Ecological Vulnerability of Lake Basin by Integrating Human Activity Indicators based on RS and GIS: A Case of Fuxian Lake in Yunnan Province, China

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Abstract. The variation of landscape pattern and vulnerability can indicate the ecological environmental state. This study established a model for landscape pattern vulnerability based on human activity intensity by taking five sets of land use data (1995, 2000, 2005, 2010 and 2015). Landscape sensitivity index, landscape adaptability index and human activity intensity of land surface were all used to compute the landscape vulnerability index. In virtue of Fragstats 4.2 and ArcGIS 10.5, landscape index can be obtained and spatial-temporal distribution and evolution of landscape pattern vulnerability were analysed. Results showed that, (1) from 1995 to 2015, the human activity intensity and landscape pattern vulnerability in the Fuxian Lake Basin deteriorated gradually, the area of higher intensity/vulnerability and high intensity/vulnerability dramatically expanded with time. (2) the spatial heterogeneity of landscape pattern vulnerability increased, there are significant differences between the north, south ends and east, west sides of Fuxian Lake. (3) The global spatiality of landscape pattern vulnerability exhibited strong positive correlation with the significant form of spatial agglomeration, and the positive spatial autocorrelation continued to keep on but the tendency of spatial concentration was slightly decreasing over time. The local autocorrelation mainly based on high-high accumulation zone and low-low accumulation zone had stronger spatial autocorrelation among neighbouring space units. Due to the implementation of the protection policy, the landscape pattern vulnerability in the east sides of Fuxian Lake had expressed declining trend, but that in the north need more attention and protection.

1. Introduction
At present, researches on landscape pattern vulnerability have received much attention by international and domestic scholars, especially under the context of land use change [1-3]. Landscape pattern determines the distribution form of resources and environment [4], which is closely related to various ecological processes in the landscape and has a profound impact on anti-interference ability, resilience, system stability and biodiversity [5]. Otherwise, since the 21th century, human transformation of land uses has led to the variation of landscape pattern and further to the structure and function [6-8]. The change of landscape pattern has important influence on global and regional ecological environment [9-11]. More and more ecological problems such as landscape loss, environmental contamination, reduction in biodiversity, have appeared in various parts of the world, and the landscape fragmentation and vulnerability has been increasing [12, 13]. At present, domestic and foreign studies are increasingly focusing on dynamic changes of landscape pattern [14], landscape ecological security.
Landscape ecological risk [16], and landscape ecological vulnerability [17, 18]. Landscape pattern vulnerability which can reflect the fragile and disturbance degree of landscape ecological system by the outside is an important indicator to measure the local ecological security. The vulnerability assessment of landscape pattern and its dynamic change have become the hotspot and important research field of landscape ecology [19, 20]. Understanding landscape pattern vulnerability from spatial and temporal perspective is essential for land use plan and landscape pattern management to improve the ecological civilization construction.

The landscape pattern vulnerability is generally evaluated by two indexes: landscape sensitivity and landscape adaptability [21], but the model is not comprehensive enough to consider human activities. With the continuous improvement of social and economic development and urbanization construction level, it is the change of land use caused by human activities that directly or indirectly changes the structure and pattern of landscape types [22] and affects the temporal and spatial evolution of the landscape pattern vulnerability. Therefore, human activity intensity should be introduced into the model of landscape pattern fragility to evaluate regional landscape fragility more reasonably. The fragility of landscape pattern changes with the change of time and space, which has a high degree of spatial variability and spatial relevance. With the development of GIS and other technologies, remote sensing (RS) and spatial analysis are widely used to study landscape pattern [23], and spatial overlay and interpolation methods are also used to study the spatial pattern and extent of landscape pattern vulnerability. Spatial analysis supported by a geographic information system (GIS) is the most useful methods [24, 25] that can quantify and visualize the variations of landscape pattern vulnerability during the study period.

Fuxian Lake is the largest water storage lake and the largest plateau deep water lake in China. In recent years, with the rapid development of regional social economy, the landscape pattern of the basin has changed to different degrees. In order to develop and optimize the management and protect Fuxian Lake, it is very important to study the vulnerability of the landscape pattern in Fuxian Lake basin. In this paper, based on the land vector data of Fuxian Lake basin in 1995, 2000, 2005, 2015 and the previous studies on landscape sensitivity and adaptability, human activity intensity was introduced to construct the vulnerability index of landscape pattern. By using ArcGIS and Fragstats software, the spatial variation and related spatiotemporal evolution of the fragility of landscape pattern in the research area are analyzed, and the research results have certain application value for the reasonable development and protection of landscape pattern.

2. Study area and methods

2.1. Study area

Fuxian Lake Basin is located in Yu Xi City, Yunnan Province, located in the center of the central yunnan basin, 60 km southeast of Kunming, spanning Chengjiang, Jiangchuan and Huaining counties. The geographical position is 24°21'28"~24°38'00"N, 102°49'12"~102°57'26"E. Fuxian Lake belongs to Xijiang river system in Nanpanjiang river basin, covering an area of 674.69 km². Its administrative scope includes Fenglu town, Longjie town, Yousuo town, Jiucun town and Haikou town of Chengjiang county, Luju town and Jiangcheng town of Jiangchuan district, and Qinglong town of Huaining county. The basin belongs to the central Yunnan laterite plateau basin area, which is dominated by the plateau landform. Due to the influence of the tectonic basin, the surrounding topography of the region is high, the middle is low, and the relative height has big difference. Fuxian Lake is located in the subtropical monsoon climate zone, a sub-humid subtropical monsoon climate. Winter and spring are controlled by the dry heating flow in the subcontinent of northern India and the dry and cold air flow in the south, while summer and autumn are mainly influenced by the warm and wet flow in the southwest of the Indian Ocean and the warm and wet current in the southeast of the Beibu Gulf. The average annual temperature is 15.5 degrees and the annual rainfall is 800-1100 mm. It is an important part of the tourist area of “three lakes, five mountains and one city” in central Yunnan.
province. The development of social economy has basically formed an economic pattern dominated by grain, supported by flue-cured tobacco and dominated by pig, vegetable and township enterprises.

![Location of Fuxian Lake Basin](image)

**Figure 1. Location of Fuxian Lake Basin.**

2.2. Methods

2.2.1. Human activity intensity model. From the perspective of the concept of land use/cover, human activity intensity of land surface (HAILS) can be defined as the extent to which humans in a certain region utilize, transform and develop the natural cover of the land surface, which can be reflected by the type of land use/cover [26]. Obviously, human activity intensity of land surface refers to the extent to impacts of human economic and social activities on certain regional natural complex [26, 27]. The calculation formula of human activity intensity of land surface is as follows:

\[
S_{CLE} = \sum_{j=1}^{m} (SL_j \cdot CI_j)
\]

(1)

\[
HAILS = \frac{S_{CLE}}{S} \times 100\%
\]

(2)

where \( HAILS \) is human activity intensity; \( S_{CLE} \) is the area of Construction land equivalent; \( S \) is the total land area; \( SL_j \) is the area of the \( j \) type of land use; \( CI_j \) is the conversion index of construction land equivalent; \( m \) is the total number of land use types.
Table 1. Conversion index of construction land equivalent of different land use/cover types [26].

| Land use/land cover type                  | Features description                        | CI   |
|------------------------------------------|---------------------------------------------|------|
| farmland                                 | Paddy field/dry land The natural cover of the surface is altered: 1-year crops are planted | 0.2  |
| forest/sparse woodland/shrubland         | The natural cover of the surface is not altered and used. | 0    |
| woodland                                 | Other woodland The natural cover of the surface is altered: perennial crops are planted | 0.133|
| Natural grassland/improved grassland     | The natural cover of the surface is not altered but used | 0.067|
| grassland                                | Artificial pasture The natural cover of the surface is altered: perennial plants are cultivated | 0.133|
| Construction land                        | Urban land/rural residential land/other construction land The surface layer is blocked by compartments, moisture, nutrients, air and heat exchange | 1    |
| canal/lake/beach/marshland              | The natural cover of the surface is not altered and used. | 0    |
| Water body                               | Reservoir and pond The natural cover of the surface is altered and blocked by compartments, moisture, nutrients, air and heat exchange | 0.6  |

2.2.2. Landscape pattern vulnerability model. The landscape pattern vulnerability mainly includes the following two attributes: sensitivity, that is, the response of the system to interference at different time and spatial scales; adaptability, that is, the adaptive adjustment ability of the landscape system after the sensitivity response to external interference [28]. Landscape fragility index (LVI) is a quantitative expression of the fragility of landscape pattern. In this study, Fragstats4.2 software was used to calculate the relevant landscape index, and construct the landscape vulnerability index by landscape sensitivity index (LSI), landscape fitness index (LAI) and human activity intensity (HAILS) based on the relevant literature [29]. LSI represents the sensitivity of landscape pattern to external interference, consisting of landscape interference index (U) and landscape type fragility index (V). Landscape disturbance index (U) includes fragmentation index (FN), reciprocal fractal dimension (FD) and dominance index (DO), and the corresponding weights of each index are 0.5, 0.3 and 0.2 respectively [30]. According to previous research results [31] and combined with the ecological environment of Fuxian Lake basin, the landscape fragility weight values of cultivated land, grassland, woodland, water body and construction land were assigned as 5, 4, 3, 2 and 1 due to the lack of unused land in the study area, and the weight values were all normalized. The specific calculation formula of each index is as follows:

\[
LSI = \sum_{i=1}^{n} U_i \times V_i
\]  

\[
U_i = aFN_i + bFD_i + cDO_i
\]  

\[
LAI = PRD \times SHDI \times SHEI
\]  

\[
LVI = LSI \times (1 - LAI) \times HAILS
\]

2.2.3. Spatial correlation analysis. As a typical regionalized variable, landscape vulnerability index can be analyzed by spatial statistics for its spatial heterogeneity [32]. Spatial autocorrelation is an
important index to test whether the attribute value of a certain element is significantly related to the attribute value of its adjacent space [33, 34], which can reveal the similarity or correlation between the spatial reference unit and its adjacent spatial unit attribute characteristic values. In this paper, Moran’s I index (global spatial autocorrelation) and LISA index (local spatial autocorrelation) were selected to analyze and study the spatial correlation of landscape vulnerability. Global spatial autocorrelation is used to analyze the aggregation degree of spatial similar attributes, while local spatial autocorrelation is used to analyze the range and characteristics of spatial aggregation. The formula are as follows:

\[
Global\ Moran’s\ I = \frac{\sum_{k=1}^{n} \sum_{l=1}^{n} \omega_{kl} (P_k - P_{mean}) \times (P_l - P_{mean})}{\sum_{k=1}^{n} \sum_{l=1}^{n} \omega_{kl} \times \sum_{k=1}^{n} (P_k - P_{mean})^2}
\]

\[
Local\ Moran’s\ I_k = \left[ \frac{P_k - P_{mean}}{\left( \sum_{l=1, l \neq k}^{n} \frac{P_l^2}{(n-1)} - P_{mean}^2 \right)} \times \sum_{l=1}^{n} \omega_{kl} (P_k - P_{mean})\right]
\]

where \(P_k\) and \(P_l\) respectively refers to the location value of the patch; \(k, l\), and \(\omega_{kl}\) refer to weights matrix; and \(n\) is the number of patch.

2.3. Date source and processing

2.3.1. Data source. The basic data is the raster data of land use types in 1995, 2000, 2005, 2010 and 2015 in Fuxian Lake Basin (figure 2), with a spatial resolution of 30 m. It comes from the data center of resources and environmental sciences, Chinese Academy of Sciences (http://www.resdc.cn/). The data divides the land use types into 6 first-grade landscape types and 21 second-grade landscape types. Since the study area does not involve unused land, the landscape types in this study are mainly cultivated land, grassland, woodland, water body and construction land. The DEM data used in the study was ASTER GDEM V2 30M, which was derived from the geo-spatial data cloud website (http://www.gscloud.cn), and was split and projected with the help of ArcGIS 10.5, then cut out with the boundary of Fuxian Lake Basin.

Table 2. Land use/land cover remote sensing monitoring data classification system

| Level 1 class | Level 2 class                        |
|---------------|--------------------------------------|
| 1 Cropland    | 11 Paddy field                      |
| 2 Woodland    | 21 Forest                           |
| 3 Grassland   | 31 High coverage grassland          |
| 4 Water body  | 41 Canal                            |
| 5 Construction land | 51 Urban land               |
| 6 Unused land | 61 Sand                             |
|               | 2 Dry land                          |
|               | 22 Shrubwood                        |
|               | 3 Moderate coverage grassland       |
|               | 33 Low coverage grassland           |
|               | 4 Canal                             |
|               | 44 Permanent glaciers and snow cover|
|               | 51 Urban land                       |
|               | 52 Rural residential area           |
|               | 53 Other construction               |
|               | 61 Sand                             |
|               | 62 Gobi                             |
|               | 63 Saline-alkali soil               |
|               | 64 Bare rock stone                  |
|               | 65 Bareland                         |


2.3.2. Data processing. In order to explore the spatial differentiation and improve the precision in calculating the landscape vulnerability, the spatial visualization was carried out in this study. The study area was divided into a grid of 1 km × 1 km by using equal-spacing system sampling to divide the cell grid according to the landscape pattern and ecosystem characteristics of the study area. There were 766 sample areas, namely the landscape vulnerability community (figure 2). The human activity intensity and landscape vulnerability for each plot were calculated respectively, and the calculated results were assigned to the centre point of each plot. The spatial distribution of human activity intensity and landscape vulnerability was obtained by inverse distance weight interpolation analysis.

![Figure 2. Land-use landscape type in Fuxian Lake Basin in 1995, 2000, 2005, 2010 and 2015.](image)

3. Results and analysis

3.1. Temporal-spatial variation of human activity intensity

3.1.1. Regional classification of human activity intensity. According to the human activity intensity model, the human activity intensity in Fuxian Lake Basin was calculated in five periods. Based on ArcGIS 10.5, the natural break point method was adopted to classify the human activity intensity in Fuxian Lake Basin into five levels, including level I (HAILS ≤ 4.5669%), level II (4.5669% < HAILS ≤ 12.2956%), level III (12.2956% < HAILS ≤ 24.2399%), level IV (24.2399% < HAILS ≤ 44.2642%) and level V (HAILS > 44.2642%). Its spatial distribution is shown in figure 3.
3.1.2. Temporal-spatial variation characteristics of human activity intensity. As can be seen from figure 3 and table 2, the human activities intensity showed an upward trend from 1995 to 2015. The area of higher intensity increased significantly from 1.4456% to 1.7319%, mainly focusing on the rapidly developing area of Fenglu town, seat of Chengjiang county, which were transformed from the high human activities intensity in the early stage. The area of high intensity showed an increasing trend year by year, with a growth rate of 17.19% from 1995 to 2015, which was mainly distributed in the northern and southern part of Fuxian Lake, especially in the northern region. The medium-intensity level showed a decreasing trend, mainly concentrated in the west bank of Fuxian Lake, and changed from medium-intensity level to low-intensity level. The main reason was that the policy for returning farmland to forest to protect Fuxian Lake was implemented in the west bank, but the area in the north showed an expanding trend. The lower intensity level showed a decreasing trend on the whole, but fluctuated in the middle period, mainly from the medium intensity level in the west bank. The low-intensity level increased first and then decreased, reaching its maximum in 2005. It was mainly distributed in Fuxian Lake and its outermost areas, which were lakes and mountainous areas with great relief.

Table 3. The area proportion of each human activity intensity level from 1995 to 2015 in Fuxian Lake Basin.

| Year  | Lower intensity | Low intensity | Medium intensity | High intensity | Higher intensity |
|-------|----------------|---------------|------------------|---------------|-----------------|
| 1995  | 46.01          | 30.64         | 15.03            | 6.87          | 1.45            |
| 2000  | 45.66          | 30.49         | 14.80            | 7.60          | 1.45            |
| 2005  | 45.26          | 31.45         | 14.38            | 7.47          | 1.43            |
| 2010  | 45.23          | 31.59         | 13.98            | 7.77          | 1.43            |
| 2015  | 44.97          | 31.40         | 13.84            | 8.06          | 1.73            |

3.2. Temporal-spatial evolution of landscape pattern vulnerability

3.2.1. Regional classification of landscape pattern vulnerability. According to the landscape vulnerability calculation formula, the landscape ecological vulnerability index of 766 ecologically fragile communities in the study area was obtained, and the landscape vulnerability was taken as the attribute value of the grid center point in ArcGIS 10.5, and the spatial distribution map for the
landscape vulnerability in the study area was obtained by interpolation with the inverse distance weight (figure 4). Due to landscape pattern different differences influenced by natural and humanistic factors, therefore, in order to better performance in the study area vulnerable degree of spatial and temporal variation characteristics of landscape pattern, using ArcGIS natural breakpoint method the study area is divided into five grades partition, namely lower vulnerability (level I), low vulnerability (level II), Medium vulnerability (level III), high vulnerability (level IV) and higher vulnerability (level V), and the area statistics are conducted at different levels (table 3).

![Figure 4. Spatial distribution of landscape pattern vulnerability in Fuxian Lake Basin. I: Lower vulnerability; II: Low vulnerability; III: Medium vulnerability; IV: High vulnerability; V: Higher vulnerability.](image)

3.2.2. Temporal-spatial evolution characteristics of landscape pattern vulnerability. As shown in table 3, 4 and figure 4, the area of higher vulnerability and high vulnerability continued to increase significantly in the study area, while the area of medium vulnerability and low vulnerability continued to decrease significantly, while the area of lower vulnerability increased and decreased during the study period, but there was little change at the end of the study period and the beginning of the study period. The area of higher vulnerability increased by 544.18 hm$^2$ from 1995 to 2015, with a rise rate of 35.33%. The area of high vulnerability increased by 998.71 hm$^2$, an increase of 14.47%. The area of the medium and low vulnerability levels decreased by 906.67 hm$^2$ and 629.38 hm$^2$ respectively. Although there was a slight decrease in the area of lower vulnerability, due to the implementation of the policies of returning farmland to forests and lakes in Yuxi city, the area of lower vulnerability continued to increase in 2005 and 2010, resulting in little change in the area of lower vulnerability during the study period, with only a decrease of 6.84 hm$^2$. According to the statistics, the fragility value of 31.07% of the fragile landscape communities (238 grids) in the study area increased, the fragility value of 28.98% of the fragile landscape communities (222 grids) decreased, and the fragility value of 39.95% of the fragile landscape communities (366 grids) remained unchanged. This indicates that the landscape fragility of the study area is improved, deteriorated and unchanged, and the main ones that remain unchanged are the lower vulnerable areas, the higher vulnerable areas and the higher vulnerable areas are on the rise, while the lower vulnerable areas and the middle vulnerable areas are on the decline.
Table 4. The area proportion of each landscape pattern vulnerability level from 1995 to 2015 in Fuxian Lake Basin.

| Year | Lower vulnerability area (hm²) | Lower vulnerability percent (%) | Low vulnerability area (hm²) | Low vulnerability percent (%) | Medium vulnerability area (hm²) | Medium vulnerability percent (%) | High vulnerability area (hm²) | High vulnerability percent (%) | Higher vulnerability area (hm²) | Higher vulnerability percent (%) |
|------|-------------------------------|---------------------------------|------------------------------|-------------------------------|---------------------------------|----------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 1995 | 22577                         | 33.81                           | 19460                        | 29.14                         | 16302                          | 24.41                            | 6899                          | 10.33                         | 1540                          | 2.31                          |
| 2000 | 22391                         | 33.53                           | 19306                        | 28.91                         | 15905                          | 23.82                            | 7441                          | 11.14                         | 1734                          | 2.60                          |
| 2005 | 22782                         | 34.12                           | 19198                        | 28.75                         | 15765                          | 23.61                            | 7436                          | 11.13                         | 1599                          | 2.39                          |
| 2010 | 22807                         | 34.15                           | 19161                        | 28.69                         | 15638                          | 23.42                            | 7468                          | 11.18                         | 1705                          | 2.55                          |
| 2015 | 22570                         | 33.80                           | 18830                        | 28.20                         | 15395                          | 23.05                            | 7898                          | 11.83                         | 2084                          | 3.12                          |

At the same time, the spatial distribution of landscape fragility in the study area is quite different (figure 4 and 5). In terms of space, the higher vulnerability area and the high vulnerability area increase in the north and south, while the lower vulnerability area increases in the north and decreases in the south, and the medium vulnerability area mainly decreases in the east coast. The areas with significant spatial changes mainly focus on the north and south ends of the Fuxian Lake Basin and the western coastal areas. From 1995 to 2000, the coastal areas in the three directions of Fuxian Lake including south, north and west changed significantly, and the landscape fragility of most areas showed an increasing trend. The higher fragility and high fragility area of three directions coast all showed an expanding trend. All of these changes are closely related to the increase of human activity intensity. During this period, woodland was reclaimed for farmland, and the wetland around Fuxian Lake was converted into farmland and construction land. Change significantly in northern region from the coast to the northern extension from 2000 to 2005, but fragile degrees are from rising to failing in most of the area. In this phase, for returning farmland to forest and returning farmland to water surrounding the Fuxian Lake, the effect of those conversion policy effect is very significant, especially in the west coast of Fuxian Lake the landscape vulnerability index dropped significantly. The period from 2005 to 2010 was the period when the landscape vulnerability changed the least, with little change and only in the west coast the landscape vulnerability further declined for the further strengthening protection policy. However, with the development of social economy, due to the increase of population and the expansion of construction land, the higher and high landscape fragility of the alluvial plain in the north extends from due north to northeast. From 2010 to 2015, with the further improvement of social and economic development level, the southern and northern ends of the study area showed an increase in the area of rising landscape vulnerability. The areas of higher vulnerability and high vulnerability were further expanded, especially in the northern and northeastern, the regions of higher vulnerability and high vulnerability were connected rapidly. The main reasons are the good geographical conditions that include low terrain, good water and heat conditions. So, there are high degree of land development and utilization, rapid development of agriculture and tourism in these areas.
3.3. Spatial autocorrelation of landscape pattern vulnerability.

3.3.1. Global spatial autocorrelation. The spatial correlation of variables can be determined by geostatistics, and the vulnerability index of landscape pattern is assigned to plots at all levels in the region by ArcGIS10.5 software, so as to conduct spatial statistical analysis on the whole and part of the region and explore the spatial correlation of the landscape pattern vulnerability in the basin. According to the neighbourhood criteria, the spatial weight matrix was established, the global Moran I coefficient was calculated, and the significance test of the approximate normal distribution was carried out (table 5) to reflect the average correlation degree and spatial distribution pattern of the landscape vulnerability in the whole study area. In the five study periods, the $P$ value was less than 0.0001, and the $Z$ score was much higher than the two-side test threshold of 99% confidence interval of normal distribution (2.58). The global Moran I coefficients in 1995, 2000, 2005, 2010, and 2015 were 0.6268, 0.6253, 0.5991, 0.5947, and 0.5739, respectively, showing a slight decline overall. It shows that the spatial distribution of landscape pattern vulnerability in the study area is highly correlated, not randomly distributed, but shows a significant spatial agglomeration pattern, and the spatial distribution shows a general trend of high value or low value adjacency.
### Table 6. Global Moran’s I of landscape pattern vulnerability

| Year | Moran I | Z score | P value |
|------|---------|---------|---------|
| 1995 | 0.6268  | 31.2899 | 0.0001  |
| 2000 | 0.6253  | 31.2217 | 0.0001  |
| 2005 | 0.5991  | 29.9459 | 0.0001  |
| 2010 | 0.5947  | 29.7370 | 0.0001  |
| 2015 | 0.5739  | 28.6964 | 0.0001  |

#### 3.3.2. Local spatial autocorrelation

Since the global spatial autocorrelation index can test the spatial distribution pattern of a certain element in the whole region, but cannot be used to measure the spatial correlation pattern of elements or attributes between adjacent regions [28,35], it is necessary to discuss the correlation degree between a certain geographical element or attribute of a local community and the same element or attribute on the adjacent local community [36,37]. For this reason, this paper further analyzed the landscape pattern vulnerability of the research unit in terms of local spatial correlation pattern, conducted spatial clustering analysis with the help of ArcGIS10.5 software, and obtained the LISA cluster map of the research area from 1995 to 2015 (figure 6) and the LISA significance test map (figure 7) to analyze the attribute of local area and adjacent area related degree, so as to explore the different directions in the study area landscape pattern vulnerability model of spatial agglomeration.

As can be seen from Table 5 and Figure 6, local indicators and global indicators are consistent, both of which reflect that the landscape fragility in the study area is mainly high-high, low-low aggregation, and the aggregation phenomenon is very obvious. During the study period, the high-high area of landscape pattern vulnerability was mainly concentrated in the northern part of northern and the southern end of Fuxian Lake, with a strong positive correlation between adjacent spatial units. This area is mainly higher vulnerability area and high vulnerability area, especially the northern area, which has strong high value radiation effect on the surrounding area. From 1995 to 2015, the range of the high-high landscape pattern vulnerability in the northern increased significantly, which was reflected in the fact that high-high areas of the northern and northeastern were connected step by step in 2005, 2010 and 2015. In this range, villages and towns are concentrated, and human interference is strong, resulting in an increase in landscape fragmentation. Low-low landscape pattern vulnerability aggregation areas are mainly concentrated in Fuxian Lake and the northeast forest area. During the study period, the range of low-low areas in the north increased significantly, and the effect was obvious after the conversion of farmland to forest. The woodland area expanded continuously, the diversity of landscape pattern gradually increased, the landscape connectivity increased, and the internal stability of the system gradually enhanced. However, the southern part of the study area showed a significant decline during the study period, mainly due to the conversion of the forest land into arable land, construction land, grassland, etc., so the degree of fragmentation was increasing. At the same time, there were significant differences between the east and the west sides of Fuxian Lake. With the development of tourism, human activity intensity increased in the middle of the east bank, leading to a high-high concentration in tourist attractions in the middle of the west bank, while that in the east bank was not obvious. In addition, high-low and low-high aggregation areas are rare and scattered in the research area.
As can be seen from figure 7, the significance level corresponding to the high-high landscape pattern vulnerability aggregation area is the strongest, with the $P$ values mostly at 0.0001, and the rest all reaching the significance level of 0.05. And the low-low value distribution areas generally reached the significant level of 0.01 and 0.05. There was a significant difference between the bank and center of the lake. The low-low aggregation area in the center of the lake reached the significance level of 0.01, while the low-low aggregation area in the bank of the lake reached the significance level of 0.05. In 2005, the range of where the significance level is 0.05 increased significantly in low-low aggregation area in northeast forest area. From 1995 to 2015, the significance level of landscape pattern fragility showed a downward trend, and the high-high aggregation areas at the north and south ends with a significance level of 0.0001 showed a significant decrease.

4. Conclusion
Take Fuxian Lake Basin as the research object of this research, in the full understanding the landscape pattern vulnerability and on the basis of the concept and connotation, embedding human activities intensity, for the first time with the landscape sensitivity, adaptability to build landscape vulnerable
degree model, the fragile landscape pattern index in the studied area are analyzed in spatial interpolation and space-time evolution. From 1995 to 2015, the landscape pattern vulnerability in Fuxian Lake Basin showed an overall rising trend, with higher and high vulnerability mainly distributed in Yousuo town, Fenglu town and Luju town in the southwest of Fuxian Lake, where villages and towns were concentrated and human activities were intense. The scope of higher and high landscape pattern vulnerability also expanded significantly with time, but the landscape pattern vulnerability in the western bank of Fuxian Lake is obviously reduced due to the protection policy influence of the returning farmland to forest and farmland to lake. The fragility of landscape pattern in the study area is positively autocorrelated in the global spatial distribution, showing a significant spatial agglomeration pattern, with few high-low and low-high aggregation areas scattered in the study area, but the spatial agglomeration intensity shows a slow decline trend. The local autocorrelation is mainly characterized by high-high, low-low agglomeration of landscape fragility. The high-high area is mainly distributed in the high fragmentation area with high human activity intensity, while the low-low agglomeration area mainly appears in the lake and forest dense area. The high-high area expands with time, but the low-low area shrinks during the study period. Natural geographical conditions are the primary influencing factors for the spatial distribution of landscape fragility, while human factors such as social and economic activities and policy systems have an important impact on the spatial evolution of landscape fragility, which is the main reason for the increasing landscape fragility in the north and south and the decreasing landscape fragility in the west, thus enhancing the spatial heterogeneity. From this point of view, the changes caused by human disturbance to the environment cannot be ignored. In order to maximize the economic benefit, we should pay attention to the fragility changes of landscape pattern and further strengthen the protection for ecological environment. Especially in areas where human activities are intense, we should control the expansion rate of construction land, formulate reasonable land development and utilization plans, and ensure that social development is compatible with the environment.

The current future earth project and sustainability science emphasize the integration of natural and social elements and the study of spatiotemporal evolution[38]. The fragility of landscape pattern can directly reflect the fragility of the research area from the spatial perspective. The distribution of natural landscape is an important factor, but with the development of social economy, the influence of human disturbance on the fragility of landscape pattern is increasingly important. The vulnerability index of landscape pattern constructed by the superposition of human activity intensity can better reflect the influence of human disturbance, which is more accurate than the interpretation of vulnerability by landscape index alone. Therefore, social and natural data should be further integrated in the assessment of the vulnerability of landscape pattern, and the study on the vulnerability of social-ecological composite landscape pattern should be the direction of future efforts. At the same time, the evaluation of vulnerability index, the weight evaluation of disturbance index, and the influence degree of human activity intensity, landscape sensitivity index and landscape fitness index on vulnerability need to be further discussed and studied.

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References
[1] Bonilla-Bedoya, S., López-Ulloa, M., Vanwalleghem, T. et al. (2017) Effects of land use change on soil quality indicators in forest landscapes of the Western Amazon, Soil Science, vol. 182: pp. 128-136.
[2] Qian, F. K., Chi, Y. R., Lal, R. et al. (2020) Spatio-temporal characteristics of cultivated land fragmentation in different landform areas with a case study in Northeast China, Ecosystem Health and Sustainability, vol. 6.

[3] Douglas, I. (2019) 50 years change in urban land use and ecological planning globally in the era of design with nature, Ecosystem Health and Sustainability, vol. 5: pp. 185-198.

[4] O'Neill, R. V., Ritter, K. H., Wickham, J. D. et al. (1999) Landscape pattern metrics and regional assessment, Ecosystem Health, vol. 5: pp. 225-233.

[5] Turner, M. G., Romme, W. H., and Gardner, R. H. (1993) A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes, Landscape Ecology, vol. 8: pp. 213-227.

[6] Arnaiz-Schmitz, C., Schmitz, M. F., Herrero-Jauregui, C. et al. (2018) Identifying socio-ecological networks in rural-urban gradients: Diagnosis of a changing cultural landscape, Science of the Total Environment, vol. 612: pp. 625-635.

[7] Szymura, T. H., Szymura, M., Zajac, M. et al. (2018) Effect of anthropogenic factors, landscape structure, land relief, soil and climate on risk of alien plant invasion at regional scale, Science of the Total Environment, vol. 626: pp. 1373-1381.

[8] Wu, W., Li, C. L., Liu, M. et al. (2020) Change of impervious surface area and its impacts on urban landscape: an example of Shenyang between 2010 and 2017, Ecosystem Health and Sustainability, vol. 6.

[9] Chen, L. G., Yang, X. Y., Chen, L. Q. et al. (2015) Impact assessment of land use planning driving forces on environment, Environmental Impact Assessment Review, vol. 55: pp. 126-135.

[10] Tsai, Y. S., Zia, A., Koliba, C. et al. (2015) An interactive land use transition agent-based model (ILUTABM): endogenizing human-environment interactions in the Western Missisquoi Watershed, Land Use Policy, vol. 49: pp. 161-176.

[11] Wang, Y. Q., Shao, M. A., Zhang, C. C. et al. (2015) Choosing an optimal land-use pattern for restoring eco-environments in a semiarid region of the Chinese Loess Plateau, Ecological Engineering, vol. 74: pp. 213-222.

[12] Lam, N. S. N., Cheng, W. J., Zou, L. et al. (2018) Effects of landscape fragmentation on land loss, Remote Sensing of Environment, vol. 209: pp. 253-262.

[13] Lam, N. S. N., Cheng, W. J., Zou, L. et al. (2018) Effects of landscape fragmentation on land loss, Remote Sensing of Environment, vol. 209: pp. 253-262.

[14] Canellas-Bolta, N., Riera-Mora, S., Orenco, H. A. et al. (2018) Human management and landscape changes at Palaikastro (Eastern Crete) from the Late Neolithic to the Early Minoan period, Quaternary Science Reviews, vol. 183: pp. 59-75.

[15] Lu, Y., Wang, X. R., Xie, Y. J. et al. (2016) Integrating future land use scenarios to evaluate the spatio-temporal dynamics of landscape ecological security, Sustainability, vol. 8.

[16] Soloviova, N. V. (2019) Ecological risk modelling in developing resources of ecosystems characterized by varying vulnerability levels, Ecological Modelling, vol. 406: pp. 60-72.

[17] Liu, G. J., Wang, J. L., Li, S. H. et al. (2019) Dynamic evaluation of ecological vulnerability in a lake watershed based on RS and GIS technology, Polish Journal of Environmental Studies, vol. 28: pp. 1785-1798.

[18] Zang, Z., Zou, X. Q., Zuo, P. et al. (2017) Impact of landscape patterns on ecological vulnerability and ecosystem service values: An empirical analysis of Yancheng Nature Reserve in China, Ecological Indicators, vol. 72: pp. 142-152.

[19] Guo, B., Fan, Y. W., Yang, F. et al. (2019) Quantitative assessment model of ecological vulnerability of the Silk Road Economic Belt, China, utilizing remote sensing based on the partition-integration concept, Geomatics Natural Hazards & Risk, vol. 10: pp. 1346-1366.

[20] Kang, H., Tao, W. D., Chang, Y. et al. (2018) A feasible method for the division of ecological vulnerability and its driving forces in Southern Shaanxi, Journal of Cleaner Production, vol. 205: pp. 619-628.
[21] Liang, J. X., and Li, X. J. (2018) Characteristics of temporal-spatial differentiation in landscape pattern vulnerability in Nansihu Lake wetland, China, Chinese Journal of Applied Ecology, vol. 29: pp. 626-634.

[22] Du, J. L., Zhu, J. W., Xie, J. C. et al. (2018) Changes of land use and landscape pattern in the Guanzhong Area in recent 25 year, Arid Zone Research, vol. 35.

[23] Chubaty, A. M., Galpern, P., and Doctolero, S. C. (2019) The R toolbox grainscape for modelling and visualizing landscape connectivity using spatially explicit networks, Methods in Ecology and Evolution: pp. 1-5.

[24] Zhang, X. R., Wang, Z. B., and Lin, J. (2015) GIS based measurement and regulatory zoning of urban ecological vulnerability, Sustainability, vol. 7: pp. 9924-9942.

[25] Laterra, P., Barral, P., Carmona, A. et al. (2016) Focusing conservation efforts on ecosystem service supply may increase vulnerability of socio-ecological systems, Plos One, vol. 11: pp. 1-15.

[26] Xu, Y., Sun, X. Y., and Tang, Q. (2015) Human activity intensity of land surface: concept, method and application in China, Acta Geographica Sinica, vol. 70: pp. 1068-1079.

[27] Jia, Y. Y., Tang, X. L., Tang, F. L. et al. (2019) Research on human activity intensity and its impact on wetland landscape pattern in the middle and lower reaches of the Yangtze River Basin, Resources and Environment in the Yangtze Basin: pp. 1-14.

[28] Sun, C. Z., Yan, X. L., and Zhong, J. Q. (2014) Evaluation of the landscape patterns vulnerability and analysis of spatial correlation patterns in the lower reaches of Liaohe River Plain, Acta Ecologica Sinica, vol. 34: pp. 247-257.

[29] Zhang, H., Chen, H., Shi, Q. Q. et al. (2020) Spatio-temporal evolution and driving factors of landscape ecological vulnerability in Shaanxi Province, Arid Zone Research, vol. 37: pp. 496-505.

[30] Tian, P., Li, J. L., Jiang, Y. M. et al. (2019) Ecological vulnerability of the bay landscape and its response to human activities: a case study of the East China Sea, Acta Ecologica Sinica, vol. 39: pp. 1463-1474.

[31] Sun, X. Y., Zhang, D. Z., Shan, R. F. et al. (2018) Landscape pattern and its vulnerability of Nansihu Lake basin during 1980-2015, Chinese Journal of Applied Ecology, vol. 29: pp. 635-642.

[32] Wei, W., Shi, P. J., Lei, L. et al. (2014) Eco-risk analysis of Oasis Region based on landscape structure and spatial statistics method - a case study of Wuwei and Minqin Oases, Journal of Natural Resources, vol. 29: pp. 2023-2035.

[33] Zhang, Y. J., Qu, J. G., Li, D. et al. (2019) Study of the landscape pattern vulnerability and spatial correlation patterns in the Harbin Section of the Songhua River basin, Geography and Geo-Information Science, vol. 35: pp. 105-110.

[34] Contina, J. B., Dandurand, L. M., and Knudsen, G. R. (2020) A spatiotemporal analysis and dispersal patterns of the potato Cyst Nematode Globodera pallida in Idaho, Phytopathology, vol. 110: pp. 379-392.

[35] Xia, C., Yeh, A. G. O., and Zhang, A. Q. (2020) Analyzing spatial relationships between urban land use intensity and urban vitality at street block level: A case study of five Chinese megacities, Landscape and Urban Planning, vol. 193: pp. 18.

[36] Zhou, S. Y., Chang, J., Hu, T. H. et al. (2020) Spatiotemporal variations of land use and landscape ecological risk in a resource-based city, from rapid development to recession, Polish Journal of Environmental Studies, vol. 29: pp. 475-490.

[37] Jung, P. H., Thill, J. C., and Issel, M. (2019) Spatial autocorrelation statistics of areal prevalence rates under high uncertainty in denominator data, Geographical Analysis, vol. 51: pp. 354-380.

[38] Lu, D. D. (2014) The framework document of "Future Earth" and the development of Chinese geographical science: The foresight of cademanician HUANG Bingwei's statement, Acta Geographica Sinica, vol. 69: pp. 1043-1051.