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Landscape Pattern Evolution and Its Response to Human Disturbance in a Newly Metropolitan Area: A Case Study in Jin-Yi Metropolitan Area

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Abstract: The impact of human interference on the ecological environment has attracted a significant amount of attention. In this study, hemeroby index (HI) was constructed to quantify the degree of human disturbance, and the relationship between HI and landscape pattern index was explored in a newly metropolitan area. The main objectives of this study were to analyze the temporal and spatial characteristics of landscape pattern and human disturbance in the process of urbanization of county-level cities in China, and to explore the relationship between the landscape pattern index and human disturbance under different disturbance intensity. The conclusions showed that: (1) the degree of human interference in the new area is on the rise, with a slow increase from 1980 to 2010, but since 2010, human interference has increased significantly. The diffusion of human disturbance intensity has obvious spatial directivity, spreading from east to west. (2) The impact of human activities on landscape pattern is shown as increasing fragmentation and increasing number of landscape types. With the enhancement of human activities, the heterogeneity and fragmentation of landscape types in the region reach their highest points. With the continuous increase of human activities, on a certain scale, the landscape types will gradually tend to be the same, and the same type of landscape patches will become one piece and tend to be integrated. This phenomenon is particularly obvious at the patch type level. (3) There is an inflection point value between human disturbance and landscape pattern index in landscape or patch type. On both sides of the inflection point value, the landscape pattern parameters and human disturbance have obvious opposite trends. (4) In the low interference range ($1 \leq \mathrm{HI} < 4$), with the increase of human interference, more heterogeneous structures (shown in the increase of SHDI) are brought to the landscape, there is more landscape fragmentation (shown in the decrease of LPI, CONTRACT, and AI), and the patch shape and landscape structure tend to be complex (shown in the increase of LSI, SQP, ED, and other indexes); in the high interference range ($4 \leq \mathrm{HI} \leq 7$), due to human intervention, the increase of LPI, contract, and AI indicates that intense human activities turn the landscape into a broken and scattered structure and tend to be consistent and homogeneous. LSI, SQP, and ED were negatively correlated with HI at this stage, indicating that with the enhancement of human activities, the complexity of landscape shape decreased.

Keywords: human disturbance; landscape pattern index; Jin-yi metropolitan area

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Citation: Wu, T.; Zha, P.; Yu, M.; Jiang, G.; Zhang, J.; You, Q.; Xie, X. Landscape Pattern Evolution and Its Response to Human Disturbance in a Newly Metropolitan Area: A Case Study in Jin-Yi Metropolitan Area. *Land* **2021**, *10*, 767. https://doi.org/10.3390/land10080767

Academic Editor: Audrey L. Mayer

Received: 27 June 2021
Accepted: 16 July 2021
Published: 21 July 2021

1. Introduction

The Anthropocene epoch marks a fundamental change in the relationship between humans and nature [1]. In the past 30 years, due to the growth of population and the acceleration of urbanization, the impact of human activities on the earth's surface has approached or exceeded the changes brought about by natural factors in intensity, breadth, and speed. Human activities have become the third driving force behind solar energy and internal energy of the earth system [2]. Previous studies have found that human disturbance has completely replaced the impact of natural factors in both developed and developing regions [3–5]. Excessive human activities not only affect human food supply, material supply, and water supply system but also threaten human health and human well-being [6]. On global and regional scales, more and more intense human disturbance activities have had an irreversible and significant impact on surface landscape structure and ecological function and caused a series of ecological and environmental problems, such as soil degradation, habitat destruction, and species diversity decline, which have become a great threat to the sustainable development of human society [5–13].

Therefore, exploring the impact of human activities on the landscape pattern is an increasing concern of scholars and government decision-making departments, and monitoring and evaluating human interference has become one of the hotspots and important areas of landscape ecology research [5,12,14–17]. Landscape is a complex topic composed of land, space, and matter, which is the mark of natural processes and human activities on the earth [18]. Compared with the characteristics of natural disturbance, such as suddenness, short duration, and unpredictability, human disturbance can be controlled and managed scientifically by adjusting policies and means [19–21]. Many scholars have carried out scientific research on the spatial differentiation of human disturbance and its relationship with landscape patterns [7,16,22–26]. These landscape data contain a lot of information related to human activities, which can indirectly reflect the intensity of human disturbance to the ecosystem [11,17]. However, most scholars focus on the impact of single human disturbance factors such as urbanization, farming, or deforestation on the ecological environment, and few focus on the overall impact of human disturbance [12,22,24]. In recent years, some scholars try to quantify human interference by creating an "interference index" based on remote sensing, socio-economic indicators, and field survey data [5,11,25,27]. Among them, the hemeroby index is used to measure the impact of human intervention measures on ecological components or ecosystems and then to indicate the impact of human activities on the natural environment [28–31]. Hemeroby index provides a feasible method for quantitative measurement of human interference intensity on land use and is used by many researchers to quantify the impact of land use change on the surface environment [32–34].

However, the current study of human interference evaluation is mainly based on the interference evaluation method of land use cover change (LUCC), that is, to assign different types of land cover to different interference levels. This method does not fully take into account the spatial distribution differences of patch types in regions and grids, which may result in the same evaluation results for regional units with the same patch type area but a completely different layout. In other words, the evaluation results of the two plots are the same but their spatial layout is different. Moreover, due to the different spatial layout structure of the plot its practical ecological significance is diverse. Is it reasonable to try to avoid the above problems? This requires us to fully consider the spatial structure of patch types when calculating human disturbance.

Therefore, this paper constructs a standard grid of land use types and analyzes the response relationship between landscape pattern index based on landscape and patch level and human disturbance intensity. The objectives of this study are (1) to analyze the temporal and spatial characteristics of landscape pattern and human disturbance in the process of urbanization of county-level cities in China, and (2) to explore the relationship between the typical landscape pattern index and the human disturbance under different disturbance intensity. This study provides methods and information support for land use planning and environmental managers to reasonably layout and evaluate urban landscape patterns and build an urban ecological civilization.

2. Research Area

Jin-yi metropolitan area is located in the central part of Zhejiang Province (Figure 1), the eastern part of Jinqu basin, and the junction of Jindong District and Yiwu City (119°41′~120°7′ E; 29°22′~29°3′ N), which together comprise the intersection of the Yangtze River Delta economic circle and the Economic Cooperation Zone on the west coast of Taiwan Strait. The short-term planning district of the new area includes Xiaoshun Town, Fucun Town, Caojie Town, Tangya Town, Lipu Town, Shangxi Town, Yiting Town, and Fotang Town, with a total area of 696.79 km^2. The mountainous area accounts for 33.77% and the plain 66.23% of the metropolitan area, which has a subtropical monsoon climate and an annual average temperature of 17.5 °C. The main river in the new area is Dongyang River, which runs through the south of the new area from east to west. Jin-yi metropolitan area is the fourth largest metropolitan area in Zhejiang Province, with a gross domestic product (GDP) of 1.82 × 10^{11} CNY in 2016. Jin-yi metropolitan area has distinctive regional economic characteristics, and several major industries, such as medicine and chemical industry, food, automobile parts, building materials, light industry, and textiles, which are in the trend of cluster. The study area also has developed foreign trade and is the world's largest small commodity trade center.

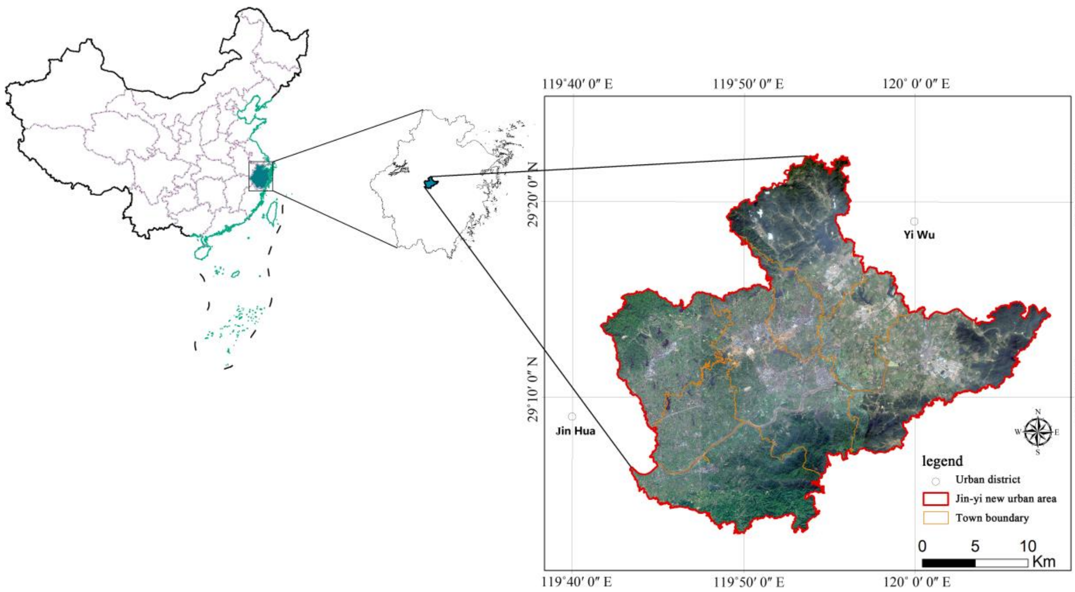


Figure 1. Schematic diagram of study area.

3. Methods

3.1. Data Sources

The applied Landsat satellite digital products (Table 1) were provided by geospatial data cloud (http://www.gscloud.cn/ (accessed on 20 May 2020)) in this study. According to the landscape characteristics and related research results of Jin-yi metropolitan area, on the basis of field investigation, and referring to the classification standard of land use mode of Chinese Academy of Sciences, the study area is divided into seven categories: forest land, grassland, cultivated land, river, lake, urban and construction land, and bare land. Taking this as the standard, the preprocessed image is visually interpreted by ArcGIS software, and the vector data of land cover types in the study area from 1980 to 2016 are obtained. These four periods reflect the development process of Jinyi region from traditional agricultural society to export economy and then to high-tech industry and ecological civilization.

Table 1. Data type and source description.

Time	Data Type	Precision	Data Source
1980–1882	Land-Cover Types	1:100,000 30 m	Topographic map (1980) Landsat4-TM (1982)
2000	Land-Cover Types	30 m	Landsat7-TM
2010	Land-Cover Types	30 m	Landsat7-TM
2016	Land-Cover Types	30 m	Landsat8-OLI

3.2. Landscape Pattern Index

Landscape pattern index is widely used in the study of landscape ecology [32,34–38]. Based on the characteristics of regional landscape distribution and the ecological significance of landscape pattern index, this paper uses the landscape pattern index comparison method to select nine landscape pattern indexes from the level of landscape and patch type in terms of density, connectivity, diversity, aggregation, and other aspects: square pixel index (SQP), maximum patch to landscape area ratio (LPI), landscape shape index (LSI), Edge density (ED), sprawl index (contract), Shannon diversity index (SHDI), average patch area (AREA-Mn), average fractal dimension (FRAC-Mn), landscape aggregation index (AI), index calculation method, meaning, and formula are shown in literature [18,39]. By using FRAGSTATS software, the landscape pattern index of grid unit and patch type in Jin-yi metropolitan area is calculated.

3.3. Calculation and Classification of Hemeroby

Most of the literature uses the seven-point scale to classify land use according to the degree of hemeroby (Table 2) [16,40,41]. Hemeroby was initially introduced for the assessment of vegetation disturbance and has been applied since the 1950s [28]. Then, Sukopp [40] went on to extend hemeroby into a system for the classification of habitats and vegetation types, introducing a scale ranging from ahemerobic (no anthropogenic influence) to metahemerobic (biocoenosis completely destroyed) [29].

Table 2. Assignment of CORINE Land Cover classes (CLC) of the DLM-DE to degrees of hemeroby.

Degree of Hemeroby	CLC-Code and CLC-Class of the DLM-DE		Hemeroby Index (HI)
1. Ahemerobic—Almost no human impact	332 Bare rocks 335 Glaciers and perpetual snow		1 1
2. Oligohemerobic—Weak human impact	311 Broad-leaved forest 312 Coniferous forest (PNV) 313 Mixed forest (PNV) 331 Beaches, dunes, sands 411 Inland marshes 412 Peat bogs	421 Salt marshes 423 Intertidal flats 521 Coastal lagoons 522 Estuaries 523 Sea and ocean	2 2 2 2 2 2
3. Mesohemerobic—Moderate human impact	312 Coniferous forest (not PNV) 313 Mixed forest (not PNV) 321 Natural grasslands 322 Moors and heathland	324 Transitional woodland-shrub 333 Sparsely vegetated areas 334 Burnt areas	3 3 3 3
4. β-Euhemerobic—Moderate-strong human impact	141 Green urban areas 231 Pastures 243 Land principally occupied by agriculture, with significant areas of natural vegetation	511 Water courses 512 Water bodies	4 4 4
5. α-Euhemerobic—Strong human impact	142 Sport and leisure facilities 221 Vineyards 222 Fruit trees and berry plantations	211 Non-irrigated arable land 242 Complex cultivation patterns	5 5 5
6. Polyhemerobic—Very strong human impact	112 Discontinuous urban fabric 131 Mineral extraction sites 132 Dump sites	133 Construction sites	6 6 6
7. Metahemerobic—Excessively strong human impacts–Biocoenosis destroyed	111 Continuous urban fabric 121 Industrial or commercial units 122 Road and rail networks and associated land	123 Port areas 124 Airports	7 7 7

Note: compilation on the basis of Sukopp 1976; Rüdisser et al., 2012; Walz and Stein, 2014.

In this paper, the grid method is used to calculate human interference. First of all, we use the fishing net creation tool in ArcGIS software to create grid units (Figure 2). Secondly, according to Table 1, the interference index of different land cover types is assigned, and then the artificial interference index of each grid unit is calculated by Equation (1). The advantage of grid method compared with administrative division boundary is that unified grid can get more information gain than by simply using administrative boundary. At the same time, the application of grid eliminates the influence of the size of management unit on the results. Furthermore, this method is based on assessment of land use units at the landscape level, and it is easy to calculate and to understand, which is important for regular monitoring and the dissemination of the results to the public.

$$HI = \sum_{i=1}^{h} \frac{S_i}{S_A} \times h \quad (1)$$

HI—Hemeroby index;
h—Number of degrees of hemeroby (here: $n = 7$);
S_A—Total area of grid unit;
S_i—Area of cover types with interference level *i*.

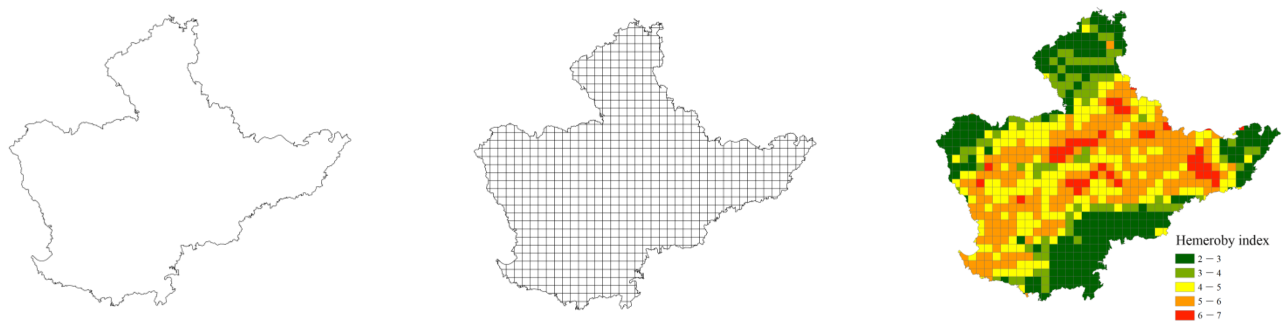


Figure 2. Schematic diagram of calculation process of human interference degree (HI).

According to the previous research results [16,40–42], combined with the landscape type and actual situation of the study area, the artificial interference index of the landscape type of the study area is assigned (from 1 to 7) (Table 2).

4. Results and Analysis

4.1. Analysis of Temporal and Spatial Variation of HI

4.1.1. Temporal Variation of HI

The overall HI in the study area is on the rise (Figure 3). From 1980 to 2000, the change of human disturbance degree was not obvious. From 2000 to 2010, the human disturbance degree began to rise slowly. After 2010, the human disturbance degree showed a significant upward trend. During 1980–2016, the area of evaluation units of degree of hemeroby changed significantly, which mainly showed that the area of β-Euhemerobic and α-Euhemerobic ($4 \leq \text{HI} < 5$) decreased year by year, and the area of Polyhemerobic and Metahemerobic ($\text{HI} \geq 5$) increased gradually, but the total area of the two experienced an overall upward trend. From 1980 to 2000, the area of each interference level remained basically invariant, indicating that the intensity of human development activities was weak, and the area of patch type remained basically unchanged in this period. From 2000 to 2010, the area of Ahemerobic Mesohemerobic and Oligohemerobic ($\text{HI} < 4$) remained basically unchanged; the area of β-Euhemerobic and α-Euhemerobic decreased with a change rate of -8.47 km^2/year, while the area of Polyhemerobic and Metahemerobic increased with a growth rate of 8.46 km^2/year. During 2010–2016, the area of Ahemerobic Mesohemerobic and Oligohemerobic changed significantly, which showed that the area of Ahemerobic and

Mesohemerobic decreased and the area of Oligohemerobic increased; the change rates were -11.85 km^2/year and 12.89 km^2/year, respectively, significantly higher than the change rates of 2000–2010. The area of Ahemerobic and Mesohemerobic in 2016 had an absolute advantage, and the change here was most intense, an increase of 212.04 km^2 compared with the area in 1980; the area of change of β-Euhemerobic and α-Euhemerobic was the second most intense; it decreased by 201.61 km^2 compared with 1980.

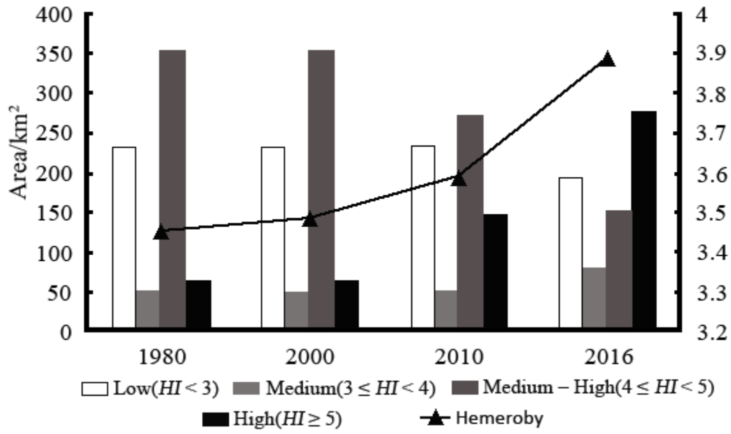


Figure 3. Hemroby of Jin-yi metropolitan area from 1980 to 2016.

4.1.2. Temporal Variation of HI

The high interference areas (HI $\geq$ 5) in the study area are mainly distributed in the middle and east of the basin (mainly Yiting town and Fotang town). These areas are located in the Dongyang River Basin in the east section of Jinqu basin, where the terrain is low and flat with strong human activities and where towns and construction land gather; the medium and high interference areas (4 $\leq$ HI < 5) are mainly distributed in the central and western parts of the basin, and the main landscape type is cultivated land, while the low interference and medium interference areas (HI < 4) are mainly distributed in the surrounding mountains, and the landscape type is mainly forest land (Figure 4). The landscapes with high disturbance level gradually expanded from east to west in the Jin-yi metropolitan area. The main reason for this change is that Yiwu City has strong radiation ability, the construction process of surrounding towns and cities is speeding up, the area of high interference level is increasing rapidly, and the high disturbance landscape replaced the landscape type with relatively low disturbance level; secondly, the area is a basin, the middle is a plain, the north and south sides are mountains, and the central area is the main concentration area of human activities.

From Figure 4, we can clearly see the convergence direction of human activity intensity in space. From 1980 to 2000, there was no obvious change in the direction of human activities. There was a high interference nucleus in the middle of Yiting town and Xiaoshun town, respectively, and the intensity of regional human interference converged here in space. From 2000 to 2010, the high interference nucleus in Yiting town began to move eastward. It can be seen from Figure 5 that at this time, the intensity of human interference in the East and middle of the new area increased significantly, and the convergence degree of high interference nucleus in the middle of Xiaoshun town increased and moved northward. During this period, the intensity of human interference in the east of the new area (near Yiwu) increased significantly every year. During 2010–2016, the agglomeration capacity of the high-value core, which moved from Yiting town to the northwest of Fotang town, increased significantly, while the high-value center in the middle of Xiaoshun town gradually moved to the north, and the convergence center in the southwest of the new area (near Jinhua) still existed. During this period, the annual average intensity of human interference continued to increase, and a new high value area of annual growth was formed in the central and western part of the new area, which was connected with the northern area. On the whole, the high interference areas in Jin-yi metropolitan area have formed the development trend of strip distribution from Jinhua and Yiwu to the central area.

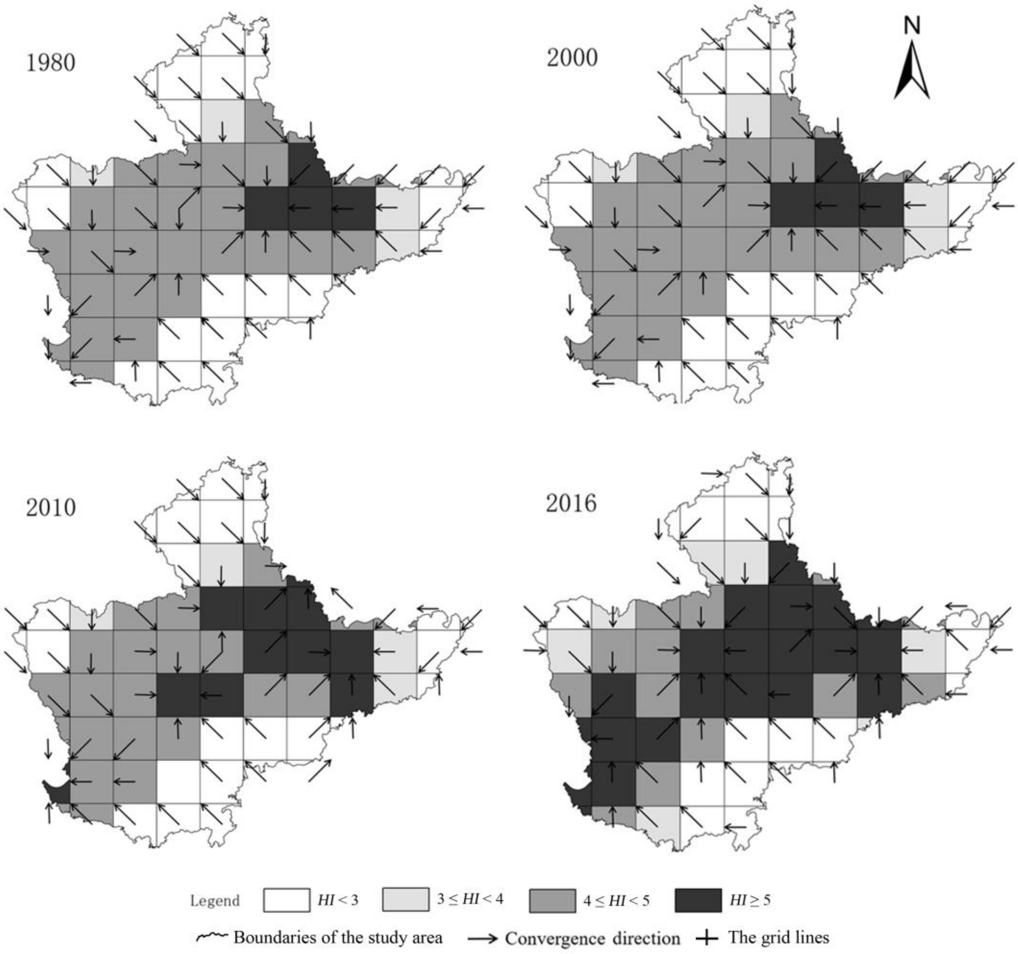


Figure 4. Hemeroby index distribution and direction change of hemeroby index in Jin-yi metropolitan area in 1980–2016.

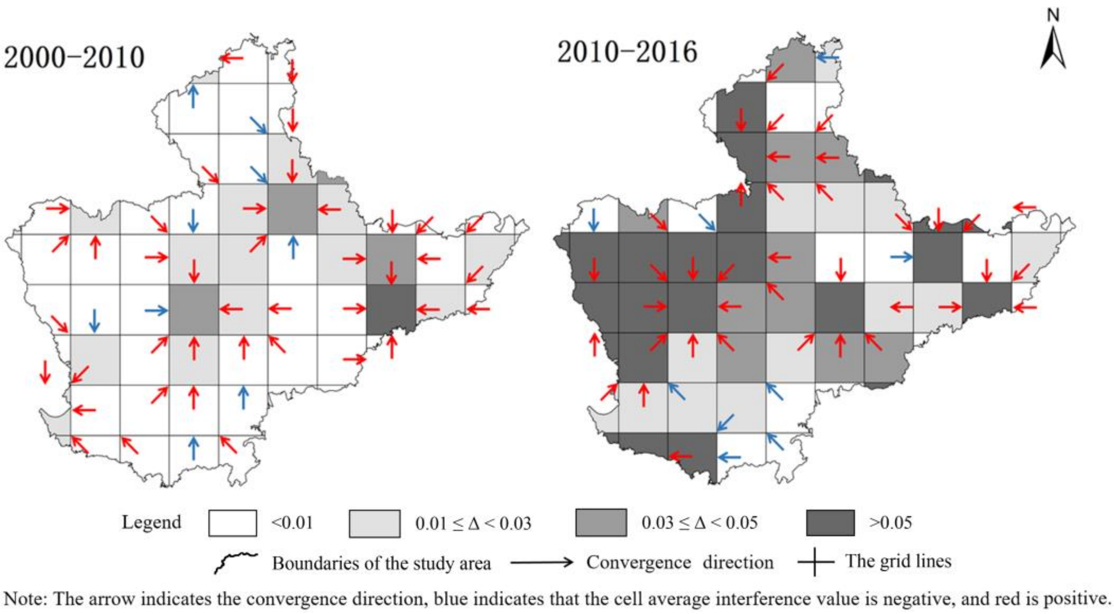


Figure 5. Spatial distribution of hemeroby's annual variation from 2000 to 2010 and 2010 to 2016.

4.2. Landscape Pattern Change

It can be seen from Figure 6 that the main landscape types in the new area from 1980 to 2016 are cultivated land and forest land, but the patch types with the most dramatic changes are urban and construction land and cultivated land.

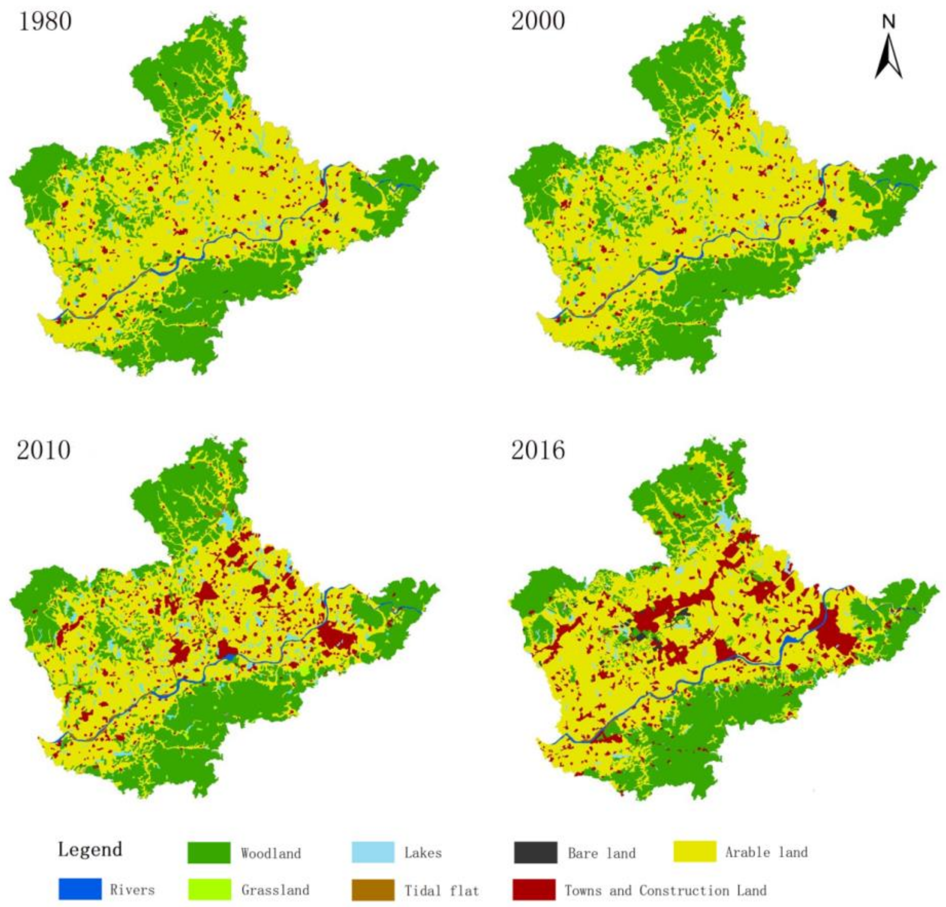


Figure 6. The changes in land use 1980–2016.

From the perspective of landscape (Table 3), the landscape pattern of Jin-yi metropolitan area has changed significantly due to the impact of human activities: (1) From 1980 to 2016, landscape fragmentation increased. Specifically, the AREA_MN index showed an overall downward trend, and its value dropped rapidly from 2000 to 2010, indicating that the enhancement of human activities led to the enhancement of landscape fragmentation, while after 2010, its value slightly increased, indicating that the landscape tended to develop stably. (2) The connectivity and dominance of plaque decreased. The results showed that the CONTAG index decreased from 72.4113 to 65.9457, indicating that the connectivity of patches in the landscape decreased, and all types of patches were scattered. SHDI increased from 0.9531 in 1980 to 1.1699 in 2016, indicating that patch types tend to be evenly distributed. Compared with 1980, patch types were relatively evenly distributed in 2016, and landscape connectivity and dominance decreased. (3) The complexity of landscape shape in this area is relatively low, but there is a trend of complex change. This is reflected in the increase of FRAC_MN index from 1.0656 in 1980 to 1.0822 in 2016. The value is close to 1, indicating that the landscape complexity of the study area is low, but the increase of the value indicates that the landscape complexity of the study area has a slight upward trend. The reason is that human activities change the landscape shape and complicate the landscape after the large-scale urban construction in the research area. At the same time, the rising trend of LSI index can also explain this phenomenon.

Table 3. The dynamic variation of landscape index in Jin-yi metropolitan area in 1980–2016.

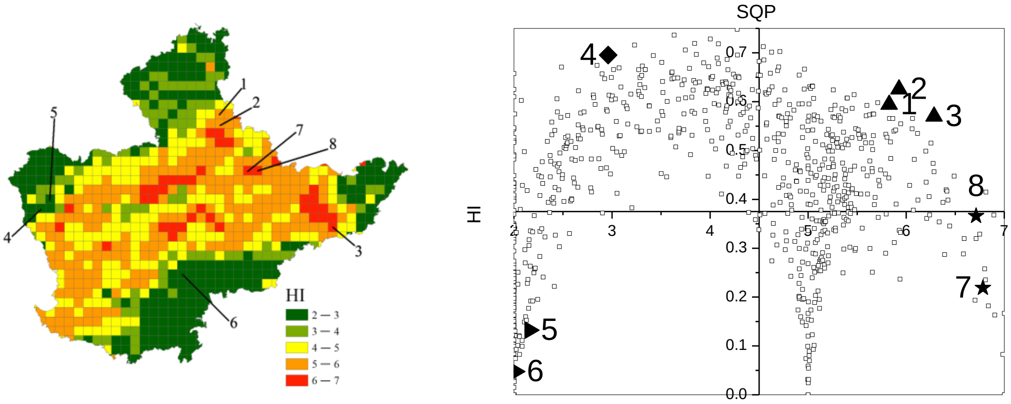
Index \ Year	1980	2000	2010	2016
PD	1.115	1.612	1.719	1.409
SQP	0.952	0.952	0.962	0.960
LPI	40.435	40.322	33.608	34.628
ED	26.992	26.977	35.250	33.773
CONTAG	72.411	72.198	66.624	65.946
SHDI	0.953	0.962	1.140	1.170
LSI	20.687	20.676	26.136	25.163
AI	95.828	95.831	94.600	94.826
AREA_MN	98.849	98.015	64.706	72.507
FRAC_MN	1.066	1.066	1.070	1.082

From the perspective of patch type, cultivated land and urban and construction land are the two land use types that are most affected by human activities (Table 3). It can be seen from Table 3 that the fragmentation degree of urban construction land is reduced with the enhancement of human activities, and the connectivity and complexity of patch shape of urban construction land are increased, mainly reflected in the landscape pattern index of LPI, ED, AREA_MN, FRAC_MN, and AI showing an increasing trend from 1980 to 2016; the LPI index of cultivated land decreased year by year, and the AI index showed a downward trend, indicating that the degree of fragmentation of cultivated land increased; large patches were divided into small patches, the aggregation degree between patches decreased, and the FRAC_MN index increased slightly, indicating that the patch shape had a trend towards complexity.

4.3. Correlation Analysis of Landscape Pattern Index and HI

4.3.1. Relationship between Square Pixel Index (SQP) and HI

The value range of SQP is 0–1. When the patch shape in the landscape becomes more and more complex or deviates from the square, SQP increases and tends to 1. It can be seen from Figure 7 that there are four types (regions) of all evaluation units (points) in Figure 7b, namely, low interference simple type, low interference complex type, high interference complex type, and high interference simple type. In the corresponding Figure 7a, the low interference simple type (points 5 and 6) is mainly distributed in the mountains on both sides, mainly in the aggregated forest land, which accounts for more than 90% of the area of the evaluation unit; and the low interference complex type is mainly distributed around the basin, with the main patch types of shrub, grass land, and water surface and other natural landscape mixed types, while the dominant patch types account for about 60% of the area of the evaluation unit (point 4). The high interference complex type is mainly distributed in the basin, mainly in the mixed type of cultivated land and urban land, and its dominant patch type generally accounts for 50–60% of the evaluation unit area (points 1, 2, and 3), while the high interference simple type mainly consists of cultivated land and urban common land, and its dominant patch type generally accounts for more than 80% of the evaluation unit area (points 7, 8).



(**a**) (**b**)

Figure 7. Space reciprocal trend of HI and SQP in evaluate unit. (The number in the figure represents the grid cell of typical human interference type, the (**a**) shows the real spatial distribution state of the evaluation grid unit and human interference, and the (**b**) shows the distribution of evaluation grid cells in HI and SQP two-dimensional coordinate systems).

As shown in Figure 8, the scatter diagram of SQP and HI is constructed, and the parabola relationship between SQP and HI is obvious. When HI value is about 4, SQP takes the maximum value. This finding is consistent with our previous research results: the impact of human activities on landscape morphology, initially manifested as increasing fragmentation and increasing number of landscape types; with the enhancement of human activities, the heterogeneity and fragmentation of landscape types in the region reach the highest point; on a certain scale, landscape types will gradually tend to be consistent when the intensity of human activities continues to increase. The same kind of landscape patches are connected and tend to become integration, and SQP will gradually become smaller and tend to 0. This phenomenon is particularly obvious at the patch type level. Therefore, it can be predicted that SQP will reach the maximum value when HI = 4 in this study area, which is the inflection point of human activities on landscape reconstruction. It can be divided into high interference interval (HI > 4) and low interference interval (HI < 4) by this partition point. Whether the landscape pattern index and human disturbance intensity have the opposite trend needs further discussion.

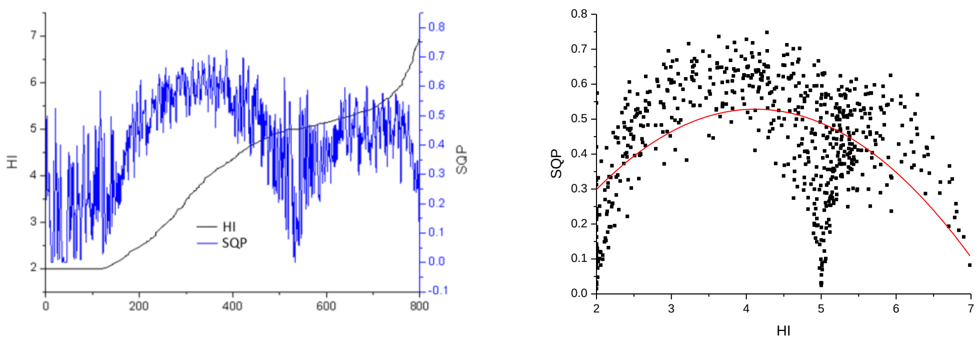


Figure 8. Relationship between SQP index and HI.

4.3.2. Correlation Analysis of Landscape Pattern Index and HI Based on Landscape Level

We take the point where HI is equal to 4 as the dividing point and discuss the relationship between HI and landscape pattern index in low interference stage (HI < 4) and high interference stage (HI > 4). As shown in Table 4, in the low interference range (1 < HI < 4), there is a very obvious linear relationship between landscape pattern index and HI. Among them, LSI, SQP, SHDI, SHEI, and ED showed significant positive correlation with HI, while LPI, CONTAG, and AI showed significant negative correlation with HI. This phenomenon is in line with the fact that the weaker human disturbance produces a more heterogeneous structure to the landscape (manifested in the increase of SHDI), increases landscape fragmentation (manifested in the decrease of LPI, contract and AI), and causes the patch shape tend to be complex in the landscape (manifested in the increase of LSI, SQP, ED, and other indexes) with the low interference environment.

Table 4. Fitting results of HI and landscape pattern index.

Hemeroby Index	Landscape Index		Fitting Equation	R-Square
HI ($1 \leq$ HI < 4)	Landscape level	SQP	$-0.2121 + 0.2368x$	0.630 **
		ED	$-60.1083 + 35.3676x$	0.695 **
		LSI	$-0.2299 + 0.8047x$	0.649 **
		LPI	$161.4853 - 32.608x$	0.794 **
		SHDI	$-3.0661 + 2.1115x - 0.2764x^2$	0.853 **
		SHEI	$-3.5843 + 2.5599x - 0.3696x^2$	0.868 **
		CONTAG	$289.665 - 136.845x + 19.6021x^2$	0.812 **
	patch type level	LSI	$-0.3865 + 0.8360x$	0.542 **
		AI	$102.0647 - 1.1726x$	0.579 **
		ED	$-53.6422 + 31.6924x$	0.647 **
		SQP	$-1.8602 + 1.4093x - 0.2024x^2$	0.655 **
		LPI	$161.3244 - 32.4197x$	0.735 **

Note: ** Sig. < 0.01.

The relationships between HI and landscape pattern indexes in high disturbance stage ($4 <$ HI < 7) were complex and fluctuated. As shown in the Table 5, there was a significant correlation between HI and the landscape pattern index in the high interference area. In the high interference range, the landscape morphology index changes tend to be complex due to the enhancement of human interference activities. LPI, CONTAG, and AI indexes, which were negatively correlated with HI in the low interference region, increased with the increase of HI in the interference region ($1 <$ HI < 4). When HI = 5, they reached their maximum value, then decreased or fluctuated slightly in $5 <$ HI < 6, and rose sharply after HI > 6, which showed a positive–negative–positive trend and indicates that the intense human activities that cause the landscape to have a broken and scattered structure tend to be consistent and homogeneous. The LSI, SQP, and ED, which are positively correlated with HI in the low interference range, are negatively correlated with HI at this stage. With the increase of HI, their values decrease, indicating that with the increase of human activities, the complexity of landscape shape is decreasing.

Table 5. Fitting results of HI and landscape pattern index based on landscape level.

Landscape Index	HI	Fitting Equation	R-Square
LPI	$4 \leq$ HI < 5	$y = -98.5048 + 36.9464x$	0.363 **
	$5 \leq$ HI < 6	$y = 318.4284 - 45.4748x$	0.544 **
	$6 \leq$ HI < 7	$y = -269.3026 + 53.04x$	0.886 **
ED	$4 \leq$ HI < 5	$y = 259.8 - 46.646x$	0.323 **
	$5 \leq$ HI < 6	$y = -56.976 + 16.4903x$	0.073 **
	$6 \leq$ HI < 7	$y = 253.586 - 35.4293x$	0.606 **
LSI	$4 \leq$ HI < 5	$y = 7.5812 - 1.1818x$	0.333 **
	$5 \leq$ HI < 6	$y = -0.5134 + 0.4308x$	0.073 **
	$6 \leq$ HI < 7	$y = 7.3397 - 0.8857x$	0.606 **
CONTAG	$4 \leq$ HI < 5	$y = -44.1990 + 24.4526x$	0.342 **
	$5 \leq$ HI < 6	$y = 263.2853 - 36.6256x$	0.524 **
	$6 \leq$ HI < 7	$y = -165.8786 + 35.7405x$	0.470 **
SHDI	$4 \leq$ HI < 5	$y = 3.4913 - 0.6142x$	0.316 **
	$5 \leq$ HI < 6	$y = -2.2920 + 0.5340x$	0.282 **
	$6 \leq$ HI < 7	$y = 4.9034 - 0.6774x$	0.901 **

Table 5. *Cont.*

Landscape Index	HI	Fitting Equation	R-Square
SHEI	$4 \leq HI < 5$	$y = 2.4478 - 0.4139x$	0.326 **
	$5 \leq HI < 6$	$y = -3.0352 + 0.6745x$	0.545 **
	$6 \leq HI < 7$	$y = 4.9022 - 0.6616x$	0.483 **
AI	$4 \leq HI < 5$	$y = 88.8632 + 2.0374x$	0.319 **
	$5 \leq HI < 6$	$y = 102.2016 - 0.6276x$	0.055 **
	$6 \leq HI < 7$	$y = 90.0164 + 1.4124x$	0.486 **
SQP	$4 \leq HI < 5$	$y = 1.9029 - 0.3073x$	0.356 **
	$5 \leq HI < 6$	$y = -0.5390 + 0.1783x$	0.111 **
	$6 \leq HI < 7$	$y = 2.6680 - 0.3573x$	0.692 **

Note: ** Sig. < 0.01.

4.3.3. Correlation Analysis of Landscape Pattern Index and HI Based on Patch Level

The results show that there is a correlation between the overall landscape pattern index and the degree of human disturbance, but the response of different patch types to human disturbance is also different. In this study, the patch type with the largest proportion of area and larger than 0.5 km^2 in the evaluation unit was selected, and then the landscape pattern index of the patch type was calculated. As shown in Figure 9, in the low interference range ($1 < HI < 4$), similar to the landscape level, HI, is positively correlated with LSI, SPQ, and ED indexes, that is, with the increase of interference intensity, plaque morphology tends to be complex; HI was negatively correlated with LPI and AI, that is to say, with the slight increase of interference, the patch types gradually become fragmented.

As shown in Figure 10, in the high interference range ($4 < HI < 7$), the change of plaque type morphological index tends to be complex due to the enhancement of human interference activity. The AI index, which originally was negatively related to HI in the low interference range, increases with the increase of HI in the high interference range. LPI increases with the increase of hi in the high interference range. When HI is equal to about 5, LPI reaches the maximum value then decreases or fluctuates slightly in $6 > HI > 5$ and rises sharply after HI is greater than 6. This change trend of LPI index is consistent with that of landscape level. The relationship between LSI, SQP, ED, and HI was consistent with landscape level and showed significant negative correlation.

It can be found that there is an inflection point value between human disturbance and landscape pattern index in both landscape level and patch type level, i.e., on both sides of HI = 4, the relationship between them has obvious opposite change trend from the perspective of curve change. A general law of the influence of human activities on the surface morphology can be inferred from this: with the continuous increase of the intensity of human activities, the surface morphology experiences the process of first breaking, complicating, and then homogenizing, that is, a development process from simple (single)–complex–simple (single). There are two changing stages of human disturbance and landscape pattern index. There is obviously different change trend of morphological index in the low interference stage and the high interference stage. This conclusion reminds us that when we use landscape index to measure and analyze human disturbance, we must discuss and calculate it separately in different stages.

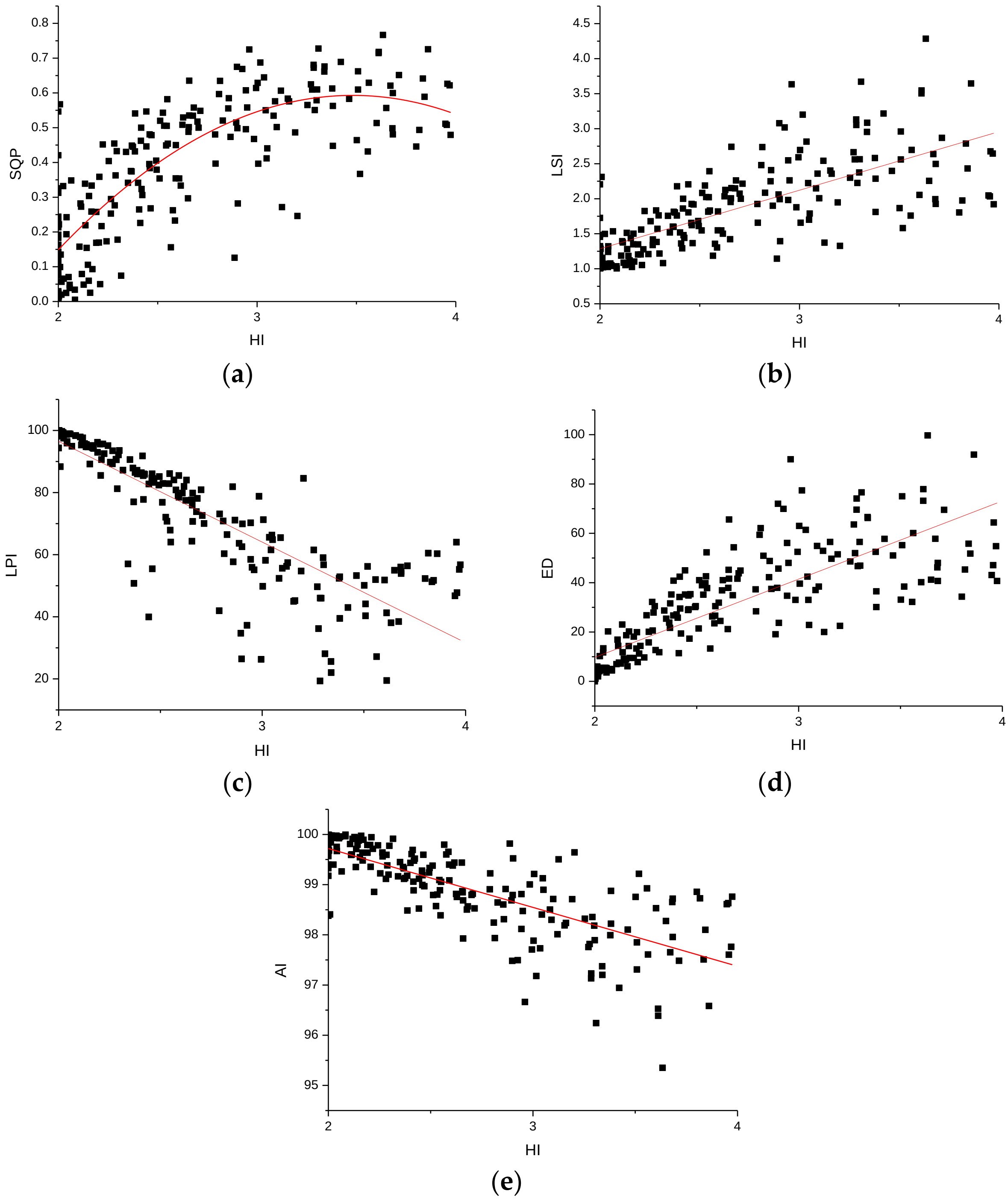
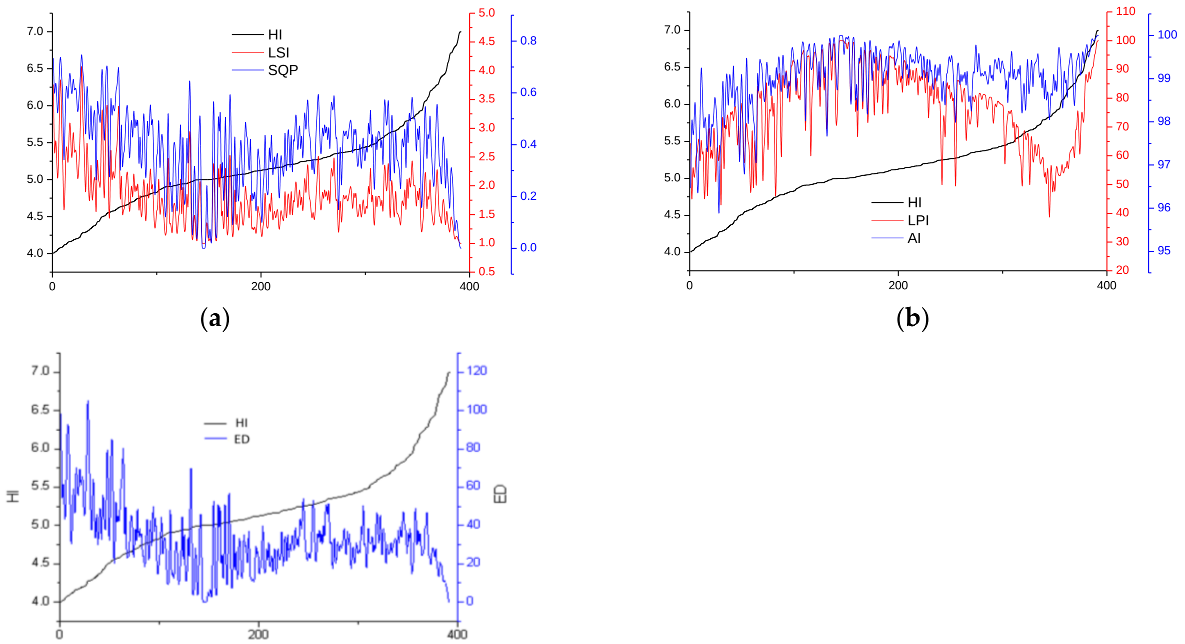


Figure 9. Relationship between different morphological indexes ((**a**) SQP, (**b**) LSI, (**c**) LPI, (**d**) ED, and (**e**) AI) and HI (1 < HI < 4) based on patch level.



(**a**) (**b**)

(**c**)

Figure 10. Relationship between different morphological indexes ((**a**) SQP, LSI; (**b**) LPI, AI; (**c**) and ED) and HI (4 < HI < 7) based on patch level.

5. Discussions

In recent years, with the increase of population and economic growth, the intensity of human interference has increased over time, which is also an inevitable consequence of urbanization and the increase of population. For example, Zhou et al. found that the intensity of human disturbance in Jiangsu coastal areas increased from 1995 to 2013 [43]. Zang Zheng's study on Yancheng Nature Reserve also showed that the intensity of human disturbance in the study area gradually increased from 1987 to 2013 [44]. In this study, from the perspective of time, the change of human interference degree was not obvious from 1980 to 2000, but the human interference degree began to rise slowly from 2000 to 2010, and it showed a significant upward trend after 2010. As far as the area of human disturbance intensity is concerned, the area of evaluation units of degree of hemeroby changed significantly during 1980–2016, which mainly showed that the area of Euhemerobic ($4 \leq$ HI < 5) decreased year by year, and the area of Polyhemerobic and Metahemerobic (HI ≥ 5) increased gradually, but the total area of the two experienced an overall upward trend, which indicated that the degree of disturbance in Jin-yi metropolitan area was increasing. Spatially, the high interference areas (HI ≥ 5) in Jin-yi metropolitan area are mainly distributed in the middle and east of the basin (mainly Yiting town and Fotang town). These areas are located in the Dongyang River Basin in the east section of Jinqu basin, where the terrain is low and flat with strong human activities, and where towns and construction land gather. The medium and high interference areas ($4 \leq$ HI < 5) are mainly distributed in the central and western parts of the basin, and the main landscape type is cultivated land, while the low interference and medium interference areas (HI < 4) are mainly distributed in the surrounding mountains, and the landscape type is mainly forest land. The landscapes with high disturbance level gradually expanded from east to west in the Jin-yi metropolitan area. The main reason for this change is that Yiwu City has strong radiation ability, the construction process of surrounding towns and cities is speeding up, the area of high interference level is increasing rapidly, and the high disturbance landscape replaced the landscape type with relatively low disturbance level. Secondly, the area is a basin, the middle is a plain, the north and south sides are mountains, and the central area is the main concentration area of human activities. It can be seen that the areas with low interference level and medium low interference level are mainly distributed in the surrounding mountainous areas. Because of the undulating terrain of mountainous areas, these areas are not conducive to agricultural activities and urban construction and are less disturbed by human beings, basically maintaining the natural landscape, so the degree of human interference is low. At the same time, it also shows that the degree of human disturbance is not only closely related to the intensity of human activities but also related to the topography. Generally speaking, the plain area is conducive to human activities, and the degree of human disturbance is large and tends to expand. Guo et al. also concluded that the intensity of human activities in Qinling Mountains was limited by the terrain, which affected the spatial distribution of landscape pattern [45,46].

From the perspective of landscape level, the landscape fragmentation of Jin-yi new urban area increased from 1980 to 2016. Specifically, the AREA_MN index showed an overall downward trend, and its value dropped rapidly from 2000 to 2010, indicating that the enhancement of human activities led to the enhancement of landscape fragmentation; after 2010, its value slightly increased, indicating that the landscape tended to develop stably. The continuous decrease of CONTAG index indicates that the connectivity of patches in the landscape was reduced, and all types of patches were scattered. All these indicate that the landscape of Jin-yi new urban area has been gradually fragmented in recent decades; the large patches were divided into several small patches under the influence of human activities, and the connectivity between patches was weakened. From the perspective of patch type, cultivated land and urban and construction land are the two land use types that are most affected by human activities. The fragmentation degree of urban construction land was reduced with the enhancement of human activities, and the connectivity and complexity of patch shape of urban construction land were increased. From 1980 to 2016, the LPI index of cultivated land decreased year by year, while the AI index showed a downward trend, indicating that the fragmentation degree of cultivated land increased; the large patches were divided into small patches, and the aggregation degree between patches decreased. FRAC_MN increased slightly, which indicated that the shape of plaque had a trend of complexity.

In addition, the process of landscape pattern transformation by human activities is similar to the process of urban expansion to a certain extent. Population growth and regional expansion are the main manifestations of urbanization [47]. By comparing the urban expansion dynamics of Guangzhou and Shenzhen from 1975 to 2015, Meng et al. found that in the development process of the two cities, the urban landscape fragmentation index and shape index experienced a sharp rise at first and then a decline. The urban landscape showed fragmentation and complexity at first, then homogenization and regularization [48]. In this study, we found that the response relationship between landscape pattern index and human disturbance degree is similar to the urbanization process. Through polynomial fitting, we found that there is an obvious "turning point" (HI = 4) in relationship between them. In the low disturbance area, LPI, CONTAG and AI were significantly negatively correlated with HI, while LSI, SQP, SHDI, SHEI, and ED were significantly positively correlated with HI, which indicated that on the basis of the original landscape, with the increase of human interference degree, human activities would break the previously connected natural landscape, divide and reorganize the landscape, and the dominance and connectivity of patches would decline. The landscape characteristics showed that the degree of fragmentation increased and the landscape diversity increased. When human activities reach the high disturbance range, the change of landscape morphology index tends to be complex due to the enhancement of human disturbance activities. LPI, CONTAG, and AI indexes, which have negative correlations with HI in low interference area increase with the increase of HI in interference area, reached the maximum at HI = 5 then decreased or fluctuated slightly at $6 > HI > 5$ and increased sharply after $HI > 6$, which indicated that intense human activities causing landscape fragmentation and scattered structure tend to be consistent and homogeneous. LSI, SQP, and ED, which are positively correlated with HI in the low disturbance area are significantly negatively correlated with HI at this stage. With the increase of HI, their values decreased, indicating that the complexity of landscape shape decreases with the enhancement of human activities. SHDI and SHEI first decreased, then increased, and then decreased sharply, which also reflected the process of human activities to transform the surface. Firstly, the natural landscape was fragmented, secondly, the diversity of natural landscape increased (SHDI index increased), then man-made landscape replaced the natural landscape (SHDI index decreased), then man-made landscape continued to develop, the diversity of man-made landscape increased (SHDI index increased), and finally in the fierce human activities the landscape homogeneity (SHDI) tended to zero.

6. Conclusions

In order to optimize the calculation method of human disturbance and explore the response relationship between landscape form and human disturbance degree, this paper takes Jin-yi metropolitan area as an example, analyzes the spatial-temporal characteristics of its landscape dynamics and human disturbance degree from 1980 to 2016, discusses the relationship between human disturbance degree (HI) and landscape pattern index, and obtains the following conclusions.

(1) The degree of human disturbance in the new area shows an upward trend, with a small increase from 1980 to 2010 and a significant increase after 2010. During 2010–2016, the annual average intensity of human disturbance increased significantly, the high value center of human activities in the east of the new area gradually moved to the west, while the southwest and the convergence point in Xiaoshun town gradually moved to the north, forming a trend of human activity intensity diffusion between Yiwu and Jinhua.
(2) There is a significant correlation between landscape morphology index and HI. Generally, with the continuous increase of the intensity of human activities, the surface morphology experiences the process of breaking, complicating and homogenizing first, that is, a simple (single)–complex–simple (single) development and change process. In the process of increasing human disturbance, there are obvious inflexion points in landscape pattern index. The trends of landscape pattern index changes on both sides of inflexion point are opposite.
(3) There is a low disturbance stage and a high disturbance stage between human disturbance degree and landscape pattern index. There are obvious differences in the change trends of the two stages. There is a simple and obvious linear relationship in the low interference stage, and the relationship changes are complex in the high interference stage, but the linear relationship is not obvious.

The human–nature relationship is a large, complex system [49]. Therefore, in addition to the use of land cover type and landscape pattern index, the social and economic development index should also be taken into account, so that the evaluation results can truly reflect the ecological and environmental conditions of different regions under the influence of human activities [50]. In the future, the research of human disturbance may need to pay more attention to the following points: firstly, remote sensing data should be used as the main means of data collection to facilitate data management and database construction. Secondly, the evaluation indexes should be comprehensively optimized based on society, the economy, and the ecological environment system. Finally, the spatial change trend of regional human disturbance intensity and the coping mechanism should be clarified for the construction of urban ecological civilization.

Author Contributions: T.W.: Conceptualization, Writing—original draft; P.Z.: Writing—original draft; M.Y.: Methodology, Writing—original draft; Jiang, G.J.: Investigation, Resources; J.Z.: Funding acquisition, Supervision; Q.Y.: Investigation, Supervision; X.X.: Conceptualization, Project administration. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Natural Science Foundation of Zhejiang Province, China (LY19D010007), and the Open Fund of Key Laboratory of Coastal Zone Exploitation and Protection, Ministry of Natural Resource (2019CZEPK09).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

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