Dynamic Changes of Landscape Pattern and Vulnerability Analysis in Qingyi River Basin

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Abstract: Environmental vulnerability research is one of the core areas of global environmental change research. Over the past 10 years, ecologically fragile zones or transition zones had been significantly affected by environmental degradation and climate change and human activities. In this paper, we analyzed the spatial and temporal changes of landscape pattern and landscape vulnerability degree in Qingyi River Basin by calculating the landscape sensitivity index and landscape restoration degree index based on Landsat images of 2005, 2010 and 2015. The results showed that: (1) The top conversion area was farmland, woodland and grassland area decreased, city land and rural residential land increased fastest. (2) The fragility of the landscape pattern along the Qingyi River gradually increased between 2005 and 2015, the downstream area was influenced by the influence of human activities. (3) Landscape pattern changes and fragility are mainly affected by urbanization. These findings are helpful for understanding the evolution of landscape pattern as well as urban ecology, which both have significant implications for urban planning and minimize the potential environmental impacts of urbanization in Qingyi River Basin.

1. Introduction

Landscape pattern is the concrete manifestation of landscape heterogeneity. Landscape pattern analysis is a kind of research method of landscape structure and spatial configuration, which is the basis of landscape function and dynamic analysis¹. Due to human activities, city construction and other interference factors, the distribution of landscape types and spatial structure had been undergoing significant changes in Qingyi River Basin. Therefore, it is an important way to understand the relationship between human activities and the natural environment by analyzing the dynamic changes and fragility of the landscape pattern along the Qingyi River Basin, and understanding its causes and mechanisms².

Previous studies on the landscape pattern were mostly concentrated in the field of land use and landscape pattern change³, landscape ecological risk assessment⁴, landscape ecological security⁵ and other fields. Zhang et al.⁶ studied the spatial differentiation characteristics of land use and landscape pattern in the lower reaches of the Yellow River. Gao et al.⁷ constructed the landscape ecological risk index, using GIS and geostatistics to study the ecological risk spatial differentiation of the law to explore. These studies have formed a relatively perfect evaluation method for the landscape
pattern. However, there are few studies on the fragility of landscape pattern. Sun et al. [7] evaluated the fragility of the landscape pattern of the lower Liaohe River Plain, but the landscape pattern of the lower Liaohe River Plain was distinct from Qingyi River Basin. Therefore, it is necessary to study the fragility of the Qingyi River Basin, which flows mainly through the local area in the urban area.

This study quantitatively analyzed the dynamic changes and landscape fragility of landscape pattern in the eastern and middle reaches of the Qingyi River Basin based on remote sensing technology, Fragstats 4.2 software and GS + spatial analysis technique. The research results have certain application value for the rational exploitation and utilization of landscape pattern in the study area and similar areas.

2. Study areas and Methods

2.1. Study Areas
Qing Yi River belongs to the Huaihe River Shaying river system, is one of the important tributaries of the Shaying River (Figure 1), originates in Xinzheng City, Henan Province, flows through Changge City, Xuchang City, Yanling County and Luohe City Linying County, imports Ying River in Yanling County. It is 149km in length, with an area of 2362km², accounting for nearly 32.1% of the Ying River Basin. It is a semi humid continental monsoon climate in warm temperate zone with four distinct seasons and frequent droughts and floods. Summer is hot and rainy, cold and dry in winter, windy spring drought, autumn and cool. The average annual temperature is about 15 degrees centigrade, and the average annual rainfall is 550 ~ 700mm. Within the scope of the Qingyi River Basin, urban concentration, human activities are strong, human interference is great, the landscape pattern is complete and typical features, and it has a typical representative significance in urban rivers.

![Figure 1. Geographical location of study area](image)

2.2. Data and preprocessing
Three scenes of cloud-free Landsat TM/ETM+ images in the years of 2005, 2010 and 2015 were acquired for the extraction of urban land-use. Images from track number 124/36 were obtained from the United States Geological Survey (USGS) website (http://glovis.usgs.gov/). The Henan administrative division vector (1:500000) and Henan Province, topographic map (1:50000) were also used in this paper. Under the support of ENVI5.2 software, three phase TM remote sensing images are cropped, and then synthesized, geometrically corrected, interpreted and processed, and the distribution of land use in the three stage is obtained. Referring to the technical regulations of land use survey in
China, the landscape types of land use are classified into seven types: grassland, woodland, water area, paddy field, dry land, city land and rural residential land (Figure 2).

**Figure 2** Geographical location of study area and the landscape type

### 2.3 Methodology

Firstly, the spatial superposition of the landscape pattern of the three periods was taken, and the transfer matrix of the landscape type was obtained. Then, the study area was divided according to the equidistant sampling method, the landscape pattern index of each grid area was calculated and the landscape fragility index. Finally, we used geostatistics software GS+ and ArcGIS software to get the spatial distribution map of landscape vulnerability index.

#### 2.3.1 Dividing the grid

In order to ensure the integrity of each scale information and the accuracy of the quantitative evaluation process, according to the scope of the study area and the sampling workload, this study uses the equidistant sampling method to divide the study area into 5km × 5km square cell grid, That is, landscape vulnerability of the district, a total of 100 sample area. To calculate the size of the landscape fragility of each sampling area, and assign the attribute value to the sampling area center point.

#### 2.3.2 Construction of Landscape Fragility Index

The fragility of the landscape pattern is related to its own sensitivity and the ability to recover from external disturbances, which can reflect the degree of anti-interference in a region. According to the concept and connotation of landscape fragility [7,8], the landscape index is calculated by FRAGSTATS 4.2 software, and the landscape vulnerability index is constructed by landscape sensitivity index and landscape restoration index.

1. **Landscape sensitivity index**

Landscape sensitivity is the rate at which a component of a landscape changes by natural or human disturbance. The greater the rate, the stronger the sensitivity [9]. In this paper, the landscape disturbance and landscape vulnerability are constructed first, and then the two indices are superimposed to reflect the sensitivity of the landscape pattern after being disturbed by the outside world. The landscape sensitivity index LSI expression is:

\[
LSI = \sum_{i=1}^{n} u_i \times v_i
\]

Where \( n \) is the number of landscape types and \( i \) is the landscape type. The landscape disturbance index \( u_i \) is based on the three types of index - the degree of fragmentation, the degree of separation index and the dominance degree, which are representative and closely related to the disturbance. The landscape type disturbance index is constructed:

\[
u_i = a f_i + d_i
\]

Where \( f_i \) is the fragmentation index, the smaller the value, the smaller the fragmentation; \( d_i \) for the
dominance index. According to the study area and the related research results [9], the weights of fragmentation, separation and dominance are set to 0.5 and 0.2 respectively.

The vulnerability of the study area is divided into four grades: the dryland and the paddy field belong to the cultivated land category, the landscape pattern type is the most sensitive, the human activity is strong, is divided into high vulnerability, gives the weight 7; Forest land and grassland are also easy to be affected by human, divided into higher vulnerability, giving weight 5; the water land in Qingyi River Basin is mainly Qingyi River, landscape pattern is difficult with other types of mutual transformation, divided into low vulnerability, give the weight of 3; city and rural residential land are the most stable landscape pattern type, generally not with other types of mutual conversion, it is divided into low vulnerability, given the weight of 1. After the standardized treatment of landscape types with SPSS, the vulnerability degree of each landscape type \( v_i \) was obtained.

(2) Landscape restoration index

The fragility of the landscape pattern is also closely related to the resilience of the system. The landscape fitness index LRI was constructed by plaque richness density index PRD, Shannon diversity index SHDI and Shannon homogeneity index SHEI.

\[
LRI = PRD \times SHDI \times SHEI \quad (3)
\]

(3) Landscape vulnerability index

According to the established landscape sensitivity index and landscape restoration index, the landscape vulnerability index LVI was constructed. The higher the LVI, the higher the sensitivity of the area, and the worse the recoverability.

\[
LVI = LSI \times (1 - LRI) \quad (4)
\]

2.3.3 Spatial distribution of landscape fragility. Based on the analysis of the theoretical model of semi-variance function, the common Kriging method is used to interpolate the spatial distribution of 2005, 2010 and 2015, and the relative index method is used to analyze the landscape fragility of the fragility index. First, the fragility index is processed by histogram and log (logarithmic) transformation. Then, the interval of fragility is set to 0.1, and the study area is divided into five hierarchical regions, namely, low-level fragile area (LVI ≤ 0.02), lower-level fragile area (0.02 ≤ LVI ≤ 0.1), medium fragile areas (0.1 ≤ LVI ≤ 0.2), higher fragile areas (0.2 ≤ LVI ≤ 0.3) and high fragile areas (LVI ≥ 0.3).

3. Results

3.1 Dynamic change of landscape element types

As shown in table 1 and 2, the transformation of complex various types of landscape elements in the Qingyi River Basin from 2005 to 2015. Paddy fields, rural residential land and dry land and other types of conversion more active in 2005-2010 years. A large area of paddy field into dry land, accounting for the total area of the conversion of 45.37%, results showed that agricultural activities have a significant impact on the change of Qingyi River Basin area of paddy field. The conversion of dryland into rural residential land and urban land area accounted for 38.38% and 6.11% of the total conversion area respectively, mainly due to the construction of the occupied city the part of dry as its foreign expansion. Grassland conversion to dry land area accounted for 64.45% of the total conversion area, indicating that the grassland was cultivated from 2005 to 2010, and the ecosystem of Qingyi River Basin was destroyed.
Table 1. The transfer matrix of landscape elements from 2005 to 2010 km²

| 2005     | GL  | WL | W  | UL  | RRA | PF  | DL   | TA   | All |
|----------|-----|-----|----|-----|-----|-----|------|------|-----|
| 2010     |     |     |    |     |     |     |      |      |     |
| GL 47.22 | 0.10| 1.30| 15.61|17.01|64.24|     |      |      |     |
| WL 0.00  | 20.63|     | 0.00| 0.00|20.63|     |      |      |     |
| W 3.04   |     | 0.34| 0.34| 4.95| 5.63| 8.68|      |      |     |
| UL 1.02  |     | 62.63| 3.03| 12.38|93.81|117.27|      |      |     |
| RRA 3.52 | 0.02| 0.84| 296.68| 0.27|77.80| 82.44|379.13|      |     |
| PF 1.28  |     | 0.56| 23.46| 91.97|93.81|117.27|      |      |     |
| DL 8.23  | 0.00| 0.23| 0.30| 42.62|3.22|1662.19|54.60|1716.79|     |
| TA 12.77 |     | 1.53| 1.24| 47.85|3.83|202.70|269.92|2385.78|     |

Notes: GL is Grassland; WL is Woodland; W is Water land; UL is Urban land; RRA is Rural residential land; PF is Paddy field; DL is Dry land; TA is Transferable area (the same below).

Dry land turns out the largest area in 2010-2015, most of the transformation of rural residential land and city land conversion area. Conversion area in this period accounted for 54.06% of the total area and 32.71%, indicating that the process of urbanization during this period on the Qingyi River Basin landscape elements of the type of impact is relatively strong. The water area and paddy field was mainly transformed into dry land, conversion area respectively of the total conversion area of 90.30% and 97.48%. This indicates that the dry channel and paddy field have been converted into dry land after partial flood reduction. The proportion of grassland and forest land converted to other land use types accounted for 78.31% and 64.63% of the total, and converted into dry land, urban land and rural residential land.

Table 2. The transfer matrix of landscape elements from 2010 to 2015 km²

| 2010     | GL  | WL  | W  | UL  | RRA | PF  | DL   | TA   | All |
|----------|-----|-----|----|-----|-----|-----|------|------|-----|
| 2015     |     |     |    |     |     |     |      |      |     |
| GL 4.62  | 4.24|     | 1.43| 10.97|16.65|21.26|      |      |     |
| WL 0.04  | 6.60| 0.13| 0.57| 11.33|12.06|18.66|      |      |     |
| W 0.04   | 0.42| 0.51| 0.57| 4.26 | 5.38| 5.80|      |      |     |
| UL 5.14  |     | 73.88| 51.21| 65.62|122.73|196.61|      |      |     |
| RRA 5.40 | 0.19| 0.23| 0.30| 179.63|2.64|108.46|117.22|296.85|     |
| PF 49.01 | 9.60| 7.45| 4.36| 145.71|114.30|330.43|1846.59|      |     |
| DL 59.62 | 14.03| 8.25| 5.17| 199.50|117.26|200.64|      |      |     |

3.2 Temporal and spatial evolution of landscape fragility

Comprehensive analysis of figures 3 and 4, it shows that the fragility of landscape pattern in the study area is on the rise. The supernatant of Qingyi River Basin spatial pattern change is more significant. The upper reaches of the region are mainly in the low fragile areas, the lower reaches of the region with high fragile areas, the middle reaches of the region the most obvious changes. The area of the lower vulnerable area in 2005 was the largest, accounting for 83.61% of the area of the study area. The area of medium fragile area in 2010 and 2015 was the largest, accounting for 76.76% and 70.49% of the study area respectively, which indicated that the ecological environment system was susceptible Interference, increased vulnerability to the landscape.
Specifically, compared with 2005, the average annual conversion is low in 2010 to moderate vulnerable area of the fragile region area is the fastest, reached 355.20km²/a, which shows that the disturbance in the research area of human activities during this period of relatively strong vulnerability level transition from low level to high level. The high vulnerable areas have increased compared to 2005, which accounted for 10.4% of the total area, the most prominent position change is Qingyi River area, shows that in recent years, with the development of the city, the extent of damage to the local human landscape increase, cause landscape sensitivity index increased, the landscape fragility index rose.

In 2015, the landscape level distribution of the vulnerability change is the most obvious in the area of high vulnerability area expanded significantly, the area is 3.77 times in 2000, other vulnerability level into high level vulnerability area accounted for 18.94%. This change mainly occurred in the land and the most obvious change in the construction area of paddy field. The large-scale urbanization construction, especially the rapid development of the second, third industry, makes the local landscape pattern fragility gradually rise.

4. Conclusion
(1) With the modernization of city, the landscape pattern of Qingyi River Basin in Qing more violent. There is a complex interchange between the various landscape types in 2005-2015. The dry land is the largest conversion type of landscape type; Patches of urban land and rural residential areas increased very rapidly. The overall landscape of Qingyi River fragmentation and landscape heterogeneity increased, city construction has a certain effect on cutting the original land, landscape spatial distribution is not balanced.

(2) From 2005 to 2015, the vulnerability of landscape pattern in the study area showed an upward trend as a whole, and the spatial difference was obvious. Low vulnerable area mainly distributed in the
upstream of Qingyi River Basin, the lower the fragile area and moderate vulnerable area distribution in the middle level area; fragile area distribution range and gradually expand in the downstream region. This indicates that human activities on the ecological vulnerability of landscape in the lower reaches of deep, downstream areas should be considered at the time of economic development impact on the local environment.

(3) With the gradual completion of the process of the city, the ecological vulnerability will gradually stabilize in Qingyi River Basin. In addition, the landscape fragility index has some limitations, such as low vulnerability does not mean that the quality of the ecological environment is good, the only representative of the regional ecological restoration in a relatively stable state, with the better recovery.

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Author Contributions
The paper was coauthored by Ziwei Li; Chaoying Xie; Xiaohui He; Hengliang Guo; Wang li, where “Xiaohui He and Ziwei Li conceived and designed the experiments; Chaoying Xie performed the experiments; Xiaohui He and Hengliang Guo analyzed the data; Wang li contributed reagents/materials/analysis tools; Xiaohui and Ziwei Li wrote the paper”.

Conflicts of Interest
The authors declare no conflict of interest.

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