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Tourism-Related Vegetation Dynamics and Implications for Sustainable Ecosystem Management in the Ejinah Poplar Forest Region

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Abstract

This study utilizes NDVI and climate data from 2000 to 2020 to analyze the spatiotemporal characteristics of vegetation changes in different Ejinah Poplar Forest National Nature Reserve areas. Factor and residual analyses were employed to disentangle and quantify the contribu tions of climate factors and human activities to vegetation changes. The results indicate: 1. NDVI showed a fluctuating upward trend with a rate of 0.0067. Vegetation growth in tourism activity areas was better than in non-tourism areas, with significant overall vegetation improvement. 2. Among driving factors, human activities predominantly contributed to vegetation restoration, accounting for 60–80% of the impact in over 70% of the region. 3. Tourism-related factors explained 47% of the total variance in the selected indicators and showed a positive relationship with vegetation coverage in tourism areas. The comparison between tourism and non-tourism areas provides new insights into the spatially varying relationships between human activities and vegetation dynamics in ecologically fragile nature reserves. These findings provide scientific evidence for integrating vegetation monitoring, ecological conservation, and sustainable tourism planning while highlighting the importance of considering overlapping environmental and human influences.

Keywords: sustainable tourism; ecotourism; Ejinah Poplar Forest; vegetation dynamics; NDVI; ecosystem management

1. Introduction

With the intensifying global challenges of climate change, ecological security has become a central concern in contemporary society. Vegetation, a crucial component of terrestrial ecosystems, is vital in maintaining ecological balance, promoting biodiversity, and ensuring ecosystem services [1]. Numerous studies have demonstrated that climatic factors are among the key drivers influencing vegetation growth and distribution. Prior research has provided important theoretical foundations for understanding the relationship between climate and vegetation [2–6]. However, with the rapid development of socio-economic activities, the impact of human activities on ecosystems has become increasingly prominent. Previous studies have also examined the combined effects of human activities on vegetation dynamics, highlighting the importance of considering both drivers when assessing ecosystem changes [7–9].

Among human activities, tourism has emerged as an important factor influencing ecosystem dynamics, particularly in ecologically sensitive regions. Compared to other

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Academic Editor: Lucian Dinca

Received: 16 September 2026
Revised: 30 October 2026
Accepted: 6 November 2026
Published: 27 November 2026

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activities such as urban development, mining, and transportation infrastructure [10–13], tourism involves complex interactions between natural environments and socio-cultural factors. These interactions are particularly pronounced in sensitive areas such as nature reserves [14]. Tourism activities directly influence vegetation cover, species diversity, and ecological structure, while indirectly affecting the local ecological environment through social factors such as visitor behavior, tourism development models, infrastructure construction, and management practices [15–17]. Tourism has increasingly become a core factor driving ecosystem transformation in nature reserves. Ecological water conveyance is an important human intervention influencing vegetation dynamics in the Ejina Populus euphratica nature reserve. By improving water availability, water conveyance may support vegetation recovery and alter the ecological conditions under which tourism develops. Meanwhile, tourism activities may influence vegetation through infrastructure development, visitor pressure, and conservation-related investments. These processes may operate simultaneously, making it difficult to distinguish their individual effects on vegetation change. Although previous studies have examined environmental restoration and tourism-related ecological impacts, the combined influence of ecological water conveyance and tourism on vegetation dynamics requires further investigation. This study therefore examines vegetation changes in tourism and non-tourism areas while acknowledging the potential overlapping effects of these anthropogenic drivers.

Although existing research has highlighted the dominant role of human activities in vegetation changes, systematic studies on the specific impacts of tourism activities on vegetation remain insufficient. This gap is especially evident in nature reserves, where the specific mechanisms by which tourism activities drive vegetation changes have not been thoroughly explored. Ejinah Poplar Forest is a typical nature reserve and tourism destination with unique ecological resources and fragile ecological carrying capacity. Its ecosystem is susceptible to tourism activities. However, current research predominantly focuses on analyzing the spatiotemporal changes in vegetation cover while often overlooking the role of tourism activities as a driving factor [14–18]. However, the relationships between tourism activities and vegetation dynamics remain insufficiently understood, particularly when tourism development overlaps with climatic variability, ecological restoration, and other human interventions. Therefore, this study aims to systematically analyze the dynamic vegetation changes in the scenic area of Ejinah Poplar Forest and its surrounding regions, focusing on the role of tourism activities in driving these changes. Additionally, it seeks to identify the specific human activity factors that positively and negatively impact ecological and vegetation resource changes. The innovation of this study lies in its use of NDVI data, climate factors, and tourism activity data, and it systematically compares vegetation dynamics in tourism and non-tourism areas by employing trend analysis, residual analysis, and factor analysis. It quantifies the extent to which tourism activities impact ecological changes and differentiates the effects of tourism activities across multiple scales. This multi-dimensional analytical perspective provides a new framework and insight for studying the relationship between tourism activities and ecological environments. Based on these research gaps, this study addresses three research questions: (1) How do spatiotemporal vegetation dynamics differ between tourism and non-tourism areas? (2) What are the relative contributions of climatic factors and human activities to vegetation changes? (3) How do tourism-related factors differ from other human activities in their relationships with vegetation dynamics?

2. Overview of the Study Area, Data, and Methodology

2.1. Overview of the Study Area

The Ejinah Poplar Forest National Nature Reserve is located in the center of Ejinah Banner, Inner Mongolia, with geographic coordinates ranging from 101°03′ E to 101°17′ E

and 41°30′ N to 42°07′ N. The location and extent of the study area are shown in Figure 1. The reserve is an important ecological protection area in arid inland regions and a representative nature reserve for tourism [19]. Tourism activities are concentrated in the experimental area, spanning 101°04′ E to 101°07′ E and 41°57′ N to 41°58′ N. This study defines the primary areas of tourism activities as "tourism areas," while other regions are classified as "non-tourism areas." The Poplar Forest plays a pivotal role in arid ecosystems, providing essential ecological functions such as maintaining biodiversity, water conservation, soil and water retention, windbreak and sand fixation, and climate regulation [20,21]. The reserve's terrain is fan-shaped, with most of the area at 850 to 950 m. The topography slopes from southwest to northeast, with relatively flat central zones. The annual average temperature in the area is 8.3 °C, and annual precipitation ranges from 37.9 to 49.3 mm.

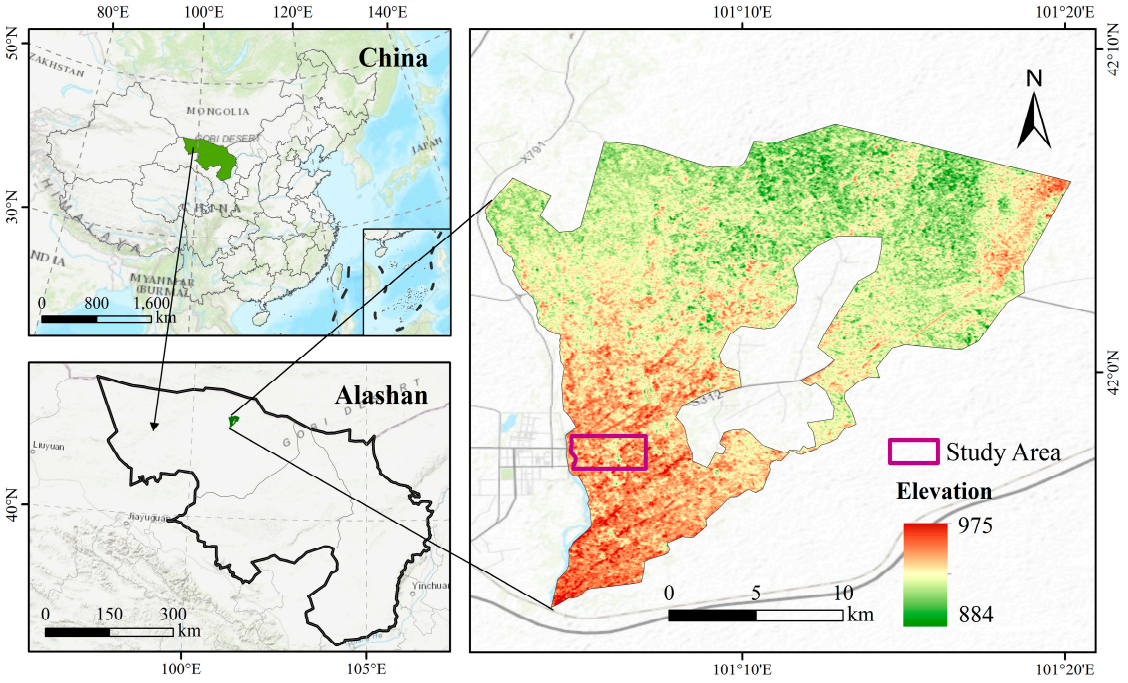

Figure 1. Location and extent of the study area.

2.2. Data Sources

The NDVI (Normalized Difference Vegetation Index) is calculated as the ratio of the difference between near-infrared and red reflectance to their sum, which is used to analyze vegetation changes in the study area. The data were obtained from the National Ecological Science Data Center (http://www.nesdc.org.cn/ accessed on 5 June 2024). This dataset, derived from the Landsat 5/7/8 remote sensing data via the Google Earth Engine platform, underwent preprocessing and smoothing to extract the maximum annual NDVI value for each pixel between 2000 and 2020. The spatial resolution of the dataset is 30 m [22]. Annual maximum NDVI was selected to characterize peak vegetation conditions and assess long-term vegetation changes in the arid study region. This approach helps capture vegetation growth during periods of maximum greenness while reducing the influence of seasonal fluctuations and low vegetation activity during dry periods. NDVI and FVC datasets required for this study were obtained through clipping and pixel binary modeling processes. Temperature and precipitation data were sourced from the National Tibetan Plateau Data Center, using monthly average temperature datasets with a 1-km resolution (1901–2022) [23,24]. The datasets and their sources are summarized in Table 1.

Table 1. Summary of datasets used in this study.

Dataset	Source	Temporal Coverage	Spatial Resolution
NDVI	National Ecological Science Data Center	2000–2020	30 m
Temperature	National Tibetan Plateau Data Center	2000–2020	1 km
Precipitation	National Tibetan Plateau Data Center	2000–2020	1 km
Land-use data	National Tibetan Plateau Data Center	2000, 2005, 2010, 2015, 2020	30 m
Tourist numbers	Ejina Banner Statistical Communiqué	2000–2020	Not applicable
Tourism revenue	Ejina Banner Statistical Communiqué	2000–2020	Not applicable
Scenic-area development plan	Ejinah Poplar Forest Scenic Area Development Plan	2015–2025	Not applicable
Management policies	Relevant government and reserve management documents	2001–2016 (policy introduction dates)	Not applicable

2.3. Methodology

2.3.1. Theil-Sen Trend Analysis and Mann–Kendall Test

The Theil-Sen trend analysis method is a non-parametric slope estimation technique that calculates trends based on clustering and ranking [25]. Compared to conventional linear regression methods, this algorithm has robust error-avoidance capabilities. After obtaining the spatiotemporal NDVI trends from 2000 to 2020, combined with NDVI classification ranges (Table 2), it enables a more intuitive and effective analysis of the spatiotemporal trends of different vegetation coverage types.

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right), \forall j > i \quad (1)$$

In Equation (1):

Xi and Xj represent the ith and jth data samples, respectively. The median is the median function. $\beta > 0$ indicates an increasing NDVI trend, while $\beta < 0$ indicates a decreasing trend. The statistical significance of NDVI trends was assessed using the Mann–Kendall test.

Table 2. The NDVI index classification and range description.

Vegetation Coverage Type	NDVI Value	Description
No Vegetation Coverage	−1~0.2	Areas covered by water, agricultural land, or buildings.
Low Vegetation Coverage	0.2~0.35	Sparse vegetation, with significant bare land.
Medium Vegetation Coverage	0.35~0.5	Most land covered by forests, shrubs, or herbs. NDVI.
High Vegetation Coverage	0.5~1.0	Land almost entirely covered by dense vegetation.

2.3.2. NDVI Classification

Scientific classification of NDVI facilitates more effective monitoring of changes in natural ecosystems. The study area is situated in an extremely arid desert zone in the northern temperate belt, with low annual precipitation and high evaporation rates [26]; the vegetation is predominantly composed of slow-growing xerophytes and ultra-xerophytes. Based on the region's climate characteristics and vegetation growth conditions, the NDVI ranges for different vegetation cover types were adjusted, drawing from previous studies [27]. This allows a more accurate reflection of the ecological characteristics of the study area. NDVI values were classified into four levels, as shown in Table 2.

2.3.3. Multiple Regression Residual Analysis

Multiple linear regression residual analysis calculates the residuals between observed and estimated values. Using NDVI and related meteorological data, this method effectively

differentiates the impacts of human activities and climate factors on vegetation changes. Its advantage lies in analyzing unobservable factors affecting vegetation changes that are not captured by the model, thus avoiding potential biases. This method enables detailed exploration of the specific effects of climate changes and human activities on NDVI dynamics and quantifies their relative contributions [28,29]. The equations are as follows:

$$NDVI_{CC} = a \cdot Tmp + b \cdot Pre + c \quad (2)$$

$$NDVI_{HA} = NDVI_{obs} - NDVI_{CC} \quad (3)$$

where

$NDVI_{CC}$ and $NDVI_{obs}$ are the predicted NDVI (via regression) and observed NDVI (from remote sensing), respectively (dimensionless).

a, b, c are model parameters.

Tmp and Pre represent average temperature and accumulated precipitation during the growing season.

$NDVI_{HA}$ is the residual term. Temperature and precipitation were selected for the residual analysis because they represent key climatic controls on vegetation growth. Solar radiation was examined separately through partial correlation analysis to assess its relationship with NDVI. It was not included in the regression model to maintain a parsimonious framework focused on temperature and precipitation. However, excluding solar radiation may leave part of its influence within the residuals attributed to human activities. The residual component was used as an indirect indicator of human activity influences on vegetation changes. However, this approach assumes that the regression model adequately captures the effects of the selected climatic variables. The residuals may also reflect omitted climatic factors, hydrological conditions, delayed vegetation responses to climate, and model uncertainties. Therefore, residuals should not be interpreted as exclusively representing human activities.

2.3.4. Determining Driving Factors and Contribution Rates

The slopes of $NDVI_{CC}$ and $NDVI_{HA}$ indicate the effects of climate change and human activities on NDVI trends. Positive slopes suggest drivers contributed to NDVI growth, aiding vegetation restoration, while negative slopes indicate declines [30]. Contribution rates were calculated to assess the relative impacts of climate change and human activities on vegetation cover changes, as shown in Table 3.

Table 3. Criteria for Determining Drivers and Contribution Rate Calculation.

Slope($NDVI_{obs}$) [a]	**Driver Factors**	**Criteria for Differentiation**		**Contribution Rate (%)**	
		Slope($NDVI_{CC}$) [b]	**Slope($NDVI_{HA}$) [c]**	**Climate Change**	**Human Activities**
>0	CC&HA	>0	>0	$\frac{slope(NDVI_{cc})}{slope(NDVI_{obs})}$	$\frac{slope(NDVI_{HA})}{slope(NDVI_{obs})}$
	CC	>0	<0	100	0
	HA	<0	>0	0	100
<0	CC&HA	<0	<0	$\frac{slope(NDVI_{cc})}{slope(NDVI_{obs})}$	$\frac{slope(NDVI_{HA})}{slope(NDVI_{obs})}$
	CC	<0	>0	100	0
	HA	>0	<0	0	100

Note: [a], [b], and [c] represent the trend rates based on observed NDVI values, predicted NDVI values, and NDVI residual trend rates, respectively. Among these, [b] and [c] specifically indicate the NDVI trend rates during the growing season influenced by climate change and human activities.

2.3.5. Vegetation Coverage Calculation

Fractional Vegetation Coverage (FVC), a key indicator of surface vegetation conditions, reflects vegetation growth in a region. It provides standardized data for analyzing the

relationships between vegetation changes and driving factors. Using a pixel binary model, FVC is calculated as follows [31]:

$$\mathrm{FVC} = \frac{\mathrm{NDVI} - \mathrm{NDVI_{soil}}}{\mathrm{NDVI_{veg}} - \mathrm{NDVI_{soil}}} \quad (4)$$

where $\mathrm{NDVI_{soil}}$ and $\mathrm{NDVI_{veg}}$ are endpoints representing bare soil and full vegetation, respectively, derived from cumulative NDVI frequencies (5% and 95%). Values of FVC < 0 were set to 0, and FVC > 1 were set to 1 to eliminate anomalies.

2.3.6. Exploratory Factor Analysis

When exploring the response characteristics and relative importance of climatic factors and human activities on vegetation, the numerous selected factors and the potential correlations between them make it insufficient to rely solely on correlation coefficients to objectively reflect the relationship between Fractional Vegetation Coverage (FVC) and other human activity factors. Exploratory factor analysis effectively reduces the dimensionality of data and simplifies its complexity. This study uses this method to accurately and effectively reveal the intrinsic relationships between variables and summarize the impact of human activities at different scales on vegetation changes. Assuming a multivariate system can be represented by n random variables

$[\mathrm{x} = (\mathrm{x_1}, \mathrm{x_2}, \ldots, \mathrm{x_n})']$, the model of F and A is as follows:

$$x - \mu = AF + \varepsilon \quad (5)$$

$\mathrm{A} = (\mathrm{a_{ij}})$ is the loading matrix, F represents the common factors, and ϵ denotes the specific factors. The variance (Var) and contribution of the factors [32,33] can be calculated as follows:

$$\text{Contribution} = \frac{\sum_{i=1}^{n} \alpha_{ij}^2}{\sum_{i=1}^{n} \mathrm{Var}(X_i)} \quad (6)$$

3. Results

3.1. Comparative Analysis of NDVI Spatiotemporal Evolution

To thoroughly analyze the interannual changes in vegetation within the study area, the average NDVI values for each year from 2000 to 2020 were calculated. The results indicate that the NDVI within the reserve shows a fluctuating upward trend, with an average annual growth rate of 0.0067 (Figure 2a), suggesting an overall improvement in vegetation conditions.

Further analysis reveals that the annual NDVI growth rate in tourism areas is 0.0011 higher than in non-tourism areas (Figure 2b), indicating that vegetation growth in tourism areas is relatively better. By examining the growth rates of different vegetation coverage types, it was observed that medium and high vegetation coverage areas in tourism zones exhibit an increasing trend, with high vegetation coverage areas showing a particularly significant growth rate of 0.78, representing a "cliff-like" growth pattern.

In contrast, the low (0.03), medium (0.18), and high (0.43) vegetation coverage areas in non-tourism zones also show growth, but the differences in growth rates among these types of vegetation coverage are relatively small (Figure 2c). This phenomenon is likely closely related to the intervention of tourism activities.

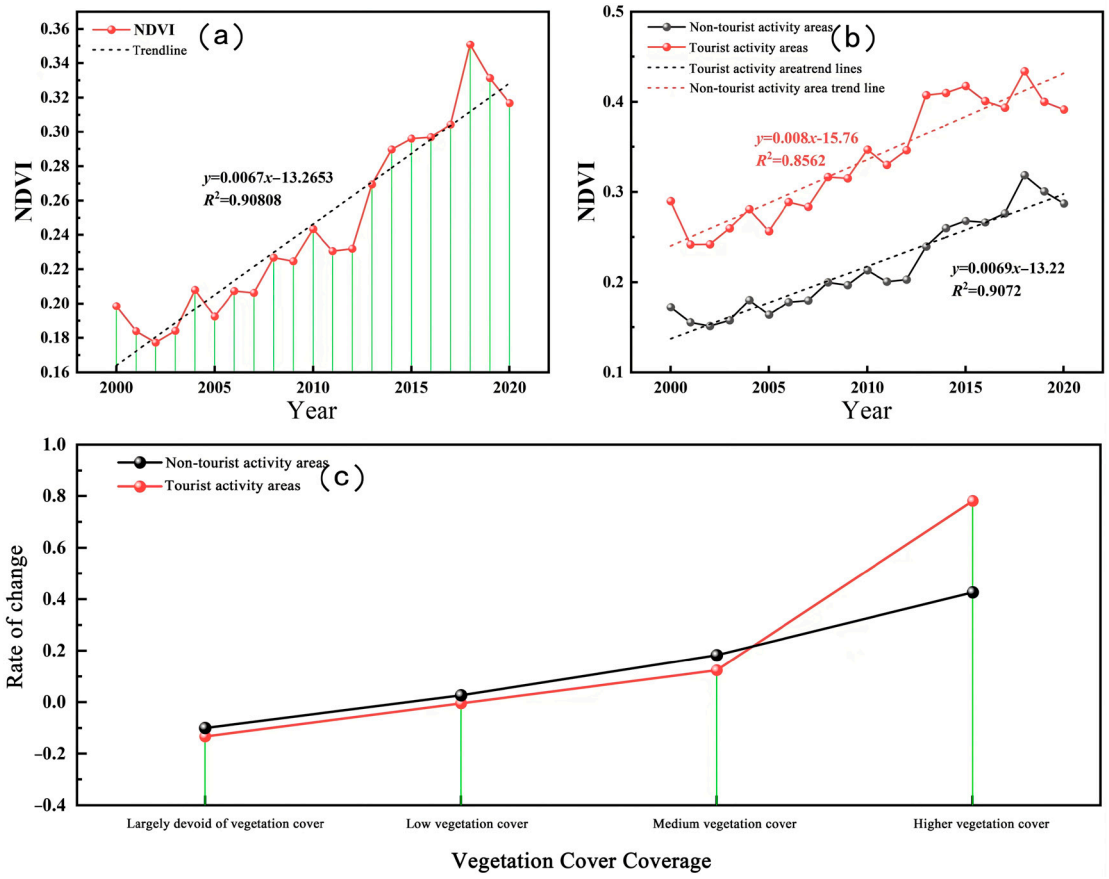

Figure 2. Interannual variation in NDVI in the study area from 2000 to 2020 (**a**); Interannual variation in NDVI in different regions (**b**); Area change rate of different vegetation cover types (**c**).

To gain a more intuitive understanding of the spatial changes in vegetation across different regions of the study area, this research utilized Theil-Sen trend analysis and the Mann–Kendall test to determine spatial variation trends for different vegetation coverage types. The results indicate that, during the sample period, vegetation coverage in the study area exhibited a significant increasing trend, accounting for 79.68% of the total area (Figure 3f). This finding aligns with the research of Tang Yongkang et al. [14].

The proportion of significantly increased vegetation coverage in tourism areas (88% of the total tourism area, Figure 3) is 7% higher than in non-tourism areas. The main growth in tourism areas occurred in high vegetation coverage zones, which increased by 85 hectares compared to 2000. Conversely, areas with low vegetation coverage decreased substantially, with a decline of 52%. The regions experiencing significant reductions were primarily concentrated near the scenic area entrances and visitor service centers. In contrast, areas of significant reduction in non-tourism zones were more dispersed.

Overall, the vegetation recovery and growth in tourism areas were better than in non-tourism areas. This phenomenon further suggests a strong correlation between tourism activities and vegetation dynamics. Tourism activities have a dual impact on the ecological environment: on the one hand, the development of tourism necessitates the construction of extensive infrastructure, which can lead to vegetation destruction; on the other hand, tourism in nature reserves often emphasizes the protection of core natural resources, thereby promoting vegetation recovery and growth to some extent.

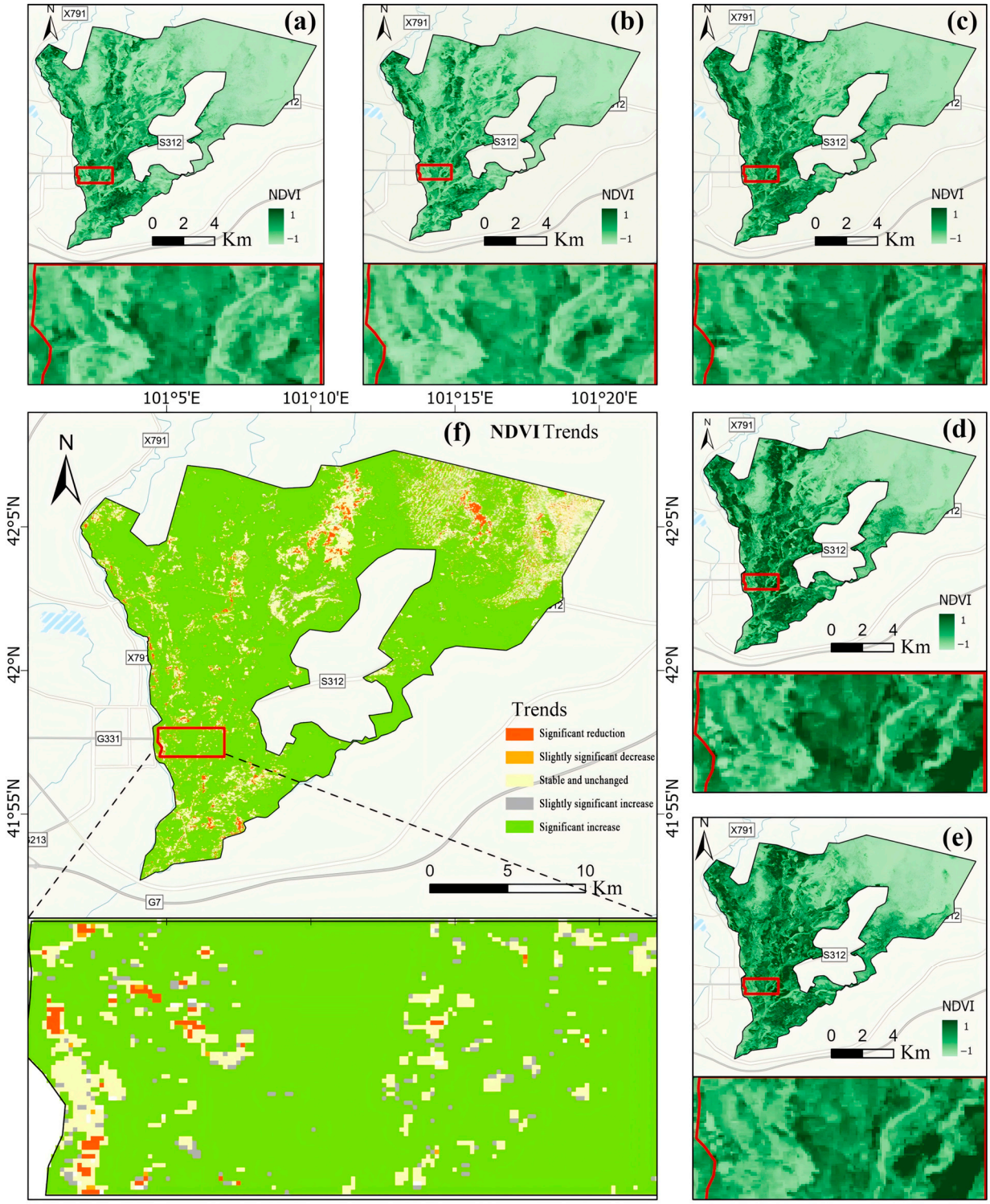

Figure 3. Vegetation cover and change trends in the study area. (**a**) NDVI-based vegetation cover in 2000; (**b**) NDVI-based vegetation cover in 2005; (**c**) NDVI-based vegetation cover in 2010; (**d**) NDVI-based vegetation cover in 2015; (**e**) NDVI-based vegetation cover in 2020; and (**f**) vegetation-cover types and their change trends from 2000 to 2020.

3.2. NDVI Driving Force Analysis

3.2.1. The Impact of Climatic Factors on NDVI

Vegetation changes are primarily influenced by the combined effects of climatic factors and human activities. To further investigate the driving factors of NDVI, this study employed

a partial correlation analysis model to reveal the spatial correlations between NDVI and annual cumulative precipitation, annual mean temperature, and annual cumulative solar radiation (Figure 4).

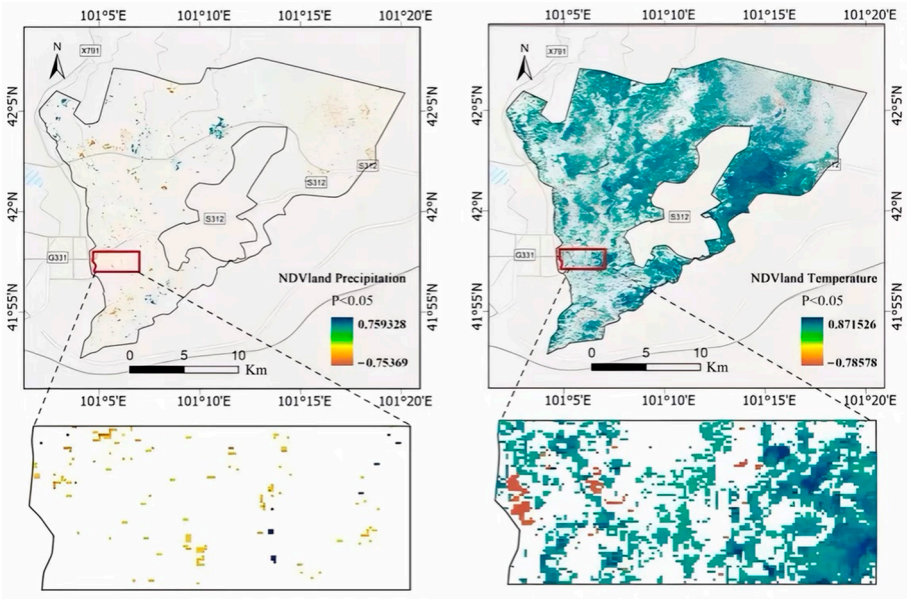

Figure 4. Partial correlation between NDVI and meteorological factors and significant partial correlation area.

The analysis results indicate that precipitation had an insignificant impact on vegetation changes during the study period. In contrast, temperature (correlation coefficient ranging from −0.79 to 0.87) and solar radiation (from −0.90 to 0.87) exhibited significant positive and negative effects on vegetation changes, respectively. The corresponding regions' correlation coefficients were consistent with the affected areas, resulting in a relatively weak combined effect of temperature and solar radiation on NDVI.

Overall, while climatic factors have some influence on vegetation changes, the vegetation dynamics in the Ejinah Poplar Forest National Nature Reserve over the 21-year period were predominantly less impacted by climatic factors. This aligns with findings from related studies [18]. This phenomenon may be attributed to the region's arid and extreme climatic characteristics, its ecological adaptability, and possibly the influence of human activities.

Improper human behaviors, such as trampling and vegetation destruction, may directly lead to plant mortality or restricted growth. This is particularly evident in areas with intense solar radiation, where strong sunlight and insufficient water resources make plants more vulnerable.

3.2.2. Impact of Human Activities on NDVI

Although climatic factors influence vegetation changes, their impact may be relatively minor. Understanding the relationship between NDVI and land cover types is essential for comprehending the spatiotemporal changes in land cover and the disturbances caused by human activities on vegetation. By overlaying NDVI with land use data, this study analyzed the trends in land use changes under different vegetation coverage types in the study area during 2000, 2005, 2010, 2015, and 2020.

The findings (Figure 5) reveal that in tourism activity areas, farmland areas within regions of no and low vegetation coverage showed slight fluctuations, while grassland areas experienced a slight decline, particularly between 2015 and 2020. Concurrently, areas of bare land and impervious surfaces exhibited an increasing trend, with bare land

continuously expanding and impervious surface areas growing rapidly. From 2000 to 2020, the proportion of impervious surfaces in no and low vegetation coverage areas increased by 3.54%. Notably, during 2015–2020, impervious surface areas rose significantly, from 1.84% to 4.44% (Figure 5a,b).

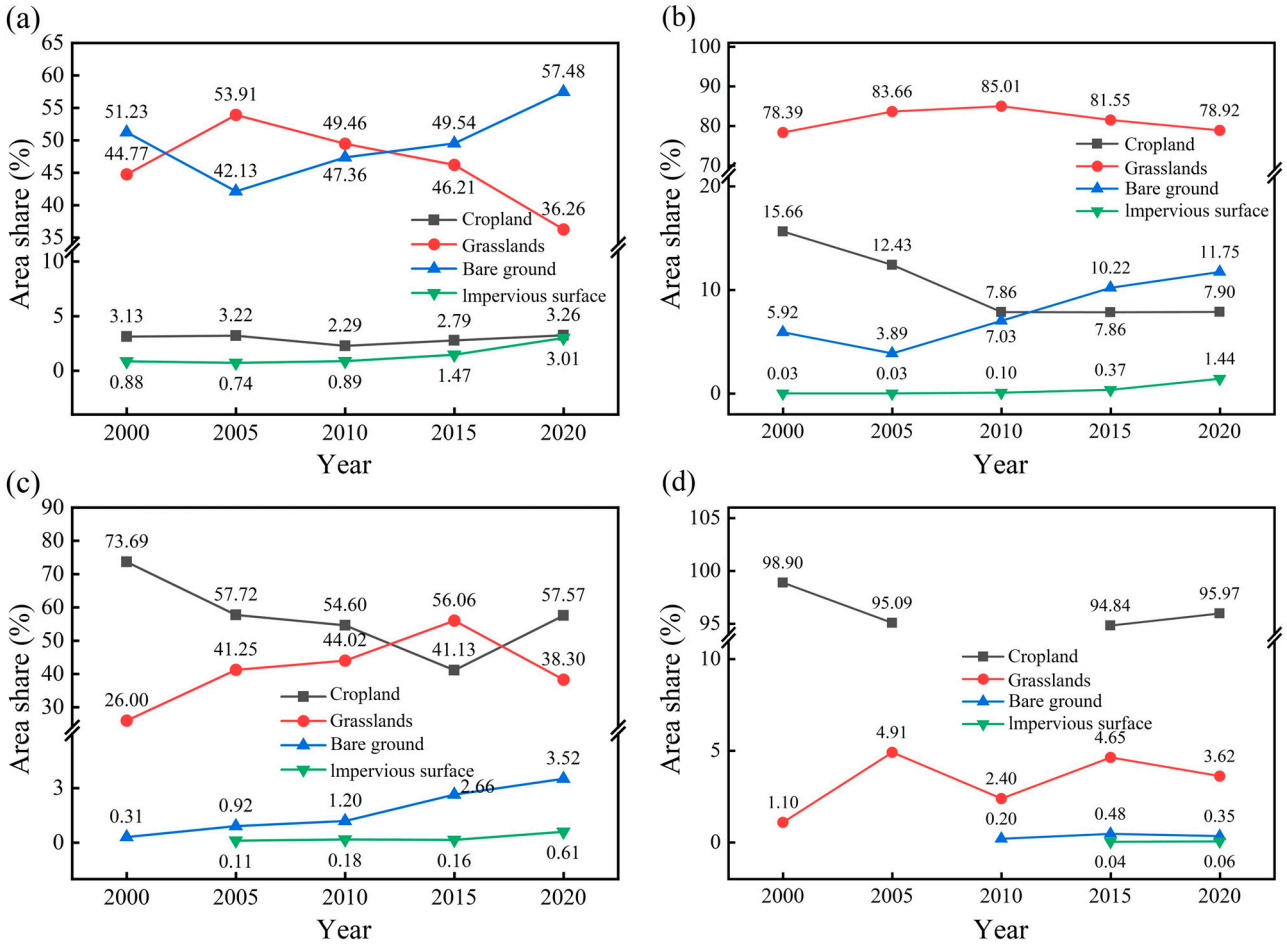

Figure 5. Area share of land use types under different vegetation cover types in the tourism activity area: basically no vegetation (**a**), low vegetation (**b**), medium vegetation (**c**), high vegetation (**d**).

This change may be associated with the 2015–2025 scenic area development plan released in 2015 for the Ejinah Poplar Forest Scenic Area. During the tourism development, infrastructure construction extensively occupied areas with no or low vegetation coverage.

In contrast, medium and high vegetation coverage areas primarily comprised farmland and grassland (Figure 5c,d), accounting for over 90% of the total area. The proportions of bare land and impervious surfaces in these areas increased slightly. This phenomenon is likely related to the characteristics of the study area, which is a typical nature reserve and tourism destination where core tourism resources are given priority protection during development. As a result, land use changes in these areas remain relatively stable.

In non-tourism activity areas (Figure 6), the changes in land cover types in regions with no and low vegetation coverage were similar to those observed in tourism activity areas. Farmland areas showed slight fluctuations, while bare land and impervious surface areas increased. Notably, in areas with no vegetation coverage, bare land significantly rose from 68.24% to 87.64%, and impervious surfaces in low vegetation coverage areas increased from 0.03% to 0.75%.

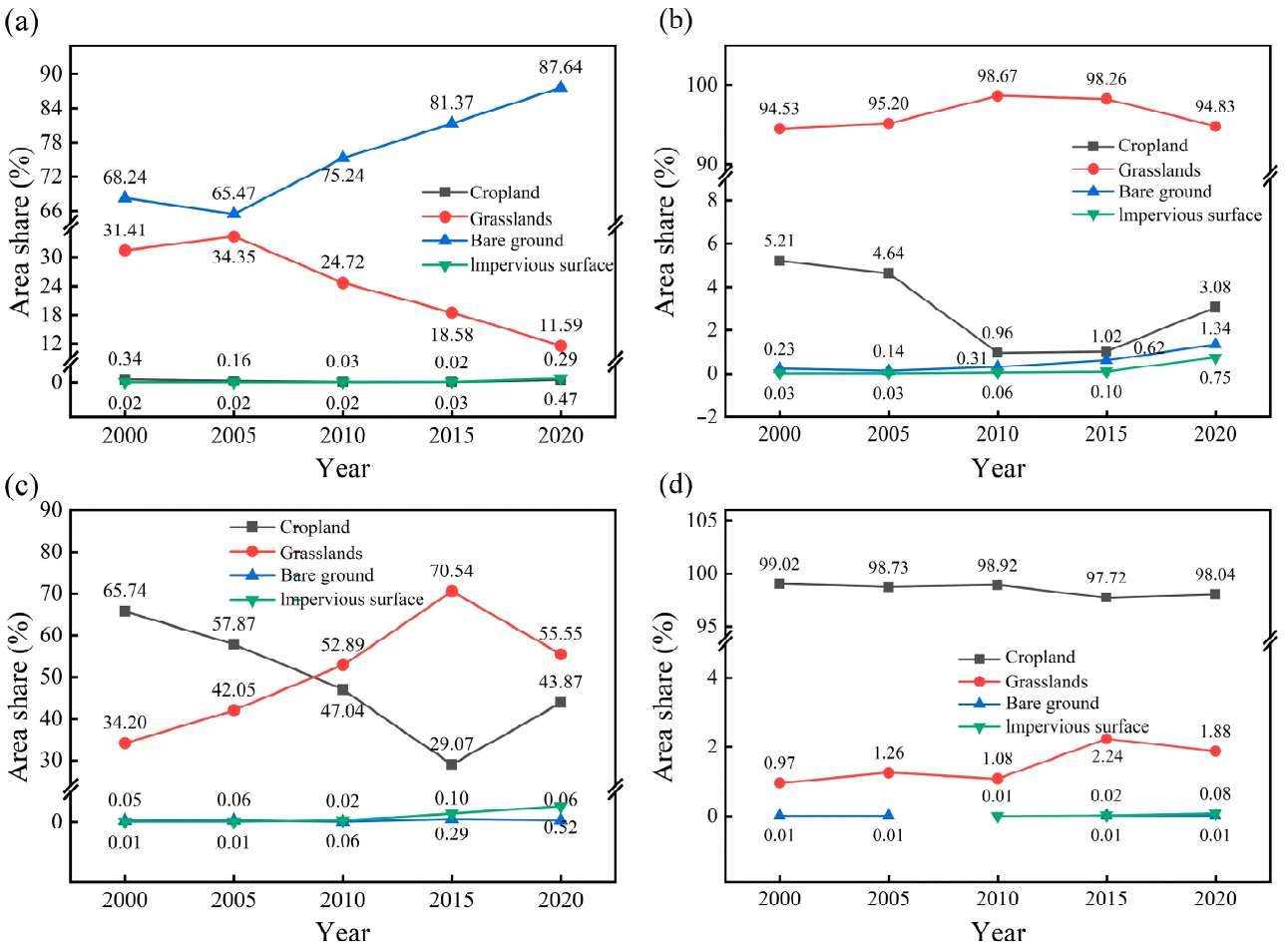

Figure 6. Percentage of land use type area under different vegetation cover types in non-tourism activity areas: basically no vegetation (**a**), low vegetation (**b**), medium vegetation (**c**), high vegetation (**d**).

However, unlike the changes in tourism activity areas, the proportion of impervious surfaces increased across all vegetation coverage types during 2015–2020. The most significant growth occurred in low and medium vegetation coverage areas, where by 2020, the proportion of impervious surfaces in medium and high vegetation coverage areas increased by 0.58%. This indicates that medium and high vegetation coverage in non-tourism activity areas experienced stronger negative impacts from human activities compared to tourism activity areas.

The differences in land use changes under medium and high vegetation coverage types between tourism and non-tourism activity areas may be attributed to the influence of tourism activities. Tourism activity areas tend to emphasize protecting core tourism resources, leading to less pronounced negative impacts on vegetation. Although changes in land use coincided with the implementation of tourism development policies, this temporal association does not establish a direct causal relationship. Land-use transformations may also reflect ecological restoration, conservation policies, water management interventions, and other human activities. Therefore, the observed changes are interpreted as associations rather than direct consequences of tourism policies.

3.2.3. Contribution of Different Factors to NDVI

The above analysis indicates that human activities and climatic factors have influenced vegetation changes in the study area. To further clarify their respective impacts on NDVI, residual analysis was conducted, revealing that the combined effects of climatic factors and human activities are the primary drivers of vegetation changes in the study area (Figure 7).

Specifically, 89.58% of non-tourism areas and 91.78% of tourism areas experienced positive contributions from both factors, while 3.11% of tourism areas and 4.60% of non-tourism areas were negatively affected by the combined influences of climate and human activities.

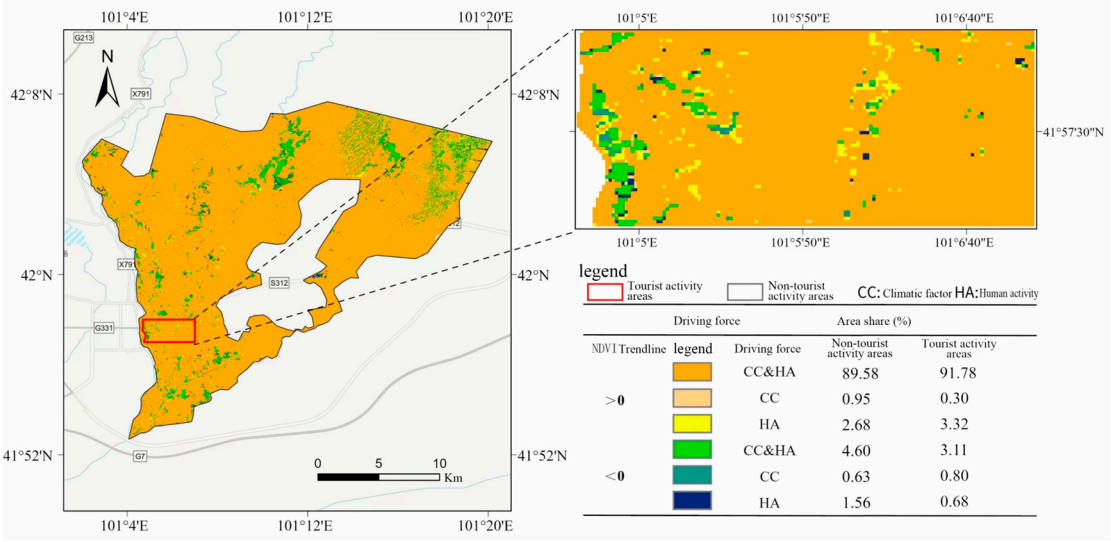

Figure 7. Residual analysis of NDVI with climate and human activities.

In tourism areas, regions negatively impacted by climate and human activities were concentrated near scenic area entrances or visitor centers, while such areas in non-tourism zones were more dispersed. Regarding individual driving factors, vegetation growth driven by human activities was more pronounced, particularly in tourism areas, where the proportion of vegetation growth reached 3.32%. In contrast, areas of vegetation degradation caused by human activities were more prominent in non-tourism areas (1.56%) than in tourism areas (0.68%).

Comparatively, the areas of vegetation growth and degradation solely driven by climatic factors were relatively small, underscoring the dominant role of human activities—especially tourism-related activities—in shaping vegetation dynamics in the region.

Based on Figure 8 and Table 3, there are both differences and similarities in the distribution of climatic and human activity contributions between tourism and non-tourism areas. In terms of the proportion of pixels contributed by climatic factors, 92.4% of the tourism areas and 84.88% of the non-tourism areas show vegetation influenced by a 0–40% climate contribution, while the proportion of pixels with a 60–100% climate contribution remains minimal. This further validates that climatic factors have a relatively low impact on vegetation changes.

When analyzing the proportion of pixels contributed by human activities, the differences between tourism and non-tourism areas become more pronounced (Table 4). In the 0–40% range, the proportion of human activity pixels in non-tourism areas is 3.80%, higher than the 2.10% observed in tourism areas. Conversely, in the 60–80% range, the proportion of human activity pixels in tourism areas is significantly higher at 75.07%, compared to 69.81% in non-tourism areas. This disparity may reflect the more significant environmental impact of tourism activities in the region.

A comprehensive analysis indicates that the proportion of human activity pixels is most prominent in the 60–80% range, demonstrating that human activities dominate vegetation changes. This is particularly evident in tourism areas, highlighting the significant influence of tourism-driven factors on the region's environment.

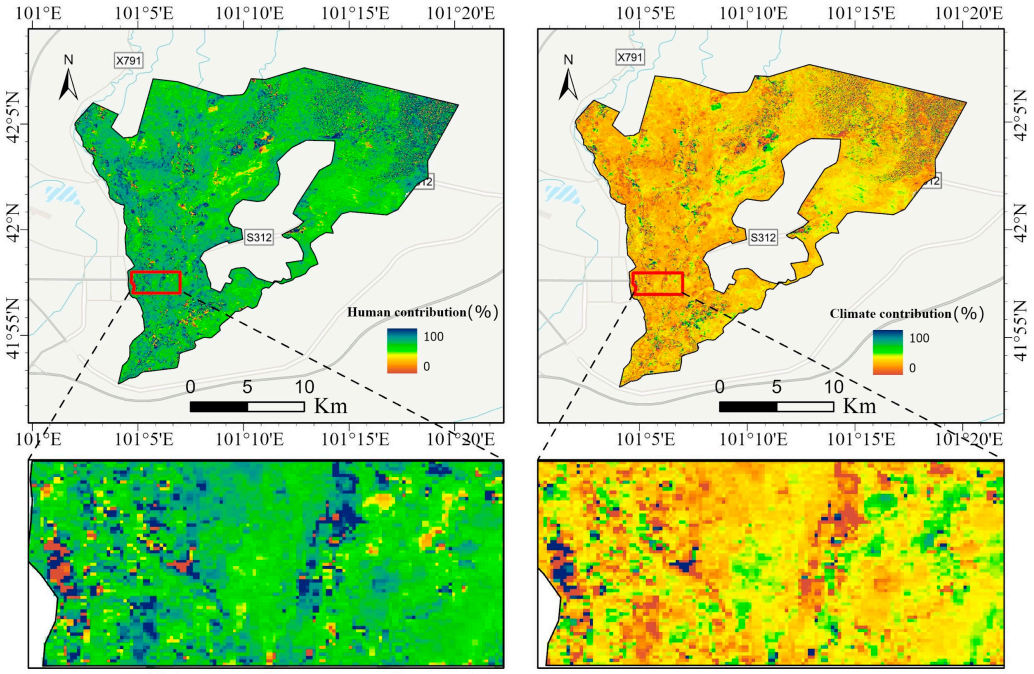

Figure 8. Contribution to climatic factors and human activities.

Table 4. Factors affecting changes in vegetation cover of Ejinah poplar forests in 2000–2022: Area share/%.

	Proportion of Pixels Contributed by Climate (%)		Proportion of Pixels Contributed by Human Activities (%)	
	Non-Tourism Areas	Tourism Areas	Non-Tourism Areas	Tourism Areas
0–20%	15.07	17.33	2.24	1.44
20–40%	69.81	75.07	1.56	0.66
40–60%	11.32	5.51	11.32	5.51
60–80%	1.56	0.66	69.81	75.07
80–100%	2.24	1.44	15.07	17.33

3.3. Correlation Analysis of the Impact of Human Activities on Vegetation at Different Scales

Given that the relative contribution of human activities to vegetation growth is more significant than that of climatic factors, this section further explores whether human activities at different scales lead to differentiated impacts on vegetation growth within the region. This analysis aims to provide critical insights into the sustainable tourism development of the Ejinah Poplar Forest National Nature Reserve. Relevant factors at multiple scales were selected for the Ejinah Poplar Forest from 2000 to 2020, including tourism activity drivers such as tourist numbers, tourism revenue, and the 2015 Poplar Forest Scenic Area Development Plan for tourism activity zones. These data were normalized to calculate the correlation between vegetation coverage (FVC), climatic factors, and human activities.

3.3.1. Correlation Between FVC and Driving Factors

This study collected data on key policies and plans implemented in the Ejinah Poplar Forest National Nature Reserve between 2000 and 2020. These include long-term policies and plans such as:

The designation of the Ejinah Poplar Forest as a national nature reserve in 2003.

The water diversion project in the Heihe River Basin initiated in 2001.

The ecological compensation policy implemented since 2006.

The scenic area management documents were introduced in 2016.

According to Table 5, all driving factors in tourism activity areas exhibited significant correlations with FVC, although precipitation showed the lowest correlation. Similarly, in non-tourism activity areas, all factors except precipitation also displayed significant correlations, consistent with earlier findings. Among the influencing factors in tourism areas, the scenic area development plan demonstrated the strongest positive correlation with FVC, with a correlation coefficient of 0.242, indicating the most substantial impact on vegetation. This was followed by tourism revenue, tourist numbers, and scenic area management policies.

Table 5. Correlation between human activity, climate factors and FVC.

	Tourism Area			Non-Tourism Area		
	Key Indicators	**Correlation Coefficient**	**Significance T-Test**	**Key Indicators**	**Correlation Coefficient**	**Significance T-Test**
Climate Factors	Temperature	0.146	**	Temperature	0.457	**
	Precipitation	0.113	**	Precipitation	0.225	
Human Activity Factors	JQGL	0.208	**			
	LYGH	0.242	**			
	BHQ	0.169	**	BHQ	0.508	*
	LYDS	0.052	**	LYDS	0.230	*
	Person	0.212	**	STBC	0.648	**
	Rmb	0.233	**			
	STBC	0.25	**			

Notes: * indicates $p < 0.05$, and ** indicates $p < 0.01$. JQGL is Scenic Area Management Policy, LYGH is Landscape Planning, LYDS represents Heihe River Basin Water Diversion, BHQ is Establishment of National Nature Reserves, and STBC represents Ecological Compensation Policy.

With the implementation of various protective policies, most ecological vegetation in tourism activity areas showed trends of recovery and growth. However, the correlation coefficients between FVC and individual factors in tourism activity areas hovered around 0.2, making it challenging to accurately determine the specific impacts of different scale policies on vegetation changes. Therefore, exploratory factor analysis provides an effective means of dimensionality reduction and summarization to further investigate the impacts of human activities at various dimensions on vegetation dynamics.

3.3.2. Results of Exploratory Factor Analysis

The previous analysis revealed significant correlations between human activities and FVC, with correlation coefficients showing minimal variation. To summarize the effects of factors at different scales on FVC changes, factor analysis was used for dimensionality reduction, given the large number of indicators and their potential interrelations. Through dimensionality reduction, multiple variables were integrated into a few comprehensive factors, simplifying the analysis process and reducing the number of variables.

According to Table 6, the factor composition showed some differences when climate and human activity indicators were transformed into comprehensive factors. In non-tourism areas, primarily associated with environmental protection policies, explained 35.58% environmental protection policies, explained 35.58% of the total variance in the selected indicators and showed a significant positive correlation with vegetation coverage ($r = 0.592$). This indicates that these policies have a significant positive impact on vegetation in non-tourism areas. Specifically, measures such as the Heihe River Basin water diversion, the establish-

ment of national nature reserves, and ecological compensation policies promoted vegetation restoration and expansion by improving water resource management, expanding ecological reserve areas, and enhancing environmental quality. In contrast, Factor 2, representing climatic factors, explained 29.02% of the total variance in the selected indicators but showed no significant correlation with vegetation coverage.

Table 6. Analysis of FVC changes in the core area of tourism activities.

	Tourism Area			Non-Tourism Area		
	Factor	**Contribution Rate (%)**	**Correlation with FVC**	**Factor**	**Contribution Rate (%)**	**Correlation with FVC**
Factor 1	Tourism Revenue Scenic Area Management Policies Tourists Scenic Area Development Plans	47.001	0.135 **	Heihe River Basin Water Diversion Establishment of National Nature Reserve Ecological Compensation Policies	35.576	0.592 **
Factor 2	Heihe River Basin Water Diversion Establishment of National Nature Reserve Ecological Compensation Policies	19.565	0.215 **	Solar Radiation Average Temperature	29.02	
Factor 3	Solar Radiation Average Temperature Average Precipitation	10.99	−0.144 **			

Notes: ** indicates statistical significance at $p < 0.01$.

Compared to non-tourism areas, when tourism activity factors directly related to scenic areas were included, comprehensive Factor 1, composed primarily of tourism activity drivers, became the dominant contributor to vegetation changes in tourism areas. It accounted for 47% of the contribution and was significantly positively correlated with FVC (correlation coefficient of 0.135, **), significantly higher than Factor 2, which was composed of national or regional policies (19.57%). Factor 3, representing climatic factors, contributed only 10.99%, further confirming the weaker role of climatic factors in vegetation changes.

Considering that vegetation growth in tourism areas is better than in non-tourism areas, the findings suggest that, on the one hand, the inclusion of tourism activity drivers likely provides a strong positive influence on vegetation restoration and growth. On the other hand, the combination of multi-scale human activity factors is more effective in promoting vegetation growth.

4. Discussion

This study monitored the vegetation dynamics of the Ejinah Poplar Forest National Nature Reserve since 2000 using NDVI data. The results show an overall trend of continuous vegetation improvement, consistent with previous findings [14]. Further analysis revealed that vegetation recovery (growth rate 0.008) and growth in tourism areas were better than in non-tourism areas (0.0069), particularly in medium and high vegetation coverage areas, where the growth in tourism zones was more significant and widespread. This finding contrasts with traditional views, arguing that tourism activities negatively impact protected area ecosystems, creating inherent conflicts with conservation goals [34]. However, this study suggests that while tourism activities may negatively affect vegetation, they can also contribute positively to vegetation recovery under certain conditions.

Through partial correlation and residual analyses, NDVI showed significant positive and negative correlations with temperature and solar radiation, respectively, but no significant correlation with precipitation. The observed relationships may reflect the complex interactions between climatic conditions and vegetation growth in this arid ecosystem. Temperature can influence vegetation growth by regulating physiological activity and the length of the growing season, whereas excessive solar radiation may increase evapotranspiration and intensify water stress. The weak relationship between precipitation and NDVI may also reflect the influence of ecological water conveyance and other water management interventions, which can modify vegetation responses to natural precipitation variability. However, these potential mechanisms were not independently quantified in this study and should therefore be interpreted cautiously. These results align with the findings of Liang et al. [35] and He Jinping et al. [36]. Residual analysis further indicated that vegetation in both tourism and non-tourism areas is primarily driven by a combination of climatic factors and human activities, with human activities playing a dominant role. Human activities contributed 60–80% to 75.07% of the tourism areas and 69.81% of the non-tourism areas. This highlights the greater reliance of vegetation growth on human activities in arid regions [37].

Analysis of land use changes under different vegetation coverage types revealed that the main differences between tourism and non-tourism areas lie in changes to impervious surface areas. In tourism areas, impervious surfaces increased primarily in regions with no or low vegetation coverage, rising significantly from 1.84% to 4.44% between 2015 and 2020. Conversely, medium and high vegetation coverage areas remained relatively stable. In non-tourism areas, impervious surface areas increased across all vegetation coverage types. This indicates that tourism activities primarily negatively impact areas with no or low vegetation coverage but offer some protective benefits for medium and high vegetation coverage areas.

On the one hand, tourism activities often involve extensive infrastructure development and improper human behavior, which can damage vegetation [38]. For instance, the significant increase in bare land and impervious surfaces after 2015 in tourism zones coincides with the implementation of the 2015–2025 Scenic Area Development Plan, which included substantial infrastructure construction. On the other hand, as a typical nature reserve, tourism activities in the study area prioritize protecting core natural resources and promoting vegetation recovery and growth to some extent [39]. For example, the Scenic Area Development Plan emphasized ecological protection, popular resource conservation, and maintaining the core competitiveness of the tourism area, focusing on allocating more funds for vegetation recovery and growth.

Further exploration of human activity drivers and factor analysis revealed differences in the underlying structure of vegetation-related indicators between tourism and non-tourism areas. In tourism areas, the factor primarily associated with tourism activities explained47%of the total variance in the selected indicators, followed by factors represent-

ing national or regional policies (19.57%) and climatic variables (10.99%). These percentages represent variance explained by the extracted factors rather than direct contributions to vegetation change. In non-tourism areas, the factor associated with environmental protection policies explained 35.58% of the total variance. These findings highlight the importance of considering tourism-related activities, environmental policies, and climatic conditions when developing management strategies for protected areas [40]. The observed vegetation changes in tourism areas should not be attributed solely to tourism development, as several human interventions may have influenced vegetation dynamics simultaneously. Conservation policies, ecological restoration measures, and water management initiatives may have supported vegetation recovery, while tourism-related infrastructure development and increased visitor activities may have introduced additional ecological pressures. Reforestation, ecological compensation programs, and changes in land-use practices by local residents may also have contributed to the observed patterns. Because these influences were not independently quantified, their individual effects cannot be distinguished from those associated with tourism activities. Therefore, the results should be interpreted as reflecting the combined influence of tourism development, environmental management, and other human interventions rather than the isolated effect of tourism.

Despite the in-depth analysis of tourism activities' bidirectional impacts on the ecological environment, this study has limitations. It primarily focused on policies, tourism revenue, and similar factors while neglecting other human activities, such as reforestation, ecological restoration, ecological subsidies for herders, and local residents' production and lifestyles. Future research should expand these areas to explore the potential impacts of various human activities on the ecological environment, providing more comprehensive theoretical support for effective ecological protection policies. Additionally, the use of annual maximum NDVI primarily reflects peak vegetation conditions rather than average growing-season vegetation status. Consequently, the observed long-term trends may not fully represent seasonal vegetation dynamics. Future studies should incorporate growing-season mean NDVI and seasonal observations to provide a more comprehensive assessment. Furthermore, attributing NDVI residuals to human activities introduces uncertainty because the residual component may also contain effects of unaccounted climatic and hydrological factors, lagged climate responses, and model errors. Consequently, the estimated human activity contributions should be interpreted as approximate indicators rather than direct or exclusive measures of human or tourism-related impacts.

5. Implications for Sustainable Tourism and Ecosystem Management

The findings of this study have important implications for sustainable tourism development and ecological conservation in the Ejinah Poplar Forest Region. The observed improvement in vegetation conditions, particularly in tourism areas, suggests that tourism development and vegetation conservation can coexist when appropriate environmental management practices are implemented. However, vegetation degradation near scenic area entrances and visitor service centers highlights the potential ecological pressures associated with tourism infrastructure and human activities. These findings emphasize the need to integrate vegetation monitoring, ecological restoration, and land-use planning into sustainable tourism management. Regular monitoring using remote sensing indicators such as NDVI can help identify environmentally sensitive areas and support timely conservation measures. Furthermore, controlling infrastructure expansion and protecting areas with high vegetation coverage may help balance tourism development with long-term ecosystem stability. These strategies can contribute to more sustainable management of tourism activities in arid and ecologically fragile nature reserves.

6. Conclusions

This study compared the spatiotemporal characteristics of NDVI changes and their driving factors in the Ejinah Poplar Forest National Nature Reserve from 2000 to 2020. Using NDVI data alongside climatic and human activity indicators, Theil-Sen trend analysis, M-K tests, and partial correlation coefficients were employed. The main conclusions are as follows: First, NDVI values in the Ejinah Poplar Forest National Nature Reserve fluctuated upward from 2000 to 2020, with an average NDVI slope of 0.0067. The NDVI slope in tourism areas was 0.008, higher than the 0.0069 observed in other regions. Secondly, longitudinal analysis showed that vegetation coverage in the reserve demonstrated a spatial distribution characterized by higher vegetation in the west and lower vegetation in the south. Medium and high vegetation coverage areas within the reserve experienced significant growth, with vegetation recovery and growth in tourism areas surpassing those in non-tourism areas. Finally, factor analysis showed that tourism-related factors explained 47% of the total variance in the selected indicators, followed by national or regional policy factors (19.57%) and climatic factors (10.99%). These percentages represent variance explained in the factor analysis rather than direct contributions to vegetation change. Tourism activities were associated with both vegetation improvement and localized degradation, suggesting that their ecological implications depend on the intensity of human disturbance and the effectiveness of environmental management. Tourism-related factors showed a significant association with vegetation dynamics and may contribute to vegetation recovery when supported by appropriate conservation policies and ecological management measures. However, the observational nature of this study does not establish a direct causal relationship between tourism development and ecosystem restoration. These findings are specific to the Ejina Populus euphratica forest region. Tourism-related effects may overlap with conservation policies and ecological compensation, while uncertainties in NDVI data and residual-based attribution limit causal interpretation. Therefore, tourism should not be considered an independent driver of vegetation restoration. Overall, this study highlights the importance of jointly considering climatic variability, human activities, and ecological management when evaluating vegetation dynamics and provides a scientific basis for sustainable tourism planning and ecosystem conservation in arid nature reserves.

Author Contributions: Conceptualization, M.W., D.Z. and A.C.; Methodology, M.W. and D.Z.; Software, M.W., D.Z. and A.C.; Validation, M.W., D.Z. and A.C.; Formal analysis, M.W.; Investigation, M.W. and D.Z.; Resources, M.W. and D.Z.; Data curation, M.W. and D.Z.; Writing—original draft, M.W. and D.Z.; Writing—review & editing, M.W. and A.C.; Visualization, M.W., D.Z. and A.C.; Supervision, M.W., D.Z. and A.C.; Project administration, M.W. and D.Z.; Funding acquisition, M.W. and D.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original data presented in the study are openly available in NDVI at https://doi.org/10.12199/nesdc.ecodb.rs.2021.012.

Acknowledgments: Meng Wang and Dakui Zhao are equally co-first authors.

Conflicts of Interest: The authors declare no conflicts of interest.

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