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Spatial-Temporal Variations of Human Impact on Forest Ecological Functions in the Yellow River Basin from 2004 to 2018

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Abstract: Human activities (e.g., exploitation, utilization, and conservation) exert substantial impact on forest ecological functions (FEF). The human influence on FEF significantly varies across developmental stages, which are attributed to the temporal and spatial in nature. This study evaluates some notable FEF indices (FEFI) in the 448 counties within the Yellow River basin (YRB) using panel data from the Seventh to Ninth National Forest Inventory. Data analysis involves employing the residual trends, geographical and temporal weighted regression. Results indicate that, firstly, the overall forest ecological function in the YRB is moderate to inferior, with superior FEF in counties endowed with more natural forest resources. Afforestation demonstrates a short-term improvement, but its effectiveness diminishes over time. Secondly, the positive spatial correlation is stronger among counties, characterized by both high-high and low-low agglomeration effects. Scattered planting, simple stand structure, and concentrated harvesting of forests at the identical stand ages hinder the formation of complex and large-scale FEF agglomerations. Thirdly, significant spatial-temporal differences exist in the impact of human activities on FEF. In the upper reaches of the basin, increased vegetation coverage through agricultural and forestry production benefited FEF, however, some over-exploitation of forests and grasslands is observed there. In the middle reaches, the economic development, expanding population and the greening activities help to improve FEF effectively, but excessive water using in agricultural production brought more difficulties to FEF improvement. In the lower reaches of the basin, improved wastelands and forest protection positively influence FEF. This study recommends that county governments should prioritize forest management with multi-species and multi-layered complex forests. Each county should define its position in regional development and ecological protection, considering the potential impacts on neighboring regions. This holistic approach promotes more effective integrated regional management.

Keywords: Forest ecological function; human activities; spatial-temporal variation; geographic temporal weighted regression

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1. Introduction

Forests, identified as the most crucial terrestrial ecosystems [1], play an irreplaceable role in sustaining the human living environment and improving climate conditions [2]. The ecological functions, which encompass carbon sink [3], water conservation [4], soil and water retention [5,6], climate regulation, environmental purification, and biodiversity protection [7,8], emphasize the significance of forests. Generally, forests face escalating pressure due to intensified human activities

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associated with urbanization and industrialization [9]. Excessive logging of forests not only depletes wood supply but also triggers ecological degradation and reduced biodiversity.

In response to forest degradation problems, some countries, such as China, have initiated ecological projects to create artificial forests (plantation), striving to improve forest coverage while meeting the demands of economic development. Although China's forest coverage has increased from 20.36% to 22.96% according to the results of the 7th to the 9th National Forest Resources Inventory. Artificial forests, compared to natural and primitive forests, have simpler stand structures and lower quality of ecological functions. The extensive development of artificial forests has led to the problems, such as poorer forest stability, severe pests and diseases, and declining soil fertility. This has resulted in China's forest ecological function index of 0.57, generally at a moderate level, which still lags behind the global average [10].

The current study focuses on the Yellow River basin (YRB), which serves as an ecological corridor connecting the east and west of China, holds the paramount importance in wind-breaking, sand-fixing, and ecological protection. The direct influence of the YRB on the evolution trend of ecological security and environmental quality in the medium to long term is evident [11,12]. Additionally, the YRB plays a crucial role in China's economic development and food security [13]. Recognizing this, the Chinese government in 2019 positioned the ecological protection and high-quality development of the YRB as a prime national strategy [14]. Understanding the changing trends in forest ecological function in the YRB and identifying key driving factors are crucial for the better utilization and protection of forest resources and the comprehensive improvement of the basin's habitat quality. The YHB exhibits almost all the typical climatic zones and topographic landscapes of northern China, with stepped socio-economic development levels across its upper, middle, and lower reaches. Thus this study can be of interest and useful to the readers, and can be universally applicable to other countries and regions.

The impacts of climate change and human activities on forest ecosystems have been longstanding concerns among researchers. Changes in climatic factors, such as fluctuations of temperature, precipitation, and duration of sunshine, strongly affect the productivity and carrying capacity of forest ecosystem [15,16,17]. Notably, human activities exert a greater impact on forest ecosystems than climate changes [18], which primarily attribute to forest governance [19,20]. Forests exhibit remarkably high biological productivity, generating a plethora of forest products, diverse flora and fauna, and associated by-products. Recent years have witnessed the direct and indirect destruction of surface vegetation due to accelerated economic growth, urban land expansion, and population explosion [21]. Population pressure has heightened the demand for agroforestry products, potentially leading to the conversion of forests into arable land or alternative uses, thereby reducing forest area and diminishing ecological functions [22,23]. But in certain regions, economic development has facilitated the optimization and upgrading of forestry structures, minimizing unnecessary waste of forest resources [24]. Additionally, forest policies and laws worldwide have led to significant expansions of forest coverage, such as in China and India, large-scale ecological restoration policies contributed significantly to the maintenance and improvement of forest ecological functions [25,26].

In terms of criteria for evaluating the ecological functions of forests, we find that relying solely on the forest coverage rate (the ratio of forest area to total land area) as a criterion is deemed unscientific. A previous study revealed more forest cover but poorer forest ecological functions in the counties of the Aojiang River basin in China [27]. Forest ecological function (FEF) emerges as a more objective and comprehensive reflection of the overall quality of forests [28]. China has established a continuous forest inventory system in 1970s and introduced the concept of the forest ecological function index (FEFI) in the Technical Provisions on the Continuous National Forest Inventory issued in 2004 [29]. The FEFI is a measure, which includes important factors, such as forest productivity, naturalness, health, and ratio of forest stand area to national land area, provides a comprehensive evaluation of FEF [30,31].

Despite advancements in our understanding of FEF, there are several limitations in the existing literature. For example, firstly, assessments of FEF were often based on forest inventory data that lack

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dynamic analyses of changes. Secondly, existing researches of FEF mainly focused on examining forests in larger regions and water basins rather than at the county level, where the major policies were implemented and human activities were carried out. Recognizing this, evaluating FEF at county level must be an important prerequisite for the current study. And finally, previous studies tended to emphasize the impact of natural factors on forest ecological functions over human activities. Considering the difficulty in changing natural factors in the short term, our focus is on investigating how to better regulate human activities to improve FEF through more practical ways.

This study evaluates the FEF of the 448 counties in the YRB using panel data from the Seventh to Ninth National Forest Inventory. Data analysis involves an application of the methods of residual trends and geographical and temporal weighted regression, which help investigate human activities bringing changes in FEF and their spatial-temporal variations across the YRB. ArcGIS software is used in data analysis. This study will contribute to enhancing the forest quality and ecosystem services of the YRB.

2. Materials and methods

2.1. Study area

The Yellow River, situated between 95°53'～119°05'E and 32°10'～41°50'N, traverses nine provinces of China from west to east: Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong, boasting a total length of 5,464 km [32]. Encompassing a vast area of 795,000 square kilometers, the Yellow River basin-YRB (Figure 1) spans four major terrain units: the Qinghai-Tibet Plateau, the Inner Mongolia Plateau, the Loess Plateau, and the North China Plain. With an average annual temperature of 3.4^{o} C and substantial inter-annual variations in precipitation ranging from 200-800 mm in most areas, the basin poses unique challenges due to significant altitude differences, complex geographical and climatic conditions, and fragile ecosystems, making it one of the world's regions with the most intense human activities [33].

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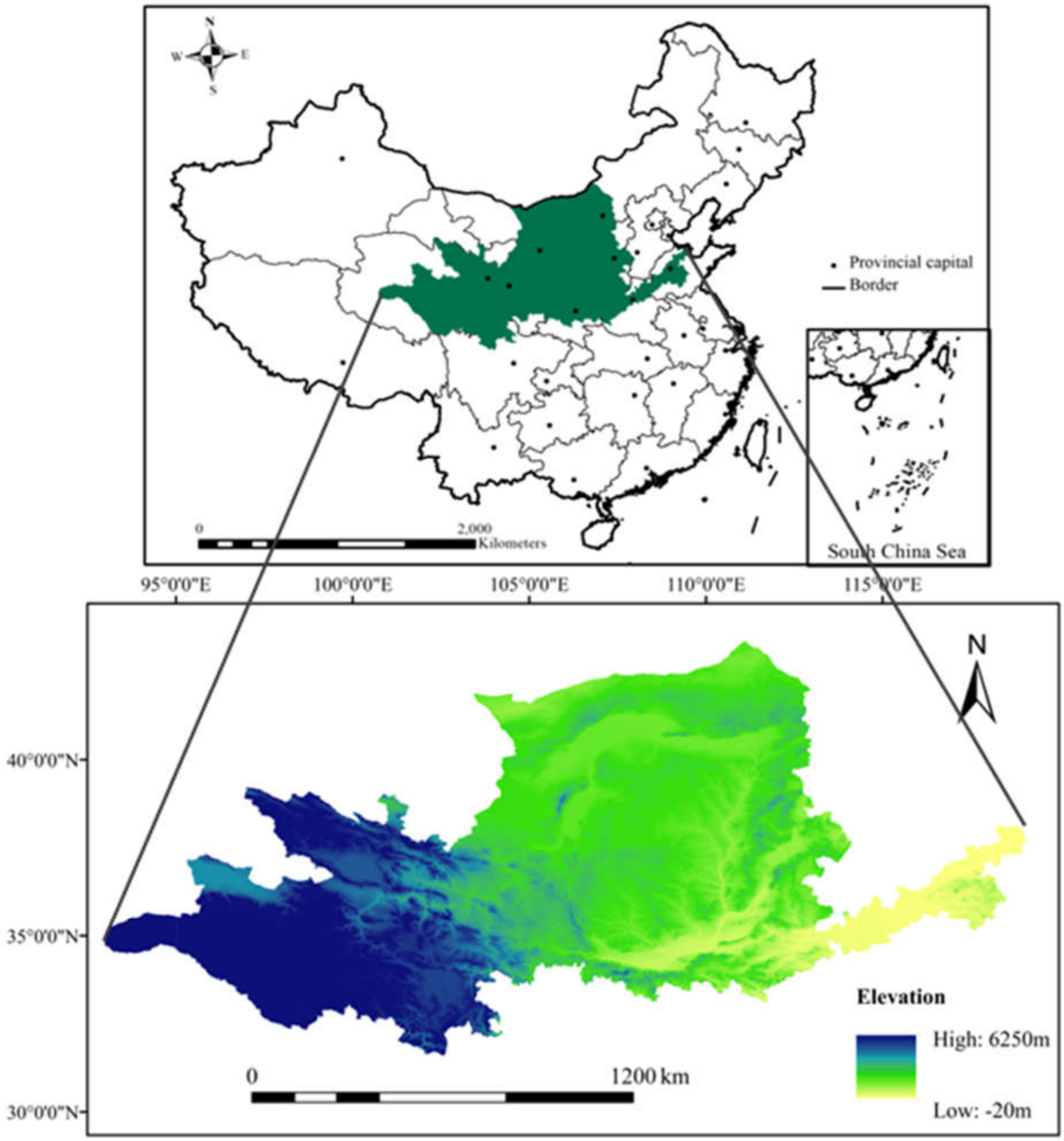

Figure 1. The Yellow River basin location.

2.2. Variables and data

The transformation in socioeconomic conditions resulting from human activities significantly influences forest ecological functions. Different societal transformation periods have shaped forest ecological functions through varying modes of production and lifestyle, affecting agricultural practices, population distribution, urbanization, and land use changes. The long-term variations in forest ecological functions are interlinked with natural factors including climate change that exerts a direct impact on forest growth, cover and types [34,35]. The influence of temperature and precipitation is also determined by altitude, which varies across the YRB. Thus, we identified eight indicators that effectively capture human activities and their impacts on FEF within YRB during 2004-2018. Three natural factors were selected as control indicators (Table 1).

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Table 1. Descriptive statistic of the indicators.

Variable category	Indicator	Definition	Unit
Human activity factors	DN	night-time light data of county-level	-
	AGRI	share of primary sector in GDP	%
	INS	share of secondary sector in GDP	%
	PS	ratio of resident population to county area	thousand people
	URB	urbanization ratio of resident population	%
	FRM	ratio of cultivated area to county area	%
	CONS	ratio of construction land area to county area	%
	PROT	class of forest land protection	-
Natural factors	TEMP	annual average temperature	℃
	PREC	annual average precipitation	mm
	ElEV	average elevation of the county	m

In this study, data pertaining to forest ecological functions and forest land protection classes at the sample plot scale are sourced from the 7th to 9th National Forest Resources Inventory of China. This system allows for detailed factor data used for the calculation of forest ecological function indices for each sample plot, totaling 114,887 sample plots across the YRB. The methodology for calculating county-level Forest Ecological Function Index is elaborated below.

Nighttime light data, owing to its objectivity and comprehensiveness, serves as a superior metric for regional economic development. The data employed in this study is an annual synthetic dataset corrected using a cross-sensor correction scheme based on the autocoder model [36]. Corresponding NPP-VIIRS Night-time Satellite Data is obtained from the National Geophysical Data Centre. Other data concerning socio-economic activities are primarily sourced from the China County Statistical Yearbook, statistical yearbooks of prefecture-level cities, and statistical bulletins of economic and social development at the county level. We address individual missing data through interpolation using the sliding average method. The policy intensity of forest protection in each county is calculated as a weighted average of the sample plot data. Land use data is acquired from the Chinese Academy of Sciences (CAS) Resource and Environmental Sciences and Data (RESD). We process the land use remote sensing monitoring data with a resolution of 1km for the years 2008, 2013, and 2018 using ArcGIS. Climate data is retrieved from the World Climate Database (https://worldclim.org).

2.3. Methods

2.3.1. Forest ecological function evaluation

Utilizing factors such as forest volume, forest naturalness, community structure, tree species structure, total vegetation coverage, canopy density, mean tree height and litter thickness, we constructed an system to calculate the forest ecological function index (FEFI) as an standard to quantify the forest ecological function [37]. Each factor and its weight are shown in Table 2.

Table 2. Evaluation factors and classification standards of forest ecological function [38].

Forest factors	Classification standard			Weight
	I	II	III	
Forest volume	$\geq 150t/hm^2$	$50t/hm^2 \sim 149t/hm^2$	$< 50t/hm^2$	0.20
Forest naturalness	1,2	3,4	5	0.15
Forest community structure	1	2	3	0.15
Tree species structure	6,7	3,4,5	1,2	0.15
Total vegetation coverage	$\geq 70\%$	$50\% \sim 69\%$	$< 50\%$	0.10
Canopy density	≥ 0.70	$0.40 \sim 0.69$	$0.20 \sim 0.39$	0.10
Mean tree height	$\geq 15.0m$	$5.0m \sim 14.9m$	$< 5.0m$	0.10
Litter thickness grade	1	2	3	0.05

For a easier calculation, classification standard I, II and III listed in table 2 are assigned the values 3, 2 and 1 respectively. We calculated FEFI for each sample plot using the formula given in Eq. 1 based on the weighted average method.

$$K = 1 \Big/ \sum_{i=1}^{8} W_i X_i \tag{1}$$

where K denotes FEFI with K taking values [0,1], a higher value of K indicates better ecological function; X_i indicates the standardized score of factor i and W_i is the weight of factor i .

The weighted average method was also used to calculate FEFI of county-level as in Eq. 2.

$$FEFI = \sum_{i=1}^{n} K_i \times s_i / S \tag{2}$$

where $FEFI$ indicates county-level FEFI; K_i is FEFI of sample plot i , s_i is the area of sample plot i and S is the sum of areas of all sample plot located within a certain county. With reference to the classification criteria developed by Technical regulations for continuous forest inventory in China (GB/T 38590–2020), FEFI was categorized into three grades: Level I [0.667,1], Level II (0.4,0.667) and Level III [0-0.4], representing different levels of forest ecological functions: good, moderate and poor , respectively [38].

2.3.2. Spatial autocorrelation analysis

We used the global Moran's I index and local Moran's I index to describe the global and local cluster characteristics of FEF, respectably [39]. The equations for these indexes are as follows:

$$Moran's I = n\sum_{i=1}^{n}\sum_{j=1}^{n}(x_i - \bar{x})(x_j - \bar{x}) \Big/ \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n}(x_i - \bar{x}) \tag{3}$$

$$LocalMoran's I = [(x_i - \bar{x}) / s_i^2] \sum_{i=1}^{n} W_{ij}(x_j - \bar{x}) \tag{4}$$

where x_i and x_j are the forest ecological function indexes of counties i and j, respectively; n is the total number of counties; $\bar{x}$ is the average of all counties; W_{ij} is the spatial weight matrix, and s_i^2 denotes the variance of x_i. The values of Moran's I range from -1 to 1. A Moran's I value tending toward 1 represents a positive autocorrelation, that is, similar values occur in adjacent locations, while a Moran's I value tending toward -1 indicates negative spatial autocorrelation. If the spatial distribution of FEFI is completely random, the value of Moran's I would approximate to 0. As for the local Moran's I, a value greater than 0 shows that the high (low) index value of county i is surrounded by neighboring high (low) values; a value less than 0 indicates that the high (low) value of county i is surrounded by neighboring low (high) values. Based on the local Moran's I, the map of Local Indicators of Spatial Association (LISA) shows four clustering patterns: high–high (H–H), low–low (L–L), high–low (H–L) and low–high (L–H).

2.3.3. Residual trends method

Residual trends method is widely used to quantify the contribution of climate change and human activities to vegetation coverage [40]. It can be expressed as:

$$\theta = FEFI_{obs} - FEFI_{pre} \tag{5}$$

$$FEFI_{pre} = \sum_{i=1}^{n} \alpha_i \times Nat_i + \varepsilon \tag{6}$$

where α_i is the regression coefficient between FEFI and each natural factor; ε is the error term. $FEFI_{obs}$ is the observed value, $FEFI_{pre}$ is the predicted value obtained from regression model. $\theta > 0$ indicates the positive impacts of human activities on FEF, while $\theta < 0$ indicates that of negative impacts.

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2.3.4. Geographic and Temporal Weighted Regression

To capture the influence of factors on FEF under different spatial and temporal conditions, we used the Geographic temporal weighted regression (GTWR). GTWR integrates the temporal and spatial information into the weighting matrix, and explores the heterogeneity of driving factors in the temporal and spatial dimensions [40]. It can also be used to handle panel data, leading to results closer to the actual situation. The specific formula is expressed as in Eq. 7 [41].

$$y_i = \beta_0(u_i, v_i, t_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i, t_i)x_{ij} + \varepsilon_i, i = 1,2,\cdots,n \tag{7}$$

where (u_i, v_i, t_i) is the space–time coordinates (longitude, latitude, and time dimension) of sample point i . $\beta_j(u_i, v_i, t_i)$ is the k -th regression parameter on sample point i and is the function of the space-time geographical position; $\varepsilon_i \sim (0, \sigma^2)$ and $Cov(\varepsilon_i, \varepsilon_j) = 0(i \neq j)$. The space-time distance is:

$$d_{ij}^{ST} = \sqrt{\lambda[(\mu_i - \mu_j)^2 + (\nu_i - \nu_j)^2] + \delta(t_i - t_j)^2} \tag{8}$$

with the following space–time weight function:

$$W_{ij}^{ST} = \exp[-(d_{ij}^{ST} / b_{ST})^2] \tag{9}$$

where (μ_i, v_i) is the longitude and latitude of each county; b_{ST} is the bandwidth of the space–time weight function. The optimal bandwidth is determined by the Akaike Information Criterion (AIC).

3. Results

3.1. Evaluation of FEF and the spatial-temporal distribution patterns

The average county-level FEFI increased from 0.427 in 2008 to 0.437 in 2018, signaling a gradual improvement in forest ecological functions. However, it was important that the overall level remained relatively low during this period, with the study area dominated by counties exhibiting moderate and poor forest ecological functions. An intriguing observation is that, from 2008 to 2013, 198 counties experienced a decline in forest ecological function, constituting 62.49% of the total area. In contrast, from 2014 to 2018, although the number of counties with decreased function increased to 204, the overall coverage decreased to only 46.29%.

Figure 2 illustrates that counties categorized as "Poor" were predominantly clustered in the central north of the YRB, characterized by an arid climate, limited precipitation, and insufficient water resources. Counties classified as "Moderate" were mainly situated in semi-humid areas with higher precipitation, falling into two subcategories: those abundant in natural forest resources, such as counties along the Qilian Mountains, Qinling Mountains, Lvliang Mountains, and Taihang Mountains, consistently exhibiting the best forest ecological functions in the basin; and those in river plain areas with rich arable land resources, such as Henan and Shandong provinces. We noted the observed instability in FEF in many counties in the lower reaches, which meant a decline from Level "Moderate" to "Poor" after a brief period of improvement.

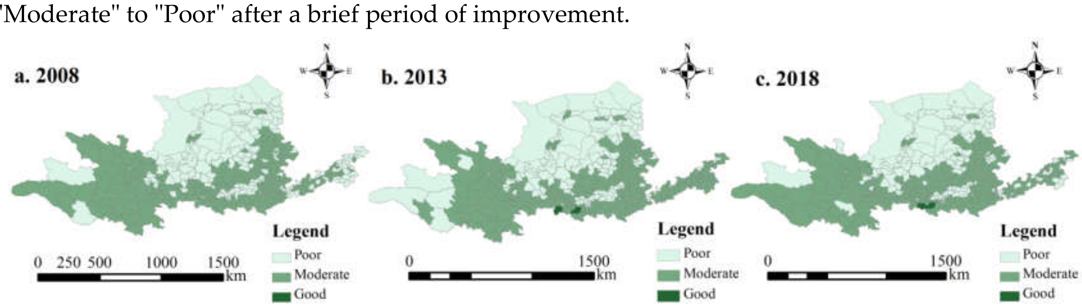

Figure 2. Spatial distribution of the FEF by forest inventory cycles (2008, 2013, and 2018).

3.2. Spatial agglomeration of FEF in the YRB

The Moran's I values increased from 0.506 to 0.562, both of which are significant at the 1% level during 2008-2018, indicating a growing positive correlation in the spatial distributions of forest ecological functions, with regions having higher or lower FEFI tending to cluster together.

Notable changes of Moran's I values were observed in the High-High and Low-Low areas (Figure 3). The H-H area, consisting of counties with better forest ecological functions, is located predominantly along the Qinling and Taihang Mountains. Over time, there is a noticeable increase in agglomeration in the eastern part of the Qinling Mountains and a decrease in agglomeration in the northern part of the Taihang Mountains. Conversely, the L-L areas, comprising counties with predominantly poorer forest ecological functions, are clustered in the upstream warm temperate steppe and desert-grassland regions. The agglomeration in these areas tended to spread outward in recent years. The High-Low and Low-High areas were randomly distributed in various regions that are not statistically significant throughout the observed period. These findings suggest that the forest ecological function of counties in the YRB is easily influenced by neighboring regions.

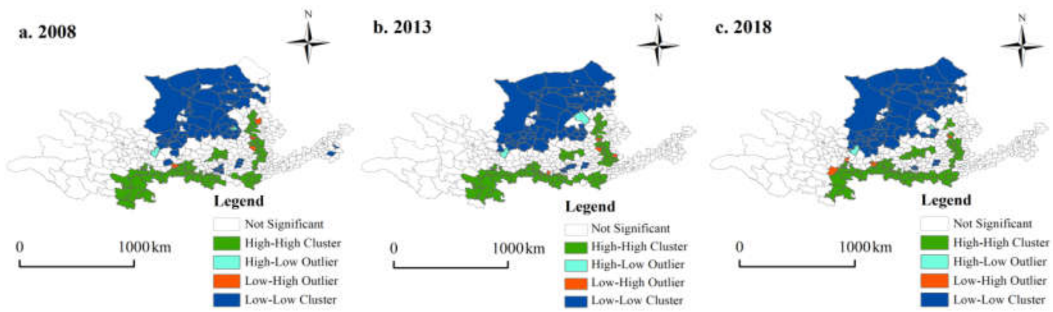

Figure 3. Local Indicators of Spatial Association (LISA) cluster map of FEF.

3.3. Identifying the impact of human activities on FEF

To determine the extent of human activities' impact on FEF, natural factors' influence (Table 1) was excluded through residual analysis. In most counties on the Qinghai-Tibetan plateau, the contribution of human activities was primarily positive in 2008 (Figure 4). However, by 2018, FEF deteriorated as the intensity of human activities increased. In downstream counties, the impact of human activities exhibited a non-linear characteristic. Specifically, in 2008 and 2018, human activities had a negative effect on FEF. However, starting from Zhengzhou city in 2013, both human activities and FEF developed coordinately in counties, suggesting that human factors were the main driving force behind improved FEF during this period.

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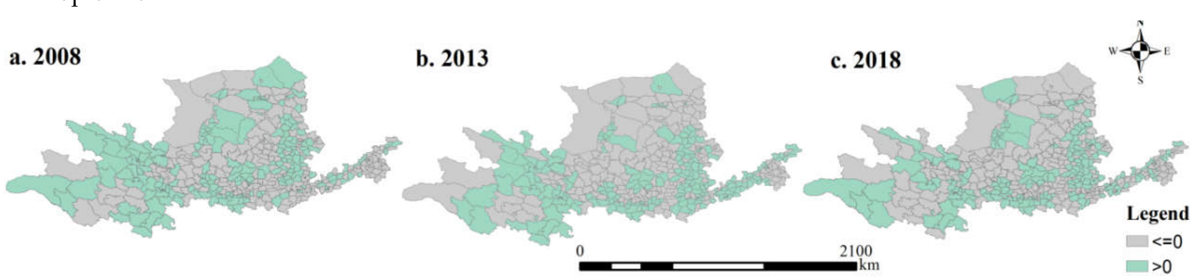

Figure 4. Spatio-temporal characteristics of the impact of human activities on FEF.

3.4. The influence of human activity indicators on FEF based on GTWR

Figure 5 illustrates the varied impact of each factor in different regions, with coefficients standardized for comparative analysis. Generally, the level of economic development (DN), the development of the secondary industry (INS), urbanization (URBI), and protection of forest land

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(PROT) did not exert significant impacts on forest ecological functions in the YRB. A brief analysis would be conducted solely on the direction of influence.

In the upstream counties, forest ecological function had improved alongside economic development. Counties extending from the southeastern part of the farming-pastoral zone in North China to Shanxi in Shaanxi province witness better forest ecological function with the development of the secondary industry. China's rapid urbanization in recent years, from a spatial-temporal perspective, appeared generally unfavorable for the improvement of FEF across most of the YRB, except for a considerable number of counties close to the estuary where positive effects of urbanization were evident. In the west of the watershed, the positive role of PROT was diminishing, covering the entire Tibetan plateau in 2008 but reducing to only counties where the region's major nature reserves were located in 2018. Conversely, in the eastern watershed, effective woodland resource conservation had improved the FEF, with this positive effect spreading from south to north within Shanxi Province.

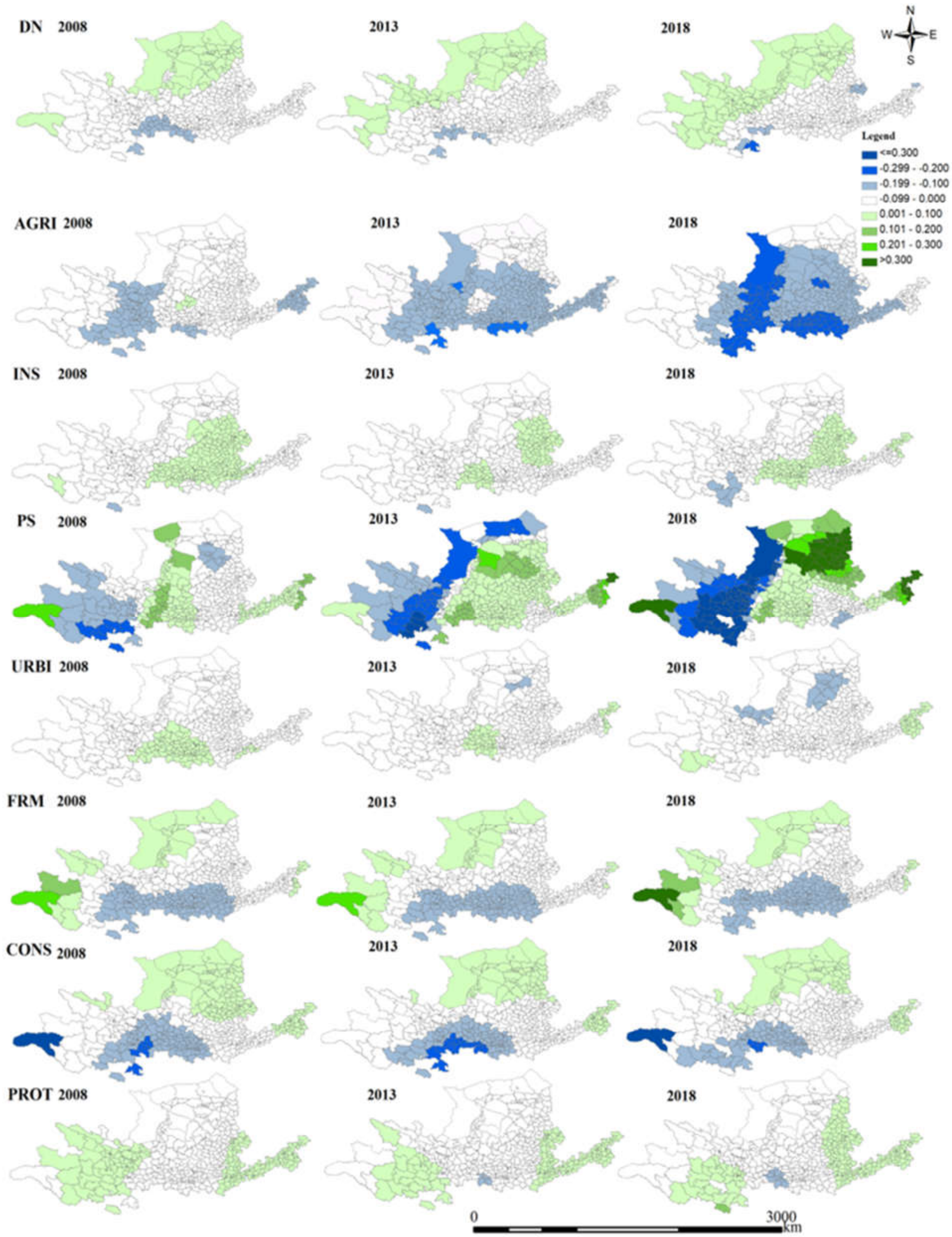

Figure 5. Spatial-temporal distribution of human activity factors affecting FEF calculated by GTWR.

Comparatively, the development of the primary industry (AGRI), especially cultivation leading to changes in production land use (FRM), an increase in population density (PS), and consequent changes in the ratio of land dedicated to urban and rural construction (CONS), exhibited a more pronounced difference in the FEF. These factors were considered core influencing factors and would be analyzed with a focus on spatial and temporal changes in the following sections.

The impact of the agricultural industry (AGRI) consistently exhibited a negative trend, and this adverse effect had become increasingly significant by 2018, extending across the Loess Plateau to downstream counties in Henan Province. Moreover, AGRI had emerged as a significant constraint in pastoral areas, particularly in regions where animal husbandry was predominant, such as Gansu, Sichuan, and Inner Mongolia, located to the west of the northern farming-pastoral transitional zone, as well as in key farm product production districts in the YRB, like the Fenwei Plain.

The influence of population density (PS) showed distinct spatial variations. In the upper reaches of the Yellow River, especially in the transition section from the Tibetan Plateau to the Loess Plateau, population growth proved detrimental to improving FEF, emerging as the most significant constraint. From the Loop Plain to the counties at the junction of upstream and midstream, the impact shifted from negative to positive, becoming a central driving force in promoting FEF. However, in the transition section from the middle to the lower reaches, the positive impact of PS reverted to a negative impact after a brief improvement in 2013. Notably, there was an increasing contribution of PS to FEF in the lower plain.

The positive impact of changes in production land use (FRM) was concentrated in alpine and arid areas with harsh natural conditions, particularly in the western and northern parts of the basin. Here, artificial planting enhanced vegetation cover and improve the ecological environment. In most districts and counties in the YRB, except those mentioned earlier, the proportion of cultivated land area was negatively correlated with FEF. This negative impact was particularly pronounced in the high loess gully and the river valley plain in the northern foothills of the Qinling Mountains.

Counties where the expansion of land used for urban and rural construction (CONS) contributed to FEF were decreasing. In 2008, these counties were distributed in the Inner Mongolia Autonomous Region, northern Shaanxi and Shanxi Provinces, and the entirety of Shandong Province. However, by 2018, it became detrimental to FEF when construction land expands in the northern counties of Shaanxi Province. CONS exerted the greatest negative effect on FEF in Tianshui City in the southern Gansu Province. Starting from this central point, the impact gradually diminished in all directions across most of the YRB.

4. Discussion

4.1. Model selection and validity of results

We made a comparison of parameters between the GTWR and OLS models. The goodness-of-fit (R^2) for the GTWR model was 0.49, surpassing that of the OLS model (0.10). Moreover, the AICc value for the GTWR model was -4290.25, smaller than the -3274.69 observed for the OLS model. These metrics indicated the superior suitability of the GTWR model for this study. Consequently, we used the results of GTWR model to delve deeper into the analysis of the impacts of human activity indicators on FEF across various counties.

4.2. Spatial-temporal variations of human activity factors driving FEF

The long-term variations in forest ecological functions were influenced by both natural and human activity factors, as well as their interactions. The direct impact of natural factors on forest ecological functions was evident in the wide variability of vegetation types, forest biomass, community structure, and naturalness concerning temperature, precipitation, and elevation. The water and thermal resources in the YRB exhibited a decrease from south to north, with more pronounced characteristics as more in the southeast and less in the northwest [40]. We found it becomes evident that annual precipitation and average temperature across counties showed an upward trend during 2004-2018. Collectively, the climate change, marked by increasing temperature and humidity, provided a more favorable environment for forest growth.

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Additionally, natural factors also significantly shaped the scope and intensity of human activities. For example, while afforestation was commonly used to rehabilitate and expand forest cover, the regeneration and maintenance of artificial forest vegetation depended on adequate water resources. In China, greening initiatives had not surpassed the 400-mm precipitation threshold [43], and the lack of water resources post-afforestation posed a risk to the existing vegetation.

We found that most counties with consistently poor FEF, as shown in Figure 2, were predominantly those with insufficient water resources, posing challenges to forest and grassland development. Reversing the issues of low total forest resources and poor quality in this region was a complex and long-term task. In contrast, counties with moderate FEF suffered less from water scarcity, and these areas can experience significant improvements in forest coverage and volume through artificial afforestation in the short term. Meanwhile, we observed an inverted U-shaped change in FEF in some counties during the study period. It probably because that the artificial forest's simple stand structure and limited resilience to natural risks underscore the importance of long-term forest stewardship, which was precisely contradicted by a prevalent emphasis on afforestation over management in most counties.

The clustering characteristics of FEF in the YRB were becoming more significant (Figure 3), indicating that it was essential to analyse the drivers of changes in FEF from a basin-wide perspective. Another reality that cannot be ignored was that the natural environment of the YRB varied greatly. Therefore, we divided the YRB into six regions according to the natural and geographic features [44], and made a comprehensive analysis of how human activities influencing FEF in different regions. We attempted to find out more reasonable paths to enhance the FEF for the entire basin through human activities, ultimately achieving sustainable development of the economy, society, and ecology.

The source area of the Yellow River, primarily covered by upland meadow and scrub vegetation, exhibits reduced forest fragility with increasing elevation [45,46]. The challenging environmental conditions at high altitudes limited large populations, reducing the overall impact of anthropogenic activities [47,48]. In areas with higher altitudes, climate effects tended to outweigh anthropogenic factors [49], emphasizing the importance of minimizing human activities to maintain the natural state of vegetation.

Qinghai, Gansu, and northwest Sichuan, positioned at the intersection of the "Qinghai-Tibet Plateau Ecological Barrier" and the "Loess Plateau-Sichuan-Yunnan Ecological Barrier," served as vital water-sourcing and recharge areas for the upper reaches of the Yellow River. Despite ecological projects stabilizing forest ecological function for a certain period, the up-river region faced challenges with the lowest forest coverage rate in the entire basin. Human activities such as grazing and farming, driven by economic constraints, led to the degradation of alpine meadows [50,51]. In these regions, strengthening infrastructure construction and improving agricultural and animal husbandry production efficiency were crucial for enhancing artificial vegetation coverage [52,53], and consequently, the ecological function of forests.

Inner Mongolia and Ningxia, constrained by natural conditions and water scarcity, faced challenges in developing the forest and grassland industries. Population growth and urbanization exerted pressure on ecological water use, impacting the long-term ecological function of forests [54]. Additionally, abundant mineral deposits drove industrial and mining land expansion, leading to the loss of natural ecosystems [55]. Urban and rural construction increasingly focused on greening, enhancing ecological livability [56]. Expanding artificial vegetation through construction emerged as an effective way to improve forest ecological functions in the region.

The Loess Plateau, comprising the principal part of the middle reaches of the YRB, exhibited distinct spatial variations in forest ecological function due to natural vegetation differences and complex terrain. The southeast, with a more stable forest system dominated by tree communities, shrub communities, and herbaceous communities [57,58], surpassed the northwest, which faces challenges from rapid population growth, urbanization, and irrational development of farming and animal husbandry [59]. Ecological projects in the Loess Plateau, supported by the Chinese government, contributed significantly to restoring net primary productivity [58,60].

In the downstream Henan and Shandong provinces, densely inhabited hilly plain areas witnessed significant impacts from economic development and irrigation on vegetation growth [61]. Conceding farmland to forests and afforestation in barren mountains improved forest cover to some extent [62]. However, the diversion of the Yellow River created highlands with depressions and hills, limiting tree species suitable for planting. Due to scattered planting of artificial forests in various counties, the simple stand structure and concentrated harvesting time impede large-scale agglomeration effects in most regions. Economic development, focusing on forestry's economic benefits [63], negatively impacted forest ecological functions.

The alluvial plains of the Yellow River Delta, characterized by saline and alkaline soils, experienced improved vegetation coverage through saline-alkaline land improvement and seed industry innovation [64]. Industry and mining development, coupled with population growth and urban agglomeration, positively impacted economic growth and forest ecological functions [65]. Wetland ecosystems faced challenges due to urbanization [66,67], but efforts to return pasture or farmland to wetlands had showed positive results in recent years [66,68].

4.3. Limitations and future work

By evaluating the forest ecological function of each county in the Yellow River basin and discussing the influencing factors, we have got some meaningful implications. Yet firstly, natural factors are very important to forest ecological functions, which can be taken as the basis for human activities improving or damaging the forest ecological functions. Although we have only briefly explored them due to the large study area and the focus on the impact of human activities, it is no doubt that a more focused exploration will lead to more valuable conclusions. Secondly, variations in forest cover types or forest utilization practices, and factors such as fires and pests can also have implications for forest ecological functions. Regrettably, for the sake of comparison, we were only able to conduct relatively basic calculations in this study. In addition, due to the large spatial span of the Yellow River Basin and the different ecological problems faced and ecological tasks undertaken by different sections, targeted research on subsections is a valuable direction for future research endeavors.

5. Conclusions

The historical and profound impact of human activities on forest resources and their ecological functions is undeniable. Observing and summarizing the temporal characteristics of changes in forest ecological functions is crucial for understanding the patterns of human activities affecting these functions. In this study, we utilized residual analysis and GTWR models to identify the most influential human activities on forest ecological functions in county-level administrative areas. Our key findings were as follows:

First, the overall forest ecological function of counties in the Yellow River basin ranged from moderate to inferior, with higher levels in counties endowed with natural forest resources. While artificial afforestation could yield short-term improvements, its long-term impact was limited.

Second, considering agglomeration effects, distinct clusters of high-high and low-low forest ecological functions in the Yellow River basin were becoming increasingly apparent. High-high agglomeration was predominantly in the eastern and southern mountainous areas, while low-low agglomeration occurred in the arid and semi-arid northwest Loess Plateau, expanding during the research period.

Third, significant spatial-temporal differences exist in the impact of human activities on forest ecological functions. Social and economic activities positively correlate with forest ecological function in the upper reaches, increased vegetation coverage through agricultural and forestry production benefited FEF, however, over-exploitation of forests and grasslands observed there inhabited the improvement of FEF. In the midstream, the development of the secondary industry, increasing population density, as well as the greening of urban and rural areas helped to improve FEF effectively, but excessive demand for water triggered by the basic status of agricultural production brought more difficulties to forest protection. In the lower reaches, the primary industry's internal structure optimization, land use improvements, population growth, and forestland protection positively affect forest ecological functions.

We anticipate that these results will offer insights into optimizing differentiated governance strategies and regional collaboration to enhance forest ecological functions throughout the watershed. We propose several recommendations for the maintenance and improvement of forest ecological functions:

1. Consider Climatic Limitations. Before implementing protective measures for forest and grassland resources, it is essential to account for the climatic conditions. In undeveloped areas like alpine woodlands and meadows, minimize artificial ecological restoration measures to reduce human disturbances and promote natural ecological recovery.
2. Formulate Localized Measures. In counties with abundant natural resources, focus on banning natural forest logging, maintaining ecosystem integrity, and improving resource utilization efficiency. In less endowed counties, enhance forest ecological functions while improving natural conditions and vegetation cover, incorporating measures like constructing mixed forests to increase species diversity.
3. Promote Integrated Development and Governance. Counties should articulate their positions in regional industrial development and ecological protection, considering the possible repercussions of ecological measures on neighboring regions. Leveraging the comprehensive effects of combined ecological measures is imperative, avoiding reliance on single ecological engineering or restoration measures.

By adhering to these recommendations, it is possible to foster sustainable development, achieve ecological conservation goals, and enhance the overall quality of the forest ecological functions in the Yellow River basin.

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References

1. Pan, Y.; Birdsey, R.A.; Fang, J.; Houghton, R.; Kauppi, P.E.; Kurz, W.A.; Phillips, O.L.; Shvidenko, A.; Lewis, S.L.; Canadell, J.G.; Ciais, P.; Jackson, R.B.; Pacala, S.W.; McGuire, A.D.; Piao, S.; Rautiainen, A.; Sitch, S.; Hayes, D. A Large and Persistent Carbon Sink in the World's Forests. *Science (New York, N.Y.)* **2011**, *333*, 988-993.
2. Keenan, R.J.; Reams, G.A.; Achard, F.; de Freitas, J.V.; Grainger, A.; Lindquist, E. Dynamics of Global Forest Area: Results from the FAO Global Forest Resources Assessment. *For. Ecol. Manag.* **2015**, *352*, 9-20.
3. Sun, B.; Zhao, H.; Lu, F.; Wang, X. Spatial and Temporal Patterns of Carbon Sequestration in the Northeastern Forest Regions and Its Impact Factors Analysis. *Acta Ecologica Sinina.* **2018**, *38*, 4975-4983.
4. Liu, X.; Zhang, W.; Feng, Y.; Zhao, X.; Gan, X.; Zhou, Q. Research on Water Conservation Function of Forest Ecosystem: Progress and Prospect. *Chinese Journal of Ecology* **2022**, *41*, 784-791.
5. Liu, X.; Pei, X.; Chen, L.; Liu, C. Study on Soil Conservation Service of Ecosystem Based on InVEST Model in Mentougou District of Beijing. *Res of Soil Water Conserv.* **2018**, *25*, 172-180.
6. Liu, R.; Wang, D.; Yang, H.; He, K.; Zhang, X.; Wen, W. Vegetation Ecological Function Evaluation and Optimization Measures in the Loess Alpine Region of Qinghai. *Science of Soil and Water Conservation* **2021**, *19*, 97-105.

 doi:10.20944/preprints202404.0349.v1

7. Kindler, E. A Comparison of the Concepts: Ecosystem Services and Forest Functions to Improve Interdisciplinary Exchange. *For Policy Econ.* **2016**, *67*, 52-59.
8. Liu, S.; Dai, L.; Wen, Y.; Wang, H. A Review on Forest Ecosystem Management towards Ecosystem Services: Status, Challenges and Future Perspectives. *Acta Ecol. Sin.* **2015**, *35*, 1-9.
9. Shen, Z.; Zhang, Q.; Chen, D.; Singh, V.P. Varying Effects of Mining Development on Ecological Conditions and Groundwater Storage in Dry Region in Inner Mongolia of China. *J. Hydrol.* **2021**, *597*, 125759.
10. Jian, N.; Zhao, H.; Liu, M. Driving Force and Potential of Forest Resource Change: Based on the Results of the Ninth National Forest Resources Inventory. *Journal of Forestry and Grassland Policy* **2022**, *2*, 64-71.
11. Zhang, W.; Wang, Y.; Li, J.; Hao, Z. Coupling Coordination Network Analysis of Ecological Protection and High-quality Economic Development in the Yellow River Basin. *Ecol Econ.* **2022**, *38*, 179-189.
12. Jin, F.; Ma, L.; Xu, D. Environmental Stress and Optimized Path of Industrial Development in the Yellow River Basin. *Resour. Sci.* **2020**, *42*, 127-136.
13. Li, T.; Zhang, Q.; Singh, V.P.; Zhao, J.; Song, J.; Sun, S.; Wang, G.; Shen, Z.; Wu, W. Identification of Degradation Areas of Ecological Environment and Degradation Intensity Assessment in the Yellow River Basin. *Frontiers in Earth Science* **2022**.
14. Guo, Z.; Tang, S.; Wang, D.; Zhang, J. Spatial Distribution and Factors Influencing Ecological Efficiency of the Yellow River Basin in China. *Front. Environ. Sci.* **2022**, *10*.
15. Boulanger, Y.; Pascual, P.J. Boreal Forests Will be More Severely Affected by Projected Anthropogenic Climate Forcing than Mixedwood and Northern Hardwood Forests in Eastern Canada. *J. Landsc. Ecol.* **2021**, *36*, 1725-1740.
16. Letelier, L.; Valderrama, A.; Stoll, A.; Garcia-Gonzales, R.; Gonzalez-Rodriguez, A. Patterns of Composition, Richness and Phylogenetic Diversity of Woody Plant Communities of Quillaja Saponaria Molina (Quillajaceae) in the Chilean Sclerophyllous Forest. *GAYANA BOT.* **2017**, *74*, 57-72.
17. Vefago, M.B.; da Silva, A.C.; Cuchi, T.; dos Santos, G.N.; Nunes, A.D.; Rodrigues, L.C.; Lima, C.L.; Gross, A.; Kilca, R.D.; Higuchi, P. What Explains the Variation on the Regenerative Component Dynamics of Araucaria Forests in southern Brazil? *Sci Agric.* **2019**, *76*, 405-414.
18. Danneyrolles, V.; Dupuis, S.; Fortin, G.; Leroyer, M.; de Romer, A.; Terrail, R.; Vellend, M.; Boucher, Y.; Laflamme, J.; Bergeron, Y.; Arseneault, D. Stronger Influence of Anthropogenic Disturbance than Climate Change on Century-scale Compositional Changes in Northern Forests. *Nat. Commun.* **2019**, *10*, 1265.
19. Agrawal, A.; Wollenberg, E.; Persha, L. Governing Agriculture-forest Landscapes to Achieve Climate Change Mitigation. *Glob Environ Change.* **2014**, *29*, 270-280.
20. Grainger, A. Forest Sustainability Indicator Systems as Procedural Policy Tools in Global Environmental Governance. *Glob Environ Change* **2012**, *22*, 147-160.
21. Bryan, B.A.; Gao, L.; Ye, Y.; Sun, X.; Connor, J.D.; Crossman,N.D.; Stafford S.; Wu, J.; He, C.; Yu, D.; Liu, Z.; Huang, Q.; Li, A.; Ren, H.; Deng, X.; Zheng, H.; Niu, J.; Han, G.; Hou, X. China's Response to A National Land-system Sustainability Emergency. *Nature* **2018**, *559*, 193-204.
22. Ma, J.; Wang, X. Differences in Industrial Environmental Efficiency of the Yangtze River Economic Belt and Their Influencing Factors: Based on the Super Efficiency DEA-Malmquist-Tobit Model. *J. Hohai Univ.* **2017**, *19*, 49-54.
23. Templeton, S.R.; Scherr, S.J. Effects of Demographic and Related Micro-economic Change on Land Quality in Hills and Mountains of Developing Countries. *World Development* **1999**, *27*, 903-918.
24. Xie, H.; Chen, Q.; Lu, F.; Wang, W.; Yao, G.; Yu, J. Spatial-temporal Disparities and Influencing Factors of Total-factor Green Use Efficiency of Industrial Land in China. *J. Clean. Prod.* **2019**, *207*, 1047-1058.
25. Edwards, P.; Giessen, L. Global Forest Governance-Discussing Legal Scholarship from Political Science Perspectives. *For Policy Econ.* **2014**, *38*, 30-31.
26. Chen, C.; Park, T.; Wang, X.; Piao, S.; Xu, B.; Chaturvedi, R.K.; Fuchs, R.; Brovkin, V.; Ciais, P.; Fensholt, R.; Tommervik, H.; Bala, G.; Zhu, Z.; Nemani, R.R.; Myneni, R.B. China and India Lead in Greening of the World through Land-use Management. *Nature Sustainability* **2019**, *2*, 122-129.
27. Fang, X. Evaluation of Forest Ecological Function in the Aojiang River Basin. *Forest Investigation Design* **2022**, 36-39+61.
28. Qian, C.; Zhao, Y.; Li, M.; Li, T. Dynamic Analysis of Forest Ecological Functions Based on Fixed Plot Data of Continuous Forest Resources Inventories from 1979 to 2012 in Guangzhou. *Journal of Nanjing Forestry University (Natural Sciences Edition)* **2022**, *46*, 205-212.
29. Wang, B.; Zhang, W.; Yang, Z. Application of Forest Ecological Indexes in Forest Resource Planning, Designing and Survey. *East China Forest Management* **2007**, *21*, 52-53+56.
30. Lockaby, B.G.; Stanturf, J.A.; Messina, M.G. Effects of Silvicultural Activity on Ecological Processes in Floodplain Forests of the Southern United States: A Review of Existing Reports. *For. Ecol. Manag.* **1997**, *90*, 93-100.
31. Zhang, X.; Zheng, C.; Tang, X.; Zhang, W. Assessment of Comprehensive Index for Forest Ecological Function in Shanghai Municipality. *Subtropical Soil and Water Conservation* **2015**, *27*, 34-37.

32. Lu, D.; Sun, D. Development and Management Tasks of the Yellow River Basin: A Preliminary Understanding and Suggestion. *Acta Ecol. Sin.* **2019**, *12*, 2431-2436.
33. Fan, J.; Wang, Y.; Wang, Y. High Quality Regional Development Research Based on Geographical Units: Discuss on the Difference in Development Conditions and Priorities of the Yellow River Basin Compared to the Yangtze River Basin. *Econ. Geogr.* **2020**, *1*, 1-11.
34. Shi, Y.; Jin, N.; Ma, X.; Wu, B.; He, Q.; Yue, C.; Yu, Q. Attribution of Climate and Human Activities to Vegetation Change in China Using Machine Learning Techniques. *AGR FOREST METEOROLOGY* **2020**, *294*, 108146.
35. Zheng, K.; Wei, J.; Pei, J.; Cheng, H.; Zhang, X.; Huang, F.; Li, F.; Ye, J. Impacts of Climate Change and Human Activities on Grassland Vegetation Variation in the Chinese Loess Plateau. *Sci. Total Environ.* **2019**, *660*, 236-244.
36. Chen, Z.; Yu, B.; Yang, C.; Zhou, Y.; Yao, S.; Qian, X.; Wang, C.; Wu, B.; Wu, J. An Extended Time Series (2000-2018) of Global NPP-VIIRS-like Nighttime Light Data from a Cross-sensor Calibration. *Earth System Science Data* **2021**, *13*, 889-906.
37. Zhang, X.; Zheng, C.; Tang, X.; Zhang, W. Assessment of Comprehensive Index for Forest Ecological Function in Shanghai Municipality. *Subtropical Soil and Water Conservation* **2015**, 27, 34-37.
38. Standardization Administration of China. Technical regulations for continuous forest inventory: GB/T 38590−2020. Beijing: Standards Press of China, 2020.
39. Tang, X.; Song, X.; Zeng, Y.; Zhang, D. Evaluation and Spatio-temporal Evolution of Forest Ecological Security in the Yangtze River Economic Belt. *Acta Ecologica Sinica.* **2021**, *41*, 1693-1704.
40. Liu, H.; Liu, F.; Zheng, L. Effects of Climate Change and Human Activities on Vegetation Cover Change in the Yellow River Basin. *Journal of Soil and Water Conservation* **2021**, *35*, 143-151.
41. Dong, F.; Li, J.; Zhang, S.; Wang, Y.; Sun, Z. Sensitivity Analysis and Spatial-temporal Heterogeneity of CO^2 Emission Intensity: Evidence from China. *Resources, Conservation &Recycling* **2019**, *150*, 104398.
42. Dong, F.; Li, J.; Zhang, X.; Zhu, J. Decoupling Relationship between Haze Pollution and Economic Growth: A New Decoupling Index. *Ecological Indicators* **2021**, *129*, 107859.
43. Gao, X.; Sun, M.; Luan, Q.; Zhao, X.; Wang, J.; He, G.; Zhao, Y. The Spatial and Temporal Evolution of the Actual Evapotranspiration Based on the Remote Sensing Method in the Loess Plateau. *Sci. Total Environ.* **2020**, *708*, 135111.
44. Wu, Q.; Zhu, J.; Zhao, X. Effects of Human Social-Economic Activities on Vegetation Suitability in the Yellow River Basin, China. *Forests* **2023**, *14*, 234.
45. Mo, X.; Liu, S.; Hu, S. Co-evolution of Climate-vegetation-hydrology and Its Mechanisms in the Source Region of Yellow River. *Acta Geographica Sinica.* **2022**, 77, 1730-1744.
46. Thakur, S.; Negi, V.S.; Pathak, R.; Dhyani, R.; Durgapal, K.; Rawal, R.S. Indicator Based Integrated Vulnerability Assessment of Community Forests in Indian West Himalaya. *For. Ecol. Manag.* **2020**, *457*, 117674.
47. Matias, L.; Linares, J.C.; Sanchez-Miranda, A.; Jump, A.S. Contrasting Growth Forecasts Across the Geographical Range of Scots Pine Due to Altitudinal and Latitudinal Differences in Climatic Sensitivity. *Glob Chang Biol.* **2017**, *23*, 4106-4116.
48. Chakraborty, A.; Ghosh, A.; Sachdeva, K.; Joshi, P.K. Characterizing Fragmentation Trends of the Himalayan Forests in the Kumaon Region of Uttarakhand, India. *Ecol Inform.* **2017**, *38*, 95-109.
49. Zhang, Y.; Sun, J.; Song, X.; Lu, Y. Revealing the Main Factors Affecting Global Forest Change at Distinct Altitude Gradients. *Ecol. Indic.* **2023**, *148*, 110131.
50. Tang, D.; Yang, K.; Zeng, L.; Liu, X.; Xin, C.; Xu, Y. Spatio-temporal Differences of Enhanced Aeolian Sand Activity in the Northeastern Tibetan Plateau over the Past 1500 Years. *Acta Geographica Sinica.* **2023**, *78*, 2284-2298.
51. Zhang, T.; Wang, J.; Ye, H.; Lai, W.; Zhang, X. Vulnerability of Alpine Ecosystems and Its Response to Climate Change and Human Activities. *Acta Ecologica Sinica.* **2024**, *44*, 1-17.
52. Hou, G.; Xu, C.; Li, X.; Qi, B. Spatial Pattern of Water Conservation Function in Hehuang Valley. *Ecological Science* **2021**, *40*, 169-176.
53. Zhu, J.; Gong, J.; Li, J. Spatio-temporal Change of Habitat Quality in Ecologically Sensitive Areas of Eastern Qinghai-Tibet Plateau: A Case Study of the Hehuang Valley, Qinghai Province. *Resources Science* **2020**, *42*, 991-1003.
54. Zhang, H.; Zhan, C.; Xia, J.; Hu, S.; Ning, L.; Deng, X. Spatial-temporal Variations and Strip Patterns of Vegetation in the Inner Mongolia of Yellow River Basin. *Acta Ecologica Sinica.* **2022**, *42*, 8818-8829.
55. Zeng, X.; Liu, Z.; He, C. Quantifying Surface Coal-mining Patterns to Promote Regional Sustainability in Ordos, Inner Mongolia. *Sustainability* **2018**, *10*, 1135.
56. Ding, M.; Sun, Z.; Liu, Z.; He, C. Impacts of Urban Expansion on Net Primary Productivity in the Agro-pastoral Ecotone in Northern China: A Case of Hohhot-Baotou-Ordos Region. *Arid Land Geography* **2017**, *40*, 614-621.

 doi:10.20944/preprints202404.0349.v1

57. Jin, B.; Zeng, Z.; Peng, P.; Wang, S.; Zhang, C.; Yang, R. Tree Biomass of Evergreen Broad-leaf Forest in Mid-subtropical Region of China at Three Succession Stages. *Hunan Forestry Science & Technology* **2017**, *44*, 42-45.
58. Yang, Y.; Zhang, P.; Wu, F.; Zhou, Y.; Song, Y.; Wang, Y.; An, S. The Significance and Countermeasures of Vegetation Construction on the Loess Plateau to Carbon Neutrality. *Acta Ecologica Sinica.* **2023**, *43*, 1-11.
59. Li, X.; Sun, C.; Sun, J.; Chen, W.; Li, X. Ecological Security Characteristics of Main Irrigated Agricultural Areas on the Loess Plateau Based on Remote Sensing Information. *Chinese Journal of Applied Ecology* **2021**, *32*, 3177-3184.
60. Shao, Q.; Liu, S.; Ning, J.; Liu, G.; Yang, F.; Zhang, X.; Niu, L.; Huang, H.; Fan, J.; Liu, J. Assessment of Ecological Benefits of Key National Ecological Projects in China in 2000-2019 Using Remote Sensing. *Acta Ecologica Sinica.* **2022**, *77*, 2133-2153.
61. Cao, Y.; Qin, F.; Pang, Y.; Zhao, F.; Huang, J. Spatiotemporal Changes in Vegetation and Hydrological Factors in the North China Plain from 2002 to 2016. *Acta Ecologica Sinica.* **2019**, *39*, 1560-1571.
62. Yang, Y.; She, Z.; Song, J.; Zhu, D. Study on Vegetation Variation Characteristics and Influencing Factors in Different Geomorphic Zones in the Chanbahe River Basin since 2000. *Ecology and Environmental Sciences* **2022**, *31*, 224-230.
63. Wang, L.; Wang, Y. Exploration on the Development of Ecological Forestry. *South China Agriculture* **2020**, *14*, 98-99.
64. Zuo, Q.; Wu, X.; Shi, J.; Wang, Q.; Liu, Z.; Zhu, A.; Yin, D.; Feng, Q.; Ji, W.; Kang, S. Constraints and Coordinated Allocation Strategies of Water and Land Resources for Sustainable Use of Coastal Saline-alkali Land in the Yellow River Delta. *Engineering Sciences* **2023**, *25*, 169-179.
65. Ren, L.; Li, Y.; Yu, M.; Yang, J.; Zhan, C.; Zhou, D. Evolution of Artificial Wetlands in the Yellow River Delta and Related Driving Factors during 1984-2015. *Journal of Agricultural Resources and Environment* **2020**, *37*, 493-502.
66. Wu, J.; Li, Y.; Yu, L.; Gao, M.; Wu, X.; Bi, X. Dynamic Changes and Driving Factors of Landscape Connectivity for Natural Wetland in Yellow River Delta. *Ecology and Environmental Sciences* **2018**, *27*, 71-78.
67. Song, Y.; Zhang, Z.; Niu, B.; Li, X. Temporal and Spatial Variations of Landscape Pattern Vulnerability in Yellow River Delta during 2005-2018. *Bulletin of Soil and Water Conversation* **2021**, *41*, 258-266.
68. Ling, Y.; Yu, J.; Yang, J.; Yu, Y.; Wang, Z.; Li, Y.; Wang, X.; Zhou, D.; Zou, Y.; Guan, B.; Ma, Y.; Lv, M. Spatial-temporal Changes of Land Use/Cover and Its Responses to the Human Activity Intensity in the Modern Yellow River Delta during 1991-2021. *Chinese Journal of Ecology* **2023**, 1-13[2023-10-11].