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Influences of Climatic Factors and Human Activities on Forest–Shrub–Grass Suitability in the Yellow River Basin, China

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Abstract: Natural and human factors co-drive changes in vegetation type and distribution. In this study, we constructed an index system covering 17 natural and human activity indicators in six dimensions by using climate data, county-level human activity data, and forest–shrub–grass suitability data from 448 sample counties in the Yellow River Basin of China in 2018. On this basis, we evaluated the influence of human activities and climatic factors on vegetation suitability using multiple regression and relative importance analysis methods. The multiple regression results demonstrate that climatic factors had positive effects on vegetation suitability in the Yellow River Basin, while the influence of human activities on vegetation suitability varied according to the situation. Specifically, economic factors such as per capita disposable income of urban residents and per capita disposable income of rural residents; urbanization factors such as population density, urbanization rate, and construction land area proportion; social development factors such as road density; and agricultural production factors such as the cultivated acreage proportion and the value added of the primary industries proportion all influence vegetation suitability. There is a great regional heterogeneity in the effects of human activities such as economic factors and urbanization factors on vegetation suitability. The relative importance analysis results show that the relative importance of the factors influencing vegetation suitability in the Yellow River Basin was as follows, in order of importance: climatic factors > agricultural production factors > urbanization factors > ecological projects > social development factors > economy factors; however, except for climatic factors, the importance of other influencing factors varied from region to region. This study provides a theoretical basis for optimizing vegetation adjustment schemes and forest and grass ecosystem layout according to regional characteristics.

Keywords: climatic factors; forest–shrub–grass suitability; human activities; Yellow River Basin

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1. Introduction

Forests and their associated environments, including land use type, topography, soil, climate, water, and all living things constitute a natural complex with intricate relationships between factors. For plots with different site conditions, their constituent elements are different in quality and quantity; this also results in a variation of the suitability of the growth and reproduction of plants and animals [1]. Therefore, the principle of "matching site with trees and forests" is of great importance.

In recent years, many studies have investigated and measured the temporal and spatial changes and influencing factors of vegetation-related indicators; in general, these indicators can be divided into two categories. The first category includes "quantitative" evaluators of vegetation, which reflect the coverage status of vegetation, involving normalized differential vegetation index (NDVI) [2,3], enhanced vegetation index (EVI) [4,5], ratio vegetation index (RVI) [6], and other indicators. In the long run, the condition of vegetation should be fundamentally determined by the physical geography and ecological environment. In the short run, the social and economic factors of human beings are undoubtedly the important driving factors affecting the dynamics of vegetation. Taking vegetation cover as an example, it is generally believed that temperature and precipitation are the main climatic factors affecting the dynamics of vegetation cover [7,8]. Some studies also focus on the influence of elevation, slope, and topographic height factors on vegetation cover dynamics [9,10]. With rapid economic development, increasing attention has been paid to the influence of human activities on the dynamics of vegetation cover, such as land use change [2,11], population density [3], gross domestic product (GDP) [12], and night light [13]. The second category includes "quality" evaluation indicators of vegetation, such as vegetation suitability [14]. However, there is still a lack of information in the literature on the influencing factors of vegetation suitability. Wang et al. (2021) evaluated the vegetation suitability of two typical revegetation species in the Loess Plateau of China, *Stipa bungeana* and *Robinia pseudoacacia*, and delineated the current and future suitable distribution boundaries [14]. In addition, land suitability analysis (LSA) for afforestation have been carried out using the MCDM-based AHP method in India [15]; however, the influencing factors of vegetation suitability were not analyzed.

We set our sights on the Yellow River Basin in China. This region includes many major agricultural production areas, such as the Huang–Huai–Hai Plain, the Fenwei Plain, and the Hetao Irrigation Area, with profound agricultural and animal husbandry heritage, and its grain and meat output accounts for about one-third of China's total. However, ecological problems and uneven development in the region still exist. On the one hand, the Yellow River remains one of the rivers with the highest sediment content, the most serious water damage, and the greatest governance challenges in the world. There are patches of ecologically sensitive and vulnerable areas. On the other hand, with the rapid development of human society, even if economic disparities between the Yellow River Basin regions are shrinking year by year [16], regional economic differences—derived from different scales such as provinces [17], cities [18], counties [19], and rural areas [20]—still exist. The Chinese government has implemented a series of major ecological protection and restoration projects in the Yellow River Basin, such as "grain for green" and "wetland protection and restoration". However, the implementation of these projects has not been satisfactory. This may be largely due to insufficient understanding of these factors, which may lead to a high degree of homogeneity of these projects in different regions, which violates the principle of rational implementation in response to differences in natural and even economic and social conditions between regions [21]. In view of the large amount of capital and labor required for the implementation of major engineering projects, it is necessary to clarify the relative importance of natural factors, socioeconomic factors, and ecological policy projects on vegetation suitability as soon as possible, so as to formulate policies more effectively.

In summary, it is important to evaluate vegetation suitability in the Yellow River Basin and explore its influencing factors. The aims of this study were as follows: (1) Based on the results of vegetation suitability evaluation in the Yellow River Basin, explore the spatial variation characteristics of forest and shrub vegetation suitability in 448 counties in the study area. (2) Carry out a quantitative analysis of the factors influencing vegetation suitability. Based on the statistical data of climate, socioeconomic and policy indicators at the county scale in the Yellow River Basin, a multiple regression model was established to investigate the influence of climate, social, economic, and policy factors on vegetation suitability, while the importance of climate and human and social activity factors on vegetation suitability was ranked based on relative importance analysis. (3) Based on the analysis results, policy recommendations are proposed for the problems in the process of carrying out vegetation restoration in the Yellow River Basin, with a view to providing a scientific basis for vegetation restoration and adjustment, high-quality development of forestry and grasses, and ecological environment construction and management in the Yellow River Basin.

2. Materials and Methods

2.1. Study Area

The Yellow River Basin is an important barrier to China's ecological security, spanning the four major geomorphological units of the Qinghai–Tibet Plateau, the Inner Mongolia Plateau, the Loess Plateau, the North China Plain, and the three major steps of China's topography, connecting the Kunlun Mountains in the west, Yin Mountain in the north, the Qinling Mountains in the south, and the Bohai Sea [22]. The Yellow River Basin's main streams and tributaries flow through the nine provinces of Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong, with a land area of about 1.3 million km^2 through county-level administrative regions. The climate is warm from west to east along the three steps of the terrain. The average annual temperature is 3.4 °C (in 2021), the average annual precipitation is 200–800 mm in most areas, and the precipitation in the Qinling Mountains in the south reaches 700–1000 mm [23]. The Yellow River Basin plays a significant role in ecological protection and food production; approximately 79.04% of the area is ecologically conserved land, and approximately 18.64% is arable land. Approximately 2.32% of the land is used for urban and rural building [24]. At present, the State Forestry and Grassland Administration of China has utilized the Yellow River Basin as a pilot area for the forest and grass vegetation suitability evaluation. In this study, 448 counties in 9 provinces in the Yellow River Basin were selected. Details of the study area are shown in Figure 1 below.

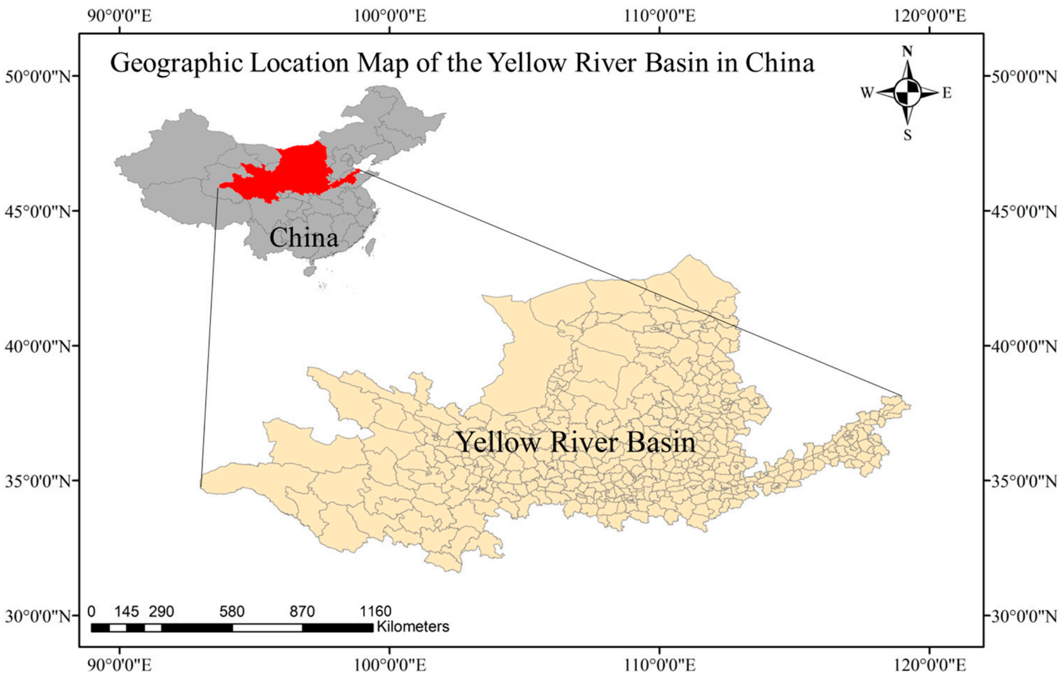

Figure 1. Geographic location of study area.

2.2. Data Acquisition and Processing

The data used in this study include vegetable suitability in the Yellow River Basin, as well as data from six dimensions: urbanization, economic, social development, agricultural production, ecological projects, and climate. Due to vegetation suitability data limitations, we only used data from 2018. Human activity data were primarily sourced from the China Statistical Yearbook (county-level), Statistical Yearbook of prefecture-level data, China

Forestry and Grassland Statistical Yearbook 2018, and China Forestry Statistical Yearbook 2002–2017 (these, in turn, gather data primarily from the China Economic and Social Big Data research platform (https://data.cnki.net/ accessed on 12 September 2022)). In the case of the few prefecture-level cities for which China Economic and Social Big Data were not found, the relevant Statistical Yearbook was used (e.g., http://tjj.baoji.gov.cn/ accessed on 28 September 2022). Climate data were obtained from World Climate Database (https://www.worldclim.org/ accessed on 11 October 2022). These indicators and their corresponding descriptions are shown in Table 1.

Table 1. The influence factors of vegetation suitability.

Latent Variable	Observed Variable	Abbreviation	Description
Forest–shrub–grass suitability	Forest–shrub–grass suitability	FSGS	Continuous variables with values ranging from 0 to 100
Urbanization factors	Population density	Pdensity	The number of permanent residents divided by the area of the administrative area, unit: 10^4 p · km^{-2}
	Urbanization rate	Urate	The local urban population divided by the total population
	Construction land area proportion	Cpropor	The area of urban development land divided by the area of the administrative district
Economic factors	Economic density	Edensity	Gross domestic product (GDP) divided by the area of the administrative district, unit: 10^8 CNY · km^{-2}
	Per capita disposable income of urban residents	UPCDI	Per capita disposable income of urban residents, unit: CNY 10^4
	Per capita disposable income of rural residents	RPCDI	Per capita disposable income of rural residents, unit: CNY 10^4
Social development factors	Road network density	Mdensity	Road mileage divided by the total land area of the administrative district, unit: km/km^{-2}
	Green coverage rate in urban built-up areas	GCrate	Green coverage rate in urban built-up areas divided by the area of the administrative district
	Number of inbound tourists per unit area	Tpropor	Number of inbound tourists divided by the total land area of the administrative district, unit: 10^4 p · km^{-2}
Agricultural Production factors	The value added of the primary industries proportion	GDP1pro	Value added of primary industry divided by GDP
	The cultivated acreage proportion	Farmpro	Cultivated land area divided by the total land area of the administrative district
	The fertilizer application per unit area	Fproper	Application of fertilizer divided by the total land area of the administrative district: unit: ton/km^{-2}
Ecological Project factors	Forest engineering	hlqd	Integer in the range of 0~5
	Grass engineering	tghc	Integer in the range of 0~1
	Wet engineering	hsqd	Integer in the range of 0~2
Climate factors	Temperature	Mtep	Annual average temperature, unit: °C
	Precipitation	Mprec	Annual average precipitation, unit: mm

2.2.1. Vegetation Suitability Data

We selected forest–shrub–grass suitability (FSGS) as a proxy variable of vegetation suitability in the Yellow River Basin. Vegetation suitability refers to the suitability of elements in the environment (including climate, soil, and topography) to provide living space and productivity for a specific vegetation type for the land use type in a specific location [15,25]. It has been demonstrated that breaking the law of vegetation zonal distribution, such as by planting vast areas of tree forests in typical forest steppe zones and grassland zones, will result in the formation of small old-growth forests on a huge scale [26]. In order to achieve sustained improvement of vegetation and increase the effectiveness of forest and grass vegetation building, it is crucial to pay attention to and properly grasp the suitability of forest and grass vegetation under the conditions of natural environmental components [27,28]. The scientific development of vegetation restoration in the Yellow River Basin will therefore benefit from investigating the appropriateness of vegetation.

The data were provided by the project "Suitability Assessment of Forest and Grass Vegetation in the Yellow River Basin" of the Chinese Academy of Forestry, which took the Yellow River Basin as the pilot area for suitability assessment of forest and grass vegetation, In addition, forest–shrub–grass suitability was evaluated using a multi-criterion decision-making (MCDM)-based analytical hierarchy process (AHP) method [15,29,30] to comprehensively assess the vegetation suitability of the site. In this project, the Yellow River Basin was divided into 8 physical geographical regions (Figure 2) according to the vegetation rating system developed by the national climate regionalization and Vegetation Map of the People's Republic of China (1:1,000,000), and with reference to the annual average temperature, precipitation, and soil regionalization data of China. Then, taking each physical geographic area as the basic unit, using various thematic data on land use type, topography, soil, climate, runoff (Table 2), and vegetation (including tree forests, shrub forests and grasslands) as the evaluation object, FSGS was obtained by the AHP method: Firstly, the contribution of different levels of secondary indicators to the growth or distribution of forest (irrigation and grass) in each natural geographic area was graded on a 100-mark scale, with higher scores denoting that the level of the indicator is more conducive for forest (irrigation and grass) growth. Secondly, the weight values of each evaluation index were obtained by the analytic hierarchy process (AHP) of multi-index decision making. Based on experts in forestry, ecology, grass science, soil and water conservation, desertification, and other research fields; industry administrators; grassroots forestry workers; and local people, two-by-two comparisons and quantitative scoring were carried out between the criterion and index levels to obtain the forest (irrigation and grass) suitability weights of each index. Finally, the FSGS (forest–shrub–grass suitability) was constructed by combining the scoring values of the secondary index levels and the weight values of each evaluation index derived by an analytic hierarchy process.

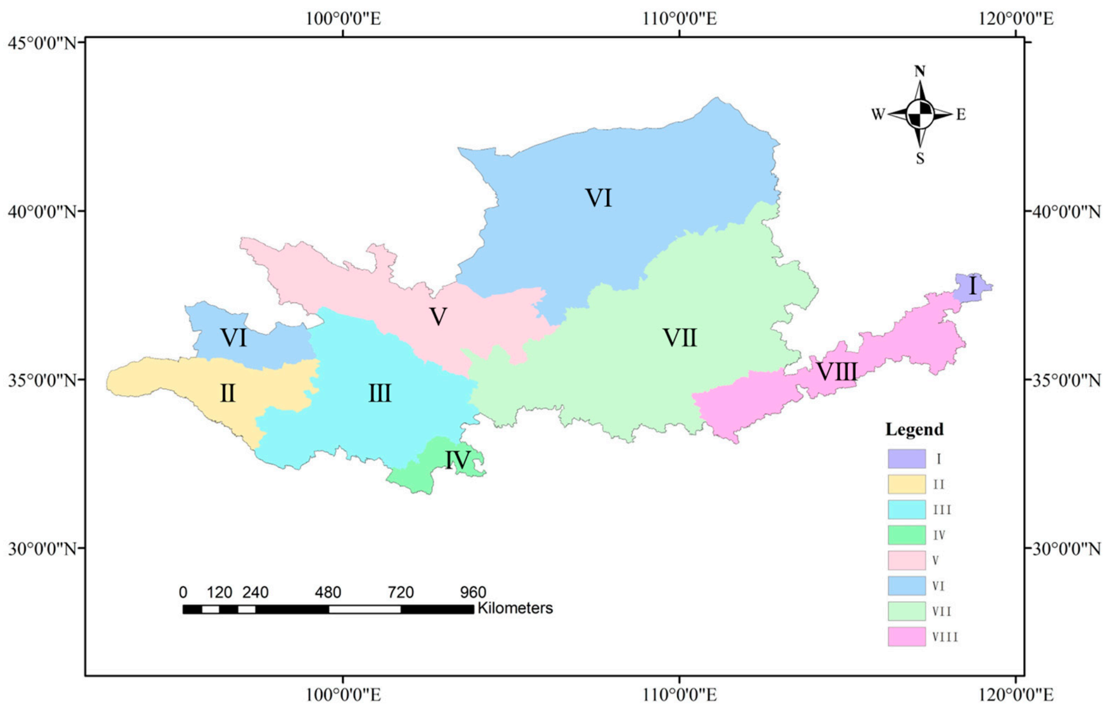

Figure 2. Geographic location of the physical geographic regions, among which from I to VIII represent the eight natural geographic divisions of the Yellow River Basin.

Table 2. Index hierarchy and data sources of vegetation suitability in the Yellow River Basin.

Criteria	Sub-Criteria	Primary Data Source
Land use type	Land use type	Data Center for Resources and Environment Sciences of Chinese Academy of Sciences (https://www.resdc.cn/DataSearch.aspx accessed on 11 October 2022)
Topography	Altitude Slope gradient Slope aspect Slope position	Geographical Information Monitoring Cloud Platform (http://www.dsac.cn/DataProduct/Dtail/20082022 accessed on 11 October 2022)
Soil	Soil depth Soil texture type Soil pH value Soil bulk density (g/cm^3) Cation exchange capacity (cmol/kg) Total nitrogen (g/kg) Total phosphorus (g/kg) Total potassium (g/kg)	National Earth System Science Data Platform (http://www.geodata.cn/ accessed on 11 October 2022).
	Alkaline nitrogen (mg/kg) Available phosphorus (mg/kg) Available potassium (mg/kg) Organic matter (g/kg)	National Data Center for Tibetan Plateau Science (http://www.tpdc.ac.cn/ accessed on 11 October 2022).
Climate	Annual average temperature Average temperature of coldest quarter Average temperature of warmest quarter Annual precipitation Precipitation of wettest quarter Precipitation of driest quarter	World Climate Database (https://www.worldclim.org/ accessed on 11 October 2022).
Runoff	Groundwater depth (mm)	National Data Center for Glaciology and Permafrost Desert Science (http://sdb.casnw.net/ accessed on 11 October 2022)

2.2.2. Human Activities

Human activities can affect geomorphic features and ecological environments. It has been concluded that urbanization expansion has an inhibitory effect on vegetation cover [31–33]. Rapid urban development leads to the extensive transformation of vegetation areas to impervious surfaces, profoundly changes the atmospheric and climatic conditions of urban areas, and leads to the urban heat island (UHI) effect, the increase in CO concentration, and air pollution [4,34], which will affect the growth conditions of vegetation and, thus, the suitability of vegetation. In this study, we selected (1) population density, (2) urbanization rate, and (3) urban development land proportion as the secondary indicators of urbanization factors. The urbanization data used included urban population, permanent resident population, construction land area, administrative area, and urbanization rate.

The Yellow River Basin is an important economic zone in China. In 2018, the GDP of 9 provinces and regions along the Yellow River accounted for 26.1% of China's total [16], indicating that the Yellow River Basin plays a very important role in China's economic and social development. However, it must be admitted that economic differences still exist among regions in the Yellow River Basin [17–20]. In this study, we selected (1) economic density, (2) per capita disposable income of urban residents, and (3) per capita disposable income of rural residents as secondary indicators to refer to economic factors. The economic data used included gross regional product (GDP), administrative area, per capita disposable income of urban residents, and per capita disposable income of rural residents.

In this study, we also selected (1) road network density, (2) green coverage rate in urban built-up areas, and (3) number of inbound tourists per unit area as secondary indicators of social development factors. The data used included highway traffic mileage, green coverage area of built-up areas, annual tourist arrivals, and administrative area.

The improvement of agricultural productivity is an important factor for the improvement of the effectiveness of vegetation restoration in the Loess Plateau [35]. In this study, we selected (1) the value added of the primary industries proportion, (2) the cultivated acreage proportion, and (3) fertilizer application per unit area as the secondary indicators to measure the factors of agricultural development. The data used included added value of the primary industry, gross regional product, cultivated land area, conversion amount of fertilizer application, and administrative area.

Among the human activity factors affecting vegetation suitability, the influence of ecological engineering projects cannot be ignored. Since 1999, the Chinese government has implemented the multi-period Grain for Green (GFG) program. By planting trees on the original cultivated land and increasing the vegetation coverage rate of steep slopes, the sloping farmland and upland land originally covered by sparse crops have been replaced by woodland and grassland, thus reversing the environmental deterioration in the Yellow River Basin. Through the joint action of climate organizations and governments [36], vegetation coverage has increased slightly. Other studies [37] found that after the implementation of GFG in China, the vegetation restoration rate was more than six times that before the implementation. Wu et al. [5] pointed out in their study on spatiotemporal evolution characteristics and driving forces of the vegetation index in Sichuan Province based on the MODIS-EVI index that the growth of EVI in Sichuan Province during 2001–2018 was mainly driven by artificial ecological engineering. Therefore, we divided the policy factors affecting the suitability of vegetation in the Yellow River Basin into three fields: (1) forestry ecological engineering, (2) grassland ecological engineering, and (3) wetland ecological engineering. Then, we studied the implementation of major projects in each field to demonstrate policy influence.

Specifically: (1) The major forestry ecological projects include the Natural Forest Protection Project, GFG Project, Three-North Shelterbelt System and other major shelterbelt system construction, Beijing-Tianjin Sandstorm Source Control Project, and Rocky Desertification Control Project. According to the implementation of the above five projects, we put forward the dummy variable of forest engineering. For each project, if the study county has implemented it, the dummy variable of the project was denoted as 1; otherwise, it was denoted as 0. The final forest engineering indicator was obtained by summing up the implementation of the 5 projects, whose values can be 0, 1, 2, 3, 4, or 5. Due to data limitations, we could not accurately obtain the implementation of each project in the study counties in 2018, so we had to use provincial data instead. The Natural Forest Protection Project and the GFG Project have been implemented in all the provinces in the Yellow River Basin except Shandong Province. In addition to Sichuan Province, the Three-North Shelterbelt System and other major shelterbelt system construction projects have been implemented in the Yellow River Basin. The Beijing-Tianjin Sandstorm Source Control Project is implemented in Inner Mongolia, Shanxi, and Shaanxi provinces, and the Rocky Desertification Control Project is only implemented in Sichuan Province.

(2) The major grassland ecological projects include the Grazing Withdrawal Project and the Beijing-Tianjin Sandstorm Source Control Project. Since 2011, China has established a subsidy and reward mechanism for grassland ecological protection in several provinces. Similarly, we selected the dummy variable of "whether the county has implemented the Grazing Withdrawal Project or not" as a proxy variable, with its value being 0 or 1. In this study, when searching the official government website or news through Baidu, if there was a report of a county in 2018 returning farming (grazing) land to grassland, or if there was a subsidy provided for returning farming land to grassland, we scored this as 1.

(3) The major wetland ecological projects include the Converting Croplands to Wetlands project and Wetland Protection and Restoration Project. In this study, dummy variables of whether the above two projects are implemented or not were constructed as proxy variables to measure the grass engineering status, with their values being 0, 1, or 2.

2.2.3. Climate Factors

Vegetation status is closely related to hydrothermal conditions. Scholars [38–40] have studied the effects of various climatic factors, such as sunshine, evaporation, humidity, temperature, and precipitation, on vegetation cover change. The natural geographical and ecological factors affecting the suitability of vegetation mainly include climate and natural disasters [41]. In this study, temperature and precipitation were selected as the secondary indexes of climatic factors.

2.2.4. Data Processing

In this study, the missing values were treated as follows: (1) The average value of corresponding indicators of each county in the same city was calculated to complete the missing data of each county. (2) For the indicator of fertilizer application per unit area, the numerator in the calculation formula is fertilizer consumption converted into pure amount. Since the county-level data of Ningxia Hui Autonomous Region only includes the physical amount of chemical fertilizer use, according to the Statistical Yearbook of Ningxia 2021, we found that the physical amount of chemical fertilizer in Ningxia in 2018 was 1.01 million tons, while the pure amount was 390,000 tons. Therefore, the conversion rate = pure amount/physical amount = 0.3861. Based on this, we converted the physical amount data for fertilizer application in counties of Ningxia into a pure amount. Similarly, the physical amount of chemical fertilizer consumption in Qinghai Province in 2018 was 228,200 tons, while the pure amount of chemical fertilizer consumption was 83,200 tons. Finally, the conversion rate between the pure amount and the physical amount was 0.3636; thus, the physical amount of each county in Qinghai was converted. (3) In the case of some individual data which were still missing after being supplemented and could not be replaced with other methods, the data were deleted during the empirical study. In addition, descriptive statistical analysis, multiple regression analysis, and relative importance analysis were carried out in this study based on version 17 of the STATA software. We chose the forward selection procedure to add the variables and used AIC and BIC as information criteria to determine the suitability of the model and found that the AIC and BIC of current model were 1847.9 and 1921.21, respectively; both of which were minimal, proving that the model is optimal at this time.

2.3. Methods

2.3.1. Multiple Regression Analysis

In real life, a variable is rarely impacted by only one factor; rather, it is frequently influenced by various factors. Multiple regression analysis can identify a functional relationship (model or equation) between the response or dependent variable and the explanatory or independent variable. Additionally, it permits us to explicitly control for a variety of additional variables that have an impact on the dependent variable, allowing us to create more accurate predictive models for the latter [42].

Previous researchers have utilized multiple regression models to investigate the effects of drought and climatic variables on vegetation dynamics [43] as well as the determinants of vegetation cover and its regional variations in China [44]. However, few studies have examined the variables determining vegetation suitability using multiple regression models. Because FSGS data in this study have a continuous value between 0 and 100, the multiple regression model that is shown below is built up to investigate the variables that affect vegetation suitability.

$$Y_i = \beta_0 + \beta_1 X_{i1} + \ldots + \beta_k X_{ik} + u_k \quad (1)$$

where Y_i, as the explanatory or response variable represents county i's vegetation suitability. X_{ik} is the explanatory variables, and u_k is the random error term. X_{ik} includes the control variables, which are composed of factors including temperature, precipitation, urbanization, economic, social development, agricultural production, and ecological engineering. $\beta_0, \beta_1, \ldots, \beta_k$, commonly referred to as regression coefficients, are model parameters. β_0

is the constant term, and $\beta_1, \ldots, \beta_k$ are the partial regression coefficients, showing the average change in y that results from one unit of change in X_i when the other independent variables remain unchanged. This study examined the regional heterogeneity of human activity and climatic factors' effects on vegetation suitability in the context of the Yellow River basin's broad regional range and the significant differences in human activity status and climatic conditions among the upstream, midstream, and downstream regions (See Appendix A for details of the division).

2.3.2. Relative Importance Analysis

When using multiple regression models to investigate the factors influencing vegetation suitability, we can only demonstrate which factors affect vegetation suitability. The importance of different factors on vegetation suitability is not known. Since the deviation coefficients obtained from the regression results cannot be compared directly, we cannot simply standardize the different influencing factors. Therefore, in order to compare the relative importance of each explanatory variable to the variation degree of the explained variable, we integrated Shapley value analysis with the relative importance analysis (RI analysis) method of Budescu [45] and Azen et al. [46]. The relative importance of the variables is measured by comparing the independent contribution of different explanatory variables to the model fit. To facilitate the analysis, the relative importance indicators were standardized so that the sum of the relative importance indicators of each explanatory variable of the model after standardization was equal to one.

The most basic principle of relative importance analysis (RI analysis) is to compare the relative importance of different variables, which essentially analyzes the additional contribution of variance explained by all possible subset models and ranks the contribution of the relevant variables. When a variable is added to a subset model, the added R^2 is the degree of contribution of the variable. Obviously, if all variables in the model are not correlated, we only need to calculate the contribution of each variable separately and then compare them. However, in most of the models, the variables are significantly correlated. In this case, we must consider the correlation to accurately assess the contribution of the variables to R^2. The relative importance of the variables in the model is defined as their additional contributions (AC) to R^2. To calculate the additional contribution of variable X, we must consider all possible scenarios in the different subset models of variable X based on the original model.

For example, There are two ways to represent X_2's contribution to Y:

$$Y = \beta_0 + \beta_2 X_2 + \varepsilon \quad (2)$$

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon \quad (3)$$

The first way is shown in Equation (2), where there is only one variable on the right-hand side, X_2, whose contribution is $RI_1 = R^2(X_2)$. The other way is to place X_2 into the model of Equation (3) and obtain the new model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (4)$$

The model's goodness of fit is R2(X1, X2). And from this, we obtain the contribution of X_2 to Y, namely $RI_2 = R^2(X_1,X_2) - R^2(X_1)$. Obviously, if X_1 and X_2 are correlated, RI_1 will overestimate X_2's contribution, while RI_2 will underestimate X_2's contribution. Budescu [45] and Azen et al. [46] evaluated the contribution of X_2 using an average treatment, i.e., $R_I = (RI_1 + RI_2)/2$. If there are k variables in the model, then there will be, correspondingly, $(2^k - 1)$ subset models. At this time, the contribution of each variable in all subset models needs to be calculated and evaluated to obtain the final appropriate contribution of each variable.

3. Results

3.1. Comparison of FSGS Results in the Yellow River Basin

Figure 3 shows FSGS scores in different regions of the Yellow River Basin. It can be seen that the vegetation suitability index of the Yellow River basin is concentrated in two grades: generally suitable (20–50) and relatively suitable (50–80). In general, FSGS increases from west to east along the Yellow River, with lower FSGS in the upper reaches and higher FSGS in the middle and lower reaches. The counties with the highest FSGS were concentrated in Henan, Shaanxi, and Shandong provinces.

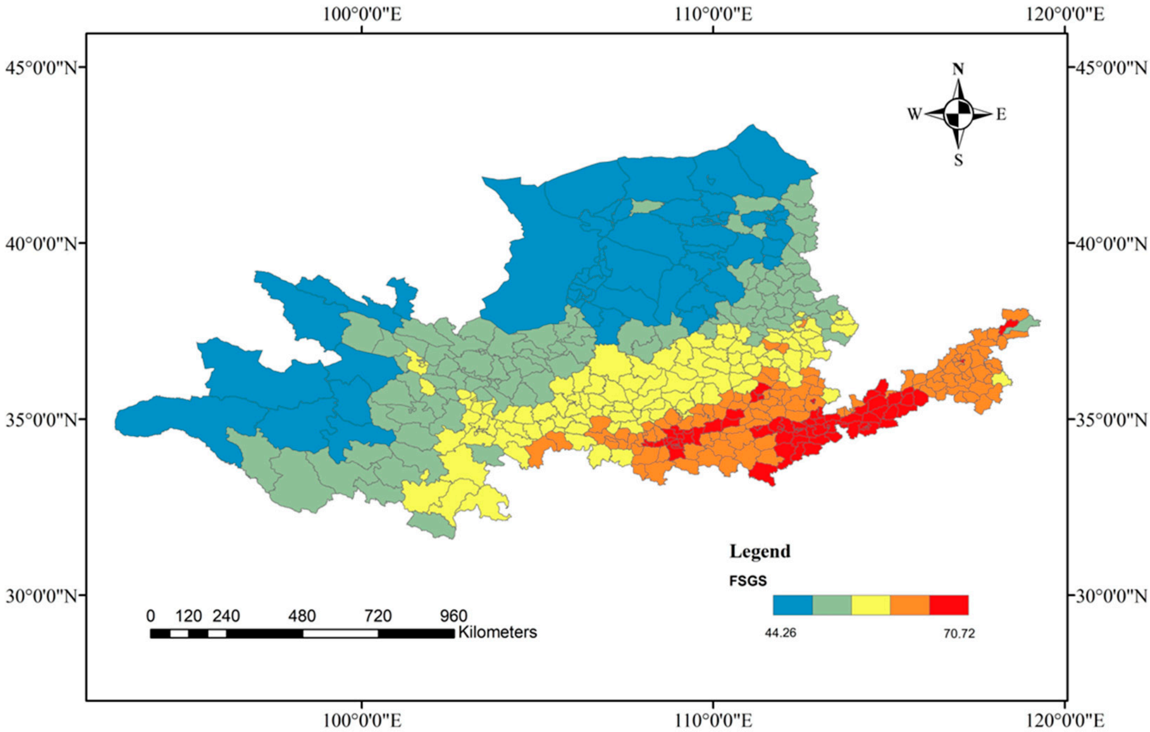

Figure 3. FSGS scores in the Yellow River Basin.

3.2. Descriptive Characteristics of the Driving Factors

Table 3 shows the basic descriptive statistics. As for climatic factors, the large temperature difference is a major feature of the climate in the Yellow River Basin, with the lowest being −4 °C and the highest being 15 °C. The precipitation here also has significant regional differences, with the lowest being 115.7 mm and the highest being 815.3 mm. In addition, due to the wide variety of natural conditions such as geomorphology, climate, and ecology in the upper, middle, and lower reaches of the Yellow River, the counties in the Yellow River Basin differ greatly in economy, urbanization, social development, and agricultural production.

Table 3. Descriptive statistical analysis of the possible influence factors of FSGS.

Variable		N	Mean	SD	Min	Max
FSGS	FSGS	448	58.48	5.890	44.26	70.72
Economic factors	Edensity	448	0.685	2.772	0.0001	41.30
	UPCDI	448	3.060	0.711	0.956	5.659
	RPCDI	448	1.259	0.439	0	3.352
Urbanization factors	Pdensity	448	0.0835	0.247	0	2.908
	Urate	448	0.526	0.212	0.0736	1
	Cpropor	448	0.126	0.151	0	1.151

Table 3. *Cont.*

Variable		N	Mean	SD	Min	Max
Social Development factors	Mdensity	446	1.464	2.600	0.0237	25.43
	Tpropor	447	2.179	16.77	0	247.8
	GCrate	447	0.311	0.124	0.00921	0.800
Agricultural Production factors	Farmpro	448	0.302	0.210	0	1.804
	GDP1pro	448	0.132	0.113	0	0.640
	Fproper	438	16.56	38.93	0	712.1
Ecological Project factors	hlqd	448	3.301	0.888	1	4
	hsqd	448	0.781	0.746	0	2
	hcgc	448	0.317	0.466	0	1
Climate factors	Mtep	448	515.4	144.4	115.7	815.3
	Mprec	448	8.874	4.279	−4.557	15.14

Note: The number of observations in this study is 448. The minimum values of variables such as population density, construction land area proportion, number of inbound tourists per unit area, and the cultivated acreage proportion were low and close to zero, so the minimum values of these variables were taken to be zero.

3.3. Regression Results

Table 4 shows that, in terms of economic factors, economic density has no discernible impact on vegetation suitability. Per capita disposable income of urban residents significantly reduces vegetation suitability, but this effect is not present in the regression of grouping in the upper, middle, or lower reaches. In contrast, per capita disposable income of rural residents significantly increases vegetation suitability, and the effect is still significant in the midstream and upstream regions after the regression of grouping, but it shows the effect of inconsistent direction of effect. In particular, the per capita disposable income of rural residents has a significant positive effect on vegetation suitability in the midstream region, a significant negative effect on vegetation suitability in the upstream region, and no significant effect on vegetation suitability in the downstream region.

Table 4. Regression results of climate factors and human activities on forest–shrub–grass suitability in the Yellow River Basin, China.

Variables		(1) Overall Sample	(2) Upstream Areas	(3) Midstream Areas	(4) Downstream Areas
Economic Factors	Edensity	0.061	−0.355	−0.040	−0.431
		(0.58)	(−1.13)	(−0.30)	(−1.58)
	UPCDI	−0.571 ***	−0.313	0.067	−0.491
		(−3.28)	(−1.33)	(0.23)	(−0.50)
	RPCDI	0.677 ***	−0.927 *	0.946 ***	0.043
		(2.76)	(−1.76)	(2.98)	(0.08)
Urbanization Factors	Pdensity	1.620 **	4.629	1.439	−0.232
		(2.31)	(1.05)	(0.79)	(−0.17)
	Urate	−1.570 **	−0.874	0.134	−1.650
		(−2.04)	(−1.20)	(0.14)	(−0.33)
	Cpropor	5.041 ***	0.325	2.252 *	0.812
		(3.60)	(0.16)	(1.75)	(0.29)
Social Development Factors	Mdense	0.064	0.251 ***	0.111 *	0.425 ***
		(1.42)	(3.60)	(1.79)	(3.13)
	Tpropor	0.005	0.031	0.008	−0.030
		(0.38)	(0.37)	(0.72)	(−0.22)
	Gcover	1.079	−1.853	0.631	4.131 *
		(1.32)	(−1.63)	(0.64)	(1.73)

Table 4. *Cont.*

Variables		(1) Overall Sample	(2) Upstream Areas	(3) Midstream Areas	(4) Downstream Areas
Agricultural Production Factors	Farmpro	1.588 *	2.315 **	3.496 ***	−3.407 *
		(1.94)	(2.25)	(4.06)	(−1.92)
	Fpropor	0.008 **	−0.006	−0.001	0.008
		(2.23)	(−0.20)	(−0.56)	(0.52)
	GDP1pro	2.640 **	−0.730	0.690	1.724
		(2.56)	(−0.55)	(0.43)	(0.27)
Ecological Projects	hlqd	0.446 ***	−1.335 ***	−0.345	−0.078
		(2.99)	(−2.84)	(−0.96)	(−0.16)
	hsqd	−0.309 *	−0.555 ***	0.025	−0.301
		(−1.96)	(−3.07)	(0.15)	(−0.71)
	hcqd	0.132	0.037	−0.912 **	0.272
		(0.49)	(0.14)	(−2.04)	(0.31)
Climatic Factors	Mprec	0.022 ***	0.016 ***	0.018 ***	0.010
		(27.61)	(14.05)	(9.58)	(1.14)
	Mtep	0.634 ***	0.305 ***	1.000 ***	3.604 ***
		(14.96)	(5.65)	(11.66)	(4.69)
n		434	160	215	59
R^2		0.890	0.888	0.914	0.659

Note: ***, **, and * indicate significance at the levels of 1%, 5%, and 10% respectively. The numbers in parentheses are t-values.

In terms of urbanization factors, urbanization rate has a significant negative effect on vegetation suitability, whereas population density and construction land area proportion both significantly promote it. In the heterogeneity test, only the construction land area proportion still significantly enhanced vegetation adaptability in the midstream region, with the effects of urbanization rate and population density on vegetation suitability becoming non-significant. In terms of social development factors, road density has no discernible impact on vegetation suitability, but the heterogeneity grouping shows that road network density significantly promoted vegetation suitability in both upper-, middle-, and lower-reach areas. Annual tourist arrivals and urban green space did not significantly affect the appropriateness of vegetation. The regression findings of the other groups were also non-significant in the heterogeneity test, with the exception of the downstream area where urban greenery coverage demonstrated a substantial positive effect on vegetation suitability.

In terms of agricultural production factors, the overall sample revealed a favorable relationship between agricultural production and vegetation suitability. Among these factors, cultivated acreage proportion and fertilizer application both positively influenced the improvement of vegetation suitability, though fertilizer application had a smaller positive impact. The value added of the primary industries proportion can also significantly promote the improvement of vegetation adaptability. After grouping regression, the cultivated acreage proportion still has a significant positive effect on the suitability of vegetation in the middle and upper reaches of the Yellow River Basin, but it has a negative inhibitory effect on vegetation suitability in the lower reaches. Fertilizer application and the ratio of primary industry output value are no longer significant in the group regression.

In terms of the implementation intensity of ecological engineering, forest engineering positively promotes the improvement of vegetation suitability, whereas wet engineering has a negative effect on vegetation adaptability. Grass engineering has no significant effect on vegetation suitability. However, by region, both the intensity of forest engineering and wet engineering showed negative inhibition on vegetation suitability in the upper reaches, while the effect in the middle and lower reaches was insignificant. The intensity of grass engineering is still not significant in group regression. The adaptability of the vegetation was significantly influenced by both the average annual precipitation and the average annual temperature, demonstrating that climatic circumstances have a substantial impact on vegetation growth.

3.4. Relative Importance Analysis Results

Table 5 shows the relative importance analysis results. Here, two climatic factors had the strongest influence on vegetation suitability in the overall sample. Specifically, the goodness-of-fit contribution of average annual precipitation was 36.91%, and the goodness-of-fit contribution of average annual temperature was 27.79%. The contribution of the cultivated acreage proportion to comparative goodness of fit was 7.62%, the green coverage rate in urban built-up areas to comparative goodness of fit was 5.67%, and the contribution of grass engineering was 5.63%, which demonstrates a great impact on vegetation suitability. All other factors contributed less than 5%.

Table 5. RI results of human activities and climatic factors on forest–shrub–grass suitability.

Variables		DS	SDS	Ranking	DS	SDS	Ranking
Economic Factors	Eden	0.0133	0.0149	10	0.0238	0.0267	6
	UPCDI	0.0061	0.0069	14			
	RPCDI	0.0044	0.0049	17			
Urbanization Factors	Pden	0.0237	0.0266	7	0.0818	0.0919	3
	Urate	0.0077	0.0086	12			
	Cpropor	0.0504	0.0567	4			
Social Development Factors	Mden	0.0177	0.0199	8	0.0313	0.0353	5
	Tpropor	0.0081	0.0092	11			
	GCcover	0.0055	0.0062	16			
Agricultural Production Factors	Farmpro	0.0678	0.0762	3	0.1059	0.1191	2
	Fpropor	0.0324	0.0365	6			
	GDP1pro	0.0057	0.0064	15			
Ecological Project Factors	hlqd	0.014	0.0157	9	0.0712	0.0799	4
	hsqd	0.0071	0.0079	13			
	hcgc	0.0501	0.0563	5			
Climate Factors	Mprec	0.3284	0.3691	1	0.5757	0.647	1
	Mtep	0.2473	0.2779	2			

Note: DS: dominance stat.; SDS: standardized domin. stat.; same below.

The results of the relative importance analysis of factors influencing vegetation suitability are provided in Table 5. Here, two climate factors have the greatest impact on the appropriateness of the vegetation in the entire sample. Particularly, the goodness-of-fit contribution of average annual precipitation is 36.91%, and the goodness-of-fit contribution of the average annual temperature contributed 27.79%. In terms of human activity factors, the contribution of the proportion of cultivated land area to the goodness of fit was 7.62%, the contribution of the proportion of built-up land area to the goodness of fit was 5.67%, and the contribution of the ecological project of grass restoration was 5.63%. The contribution of each of the other human activity factors was less than 5%.

In addition, we further analyzed the relative importance of factors influencing vegetation suitability in terms of economic, urbanization, social development, agricultural production, intensity of ecological project, and climatic factors. The results show that the relative importance of the factors influencing vegetation suitability is ranked as climatic factors > agricultural production factors > urbanization factors > ecological project factors > social development factors > economic factors, indicating that climatic factors have the strongest effect on vegetation suitability, followed by agricultural production and urbanization development factors. Economic factors have the weakest effect.

Table 6 shows the relative importance analysis results of factors influencing vegetation suitability in different regions of the Yellow River Basin. In terms of economic factors, per capita disposable income of rural residents contributes the most to the goodness of fit in the upper and middle reaches. In the lower reaches, it is per capita disposable income of urban residents that contributes the most to the goodness of fit. Economic density always contributes the least to the goodness of fit of vegetation appropriateness. When it comes to urbanization factors, the upstream region's urbanization rate contributes most to the goodness of fit of vegetation suitability, while the indicator that contributes most to the goodness of fit of vegetation suitability is urbanization rate in the midstream area and the population density in the downstream area. Among the social development factors, road density is the variable that contributes most to the goodness of fit of vegetation suitability in the upper, middle, and lower reaches. For agricultural production factors, the cultivated acreage proportion in both the upper and the middle reaches is the first, indicating it has the strongest contribution to the goodness of fit of vegetation suitability. In the lower reaches, the amount of fertilizer applied contributed most to the goodness of fit of vegetation suitability. In terms of ecological project factors, the relative importance of forest engineering is the highest in the upper, middle, and lower reaches. In terms of climate factors, the relative importance of average annual precipitation in the upstream region ranks first. In the middle and lower reaches, it is the average annual temperature that contributes the most to the goodness of fit of vegetation suitability.

Table 6. RI results of climatic factors and human activities on forest–shrub–grass suitability by regions.

Variables		The Upstream Areas			The Midstream Areas			The Downstream Areas		
		DS	**SDS**	**Ranking**	**DS**	**SDS**	**Ranking**	**DS**	**SDS**	**Ranking**
Economic Factors	Eden	0.0063	0.0071	16	0.0178	0.0194	10	0.017	0.0258	12
	UPCDI	0.075	0.0845	4	0.0357	0.0391	7	0.0436	0.0661	4
	RPCDI	0.0957	0.1078	3	0.0547	0.0598	5	0.027	0.041	10
Urbanization Factors	Pden	0.0103	0.0116	12	0.0254	0.0278	8	0.0274	0.0415	8
	Urate	0.0202	0.0228	9	0.0087	0.0096	15	0.0109	0.0166	15
	Cpropor	0.0068	0.0076	15	0.0574	0.0628	4	0.0147	0.0223	13
Social Development Factors	Mden	0.0223	0.0252	8	0.0211	0.0231	9	0.0544	0.0825	2
	Tpropor	0.0044	0.005	17	0.0116	0.0127	12	0.0086	0.013	16
	GCcover	0.0078	0.0088	14	0.0102	0.0112	14	0.0174	0.0264	11
Agricultural Production Factors	Farmpro	0.0552	0.0621	6	0.0462	0.0505	6	0.0273	0.0414	9
	Fpropor	0.0131	0.0147	10	0.0155	0.017	11	0.0339	0.0515	5
	GDP1pro	0.0082	0.0093	13	0.0046	0.005	17	0.0059	0.009	17
Ecological Projects	hlqd	0.1116	0.1257	2	0.0689	0.0754	3	0.0534	0.081	3
	hsqd	0.0594	0.0669	5	0.0057	0.0063	16	0.0315	0.0478	7
	hcgc	0.0124	0.014	11	0.0115	0.0125	13	0.013	0.0197	14
Climatic Factors	Mprec	0.3478	0.3916	1	0.2066	0.226	2	0.0338	0.0513	6
	Mtep	0.0315	0.0355	7	0.3124	0.3418	1	0.2392	0.3629	1

In addition, the relative importance of factors affecting vegetation suitability in different regions was further examined in this study from the perspectives of economic development, urbanization, social development, agricultural production, ecological project, and climate factor. Detailed results are shown in Table 7. In the upper, middle, and lower reaches of the Yellow River Basin, climatic factors rank first in relative importance, indicating that climatic factors have the greatest influence on vegetation suitability. However, there are differences in the importance ranking of other influencing factors. Specifically, the relative importance of upstream reaches is ranked as follows: climatic factors > ecological project factors > economic factors > agricultural production factors > urbanization factors > social development factors. In the middle reaches, it is climatic factors > economic factors > urbanization factors > agricultural production factors > ecological project factors > social development factors. In the downstream reaches, it is climatic factors > ecological project factors > economic factors > social development factors > agricultural production factors > urbanization factors.

Table 7. RI results of climatic factors and human activities on forest–shrub–grass suitability in six dimensions by regions.

Variables	The Upstream Areas			The Midstream Areas			The Downstream Areas		
	DS	SDS	Ranking	DS	SDS	Ranking	DS	SDS	Ranking
Economic Factors	0.177	0.1994	3	0.1082	0.1183	2	0.0876	0.1329	3
Urbanization Factors	0.0373	0.042	5	0.0915	0.1002	3	0.053	0.0804	6
Social Development Factors	0.0345	0.039	6	0.0429	0.047	6	0.0804	0.1219	4
Agricultural Production Factors	0.0765	0.0861	4	0.0663	0.0725	5	0.0671	0.1019	5
Ecological Projects	0.1834	0.2066	2	0.0861	0.0942	4	0.0979	0.1485	2
Climatic Factors	0.3793	0.4271	1	0.519	0.5678	1	0.273	0.4142	1

The above relative importance analysis results show that climate is the most important factor affecting vegetation suitability, while there are differences in the importance ranking of each type of influencing factor in human activities. The Yellow River Basin straddles the three major geographical steps of east, middle, and west of North China, with fragile natural ecology, water scarcity, and obvious regional differences in resource endowments, leading to great differences in the relative importance of different human activities in the upper, middle, and lower reaches of the Yellow River Basin.

4. Discussion

Many studies have found that climate change and human activities have an impact on vegetation cover changes in the Yellow River Basin, but few studies have quantified these changes. It is important to quantify the changes in climate factors and human activities on vegetation suitability for vegetation restoration in the Yellow River Basin [36]. The influence of vegetation cover change in the Yellow River Basin is multifactorial, and some of the existing studies only consider a single factor affecting vegetation growth and only use single equation models [47]. However, the factors influencing vegetation suitability are often relatively numerous. On this basis, this study uses multiple regression models to consider the effects of human activities on vegetation cover changes in the Yellow River Basin from various aspects, based on controlling climatic factors and considering increasingly frequent human activities such as the implementation of ecological projects, urbanization, agricultural production, etc. The impact of these human activities on vegetation cover has two sides [48]. Based on this, this study more comprehensively incorporated the effects of climate and human activity indicators on vegetation suitability based on the existing literature. At the same time, considering that it is important to measure not only which human activities and climate factors affect vegetation suitability but also to clarify the relative importance of each variable on the degree of variability of vegetation suitability, this study also introduced relative importance analysis to analyze the contribution of variables to vegetation suitability.

4.1. Comparison of FSGS Results in the Yellow River Basin

Figure 3 shows FSGS scores in different regions of the Yellow River Basin. It can be seen that the vegetation suitability index of the Yellow River Basin is concentrated in two grades: generally suitable (20–50) and relatively suitable (50–80). This may be because, despite being China's second-largest watershed, the Yellow River Basin has a variety of ecosystems, and most of its land is suitable for plant growth. However, the Yellow River Basin is primarily made up of arid and semi-arid regions, with insufficient natural resources and vulnerable ecosystems [48]. As a result, most areas only have a moderate level of vegetation suitability, with plenty of room for development. In general, FSGS increases from west to east along the Yellow River, with lower FSGS in the upper reaches and higher FSGS in the middle and lower reaches. Water resources in the Yellow

River Basin are congenitally insufficient, and there are significant regional variances in temperature, with highs in the southeast and lows in the northwest, as well as major annual variations [49]. Relative wetness index increases from northwest to southeast at all seasonal and annual scales, showing the characteristics of decreasing water and heat resources from south to north, with more in the southeast and less in the northwest. In general, drought is heavier in the upper reaches of the Yellow River Basin than in the middle and lower reaches [48,50], and climate is the key factor affecting the suitability of vegetation [51]. As a result, the suitability of the vegetation gradually declines, which is consistent with the trend of changing vegetation cover in existing studies and consistent with the trend of decreasing temperature and precipitation from middle and lower reaches to upper reaches [36].

4.2. Drivers of FSGS Variation

It can be seen from Table 5 that various factors, such as economy, urbanization, social development, agricultural production, ecological engineering, and climate, differ in the degree and direction of their influence on vegetation suitability. Additionally, the same factor's relative influence and importance ranking vary in various parts of the Yellow River Basin, including upstream, middle, and downstream.

4.2.1. Urbanization and Social Development Factors

In the existing studies, Ma et al. concluded that urbanization would promote vegetation coverage in Western China [44]. However, most studies believe that rapid urbanization expansion will have a negative impact on vegetation restoration [32,33]. Consistent with the conclusions of most studies, we find that urbanization factors significantly reduce vegetation suitability in the Yellow River Basin. This may be because the overall economic and social development of the Yellow River Basin is lagging. The higher the urbanization rate, the more economic activities were dominated by the secondary industry, thus reducing the overall vegetation suitability of the Yellow River Basin. Wang et al. argued that the increase in construction land area brought about the construction of infrastructure. Local vegetation is threatened by industrial and residential development [52]. We found that population density and the proportion of construction land area significantly improved the suitability of vegetation in the Yellow River Basin. By region, the construction land area proportion mainly plays a positive role in vegetation suitability in the middle reaches. This may be because the overall economic development of the Yellow River Basin lags, and the relatively high population density and construction land area indicate that the local economic and ecological environment is better and more suitable for human habitation. Moreover, in more economically developed areas, local governments can invest more money to protect the environment [52], thus improving the suitability of vegetation.

Among the social development factors, only the urban green coverage rate has a positive effect on vegetation suitability in the lower reaches. This may be because the green coverage rate represents, to some extent, the government's environmental protection awareness and ability. The lower reaches of the Yellow River Basin are more economically developed, so the local government is more aware of environmental protection and has the manpower and financial resources to invest in environmental protection. Road density has no discernible impact on vegetation suitability, indicating that road construction does not affect the vegetation suitability of an area. Road construction is mainly related to the level of economic development of a city, while the economic activities in the Yellow River Basin are clustered along the main river and the tributaries such as Weihe and Fenhe, which constitute the main axis of economic space in the Yellow River Basin. This distribution shows a decreasing trend from the coast of the main river or major tributaries to both sides and from the regional central cities such as Jinan, Zhengzhou, Taiyuan, and Lanzhou to the surrounding areas [49,53]. There are well-developed central cities in each sub-basin of the Yellow River Basin, making the effect of road density on vegetation suitability insignificant in the overall sample.

4.2.2. Economic Factors

Both beneficial and harmful effects on the environment may result from human activity. Among the economic factors, the per capita disposable income of urban residents significantly and negatively affects the suitability of vegetation, probably because the per capita income of urban residents represents the development of local non-agricultural industries to some extent, while the overall economic and social development of the Yellow River Basin is lagging behind, and the industrial composition is mainly secondary industries [54], of which primary processing industries account for a high proportion and energy and mineral resources extraction industries are prominent [55]. The development of these non-agricultural industries, which are based on the extraction of energy and mineral resources, can cause damage to the environment. Overall sample vegetation appropriateness increased significantly as rural per capita disposable income rose. This may be because the per capita disposable income in rural areas is somewhat reflected the level of agricultural modernization development in of those areas., and the level of agricultural modernization increases food productivity and reduces the strain of agricultural production on the environment [56,57]. Rural per capita disposable income, in turn, results in an improvement in the suitability of vegetation. The per capita disposable income of rural dwellers displays a substantial negative effect in upstream areas, which maybe be explained by the fact that the upstream area includes grazing economic regions, such as Inner Mongolia and Qinghai, with distinctive grassland pastoralism. Furthermore, overgrazing and artificial reclamation are significant contributors to ecological degradation in the upper reaches of the Yellow River [58]. As a result, the upstream region demonstrates that a rise in rural residents' per capita disposable income has a significant negative impact on the suitability of the vegetation.

4.2.3. Agricultural Production Factors

In accordance with the findings of previous studies [58,59], the regression results in this paper demonstrated that the cultivated acreage proportion, fertilizer application, and the proportion of primary industry output value significantly positively contributed to the improvement of vegetation suitability. This may be partly due to the fact that the Yellow River originates from the Qinghai–Tibet Plateau and flows through the soil erosion area of the Loess Plateau and the five major desert sands, with an overall weak geological environment. The area of moderately to extremely vulnerable areas accounts for about 37% of the land area of the Yellow River Basin; the overall spatial pattern is highest in the upper reaches, second highest in the middle reaches, and lowest in the lower reaches. Moreover, agricultural land in the Yellow River Basin is mainly distributed in the middle and lower reaches [49], which is generally consistent with the spatial change trend of vegetation suitability. On the other hand, cities with higher agricultural productivity are more likely to tend to develop modern agriculture, and the consequent increase in agricultural productivity and improvement in rural livelihoods are important economic and social factors that contribute to the effectiveness of vegetation restoration [35]. Thus, these variables in agricultural production show a positive influence on vegetation suitability, which is consistent with the results of existing studies [59]. In the total sample, midstream, and upstream region samples, the proportion of cultivated land was able to greatly enhance the improvement of vegetation compatibility, but it had a significantly adverse impact in the downstream area. With a long history of farming, the middle and lower sections of the Yellow River Basin were formerly among China's first regions of agricultural economic development. Particularly flat, primarily alluvial plains and deltas can be found downstream. The amount of cultivated land in the downstream area has a substantial detrimental impact on the appropriateness of the vegetation because of the likelihood of over-cultivation given the long history of farming in the area.

Human activities, such as per capita disposable income of urban residents, population density, rate of urbanization, application of fertilizer, and the value added of the primary industries proportion, however, only showed significance in the overall sample of the

Yellow River Basin and were not significant in the regressions of groupings in the upper, middle, or lower reaches. This may be because, while human activities such as urbanization, economic status, social development, etc., vary widely across the Yellow River Basin as a whole, there is some similarity and less variability in the upper, middle, and lower reaches within their respective regions. As a result, some variables do not show significant results in the grouped regressions.

4.2.4. Ecological Project Factors and Climatic Factors

A number of significant ecological projects, including the "Three North Protection Forests" project, the "Middle and Lower Yangtze River Protection Forests" project, and the "Natural Forest Protection" project, have been undertaken by the State Forestry Administration since the 1980s. At the beginning of the 21st century, the key ecological projects were integrated around the overall goal of the new period, and the natural forest protection project, the project of returning farmland to forest, the "Three North Protection Forests" project, and the "Middle and Lower Yangtze River Protection Forests" construction project were implemented in the Yellow River Basin. Later, the Beijing-Tianjin Wind and Sand Source Control Project, the wildlife protection and nature reserve construction project, the karst area stone desertification comprehensive treatment, and Grazing Return Project were launched.

The Yellow River Basin is a significant ecological construction area in China, and its vegetation cover has been widely researched due to the implementation of various ecological restoration projects such as "Returning Farmland to Forest and Grass", "Natural Forest Protection", and "Three North Protection Forests" [60–64]. In a study on the spatial and temporal evolution characteristics and drivers of the vegetation index in Sichuan Province based on the MODIS-EVI index, Wu et al. pointed out that the growth of EVI vegetation index in Sichuan Province from 2001 to 2018 was mainly driven by artificial ecological projects [5]. Additionally, it was discovered that the rate of vegetation restoration increased by more than six times after the Chinese reforestation program was put into place [37]. In general, forest restoration ecological projects, such as the "Program of Returning Cultivated Lands into Forest and Grassland" (RCLFG) and "Grassland Ban Program" (GBP), have greatly improved the eco-environment in Western China through facilitating structural adjustment of industries in the rural regions and exerting great impacts on the livelihoods of local farmers [65]. Although anthropogenic production activities have altered the original global climate, human-driven ecological projects, such as afforestation, planting grass, and intensification of cropland, indeed brought climate benefits. In China, vegetation increase in grassland has decreased the climate temperature by -0.08 ± 0.32 °C [66].

The intensity of the forest restoration ecological project, according to the paper's findings, had a positive impact on vegetation suitability in the overall sample, whereas the intensity of the wetland restoration ecological project had a significant negative impact, and the intensity of the grass restoration ecological project had no significant impact. Regarding particular groups, the intensity of forest restoration ecological projects and wet restoration ecological projects showed significant negative effects in the upstream area, whereas the intensity of grass restoration ecological projects showed significant negative effects in the midstream area. The major ecological projects, like reforestation projects, are slow variables with long-term effects, and the cross-sectional data used in this study cannot be used to examine their dynamic changes, which causes some bias in the results. As a result, the intensity of the major projects in this paper did not have the expected positive effect on vegetation suitability.

Studies on vegetation change have long focused on climatic causes. Temperature and precipitation are two of the key climatic variables that influence vegetation growth [62]. Both annual mean precipitation and annual mean temperature have a considerable beneficial impact on vegetation suitability, which is consistent with previous research [42]. Among these, the downstream region's annual mean precipitation was not statistically significant, which could be explained by the downstream region's lower precipitation variability and smaller sample number.

Due to data-collecting limitations, the research also lacks panel data to examine the characteristics of the regional and temporal distribution of vegetation suitability as well as the long-term impacts of economic development and urbanization on vegetation suitability. Among these data, large ecological projects, such as reforestation projects, are slow variables that have effects over a long period of time. Due to the data available, this study only examined the cross-sectional effects of human activities and climatic factors on vegetation suitability in 2018, and it cannot examine the dynamic changes and effects of the variables. As a result, the results may be skewed. Future research will track long-term data, carefully consider a range of human activities and climatic factors that may have an impact on vegetation suitability, and establish a system to assess vegetation suitability in order to thoroughly examine the impacts of human activities and climatic factors on regional vegetation changes.

4.3. Results of Relative Importance Analysis

The adjusted R-squared (adj-R^2) of the regression equation of climate and normalized vegetation index (NDVI) was used by Zhang et al. (2020) [67] to determine the magnitude of climate change effects on vegetation cover. They discovered that NDVI in cities with stronger economic development was more affected by human activity than NDVI in cities with weaker economic development. Using principal component analysis, Du et al. (2007) investigated the driving forces of vegetation cover change in the Yellow Sea and Huaihai Sea region [68]. They discovered that both the climate and human activity were major drivers of change, with climate factors dominating and human activities only playing a larger role locally. Using socioeconomic data such as population, GDP, urbanization rate, and crop sown area, Wang et al. (2017) examined the relationship between vegetation cover change and human activities and climatic factors in Inner Mongolia [69]. They found that in some areas, the role of human activities was greater than that of climatic factors. The findings of the relative importance analysis of the factors in affecting vegetation suitability in the Yellow River Basin are presented in Table 5. The findings of the analysis of the Yellow River Basin's relative importance by regions are presented in Tables 6 and 7. In general, climatic factors are the most important factors influencing vegetation suitability, and their influence on vegetation suitability is greater than that of human activities. Additionally, the relative importance of human activities varies greatly among the entire sample and the upstream, midstream, and downstream sub-regions in the Yellow River Basin. In the middle reaches of the sub-regional regressions, climate factors are more important than upstream and downstream regions, but in the upstream and downstream regions, human activity variables are more important than climate factors.

5. Conclusions

This study used climate data, county-level human activity data and FSGS data from 2018 to analyze the effects of human activity and climatic factors on vegetation suitability in the Yellow River Basin. It was found that climatic factors were the most important influencing factors on vegetation suitability, and human social activities also had a large impact on vegetation suitability effects. At the same time, there are obvious regional differences in the effects of climate and human and social activities on vegetation suitability. Because the Yellow River Basin straddles three major geographical steps in the east, middle, and west of China, there is a shortage of water resources and obvious regional differences in resource endowments such as land, energy and mining, and biology, which leads to a large variation in the influence and importance of different human activities on vegetation suitability in the upper, middle, and lower reaches of the Yellow River Basin. Our findings are as follows.

The multiple regression results showed that climatic factors had a significant positive effect on vegetation suitability. However, human activities may either enhance or inhibit vegetation suitability. In general, economic factors such as per capita disposable income of urban residents and per capita disposable income of rural residents; urbanization factors such as population density, urbanization rate, and urban development land proportion; social development factors such as road network density; and agricultural production factors such as the cultivated acreage proportion and the value added of the primary industries proportion have an impact on vegetation suitability. At the same time, the influence of human activities such as economic factors and urbanization factors has great regional heterogeneity.

The relative importance analysis results showed that the relative importance of each influencing factor of vegetation suitability in the Yellow River Basin was ranked as climatic factors > agricultural production factors > urbanization factors > ecological projects > social development factors > economic factors, indicating that climatic factors had the greatest effect on vegetation suitability, followed by agricultural production and urbanization development, and economic factors had the weakest effect. In different regions, the relative importance of vegetation suitability is still ranked first by climatic factor, but there are differences in the importance ranking of other influencing factors.

In general, the study further enriches the current literature on the factors influencing vegetation suitability. At the same time, this paper provides some theoretical basis for scientific vegetation adjustment and restoration, promoting high-quality development of forestry and grasses and ecological environment construction. In general, implementing appropriate ecological projects according to regional characteristics and carrying out moderate human social activities in the process of vegetation restoration are essential for ecological environmental protection.

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Appendix A

Table A1. Distribution of cities in the upper, middle, and lower reaches of the Yellow River.

Regions	Corresponding Provinces, Cities and Counties
The Upper Reaches	Lanzhou and Baiyin in Gansu Province; Zhongwei, Wuzhong, Yinchuan, and Shizuishan in Ningxia Hui Autonomous Region; Wuhai, Ordos, Bayannur, Baotou, and Hohhot in Inner Mongolia Autonomous Region (11 in total).
The Middle Reaches	Xinzhou, Lvliang, Linfen, and Yuncheng in Shanxi Province; Yulin, Yan'an, and Weinan in Shaanxi Province; Sanmenxia, Luoyang, Jiyuan, Jiaozuo, and Zhengzhou in Henan Province (12 in total).
The Lower Reaches	Kaifeng, Xinxiang, and Puyang in Henan; Liaocheng, Tai'an, Jinan, Dezhou, Binzhou, Zibo, and Dongying in Shandong Province (10 in total).

Table A1. *Cont.*

Regions	Corresponding Provinces, Cities and Counties
Dividing Point	(1) The section of the Yellow River above Hekou Town, Toketo County, Inner Mongolia Autonomous Region, is the upper reaches. (2) The section of the Yellow River between Hekou Town, Toketo County, Inner Mongolia Autonomous Region, and Mengjin County, Luoyang City, Henan Province, is the middle reaches. (3) The section of the Yellow River after Mengjin County, Luoyang City, Henan Province, is the lower reaches.
The Loess Plateau	The Loess Plateau is located in the inland areas of China, the middle and upper reaches of the Yellow River, and the upper reaches of the Haihe River, flowing through most of Shanxi Province, Shaanxi Province, and Ningxia Hui Autonomous Region and small parts of Qinghai Province, Gansu Province, Inner Mongolia Autonomous Region, and Henan Province.

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