center (<https://www.resdc.cn/Default.aspx>). The spatial distribution dataset of the NDVI during the growing season in China was derived from SPOT/VEGETATION NDVI satellite remote sensing data, and the maximum value synthesis method was used to generate the NDVI data for the growing seasons since 1998. The spatial resolution is 1 km. The growing seasons include spring, summer, and autumn.

2.1.2 Temporal changes

In a time-series change analysis, the trend of NDVI was calculated using the one-variable linear regression (Zheng *et al.*, 2021), and the slope of the linear regression equation was

defined as the trend rate of NDVI (Wang *et al.*, 2015; Zhu *et al.*, 2020).

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

where *Slope* is the trend of *n* years, *n* is the number of years in the study period, and $NDVI_i$ is the NDVI in the growing season in *i*. $slope < 0$ and $slope > 0$ represent the decrease and increase of NDVI in the growing season with time, respectively, and the larger the absolute value of the slope, the faster the NDVI changes during the growing season.

2.1.3 Spatial changes

In a spatial change analysis, zonal analysis requires the extraction of numerical attributes from a regular grid for a specific overlay area (Haag *et al.*, 2020). Zones can be defined by raster datasets, and the raster must be an integer type. Zonal statistics is a method used to calculate statistics on the values of a raster within the zones of other datasets. A single output value is computed for every zone in the input zone datasets, including the majority, mean, maximum, and minimum. We used zonal statistics to analyze the spatial distribution of the NDVI.

2.2 Influencing factors of vegetation changes

Regional vegetation change is not determined by a single factor, but the results of multiple factors are superimposed. Generally, the factors influencing vegetation change can be summarized as natural, socioeconomic development, and regulation factors. In the influencing system of vegetation change, the three types of factors are not isolated, but interact and work together, and regulation factors can indirectly affect socioeconomic development and natural factors by encouraging or limiting the behavior of the factors. In short, the three factors comprehensively interweave and act on vegetation change (Figure 1).

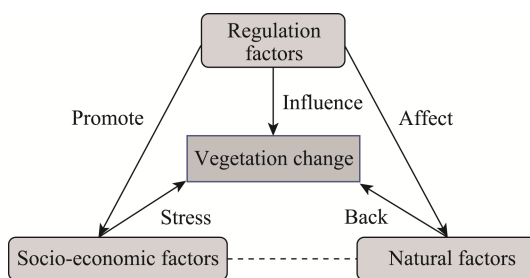


Figure 1 The possible influencing factors of vegetation change

2.2.1 Natural factors

Natural factors reflect the natural background conditions of the region, which have considerable effects on vegetation growth. Suitable conditions, such as moderate precipitation and appropriate temperatures, will create a good growth environment for vegetation; conversely, unsuitable conditions are unfavorable for growth. Therefore, natural factors are the supporting environment for the changes in vegetation on Earth.

Studies on vegetation change related to natural factors often use climate data, such as

precipitation, temperature, and radiation (Strengers *et al.*, 2010; Wang *et al.*, 2020). Vegetation turns green as the climate changes (Piao *et al.*, 2011). However, with the increase in extreme weather, vegetation mortality is also increasing, and may be even higher in the future (McDowell *et al.*, 2011). Thus, in this study, the climate data included the air temperature and precipitation that is closely related to vegetation, which was downloaded from the Resource and Environment Science and Data Center (<https://www.resdc.cn/Default.aspx>). The database of annual temperature and precipitation in China since 1980 is based on daily observation data from more than 2400 meteorological stations, which are generated by calculation and spatial interpolation processing. As one of the most professional interpolation applications, ANUSPLIN is used to analyze and interpolate multivariable climate data using a smooth spline function. It employs a method of approximating the surface using a function that can carry out reasonable statistical analyses and data diagnosis and can analyze the spatial distribution of data and realize the function of spatial interpolation (Guo *et al.*, 2020).

2.2.2 Socioeconomic factors

The factors of socioeconomic development reflect the regional economic situation and social development level, including GDP per capita, land utilization, rural population, and carbon emissions. The development of society and the economy will exert pressure on the ecological environment and change the vegetation. Many studies have demonstrated that human activities, including urbanization, industrialization, and agricultural development, are the dominant factors affecting vegetation change (Chen *et al.*, 2019; Zheng *et al.*, 2021).

(1) Economic level

Economic development is closely related to ecological changes. Economic investment has been identified as the dominant driving force of vegetation change in most study areas (Zheng *et al.*, 2021). Similar to the environmental Kuznets curve hypothesis, economic development also has a dual impact on vegetation cover; for example, during the initial stage of development, economic activities have side effects on vegetation cover. In contrast, with economic development, there is a positive correlation. In this study, we used the GDP per capita to represent the economic and development level of a region, which is calculated by the National Bureau of Statistics of China and the local statistics bureau. The GDP per capita data are from the China Statistical Yearbook, which is from the Big Data Research Platform of China's Economy and Society (<https://data.cnki.net/>). The data platform contains most of the national and provincial statistical yearbooks.

(2) Land utilization

The change in land development intensity is also a valuable indicator of regional socioeconomic development and spatial differentiation (Huang *et al.*, 2020). Land development intensity is closely related to the landscape complexity and human activities, such as research and development, infrastructure, and management (Persson *et al.*, 2010; Dietrich *et al.*, 2012). The land development intensity can be measured as the ratio of the regional construction land area to the total area of the region used in the National Plan for Major Functional Zones (2010) and the Outline of the National Land Planning (2016–2030) (2017). The regional construction land area and total area data were obtained from the China Statistical Yearbook.

(3) Population

Human activities have a considerable impact on vegetation cover change, but the popula-

tion factors that cause changes due to human activity are lacking in the study of population and vegetation cover. Total population growth has a significant negative impact on vegetation cover change. The industrial employment population growth has intensified this impact, while the improvements in population urbanization, quality, and age structure have reduced it. China's rapid urbanization has resulted in an increase in the urban population and a corresponding decrease in the rural population. Cao *et al.* (2014) argued that the decrease in the rural population had a positive impact on the increase in vegetation cover. Thus, in this study, we used the census data from the official website of the National Bureau of Statistics (<http://www.stats.gov.cn/tjsj/pcsj/>). China's population census is conducted under the State Council to comprehensively investigate the size, structure, and distribution of China's population, as well as housing in urban and rural areas, and is generally carried out once every ten years. Based on the population census, China publishes annual spot checks for population changes.

(4) Carbon emissions

Afforestation leads to an increase in vegetation cover, which can improve the carbon sequestration capacity of terrestrial ecosystems and increase carbon sinks (Arneth *et al.*, 2017). Moreover, changes in carbon emissions also affect plant growth (Fatichi *et al.*, 2019). China is the world's largest energy consumer and emitter of carbon dioxide, accounting for approximately 30% of global carbon dioxide emissions (Shan *et al.*, 2017). In fact, carbon dioxide concentration increase improved the water-use efficiency in forests; thus, carbon emissions relieved the restricted effects of vegetation growth in China (Feng *et al.*, 2021). In this study, we obtained carbon emissions data from an open-access dataset: China Emission Accounts and Datasets (<https://www.ceads.net/>). The datasets provide the most up-to-date emissions and energy accounts for China and its 30 provinces (Shan *et al.*, 2020). Carbon inventories are calculated based on energy consumption and industrial production, including China's national economic accounting system of 47 economic sectors.

2.2.3 Regulation factors

Regulation factors are human responses to the ecological environment, including regulations and policies, management methods, science, and technology. Regulations can directly or indirectly affect the temporal and spatial changes of vegetation by promoting socioeconomic development and influencing natural factors. From a management perspective, investments in agriculture and forestry-related industries are policy-oriented. In addition, planning texts, laws and regulations, and administrative systems are closely related to regulation factors. According to economic theory, the market is efficient in resource allocation, but it is not omnipotent. When the market is not able to function efficiently, government intervention is necessary to remedy the market failure to distribute goods and services efficiently. Especially in China's special socialist market economic system, government regulation would have a significant impact on vegetation change.

(1) System reform

A reasonable solution to ecological and environmental problems requires the intervention of the government. However, disputes may occur between governmental departments because of unclear rights and responsibilities. Therefore, rights and responsibilities should be clearly defined among governmental departments. It is an effective way to perfect and clarify the functions of the departments and clarify the responsibilities of the employees through

system reform. The Chinese government system reform integrated the eco-civilization with the construction of economy, ethical, society and politics, so as to activate the enthusiasm of all stakeholders to participate in environmental protection (Gu *et al.*, 2020). By clarifying the departments responsible for environmental protection and resource utilization, China's greening level can be improved. The Chinese government carried out the reform of system functions in 2018. We set dummy variables to reflect the reform differences before and after 2018. We set the dummy variable to 0 until 2018 and 1 after 2018.

(2) Protecting actions

In the process of socioeconomic development, human activities may affect the natural environment, including vegetation, and cause environmental crises. To improve the natural environment, the government has taken actions to maintain and restore ecologically valuable landscapes, such as natural forests (Yin *et al.*, 2018). China has responded to a national land-system sustainability emergency via an integrated portfolio of large-scale programs mostly since 1998 (Bryan *et al.*, 2018). We used the investments in agriculture and forestry-related industries to represent the role of regulation factors in vegetation change. The data are primarily from China's statistical yearbook, and some data are from local statistical yearbooks.

(3) Laws and policies

With the construction of an ecological civilization, China has issued many laws and policies related to vegetation and greening. These laws and policies are the formulation of rules for environmental protection and resource utilization, as well as the provisions of rights and obligations of the subjects in each link of environmental protection and resource utilization. In fact, the Chinese government implemented a series of ecological policies to promote improvement of the ecological environment (Feng *et al.*, 2021). Most vegetation is a public product with positive externalities, so rational market subjects have no awareness of active protection. Laws and policies can have clear rights and obligations to internalize positive externalities. PKU Law database (<http://www.pkulaw.com/>) contains laws and policies since 1949, and the content is updated every day. Therefore, we set "nature reserve", "green space", "forest or forestry", "grassland or grass land" as keywords to search for laws and policies data. We believe that the number of laws and regulations can be regarded as policy intensity, and the more laws and regulations are issued, the greater the policy intensity.

2.3 Measuring the possible influence of vegetation change

Specific meanings of the dependent variables and independent variables are shown in Table 1.

A regression analysis was used to measure the impact of different factors on vegetation changes. The variables are measured in different units of measurement in a multiple regression analysis; therefore, we used the standardized regression coefficients to determine which of the factors have a greater effect on the changes in the NDVI according to the equation (Menard, 2004):

$$\beta^* = \beta \times \frac{\sigma_x}{\sigma_y} \quad (2)$$

where β^* is the standardized regression coefficient, β is the regression coefficient resulting from the linear regression, and σ_x and σ_y are the estimated standard deviations of x and y , respectively.

Table 1 The dependent and independent variables

Variables	Instructions
Tem	Average air temperature in provincial regions (°C)
Pre	Average precipitation in provincial regions (mm)
GDPpc	Per capita GDP (yuan per person)
Land-use	Construction land area/Total area (%)
Rural	The number of rural residents (10 thousand people)
Carbon	Annual carbon emissions in provincial regions (Mt CO ₂)
Investment	Investment in agricultural and forestry fixed assets in provincial regions (100 million yuan)
Policy&Law	The annual number of policies and regulations issued by provincial regions
DummyVar	Set it to 0 before 2018 and 1 after 2018
NDVI	The dependent variable

3 Results

3.1 Spatiotemporal changes of vegetation

The vegetation cover in China has improved significantly, and the greening area has grown remarkably from 2000 to 2019. The NDVI values are divided into five levels: low (≤ 0.2), medium-low (0.2–0.4), medium (0.4–0.6), medium-high (0.6–0.8), and high (> 0.8). From 2000 to 2010, the area of high vegetation cover rose drastically (1,568,859 km², 16.59%), while the other types exhibited a decreasing trend, in which the area of medium-high vegetation cover declined the most (12.18%), followed by the area of low vegetation cover (2.81%). From 2010 to 2019, the area of high vegetation cover also increased considerably (914,881 km², 9.67%), the area of low vegetation cover increased slightly (0.68%), and the area of the other types decreased, with the area of medium–high vegetation cover falling the most steeply (8.74%) (Table 2).

Table 2 Classification of vegetation cover in 2000, 2010 and 2019

Levels	2000		2010		2019	
	Area (km ²)	Proportion (%)	Area (km ²)	Proportion (%)	Area (km ²)	Proportion (%)
Low	2656560	28.09	2391200	25.28	2455382	25.96
Medium-low	1073466	11.35	1056010	11.17	968517	10.24
Medium	1044075	11.04	910148	9.62	845327	8.94
Medium-high	3841472	40.62	2689320	28.43	1862571	19.69
High	842643	8.91	2411538	25.50	3326419	35.17

The spatial distribution of NDVI has varied considerably in China over the past 20 years. As illustrated in Figure 2, the value of the NDVI was high in the east and low in the west. With the Hu Huanyong Line as the boundary, which is the dividing line of precipitation, climate, and population density in China, the values in the east of the line were greater than 0.45, while those in the west of the line were less than 0.45. Similarly, the change in vegeta-

tion cover in eastern and central China was significantly higher than that in western China. The western region has changed slightly, and the only area that has increased is near the Loess Plateau. Conversely, eastern China has changed dramatically. Overall, the quantity of vegetation has been increasing; however, there has also been a sharp decrease in the Yangtze River Delta and Bohai Rim.

Figure 3 presents the difference in the NDVI values in China from 2000 to 2010 and from 2010 to 2019. From 2000 to 2010, vegetation restoration and growth improved significantly

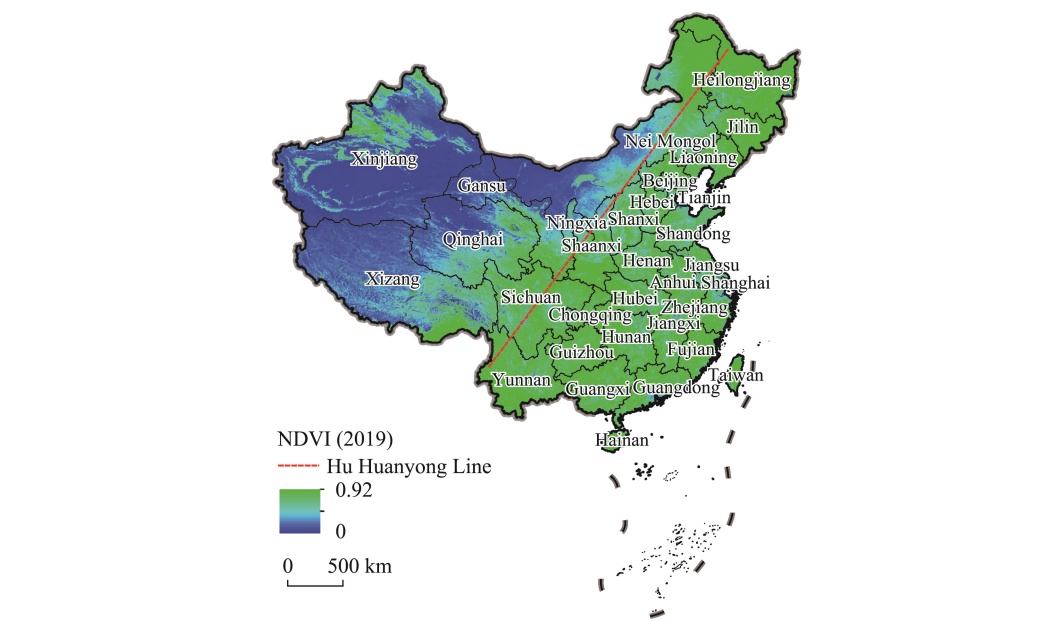


Figure 2 Spatial pattern of NDVI in China in 2019

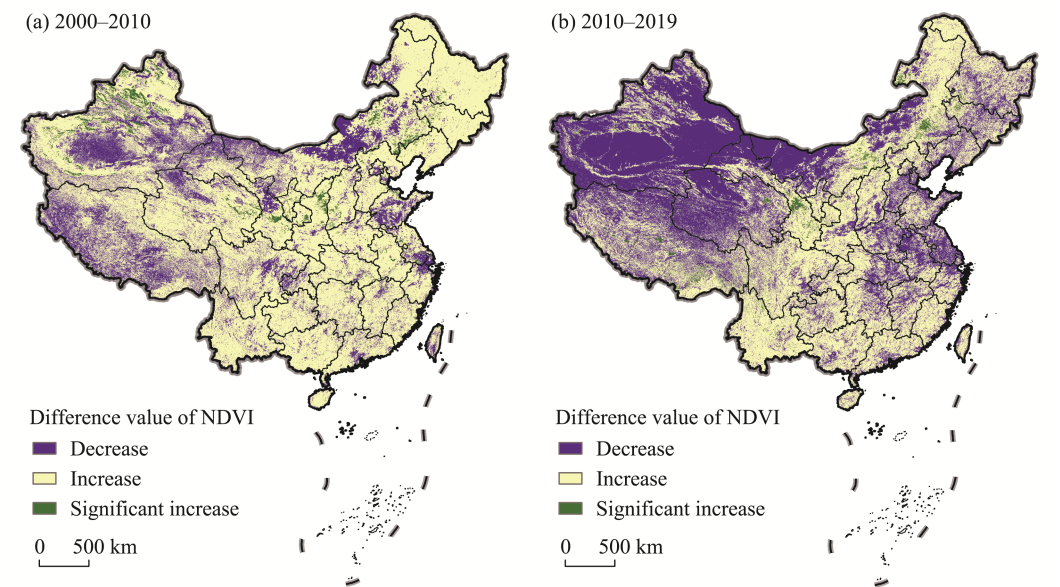


Figure 3 The difference value of NDVI in China in 2000–2010 and 2010–2019

in most areas of China, especially in oases in northeast China, the Loess Plateau, and northwest China. However, vegetation restoration in China slowed from 2010 to 2019, which was caused by varying factors in different regions. In northwest China, the NDVI value was significantly degraded owing to harsh natural conditions and unstable ecological conditions. Due to socioeconomic development in the eastern region, the increase in urban construction land slowed down vegetation recovery and growth.

For different provincial-level regions of China, the vegetation cover was developing positively, especially in the central, northeastern, and southwestern regions (Figure 4). The values in Heilongjiang, Jilin, Liaoning, Hubei, Hunan, Chongqing, Guizhou, Guangxi, Yunnan, Fujian, and Taiwan jumped from medium to high. These areas are rich in forest resources, so the effect of forest restoration is especially noticeable. For example, the NDVI of Heilongjiang increased from 0.778 in 2000 to 0.861 in 2019; therefore, it was the province with the highest vegetation cover. Furthermore, Xinjiang increased from 0.174 in 2000 to 0.219 in 2010; however, it decreased to 0.186 in 2019. As one of the most fragile and sensitive regions in China, Xinjiang's vegetation cover fluctuates regularly.

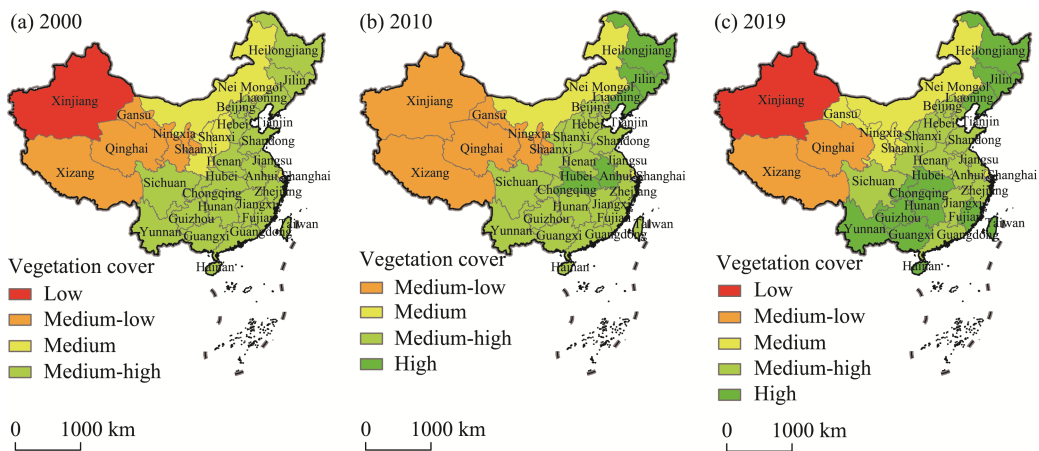


Figure 4 The classification of NDVI in China in 2000 (a), 2010 (b) and 2019 (c)

Table 3 lists the changing trends in the NDVI in the provincial-level regions of China. Shanghai, Jiangsu and Tianjin exhibited a negative growth trend, while the other provincial-level regions experienced a growth trend. Among them, Ningxia, Shaanxi, Shanxi, and Yunnan in western China witnessed the most significant growth trend, while those in Xinjiang, Shandong, Qinghai, Xizang, Zhejiang, and Taiwan only increased slightly. Ningxia, Shanxi, and Shaanxi are part of the Loess Plateau, which is one of the most environmentally sensitive areas in China. Zhejiang, Jiangsu, and Shanghai are part of the Yangtze River Delta, and Tianjin and Shandong are part of the Bohai Rim. These are regions with the most intensive economic and human activities. Xinjiang, Qinghai, and Xizang are among the most ecologically fragile regions in China, so there is not much change in vegetation.

3.2 Factors influencing vegetation changes

We used the R for the regression analysis to test the various factors affecting vegetation

Table 3 NDVI and the slope of NDVI in different provincial-level regions of China in 2000, 2010 and 2019

Provincial-level region	2000	2005	2010	2015	2019	Slope
Shanghai	0.5774	0.5257	0.5084	0.5034	0.5081	−0.00342
Jiangsu	0.7038	0.7279	0.7452	0.6810	0.6902	−0.00152
Tianjin	0.6160	0.6624	0.6673	0.6102	0.6420	−0.00001
Shandong	0.6911	0.7345	0.7042	0.6999	0.7102	0.00007
Xinjiang	0.1744	0.1879	0.2194	0.1764	0.1855	0.00025
Qinghai	0.3400	0.3614	0.3855	0.3583	0.3773	0.00149
Xizang	0.2866	0.3089	0.2998	0.3095	0.3238	0.00155
Taiwan	0.7674	0.7952	0.7892	0.7971	0.8036	0.00155
Zhejiang	0.7480	0.7634	0.7835	0.7775	0.7782	0.00158
Anhui	0.7351	0.7935	0.8147	0.7789	0.7884	0.00196
Henan	0.7311	0.7728	0.7906	0.7742	0.7823	0.00219
Beijing	0.6977	0.7225	0.7168	0.7385	0.7448	0.00230
Inner Mongolia	0.4127	0.4528	0.4468	0.4539	0.4753	0.00262
Hubei	0.7362	0.7808	0.8000	0.8037	0.8041	0.00335
Jiangxi	0.7285	0.7628	0.7775	0.7982	0.7948	0.00354
Hebei	0.6739	0.7311	0.7433	0.7319	0.7587	0.00356
Chongqing	0.7532	0.7752	0.7905	0.8152	0.8254	0.00385
Hunan	0.7331	0.7673	0.7827	0.8055	0.8079	0.00394
Heilongjiang	0.7780	0.8433	0.8457	0.8658	0.8612	0.00400
Guangdong	0.7014	0.7370	0.7439	0.7694	0.7829	0.00408
Fujian	0.7440	0.7802	0.7825	0.8197	0.8252	0.00422
Liaoning	0.7128	0.7860	0.8050	0.7955	0.8084	0.00423
Hainan	0.7455	0.7663	0.7917	0.8220	0.8222	0.00439
Gansu	0.3375	0.3705	0.3865	0.3987	0.4369	0.00470
Sichuan	0.6935	0.7313	0.7327	0.7781	0.7836	0.00475
Jilin	0.7408	0.8022	0.8200	0.8333	0.8394	0.00481
Guangxi	0.7263	0.7656	0.7877	0.8196	0.8318	0.00554
Guizhou	0.7188	0.7548	0.7815	0.8246	0.8252	0.00593
Yunnan	0.7046	0.7570	0.7562	0.8136	0.8319	0.00648
Shanxi	0.5919	0.6298	0.6715	0.6903	0.7194	0.00658
Shaanxi	0.5991	0.6603	0.6939	0.7176	0.7426	0.00720
Ningxia	0.2914	0.3124	0.3973	0.3842	0.4613	0.00852

change (Figure 5).

3.2.1 Natural factors

Natural factors are critical factors affecting vegetation cover, and the difference in vegetation cover between eastern and western China is largely related to natural factors. Therefore, we selected two factors associated with climate change: annual mean temperature and annual precipitation. The regression results suggest that annual precipitation (0.505) has a

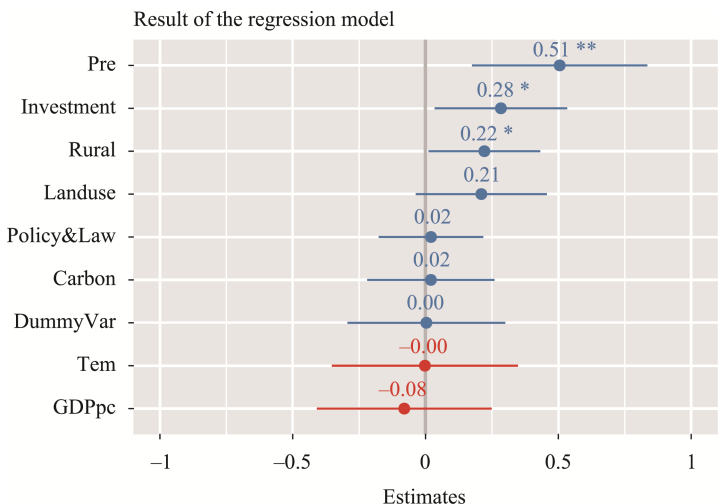


Figure 5 Results of multiple regression analysis

Note: The model's R is 0.710, which reflects a high degree of linear correlation between all the independent variables and NDVI. The R^2 is 0.505, which indicates that 50.5% of the NDVI could be explained by all the independent variables. Sig. in the model is 1.039×10^{-9} , which is less than 0.05. It proves that the variables are correlated.

more significant impact than annual mean temperature (-0.002) on vegetation change. Although both temperature and precipitation have an influence on vegetation cover, the influence of precipitation is greater than that of temperature. Vegetation growth in the three northeastern provinces is closely related to temperature because they are located at higher latitudes. For example, Heilongjiang, the northernmost province in China, experienced the largest increase in annual mean temperature of 1.21°C . The NDVI increased from 0.7780 in 2000 to 0.8612 in 2019. In the Loess Plateau region, the annual mean temperature of Shaanxi and Shanxi climbed by more than 0.6°C . The NDVI of these two provinces also increased at higher rates than those of most of the country. However, if the annual mean temperature in Shanghai, Zhejiang, and Xinjiang dropped by 1°C , the NDVI index would grow slowly or even negatively.

Furthermore, the terrain may also influence vegetation changes. The vegetation cover varies significantly between areas east and west of the Hu Huanyong Line (Figure 2). The line is the physical geographical boundary of China, which reveals the spatial pattern difference in the ecological environment in China. The line coincides with the 400 mm precipitation line and terrain dividing line, which distinguishes the sub-arid region from the sub-humid region, as well as the monsoon climate from the continental climate in China.

3.2.2 Socioeconomic factors

China's rapid urbanization has led to a large increase in the urban population and a decrease in the rural population. There was a significant positive correlation (0.222) between vegetation change and rural population reduction. Because agriculture and forestry are mostly carried out in rural areas, the excessive rural population will inevitably lead to long-term overloading of rural land, resulting in the degradation of rural land and soil erosion, which are not conducive to vegetation growth. Therefore, the reduction in the rural population has partially changed agricultural and forestry practices, which improved the intensive use and quality of rural land. China's rural population accounted for 50.32% of the total in 2010,

decreasing from 53.78% in 2000, according to several census data. It also accounted for 36.11% in 2019, according to the latest census data. Over the past two decades, the rural population in provinces where vegetation cover has increased significantly, such as Ningxia, Shaanxi, Yunnan, and Guizhou, has fallen by 25% or more.

There is no doubt that China's economy has grown rapidly in the past two decades, and economic development has had a negative impact on the ecological environment. There was a significant negative correlation (-0.08) between vegetation change and economic level. When economic development is dominated by industry and the service industry, it is bound to cause damage to agriculture and forestry, resulting in changes in vegetation cover. In China, economic development has reduced vegetation cover, particularly in the eastern region. The Yangtze River Delta, Bohai Rim, and Pearl River Delta are among the fastest-growing regions in China, but their vegetation cover has shown a decreasing trend or is growing at a very slow rate. There has been rapid growth in GDP per capita, but the corresponding NDVI growth was not significant (Figure 6). Several regions with rapid vegetation growth, such as the Loess Plateau, the southwest region, and three northeastern provinces, have experienced relatively slow socioeconomic development. Industrialization and urbanization in these regions are not high. However, vegetation coverage is relatively high and expanding rapidly. This is inseparable from the strengthening of regulations in China in recent years.

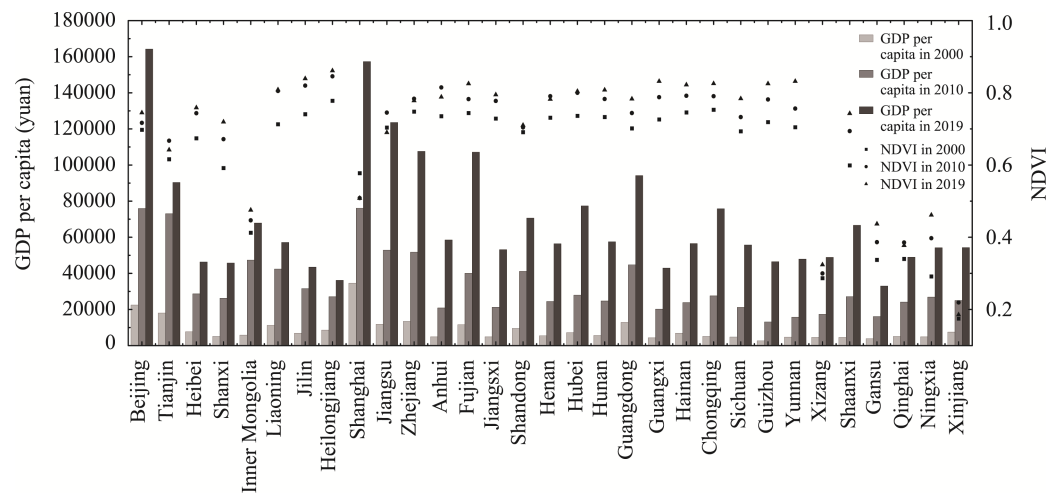


Figure 6 GDP per capita and NDVI in different provincial-level regions of China from 2000 to 2019

In addition, land utilization (0.21) and carbon emissions (0.02) demonstrated slight positive correlations with vegetation change. China pays attention to the harmony between man and land in the process of urban expansion, especially after the proposal of ecological civilization construction in 2012. As a result of the construction of sponge cities, ecological cities, and other newly constructed cities, green conditions have improved in the process of urban construction. In northern China, water is one of the most significant limiting factors for vegetation growth. Carbon emissions have increased by more than 90% in Ningxia, around 80% in Shaanxi, and more than 60% in Gansu and Shanxi over the past 20 years. The increase in carbon emissions increases the concentration of carbon dioxide, alleviates the water requirement for vegetation growth, and promotes vegetation growth.

3.2.3 Regulation factors

Regulation factors have played a strong role in promoting vegetation growth and restoration across the country. The three northeastern provinces and other regions, such as the Loess Plateau, with relatively weak economic development levels, experienced rapid vegetation growth. Several regions in central China were affected by the Rise of Central China Strategy in 2004, and the northwest regions were affected by sandstorm protection strategies, such as the Three-North Shelterbelt Program.

There is a positive correlation (0.284) between investments in agriculture and forestry-related industries and vegetation change, indicating that the more investments in these industries, the faster the growth of vegetation. From 2000 to 2019, Shaanxi increased investments by 15.49 billion yuan, and the growth rate reached 16.13%, ranking among the top in China. The growth rates of Shanxi and Guangxi were the second and third highest at 13.71% and 13.32%, respectively. Ningxia, Gansu, and Yunnan also had high growth rates of 10.59%, 8.71%, and 7.18%, respectively, which were similar to those of Heilongjiang (11.99%), Jilin (12.03%), and Liaoning (7.57%), the major agricultural and forestry provinces in northeast China. In contrast, Zhejiang (−2.86%) and Shanghai (−16.39%) reduced their investments in agriculture and forestry. Jiangsu and Shandong, which are large agricultural provinces, have experienced low growth rates compared with northeast China, which are 3.74% and 4.61%, correspondingly (Figure 7).

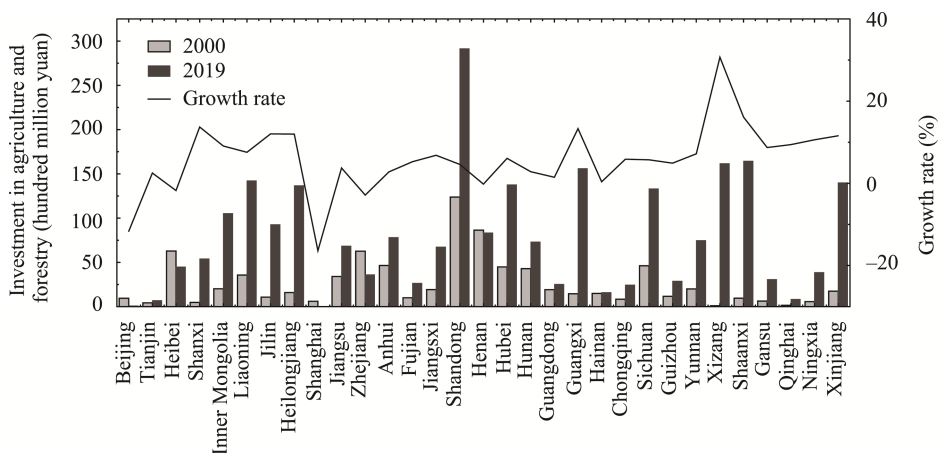


Figure 7 Investment in agriculture and the growth rate in different provincial-level regions of China in 2000 and 2019

In addition, various planning documents in China require vegetation cover. For example, the text of the Five-Year Plan, one of China's most significant plans, stipulates the relevant content of the forest cover rate. From 2000 to 2020, China experienced growth in forest coverage from 18.2% to 23.2% during the 10th to 13th Five-Year Plan periods. In the next five years (14th Five-Year Plan period), China plans to increase forest cover to 24.1% (Table 4). The implementation of strategies and plans, such as returning farmland to forest, soil erosion control, and shelterbelt strategies, has had a substantial effect on vegetation change. For example, in the provinces of the Loess Plateau, including Shaanxi, Shanxi, Ningxia, and Gansu, vegetation growth has been significantly faster due to soil erosion control and shelterbelt strategies. The growth rates in Yunnan and Guizhou are also considerably higher due

to the control of rocky desertification and rainforest recovery in these provinces.

Table 4 The target and implementation of forest cover rate from 10th to 14th Five-Year Plan periods

Five-Year Plan for China's National Economic and Social Development	10th	11th	12th	13th	14th
The target of forest cover rate (%)	18.20	20.0	21.66	23.04	24.10
The implementation of forest cover rate (%)	18.20	20.36	21.66	23.20	/

Notes: The 10th Five-Year Plan runs from 2000 to 2005, and so on to the 14th Five-Year Plan from 2020 to 2025. The implementation of forest cover rate is in 2005, 2010, 2015 and 2019 respectively, but it is temporarily blank because the target year of the 14th Five-Year Plan is 2025.

China has been reforming and improving its ecological environment management department. In 2018, the Ministry of Natural Resources and the Ministry of Ecology and Environment were established through the reform of national institutions, and the National Forestry and Grassland Administration attached to the Ministry of Natural Resources was established to integrate the management of forestry and grasslands (Figure 8). The dummy variable is 0.003, which means that government institutional reform in 2018 had a positive effect on vegetation cover.

Laws and policies (0.021) are positively correlated with vegetation coverage, so laws and policies promote vegetation growth. The central government began to issue laws and policies on vegetation change after 1978. Both the central and local governments began to work together to issue relevant laws and policies (Figure 9). It was also after 2000 that China's

Table 5 Chinese laws and regulations on vegetation protection and growth

Laws	Regulations	
	The national level	The provincial level
Forest Law of the People's Republic of China (2019 Revision)	Regulations of the People's Republic of China on Nature Reserves (2017 Revision)	Regulations of Guizhou Province on the Administration of Forest Land (2018 Revision)
Grassland Law of the People's Republic of China (2013 Revision)	Regulations on the Administration of Construction Project Protection (2017 Revision)	Regulations of Shaanxi Province on Forest Management (2000 Revision)
Environmental Protection Law of People's Republic of China (2014 Revision)	Management Rules of Felling and Regeneration of Forest (2011 Revision)	Measures of Yunnan Province for the Administration of Nature Reserves (2018 Revision)
Air Pollution Prevention Law of the People's Republic of China (2015 Revision)		Environmental Protection Rule of Guangdong province (2018 Revision)
Agriculture Law of the People's Republic of China (2012 Revision)		Regulations of Jilin Province on ecological environment Protection (2020 Revision)
Prevention and Control of Desertification Law of the People's Republic of China (2018 Revision)		Measures of Heilongjiang Province for Residential Environment Protection (2018 Revision)
Water and Soil Conservation Law of the People's Republic of China (2010 Revision)		Measures of Hebei Province for the Administration of Environmental Monitoring (2013 Revision)
The Environmental Effect Evaluation Legislation of the People's Republic of China (2018 Revision)	

Notes: Provincial regulations are incomplete statistics and some representative regulations are selected.

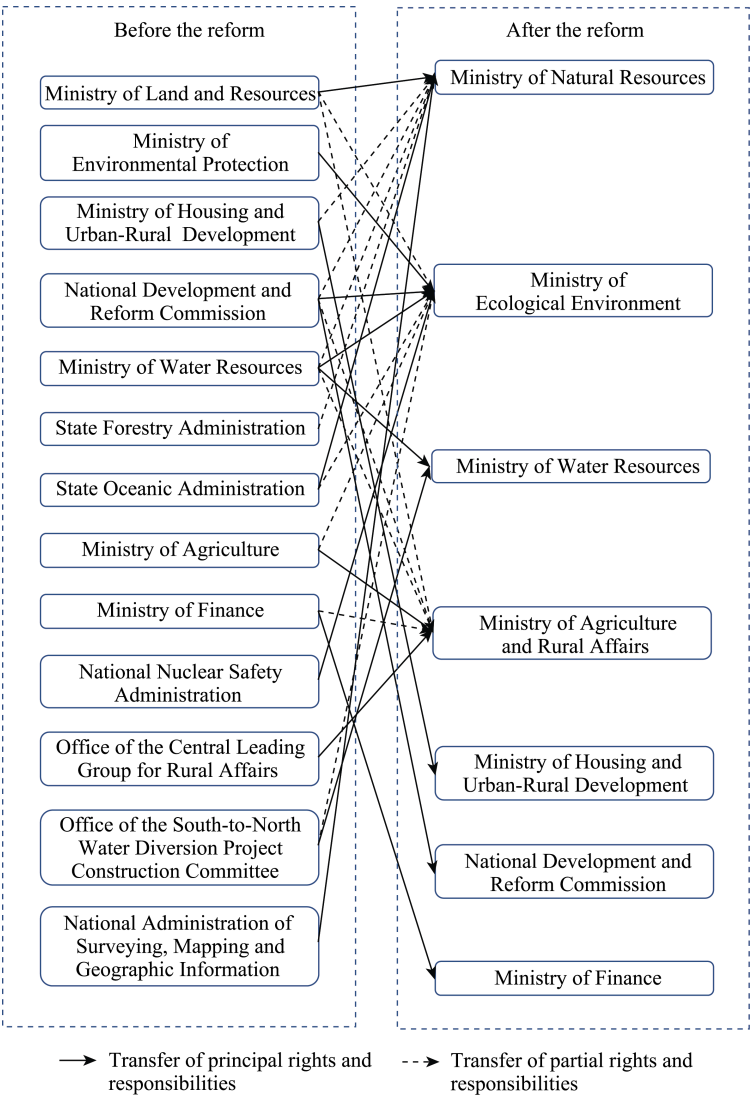


Figure 8 Reform of China's government institutions in 2018 (involving only the environmental protection sectors)

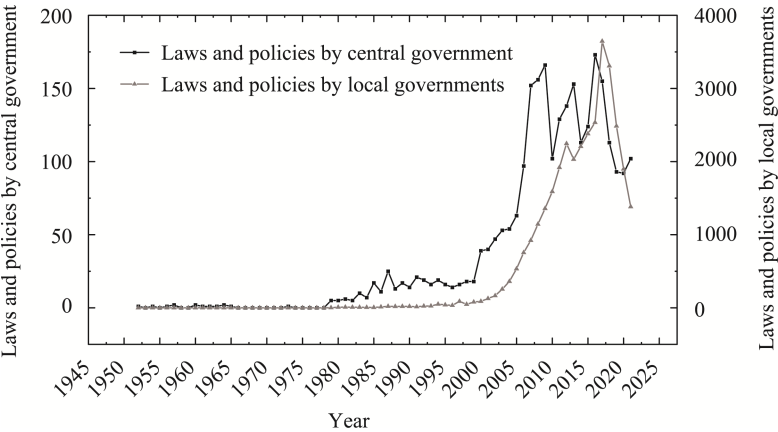


Figure 9 The laws and policies about plants in China from 1945 to 2025

land greening received widespread attention. Table 5 lists some laws and regulations on vegetation protection that are beneficial to greening. These indicate that Chinese laws and policies related to vegetation have been significantly strengthened in the last two decades. Especially in the last decade when China has been building an ecological civilization, the relevant laws and policies have obviously been strengthened in terms of level and quantity.

4 Discussion

Due to environmental degradation and climate change, the study of vegetation change has received extensive attention in recent years. The NDVI is also regarded as a valuable index for studying vegetation cover changes (Hmimina *et al.*, 2013; Ye *et al.*, 2021). The spatio-temporal patterns of vegetation change, through the study of the NDVI for China's growing seasons, especially in the provincial regions, suggest that the overall vegetation cover in China has increased; however, concerning different regions, the Loess Plateau (Shaanxi, Shanxi, Ningxia, Gansu) and southwest China (Yunnan, Guizhou) experienced substantial growth, while the Yangtze River Delta (Shanghai, Jiangsu, Zhejiang) and Bohai Rim (Shandong, Tianjin, Beijing) exhibited slow growth and even degradation. This research is similar to previous studies, while other scholars have studied vegetation changes in different regions (Li *et al.*, 2017; Qiao *et al.*, 2021).

Among the many studies on the factors of vegetation change, some have focused predominantly on climate change (Richardson *et al.*, 2013; Svenning *et al.*, 2013), while other factors have been summarized as natural factors and human activities (Chen *et al.*, 2014; Zheng *et al.*, 2021). Private interests, including enterprises and individuals, as well as governments and social organizations can represent public interests. Different types of actors would affect vegetation changes differently, but few scholars have listed the regulation factors separately from socioeconomic factors.

Government regulation can change not only the vegetation cover, but also the vegetation type. Most studies have demonstrated that the patterns of vegetation change in China vary from those in other developing countries. For example, it is publicly reported that China's greening primarily comes from forests (42%) and farmland (32%), but India's is mainly from farmland (82%), and the contribution of forests (4.4%) is small (Chen *et al.*, 2019). The increase in farmland area is often a development of agriculture, which is economically profitable due to the short growing cycle of crops. However, trees generally have a long growth cycle and therefore a long economic payback cycle. Therefore, government investment and regulation are the most effective way to promote forest area growth. In China, vegetation change is closely related to government regulations. In recent years, in response to environmental degradation, China has developed a series of strategies and measures, such as the 'integrated management of mountains, water, forest, farmland, lake, grass and sand' and 'the conviction that lucid waters and lush mountains are invaluable assets', and early prohibition of agriculture and grazing in forested areas. These measures have had a significant influence on ecological environment protection and construction, allowing aboveground and belowground biomass to recover and restore vegetation ecosystems (Sivakumar, 2007). Therefore, in this study, we considered the factors of vegetation change in China, such as natural, socioeconomic development, and regulation factors. The consideration of these fac-

tors can provide a deeper understanding of the mechanism of vegetation change in China. It can also provide a reference and reflection for the ecological restoration and growth of vegetation in China and worldwide in the future.

A positive correlation exists between natural factors and vegetation change, and precipitation has a greater impact on vegetation change than temperature. Many studies have demonstrated that precipitation is the dominant factor influencing the increase in NDVI (Fabricante *et al.*, 2009; Wang *et al.*, 2010). The higher the level of socioeconomic development, the greater the power of vegetation restoration. The current level and speed of China's socioeconomic development mainly have a positive impact on economic development. This indicates that China's economic development has begun to decouple from the ecological environment destruction represented by vegetation destruction.

Regulation factors directly or indirectly affect vegetation growth (Simmons *et al.*, 2018). In Asia, bans on logging have led to forest transitions (Mather, 2007). Forest management decentralization has facilitated the expansion of plantation forests in India (DeFries and Pandey, 2010). In southern Spain, policies of afforestation and agricultural intensification influence vegetation growth (Munoz-Rojas *et al.*, 2011). Land use restrictions on the Amazon Forest contribute to deforestation reduction in Brazil (West and Fearnside, 2021). In China, they have greatly promoted the growth of vegetation, especially agricultural and forestry investments, which demonstrated the greatest positive correlation with vegetation changes. Afforestation in the "Grain to Green" project in the Loess Plateau has also contributed greatly to vegetation restoration (Sun *et al.*, 2015). Large-scale afforestation projects in the southwest China karst area have similarly led to greening (Tong *et al.*, 2018). In addition, administrative management reforms and the construction of laws and regulations also have had a positive impact on vegetation recovery and growth. China proposed building an ecological civilization in 2010, shifting from an economy-oriented development model to one that is both economically and ecologically oriented, and launching a greening the land campaign. Through the reform and reorganization of governmental institutions, China has centralized the function of natural resources in the Ministry of Natural Resources, the function of environmental protection in the Ministry of Ecology and Environment, and the function of agriculture in the Ministry of Agriculture and Rural Affairs, thus clarifying the functions of various departments, which is conducive to the protection and growth of vegetation. The central and local governments have attached high importance to vegetation-related policies and laws over the past two decades, helping to increase China's vegetation cover.

5 Conclusions

Because most studies on vegetation change have been conducted from two aspects, natural factors and human activities, this study analyzed the spatiotemporal patterns of vegetation change in China over the past two decades using spatial analyses through ArcGIS and regression analyses through R. The driving factors of vegetation change in China were analyzed from three aspects: natural, socioeconomic development, and regulation factors.

In this study, we found that from 2000 to 2019, vegetation cover in China increased and greening was substantial, especially on the Loess Plateau and southwest China. The growth rate was the fastest and the greening was the most significant. However, the growth rate was slow in the Yangtze River Delta and the Bohai Rim region, and vegetation cover decreased

in Shanghai, Jiangsu and Tianjin.

As expected, the patterns of vegetation cover change were influenced by natural, socio-economic, and regulation factors. Natural factors have effects on vegetation change, especially precipitation. The more precipitation, the more vegetation growth. Socioeconomic development factors mainly have positive effects on vegetation change, which also suggests how to coordinate the relationship between economic development and environmental protection in future development.

Regulation factors also actively influence vegetation changes. China has actively promoted vegetation growth with investments, plans, policies, administrative reforms, and laws and regulations. This is true in particular in key areas of ecological restoration, such as the Loess Plateau and southwest China. Although some scholars have classified regulation factors as socioeconomic development factors, regulation factors have an indirect, as well as a direct, effect, especially in China's system. Therefore, it is particularly pertinent to study their roles separately.

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