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Analysis of the Spatio-Temporal Evolution Characteristics and Influencing Factors of Habitat Quality in Hubei Province over the Past Three Decades

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Abstract: A region's ability to maintain biodiversity and the health of its ecosystems depends heavily on the quality of its habitat. The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model was utilized in this investigation, in conjunction with the Geographic Detector (Geodetector) model and Geographic Information System (GIS) spatial analysis techniques, to systematically analyze the spatio-temporal evolution characteristics and underlying driving mechanisms of habitat quality in Hubei Province from 1990 to 2020. The findings indicate that over the period of thirty years, there has been a significant decline in the habitat quality index in the eastern part of Hubei Province, while the western region has maintained a relatively high level. Additionally, habitat quality in several areas declined continuously over the 30-year period. The results of spatial autocorrelation showed that the habitat quality in the western part of Hubei Province from 1990 to 2020 was mainly characterized by High-High Clusters, while the eastern parts of the province mostly showed Low-Low Clusters. According to the findings of the Geographic Detector research, the degree of influence of each driver on habitat quality varies significantly over time, with the Construction Land Index being the main factor influencing habitat quality in Hubei Province. Moreover, the interaction between factors exerted a stronger influence on habitat quality compared to individual factors. This research result has deepened the understanding of the changing law of habitat quality in Hubei Province and has laid a solid foundation for scientists to develop targeted ecological protection strategies in the future. The results of the study have provided a reference for habitat quality assessment in other regions, especially in the process of analyzing the spatial and temporal evolution patterns of habitat quality in different regions and under different ecosystem types, which has provided more reference for ecological protection.

Keywords: InVEST model; habitat quality; spatio-temporal evolution; Geographic Detector; hotspot analysis

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1. Introduction

Biodiversity serves as the cornerstone of life, and since the signing of the Convention on Biological Diversity in 1992, efforts worldwide have been directed towards conserving biodiversity [1]. Habitat quality is crucial for the health and functional integrity of ecosystems and is fundamental to sustaining biodiversity. The deterioration in habitat quality directly threatens the survival of organisms and may lead to biodiversity loss, making it a focal point in current research in ecology and conservation biology [2]. Early studies primarily focused on the evaluation of habitat quality in wild animal habitats. For instance, Xu

et al. systematically studied the distribution, habitat quality, and spatial patterns of panda habitats in the Daxiangling Mountains using 3S technology [3]. Thiel et al. investigated the impact of rural road systems on wolf habitat quality [4], while Katsvanga et al. assessed the habitat quality of baboons in their study area using normalized vegetation indices [5]. These investigations shed important light on how habitat quality affects populations of wild animals. With land use/cover change (LUCC) identified as one of the major factors influencing global climate change, understanding the influence of LUCC on regional habitat quality has become increasingly urgent. This helps in understanding and predicting climate change trends while formulating effective mitigation strategies. Global scholars have increasingly focused on examining the interconnections among climate change, habitat quality, and land use change. For example, Jetz et al. studied future trends in land use change for 8,750 terrestrial bird species as a result of climate change and land use change [6], providing strong scientific evidence for improving habitat quality. Using the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model, Liu et al. conducted a dynamic analysis of spatio-temporal changes in habitat quality in the Puh River Basin [7], while Wang et al. used the same model to predict spatial changes in habitat quality in the Min River Basin [8].

Studies on spatial and temporal variations in habitat quality vary somewhat across regions and populations, and this study focuses on Hubei Province to find the spatial and temporal patterns of habitat quality. Considering the natural environment characteristics and ecological protection needs of Hubei Province, the InVEST model selected in this study can fully consider the spatial and temporal distribution characteristics of ecosystem service functions and assess the habitat quality under different environmental conditions. Combined with the Geodetector model, we were able to effectively analyze the drivers of habitat quality changes and explore the combined effects of different socio-economic activities and natural factors on habitat quality. In addition, the application of GIS spatial analysis technology provides us with intuitive spatial data support, which makes the analysis of spatial and temporal evolution characteristics more refined. Located in the central part of China, Hubei Province has a favorable geographic location and a variety of ecological environments, covering a wide range of habitat types, including mountains, plains, lakes, and wetlands, with typical habitat qualities reflecting the complexity of ecosystem services and biodiversity in the region. Hubei Province is an important part of the Yangtze River Economic Belt, and the ecological environment of the Yangtze River Basin is of great significance for climate regulation and biodiversity conservation in China and globally. The past few decades have seen a loss and fragmentation of natural ecosystems due to the acceleration of industrialization and urbanization: Mou et al. analyzed the impacts of various drivers, including land use change and human activities, on the quality of the ecological environment and revealed that the intensification of human activities and the advancement of the urbanization process have a greater negative impact on the quality of the ecological environment [9]. Teng et al. revealed the impact of land use transition on habitat quality in resource-based cities during rapid urbanization [10]. Peng et al. focused on the trade-offs between ecological risks and spatial development in low-slope hilly areas, especially the strong impact of urbanization expansion on the ecological environment [11]. Changes in land use patterns, climate change, and anthropogenic factors have contributed to the decline in ecosystem service capabilities in the area, exerting pressure on ecosystem stability and the survival of species. Therefore, it is imperative to enhance ecological monitoring in Hubei Province to better understand the dynamics and drivers of habitat quality changes for the purpose of mitigating the negative impacts of human activities on habitats and achieving ecological balance and promoting long-term sustainable development.

The current study focuses on the effects of human activity and the temporal and spatial variations in habitat quality [12–16]. At present, geospatial analysis techniques and methods have been increasingly widely used in habitat quality modeling, especially in habitat quality evaluation and change trend analysis [17]. Through remote sensing technology, geographic information systems, spatial statistics, and model simulation, researchers have been able to obtain the spatial distribution characteristics of habitat quality, its spatial and temporal evolution patterns, and its driving factors. These methods have not only provided effective tools for assessing habitat quality but have also provided strong support for exploring its change trends and predicting future change directions [18–21]. However, there are still some shortcomings in current research. First, although there have been a large number of studies based on remote sensing and GIS, there is still a lack of sufficient systematization and depth in high-precision spatial and temporal change analysis and multi-scale dynamic monitoring. Second, most of the existing habitat quality evaluation models are limited to the analysis of single factors, ignoring the complexity under the combined effect of multiple factors, which limits the generalizability and predictive ability of the models. Finally, existing studies have been applied more in localized areas, and the trend of habitat quality change at the county scale has not yet been adequately studied and compared. Therefore, how to synthesize multiple factors, improve the accuracy of spatio-temporal dynamic monitoring, and conduct effective habitat quality assessment at different scales remains an urgent issue for current research. Based on these shortcomings, this study will adopt a more integrated approach, combining remote sensing imagery, GIS spatial analysis, and model simulation to construct a county-scale, high-precision habitat quality assessment model. By introducing multiple ecological factors and environmental variables and considering the complexity and dynamic changes in ecosystems in a comprehensive manner, we expect to fill the gaps in existing studies and provide new ideas and methods for the accurate assessment of habitat quality and the prediction of future change trends. Given the strategic importance of Hubei Province in the central region, the findings of this study can offer positive guidance for local ecological environment protection and biodiversity conservation efforts. Moreover, they aid in the establishment of an ecological civilization and the long-term sustainability of the entire central area of China by providing scientific references and insights.

2. Materials

2.1. Study Area

Hubei Province, situated in the central region of China, is geographically positioned between 29°01′53″ to 33°06′47″ north latitude and 108°21′42″ to 116°07′50″ east longitude (Figure 1). It is bordered by Jiangxi and Anhui to the east, Hunan to the south, Chongqing and Shaanxi to the west, and Henan to the north, with a total area of around 185,900 square kilometers. Located in the center of the Yangtze River, Hubei boasts an abundant water system that includes Honghu Lake and Liangzi Lake. The topography of the province is characterized by higher elevations in the west and lower ones in the east, with a western region that is predominantly mountainous, featuring ranges such as the Wudang Mountains and Shennongjia. Based on its geographic characteristics, the study area is divided into two regions: eastern Hubei (E'Dong) and western Hubei (E'Xi). Hubei Province as a research unit is typical in the study of habitat quality. First, the natural environment and biodiversity of Hubei Province are representative of central China and can reflect the trend of habitat quality changes in other similar regions. Second, Hubei Province has experienced significant impacts from human activities during urbanization in recent years, and its habitat quality has been affected by both the rapidly changing socio-economic environment and policy adjustments. Therefore, the study of habitat quality changes in Hubei Province

can not only provide a scientific basis for ecological protection in the province but also has strong generalizability and reference value and can provide a reference for ecological protection in other similar areas.

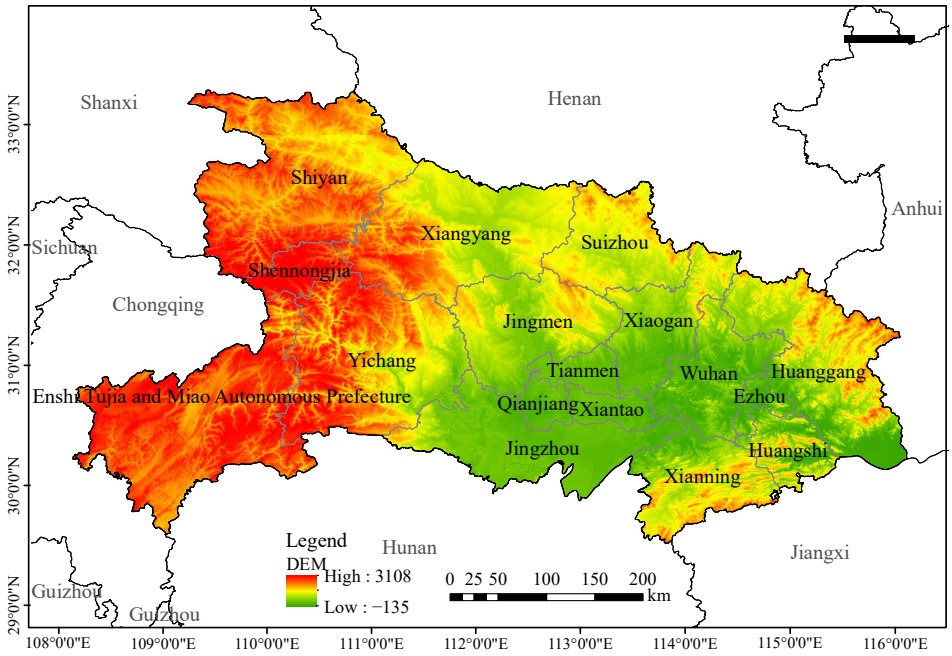


Figure 1. Overview of the research area.

2.2. Data Resource and Preprocessing

The data utilized in this study encompass multi-temporal land use data, fundamental geographic data, Digital Elevation Model (DEM) data, and meteorological data, including average temperature and average precipitation, as well as pertinent socio-economic data such as the GDP, population density, population count, Nighttime Light Index, and Construction Land Index in Hubei Province. The temporal scope spans from 1990 to 2020, with a decadal interval serving as the temporal step. The provenance and application of the data are delineated in Table 1. The DEM data were processed with ArcGIS software (Esri, 2020) to derive information on the slope and aspect of the study area. Additionally, socio-economic and meteorological data undergo spatialization to facilitate subsequent analysis of driving factors using the Geographic Detector software (GeoDetector Team, 2020).

Table 1. Data source and purpose.

Data Set	Data Type	Data Resource	Utilization
The region of the study area	Shpfile (1:10,000)	National Basic Geographic Information Resource Catalogue Service System (https://mulu.tianditu.gov.cn) (accessed on 26 September 2023)	Depart the study area
Land use data	TIF (30 m)	Chinese Academy of Sciences, Center for Resource and Environmental Sciences (https://www.resdc.cn) (accessed on 26 September 2023)	Calculate EI
DEM data	TIF (30 m)	Geospatial Data cloud (https://www.gscloud.cn) (accessed on 26 September 2023)	Driving factor

Table 1. *Cont.*

Data Set	Data Type	Data Resource	Utilization
Precipitation data	TIF (1 km)	National Earth System Science Data Center (https://www.geodata.cn) (accessed on 1 October 2023)	Driving factor
Temperature data	TIF (1 km)	National Earth System Science Data Center (https://www.geodata.cn) (accessed on 1 October 2023)	Driving factor
Population density data	TIF (1 km)	worldpop (https://www.worldpop.org) (accessed on 27 September 2023)	Driving factor
Population data	TIF (1 km)	Resource and Environmental Science Data Platform (https://www.resdc.cn) (accessed on 27 September 2023)	Driving factor
GDP data	TIF (1 km)	National Earth System Science Data Center (https://www.geodata.cn) (accessed on 27 September 2023)	Driving factor
Nighttime Light Index	TIF (1 km)	National Earth System Science Data Center (https://www.geodata.cn) (accessed on 3 October 2023)	Driving factor
Construction Land Index	TIF (1 km)	Land use data	Driving factor

All datasets are resampled to a spatial resolution of 30 m and harmonized with the WGS 1984 coordinate system to guarantee data consistency. Subsequently, the acquired habitat quality data are analyzed through spatial overlay analysis to identify the patterns and driving factors of spatio-temporal dynamics in habitat quality across various regions of Hubei Province over the past three decades.

2.3. Research Methods

2.3.1. InVEST Model

An ecosystem services valuation model called InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) is used to clarify the effects of human activities and the efficacy of management strategies [22–24]. The habitat quality module is utilized to assess and monitor the quality of biological habitats, comprising four factors: the relative impact of each threat, the relative sensitivity of each habitat to different threats, the distance between grid units and threat sources, and the degree of legal protection areas receive. Based on these four factors, the model processes land use information to obtain regional habitat quality maps, thereby evaluating various ecological attributes of the landscape such as habitat quality, degradation levels, and habitat rarity [25–27].

Habitat degradation refers to the extent of degradation in habitat quality due to the influence of threat sources, assessed through the spatial attenuation of threats, which can be modeled using linear or exponential distance attenuation functions. The magnitude of habitat degradation is related to the number of threat factors, the distance between habitat types and threat sources, the sensitivity of habitat classes to threat factors, and land use accessibility. The calculation formulas are defined as follows [28,29]:

$$\text{Linear decline}: \ i_{\text{rxy}} = 1 - \left(\frac{d_{xy}}{d_{r\ max}}\right) \tag{1}$$

$$\text{Exponential decline}: \ i_{rxy} = \exp\left(-\left(\frac{2.99}{d_{r\ max}}\right) d_{xy}\right) \tag{2}$$

$$\text{Habitat degradation}: \ D_{xy} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(w_r / \sum_{r=1}^{R} w_r\right) \times r_y \times i_{rxy} \times \beta_x \times S_{jr} \tag{3}$$

In the formulas, i_{rxy} signifies the impact of threat factors r on the grid x, d_{xy} indicates the linear distance between grids x and y, $d_{r\ max}$ stands for the maximum impact distance of habitat threat factors r, D_{xy} signifies the level of habitat degradation in the land use type j, R indicates the number of threat factors, w_r represents the weights of each threat factor, r_y denotes the intensity of threat factors, Y_r represents a group of grids affected by threat factors r, β_x stands for the level of habitat interference resistance, and S_{jr} signifies the sensitivity of land classes to threat factors.

The ability of an ecological environment to create favorable conditions for organic ecological processes is referred to as habitat quality. Its level can reflect the degree of fragmentation of regional habitats and the ability to resist habitat degradation. Higher values denote better habitat quality. The values of habitat quality vary from 0 to 1. The calculation formula is [30,31]:

$$Q_{xj} = H_j\left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right) \tag{4}$$

In the equation, Q_{xj} represents the habitat quality of grids x in land use types j, H_j denotes the habitat suitability of land use types j, k represents the half-saturation constant, and z represents the model scale constant, typically set to 2.5 by default.

Threat factors usually include the impact of human activities on habitat quality. Based on the literature on habitat quality [32–36], and taking into account the characteristics of the study area and the study objectives, bare land, dry land, urban land, rural residential areas, and other built-up areas were selected as the threat factors in this study (Figure 2), and it was found that the transfer of the remaining land use types to the five threat source factors between 1990 and 2020 was mainly concentrated in the economically developed areas with rapid urbanization in Hubei Province. Among them, dry land and bare land mainly affect the habitat quality by infringing on regional soil resources; the expansion of rural residential areas and urban land will lead to a reduction in a large amount of ecological land in the region and a decline in the habitat quality; the harm to the habitat quality caused by other built-up areas depends on the use of the construction; for example, the industrial and mining land will lead to soil and water pollution of the surrounding soil, and so on. Thus, the five types of threatening source factors threaten the regional habitat quality either directly or indirectly, and the parameters of the threatening elements (Table 2) and the sensitivity of various land use types to these threat factors (Table 3) were determined in this study.

Table 2. Threat factor parameters.

Threat Factors	Weight	Maximum Impact Distance/km	Decline Type
Rural residential areas	0.6	5	Exponential decline
Other built-up areas	1	12	Exponential decline
Bare land	0.1	3	Linear decline
Dry land	0.3	1	Linear decline
Urban land	1	10	Exponential decline

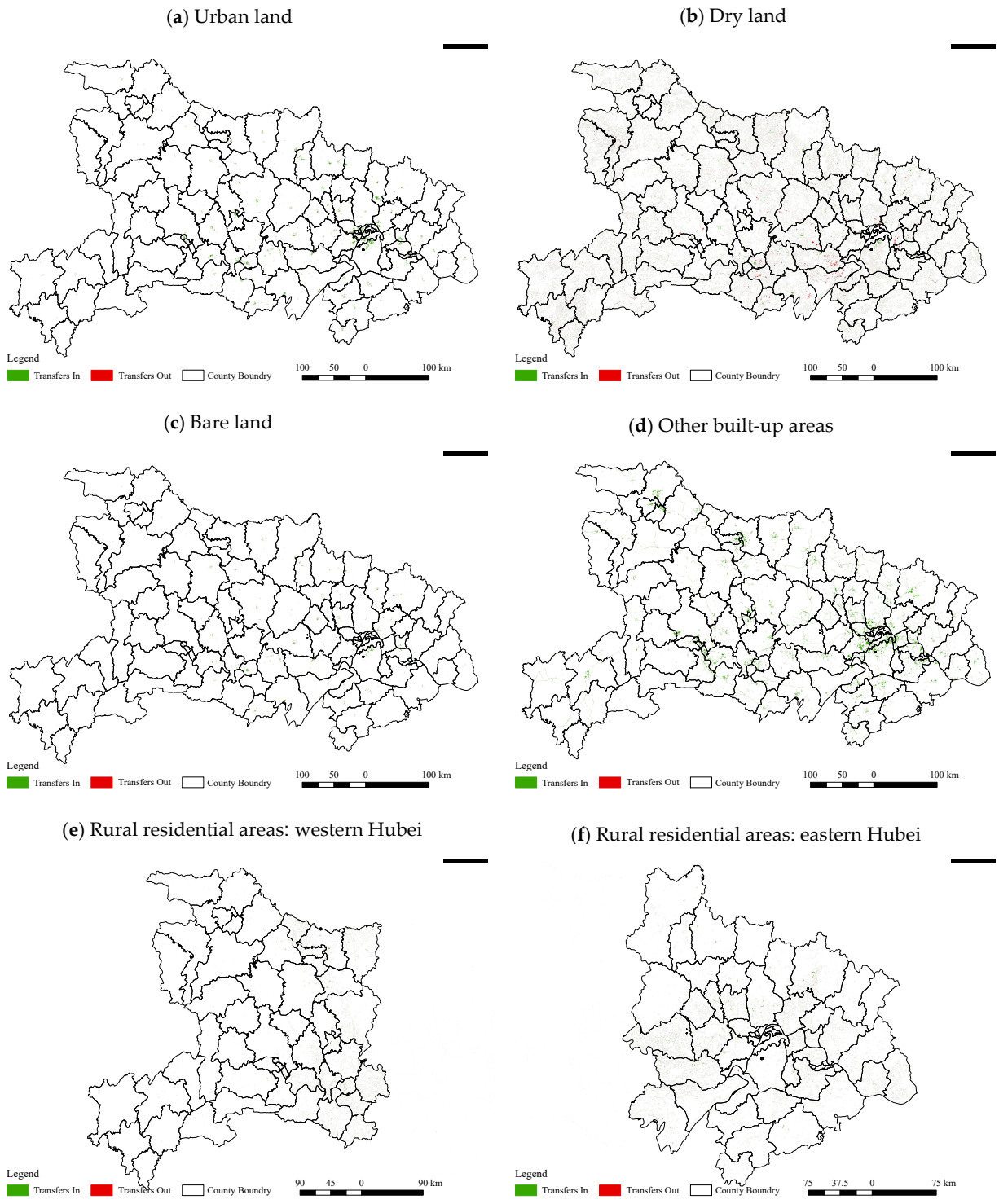


Figure 2. Changes in the five categories of threat factors in Hubei Province from 1990 to 2020.

Table 3. Sensitivity of different land use types to threat factors.

Land Use Types	Habitat Suitability	Threat Factors				
		Rural Residential Areas	Other Built-up Areas	Bare Soil	Dry Land	Urban Land
Paddy fields	0.3	0.6	0.5	1	1	0.5
Dry land	0.3	0.6	0.5	1	0	0.7
Forest land	1	0.7	0.7	1	0.7	0.7
Shrub land	0.9	0.5	0.6	1	0.6	0.6

Table 3. *Cont.*

Land Use Types	Habitat Suitability	Threat Factors				
		Rural Residential Areas	Other Built-up Areas	Bare Soil	Dry Land	Urban Land
Sparse forest land	0.7	0.7	0.6	1	0.7	0.8
Other forest land	0.5	0.7	0.6	1	0.5	0.6
High coverage grassland	0.8	0.7	0.4	1	0.7	0.6
Medium coverage grassland	0.6	0.6	0.5	1	0.5	0.6
Low coverage grassland	0.5	0.5	0.5	1	0.5	0.6
Rivers and canals	0.9	0.4	0.4	1	0.4	0.5
Lakes	1	0.6	0.5	1	0.7	0.7
Reservoirs and ponds	0.7	0.6	0.4	1	0.6	0.6
Beaches	0.6	0.7	0.7	1	0.6	0.8
Urban land	0	0	0	0	0	0.2
Rural residential areas	0	0	0	0	0	0.6
Other built-up areas	0	0	0	0	0	0
Wetlands	0.8	0.8	0.7	1	0.7	0.8
Bare soil	0	0.2	0	0	0	0.3
Bare rocky terrain	0	0.2	0	0	0	0.3

2.3.2. Spatial Autocorrelation

The Moran's I index reflects the similarity of attribute values of spatially adjacent or spatially neighboring regions [37,38]. Hot and cold spot analysis is used to measure the aggregation and differentiation characteristics of spatial changes in habitat quality and to investigate whether the spatial changes have the phenomena of high-value clustering (hot spots) and low-value clustering (cold spots) [39], and through hot spot analysis, we can determine the location of the spatial clustering of the high-value areas or the low-value areas of the habitat quality [40]. The calculation formula is mathematically expressed as follows:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2\left(\sum_i \sum_j w_{ij}\right)} \quad (5)$$

In the formula, I represents the *Moran's I* index, n is the number of spatial grid cells in the study area, x_i and x_j are the observed values of spatial cell i and spatial cell j, respectively, $\overline{x}$ is the mean value of spatial cells, and w_{ij} is the weight matrix of spatial cells i and j. The value of the *Moran's I* index is generally in the range of $[-1, 1]$, where less than 0 indicates a negative correlation in space, greater than 0 indicates a positive correlation in space is positively correlated, and equal to 0 means uncorrelated and randomly distributed.

2.3.3. Geographical Detector Model

The Geodetector is a tool developed based on Geographic Information Systems (GISs) and spatial statistics, used for quantitatively analyzing the relationships between geographical phenomena and environmental variables, revealing spatial distribution and change characteristics. Its principle involves measuring the impact of different factors on geographical phenomena to determine the relative contributions of each element and identify significant influencing factors [41,42].

This study collected and compiled a series of natural factors such as aspect, slope, elevation, precipitation, and temperature, as well as human factors like GDP, population size, population density, Nighttime Light Index, Construction Land Index, etc., as potential influencing factors (independent variables). Simultaneously, habitat quality data were selected as the dependent variable, using the equal interval and natural breakpoint methods

to divide the independent variables into 10 to 15 categories, while the dependent variable was divided into 5 categories. Geodetector was employed to conduct factor detection analysis. The detection results include single-factor detection results, interactive detection results, ecological detection results, risk zone detection results and other related aspects. Single-factor detection results reveal the explanatory power of a single factor on a particular attribute or phenomenon; interactive detection results focus on analyzing the interactions between two or more factors and their differential impact on attributes or phenomena; ecological detection results are used to compare the spatial distribution impact differences of two factors on attributes or phenomena; and risk zone detection results are used to assess the mean differences in attributes between two sub-regions.

3. Results

3.1. Spatio-Temporal Variations in Habitat Quality

This study employed the InVEST model to evaluate the habitat quality of the study region for the years 1990, 2000, 2010, and 2020 (Figure 3). The findings show that there are notable regional variations in Hubei Province's habitat quality index between 1990 and 2020. Overall, the western regions of Hubei Province consistently demonstrated better habitat quality indices compared to the eastern regions. The western portion of Hubei Province, which includes the Shennongjia Forestry District, Enshi Tujia, and Miao Autonomous Prefecture, is home to the majority of the province's high-quality habitat areas. These regions are characterized by higher altitudes, abundant forest and grassland resources, a diverse and complex topography, and high forest coverage, all contributing to elevated habitat quality levels.

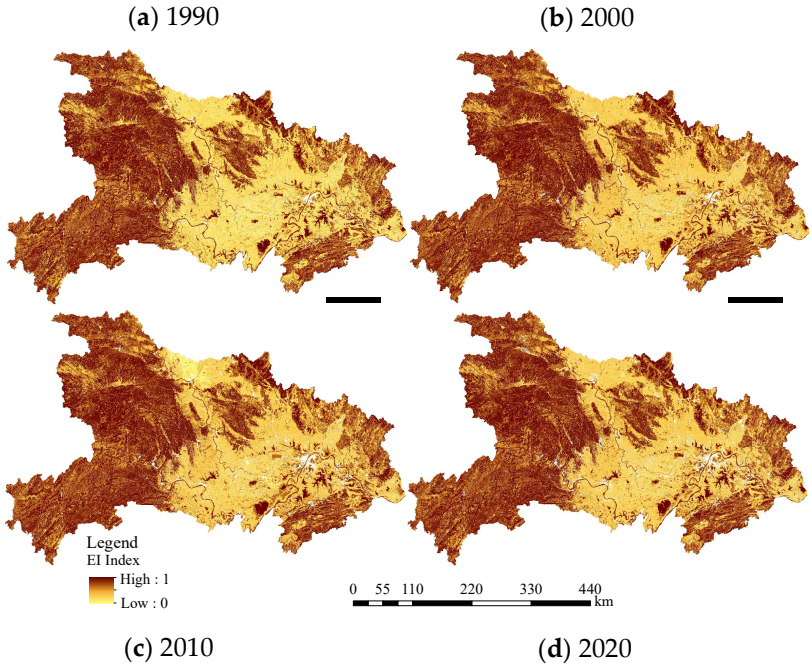


Figure 3. Distribution of habitat quality in Hubei Province from 1990 to 2020.

The eastern part of Hubei Province, in contrast, is primarily made up of plains and hilly regions with extensive grasslands. Although these regions also possess rich biodiversity, the frequent changes in land use have resulted in their habitat quality being assessed as moderate. Lower- or poorer-quality habitats are found mostly in plains with densely populated agricultural areas, numerous construction sites, and large bodies of water, especially in the central part of the Wuhan metropolitan area.

The habitat quality was categorized into five categories, "poor", "fair", "moderate", "good", and "excellent", using the equal interval classification method (Figure 4). The areas corresponding to different habitat quality levels were quantified, as shown in Table 4.

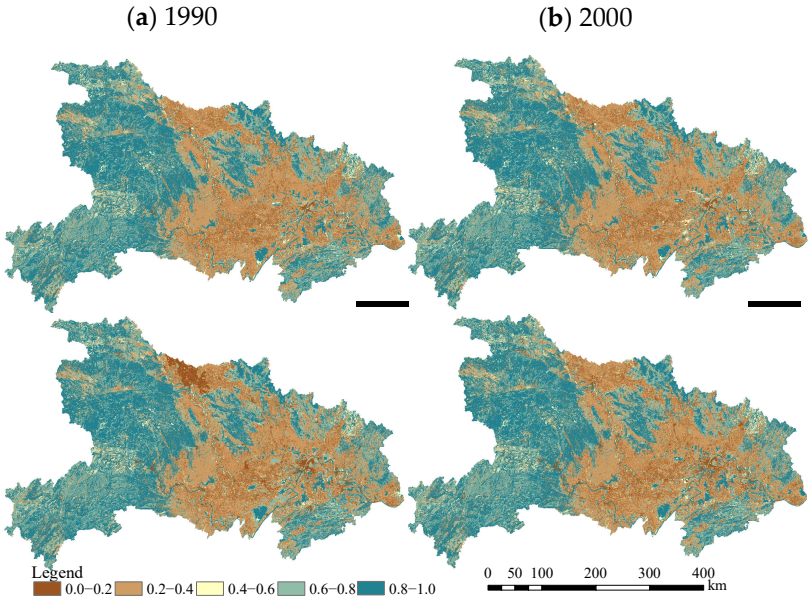


Figure 4. Spatial distribution of habitat quality at different levels in Hubei Province from 1990 to 2020.

Table 4. Proportion of different levels of habitat quality area/%.

Level	Area Proportion/%			
	1990	2000	2010	2020
Poor [0, 0.2]	6.69	6.84	8.47	8.08
Fair [0.2, 0.4]	33.92	33.66	31.49	32.42
Moderate [0.4, 0.6]	3.50	3.63	3.92	3.80
Good [0.6, 0.8]	19.68	19.78	20.18	19.71
Excellent [0.8, 1]	36.21	36.09	35.94	35.99

1. Analysis of Habitat Quality Change Characteristics

As illustrated in Table 4, the changes in the area proportions of different habitat quality levels indicate that the habitat quality in the study area remained generally stable from 1990 to 2020, albeit with some fluctuations. The percentages of regions classified as "excellent", "good", and "moderate" habitat quality levels are approximately 35–36%, 19–20%, and 3.5–4%, respectively. While the area with "fair" habitat quality first falls and then slightly increases, the area with "poor" habitat quality first increases and then slightly decreases. From 1990 to 2000 and from 2010 to 2020, changes in habitat quality were relatively minor. However, there was a minor change in the other levels between 2000 and 2010, with the area of "fair" habitat quality declining and the area of "poor" habitat quality increasing by 1.63%.

Overall, the majority of the study area's habitat quality remained stable, but certain regions experienced a noticeable decline, leading to a slight overall decrease and potential risk of degradation. These changes may be associated with rapid local economic development and urbanization, which increase the amount of land available for construction.

1. Analysis of Spatial Characteristics of Habitat Quality

To comprehensively elucidate the spatial distribution characteristics of habitat quality in different regions of Hubei Province, this study employed county-level administrative units as the primary analytical units and calculated the average habitat quality index for each region, as depicted in Figure 5. Only Wuhan City's Hannan District showed a decrease in habitat quality between 1990 and 2000, with no other locations in Hubei Province showing a decrease. Between 2000 and 2010, significant changes in habitat quality levels were observed in Hubei Province. Specifically, the habitat quality in the Tieshan, Huangshigang, and Xialu Districts of Huangshi City, as well as the Hongshan District of Wuhan City, deteriorated from "moderate" to "poor." Additionally, the Zhangwan and Maojian districts of Shiyan City experienced a decline from "excellent" to "good". The conditions in the Qiaokou District of Wuhan City and Xiangzhou District of Xiangyang City worsened from "poor" to "very poor". Meanwhile, the habitat quality in the Chibi and Xianning districts of Xianning City and Wujia District of Yichang City declined from "good" to "moderate". During the period from 2010 to 2020, approximately 92% of the regions in Hubei Province maintained stable habitat quality levels. Declines in habitat quality primarily occurred in the Duodao District of Jingmen City, the Caidian and Hannan districts of Wuhan City, and the Xiaoting District of Yichang City. Conversely, areas with improved habitat quality were concentrated in the Tieshan and Huangshigang districts of Huangshi City, Xianning District of Xianning City, and Xiangzhou District of Xiangyang City.

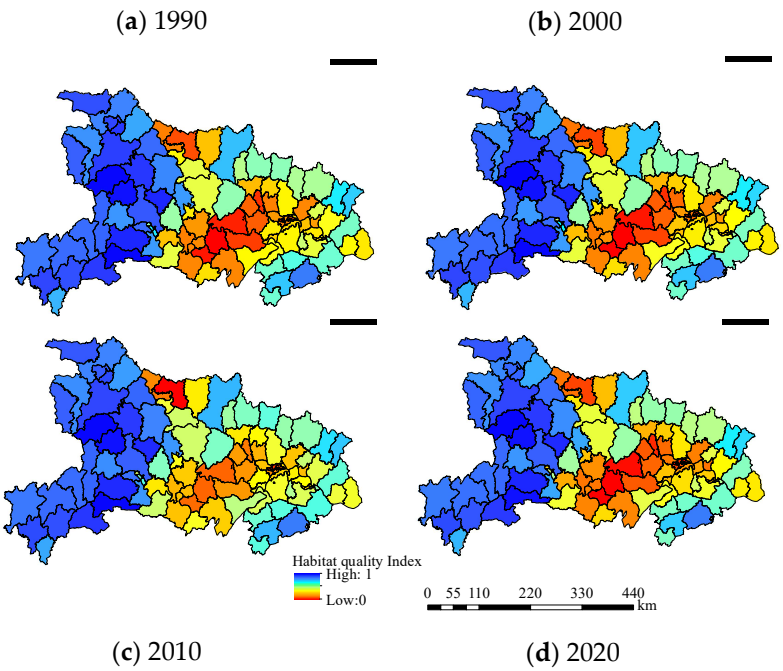


Figure 5. Statistics on habitat quality by county in Hubei Province from 1990 to 2020.

Overall, from 1990 to 2020, the habitat quality in the western part of Hubei Province remained relatively stable and gradually improved. In contrast, the eastern region experienced significant fluctuations in habitat quality, with an overall trend of deterioration. This trend was particularly pronounced in Wuhan City and its surrounding areas, where habitat quality markedly declined between 2010 and 2020. These findings indicate that ecological protection efforts in Hubei Province face significant challenges amidst urbanization and industrialization, while ongoing efforts are being made to enhance and restore habitat quality.

1. Analysis of Spatio-Temporal Evolution Characteristics of Habitat Quality

Using ArcGIS software, the habitat quality index maps of the study area for 1990 and 2020 were overlaid to obtain the habitat quality index change map from 1990 to 2020 (Figure 6). The results show that over the past 30 years, changes in habitat quality in the study area are mainly concentrated in the eastern part of Hubei Province, and the proportion of areas with decreasing indices is greater than that of areas with increasing indices; areas with degraded habitat quality are clustered in Wuhan and its surrounding economically developed areas, and areas with improved habitat quality include Honghu, Xiantao, Hanchuan, and Huangmei. Habitat conditions are more stable in the western part of Hubei Province, with Yichang City being the main area of change. Spatially, variations in habitat quality changes can be observed in the study area.

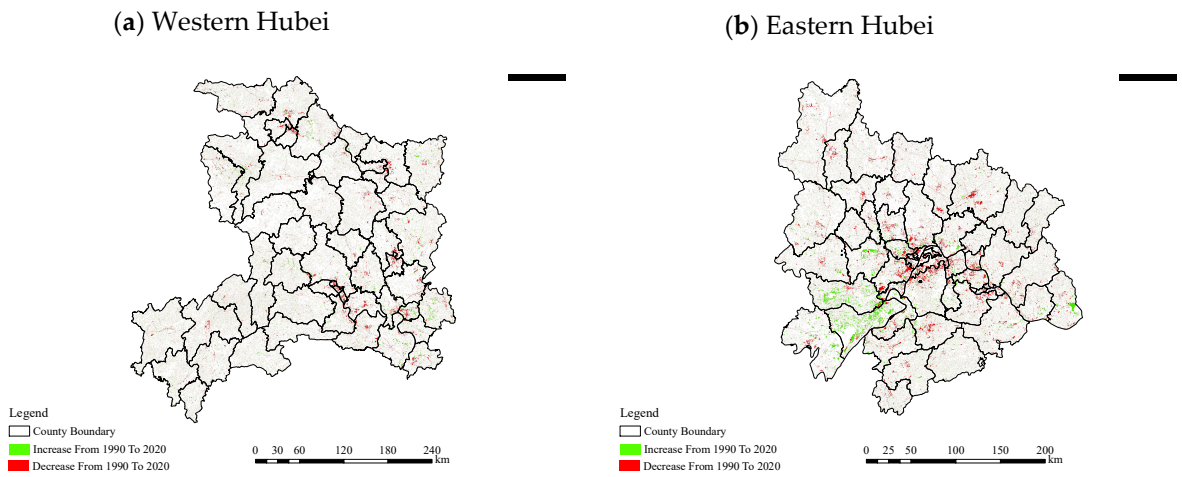


Figure 6. Changes in habitat quality in Hubei Province from 1990 to 2020.

In the eastern region, as a result of rapid economic expansion and pressure from resource exploitation, the average habitat quality index has generally declined. The degradation trend of habitat quality is more pronounced in the urban circle centered around Wuhan, which is closely related to the spatial layout of urban and rural areas and industrial and mining construction land. Wuhan, as the political, economic, and cultural center of Hubei Province, experiences high population density and intense economic activity, leading to a prominent decline in habitat quality. However, the habitat quality index increased significantly in some areas, especially in Honghu, Xiantao, Huangmei, and Hanchuan. This increase may be attributed to local ecological conservation and environmental governance measures. Western Hubei, characterized by higher terrain with mostly mountainous and forest-covered areas, maintains a relatively stable level of habitat quality index due to these factors collectively protecting the relative integrity of the ecosystem.

Overall, there are significant differences in the changes in the ecological environmental quality across different regions of Hubei Province, with some areas facing the risk of environmental degradation. Therefore, it is necessary to further increase efforts in ecological conservation and implement more effective environmental governance measures to ensure the integrity and sustainability of the ecosystem.

To visually represent the spatial changes in habitat quality, the results of habitat quality zoning for each year were overlaid and subtracted using ArcGIS, resulting in the Habitat Quality Change Map from 1990 to 2020 (Figure 6). There are five primary trends that can be seen in the variations in the habitat quality index in Hubei Province during this period: continuous decrease, decrease followed by increase, increase followed by decrease, decrease followed by increase and then decrease again, and increase followed by decrease and then increase again.

From Figure 7, it is evident that a significant proportion of areas experienced continuous deterioration in habitat quality, including urban areas and some regions of Shiyan, Shennongjia Forestry District, Xiangyang, Enshi Tujia and Miao Autonomous Prefecture, Yichang, Jingmen, Huanggang, and Huangshi, as well as the Jiangxia and Hongshan districts in Wuhan. Areas where the habitat quality index initially decreased and then increased include most areas of Xiangyang, Tianmen, some counties in Huanggang, parts of urban areas in Huangshi, and most areas in Wuhan. The index changes indicate that these areas initially experienced a decline in habitat quality but subsequently recovered, likely due to the implementation of environmental management policies, ecological conservation measures, or natural recovery. Some areas such as Fang County, Zaoyang City, Hefeng County, Xiantao City, parts of Yichang, Jingmen, Jingzhou, Xiaogan, and Xianning, as well as the Xinzhou and Dongxihu districts in Wuhan, experienced an initial increase followed by a decrease in the habitat quality index. Initially, habitat quality improved but later experienced some degree of degradation. Areas where the habitat quality index experienced fluctuations with a decrease, an increase, and then another decrease again include small parts of Yichang, Jingzhou, Xiaogan, Huanggang, some areas in Ezhou, Gucheng County, and Hannan District, as well as the Hannan District and Caidian District in Wuhan. The index fluctuations suggest a complex and dynamic ecological environment, requiring continuous adjustments and optimization of ecological conservation and management measures.

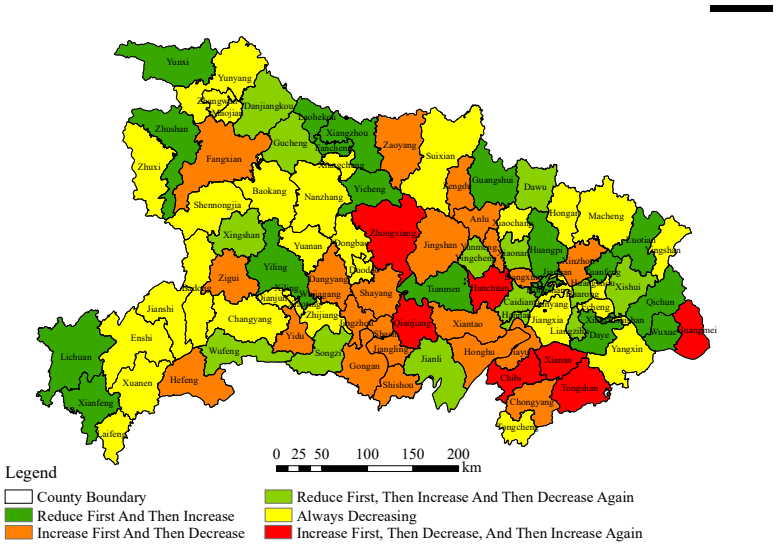


Figure 7. Changes in the county-level index of habitat quality from 1990 to 2020.

In summary, the observed trends highlight the dynamic changes in habitat quality index in various counties and districts of Hubei Province from 1990 to 2020, indicating the need for more effective ecological protection policies and management measures in the region.

3.2. Spatial Autocorrelation Analysis

Spatial autocorrelation analysis can reflect the spatial variation in habitat quality. To better study the spatial distribution characteristics of habitat quality in the study area, the Moran's I for habitat quality from 1990 to 2020 was calculated (Figure 8). The global Moran's I values of habitat quality in Hubei Province from 1990 to 2020 are 0.820, 0.819, 0.822, and 0.818, with p-values below 0.01, which pass the significance test, indicating that the habitat quality in Hubei Province exhibits significant positive spatial correlation. From the figure, it can be seen that high-high aggregation is mainly distributed in the western

part of Hubei Province from 1990 to 2020, while it is less distributed in the eastern part of the province, which is related to the land use distribution in Hubei Province. On the contrary, low-low aggregation is concentrated in the eastern part of Hubei Province, where the level of urbanization is faster and land use changes are relatively obvious.

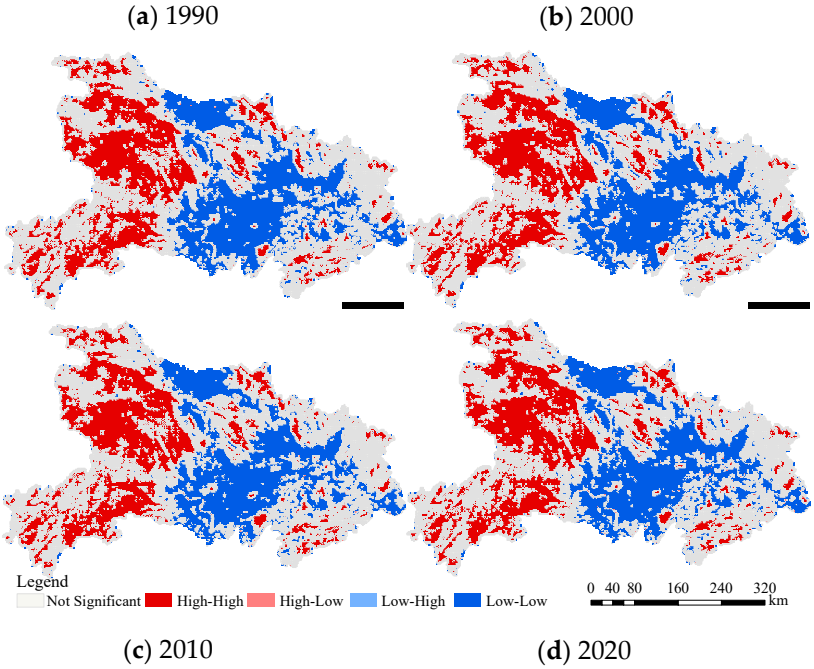


Figure 8. Spatial autocorrelation of habitat quality in Hubei Province from 1990 to 2020.

3.3. Analysis of Drivers of Habitat Quality Spatial Variation

This study employed the Geographic Detector method to analyze the driving factors of habitat quality in the study area from 1990 to 2020 (Figure 9). In terms of natural factors, a series of variables such as aspect, slope, elevation, precipitation, and temperature were selected. In terms of social factors, indicators such as GDP, population density, population data, Nighttime Light Index, and Construction Land Index were chosen. This study's findings indicate that the degree to which each driving factor influencing habitat quality varies in the study area (Table 5). Among these, the Construction Land Index is confirmed as the primary driving factor affecting the distribution of habitat quality in the study area from 1990 to 2020, followed by the Nighttime Light Index, with aspect having the least impact, suggesting that the Construction Land Index plays a dominant role among the socio-economic factors and that with accelerated urbanization, the continuous expansion of construction land directly contributes to the fragmentation of habitats and the decline in ecosystem services. The Nighttime Light Index is highly correlated with the expansion of construction land, reflecting the continuous pressure of human activities on the environment. In Hubei Province, with rapid economic growth and urbanization, the demand for construction land has increased year by year, and the land use structure has changed significantly. These changes have not only damaged the natural ecosystem but have also had a profound impact on ecological functions. The distribution of habitat quality is more significantly impacted by social factors than by natural factors, indicating that human activities have a long-term stable influence on habitat quality. Natural factors such as elevation and slope also influence habitat quality differentiation, as areas of higher habitat quality in Lakeland are predominantly located at higher elevations and on steeper slopes.

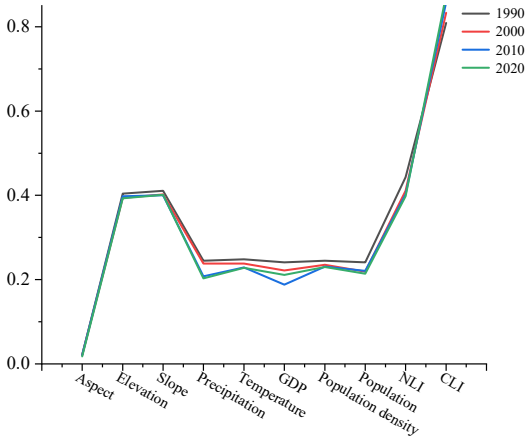


Figure 9. The explanatory power q value of influencing factors in different years.

Table 5. The explanatory power q value of influencing factors in different years.

Factors	1990	2000	2010	2020
Aspect	0.021	0.021	0.021	0.018
Elevation	0.404	0.394	0.398	0.393
Slope	0.411	0.402	0.400	0.401
Precipitation	0.245	0.238	0.208	0.203
Temperature	0.248	0.238	0.229	0.228
Gross Domestic Product	0.241	0.222	0.188	0.211
Population Density	0.245	0.235	0.231	0.230
Population	0.241	0.219	0.221	0.214
Nighttime Light Index	0.443	0.411	0.402	0.398
Construction land index	0.809	0.833	0.858	0.875

The results of the interactions of the factors affecting habitat quality in Hubei Province from 1990 to 2020 are shown in Figure 10. In 1990, the interactions among GDP, population density, and population were nonlinearly weakened, and the interactions among the remaining factors were nonlinearly enhanced or bifactorially enhanced. Between 1990 and 2020, the interactions between the Construction Land Index and the other factors were the most pronounced, with the average value of q reaching 0.8 across the four periods, and the Nighttime Lighting Index was the second highest, with the average value of q reaching 0.6 across the four periods. In addition, the maximum value of the Construction Land Index before the interaction was 0.875, and after the interaction it reached 0.954, while the maximum value of the Nighttime Light Index before the interaction was 0.443, and after the interaction it reached 0.955. Generally speaking, the interaction between factors is more significant than that of a single factor, which suggests that it is necessary to enhance the interaction between factors when formulating ecological protection and restoration strategies.

Synthesizing the results of single-factor detection and interactive factor detection, the Construction Land Index is the main driver affecting habitat quality in Hubei Province from 1990 to 2020, and its influence increased year by year. In recent years, the process of urbanization has gradually accelerated, and urbanization inevitably leads to an increase in construction land, which is followed by a shift in the land use structure, ecosystem destruction, increased pressure on resources and the environment, etc. All of these changes will directly or indirectly threaten the regional habitat quality. Therefore, to protect and improve the quality of regional habitats, it is necessary to take effective measures to limit the uncontrolled expansion of construction land and to rationalize the use of land resources.

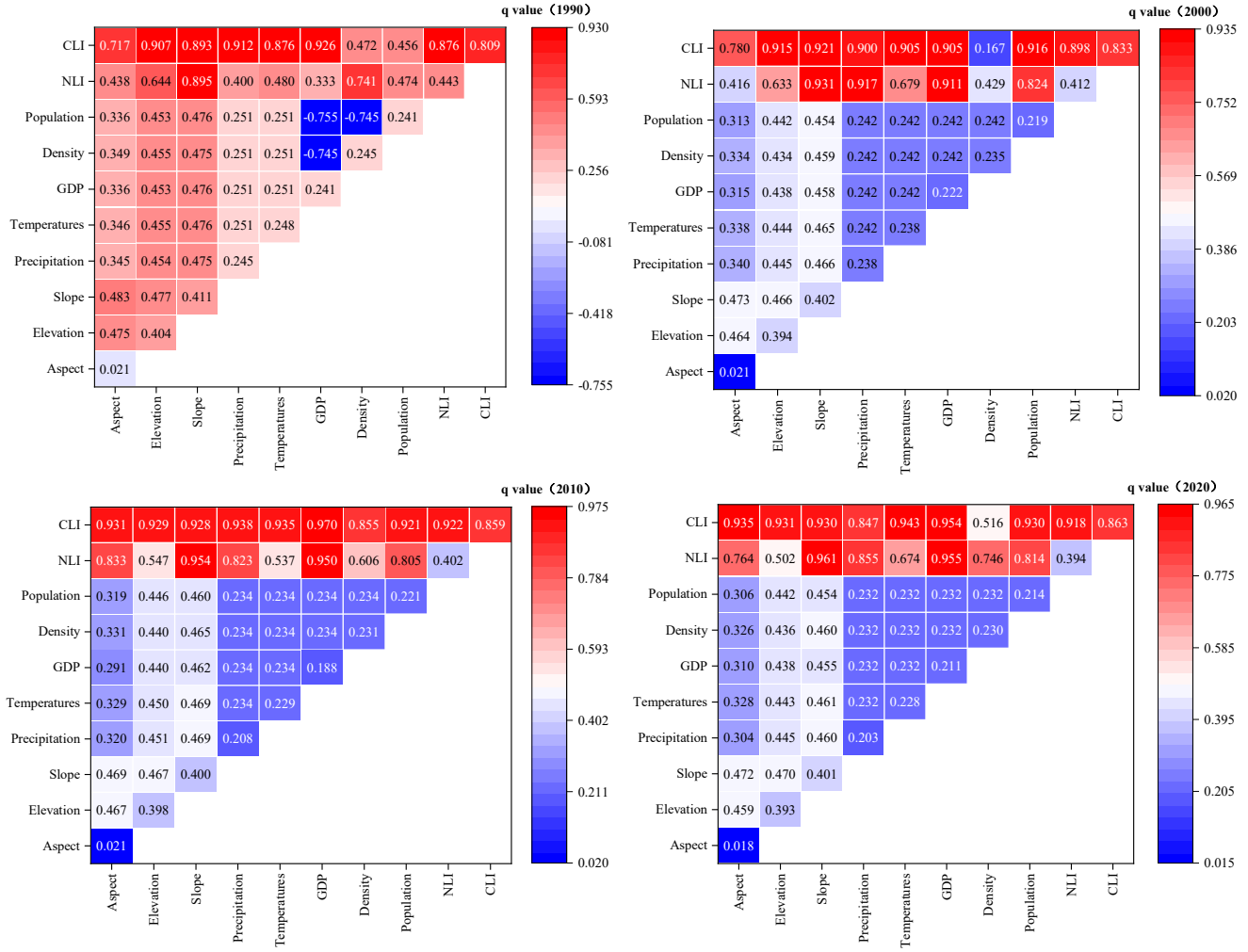


Figure 10. Interactive detection results of factors affecting habitat quality.

4. Discussion

This study calculated the habitat quality in Hubei Province with the help of the InVEST model over the past three decades, combined with the spatial analysis function of GIS to study its trends, and analyzed the spatial autocorrelation of habitat quality at the grid-cell scale, in addition to conducting an in-depth investigation of its driving mechanism through the geo-probe. The overall habitat quality of Hubei Province is high in the west and low in the east, and the major growth and decrease areas are concentrated in the eastern region, which is consistent with the findings of Cao et al. [43].

In this study, we used the habitat quality module of the InVEST model to calculate the habitat quality index in Hubei Province from 1990 to 2020, evaluating it in five levels based on the natural breakpoint method, and systematically assessed the major areas of increase and decrease in habitat quality in the region over the three decades. On this basis, we computed the average habitat quality index of each region from the perspective of counties and conducted an in-depth discussion of its trends. Compared with other related studies, this study assessed the habitat quality of Hubei Province over a long time series, and selected counties to divide it in terms of scale so as to study the characteristics of spatial distribution and the trend of change in more detail. Based on the results of this study, it is recommended that, when formulating ecological conservation strategies, geographical heterogeneity be considered and tailored measures be implemented in different regions.

This study analyzed the spatial correlation of habitat quality in Hubei Province from 1990 to 2020 by calculating the global Moran Index and the local Moran Index, revealing

the distribution pattern of habitat quality in geospatial space and its changing trend. When calculating the global Moran Index, this study considered the overall spatial distribution characteristics of habitat quality across Hubei Province, and the results of the indices obtained were all greater than 0.8, which indicates that there was an obvious positive spatial correlation of habitat quality and highlighting the necessity of this study. By analyzing the local Moran Index, the study provided the spatial distribution differences of habitat quality in different regions of Hubei Province more comprehensively. The spatial correlation results obtained in this study are consistent with the findings of Lan et al. that habitat quality is spatially significantly correlated [44]. This is because geographically proximate regions tend to have similar ecological conditions, land use types, and socio-economic activities, and the spatial similarity of these factors leads to spatial aggregation of habitat quality.

This study selected natural factors (elevation, slope direction, slope, temperature, precipitation) and socio-economic factors (population, population density, GDP, Nighttime Lighting Index, Construction Land Index) and explored the driving mechanism of the spatial differentiation pattern of the habitat quality in Hubei Province by using geodetectors and obtained the factor with the highest explanatory power: the Construction Land Index. In addition, through the interaction detection analysis, it was found that the synergistic effect of multiple factors can more effectively promote the enhancement of habitat quality and sustainable development. With the acceleration of urbanization, the role of socio-economic factors has become more prominent, especially land use changes and the continued pressure of human activities on the environment. Therefore, the synergy between socio-economic factors should be strengthened when formulating relevant policies for future ecological protection and restoration, especially the comprehensive consideration of urban planning, green infrastructure construction, and ecological restoration. Future research can further deepen the exploration of the mechanism of multi-factor interaction to provide a more scientific basis for the dynamic monitoring and protection of habitat quality. Compared with other studies, this study selected more comprehensive socio-economic factors to reveal the driving factors, and the results obtained were consistent with the findings of Liu et al. [45], showing that socio-economic factors (especially the Construction Land Index) have a significant effect on habitat quality.

The InVEST model is widely used in the calculation of physical quality of habitat quality, with the advantages of easy data acquisition, visualization of results, and high accuracy, but it also has certain limitations: the selection and setting of parameters such as threat sources and sensitivity are subjective, so the model still has room for improvement. Future studies can further explore the complex relationship between socio-economic development and habitat quality by narrowing or expanding the study area, especially in other regions or under different ecosystem types, to validate the generalizability of this study's methodology. Meanwhile, the driving mechanisms behind ecosystem services are complex, and although this study used geographic probes to detect the influencing mechanisms of habitat quality, and although a variety of natural and social factors were selected, some factors were not considered, and it is hoped that a wider range of factors can be selected to explore the driving mechanisms in a subsequent study.

The methods and results of this study not only provide a scientific basis for future habitat protection and ecological environment management in Hubei Province but also provide an important reference for the study of habitat quality change on a national scale. By combining the InVEST model, geoprobes, and spatial autocorrelation analysis, future studies can further deepen the understanding of habitat quality changes and provide theoretical support for promoting regional ecological civilization construction and sustainable development.

5. Conclusions

This study comprehensively utilized multiple techniques, such as the InVEST model, Geodetectors, and spatial autocorrelation analysis in order to quantitatively assess the habitat quality status in Hubei Province from 1990 to 2020. This study also explored its spatio-temporal evolution characteristics and key influencing factors, leading to the following conclusions:

(1) During the thirty-year study period, the habitat quality in Hubei Province remained at a high level in general, and the habitat quality in the western region is significantly better than that in the eastern region. Although the overall habitat quality in Hubei Province has declined, the proportion of "excellent"-grade areas has always remained above 35%. (2) Habitat quality indices were more stable in the western part of Hubei Province from 1990 to 2020, while indices in some counties in the eastern part declined significantly, especially in Wuhan and its surrounding cities, which may be related to the urbanization process. (3) With regard to trends in the Habitat Quality Index (HQI), a number of areas were found to have a continuing downward trend in the index, which needs to be given high priority.

The results of spatial autocorrelation showed that the global Moran's I values of the four periods were all greater than 0.8, reflecting a high degree of spatial correlation of habitat quality in Hubei Province from 1990 to 2020. From the results of the local Moran index, it can be seen that the index of habitat quality also presents the characteristics of a two-tiered spatial agglomeration, with the high values concentrated in the western part of Hubei Province, a small amount in the eastern part, and the low values concentrated in the economically more developed areas of the eastern part.

This study clearly indicated that socio-economic factors play a more significant role than physical/geographical factors in the differentiation of habitat quality in Hubei Province and that the Construction Land Index was the main driving factor. In addition, the study also found that the complex interactions among the influencing factors were mainly characterized by two modes of two-factor enhancement and nonlinear enhancement and that the interactions among the factors were stronger than the effects of individual factors on the habitat quality in Hubei Province.

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