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The comparative study on the ecological sensitivity analysis in Huixian karst wetland, China

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Abstract

This paper applies two methods to analyze the ecological sensitivity in Huixian wetland, (Guangxi province, China). The one method (the ecological unit method) is that the Huixian wetland reserve is divided into several ecological units according to different geographic condition and agricultural structure; the main factors of ecological sensitivity are selected; Delphi and Analytical Hierarchy Process (AHP) are applied to determine evaluation factors and the weight of each factor; at last, Index Accumulation Method (IAM) is adopted to evaluate the ecological sensitivity. The other method (the GIS method) is that using ecological sensitivity indexes and GIS spatial analysis module, makes a comprehensive evaluation of the ecological sensitivity in Huixian wetland. The results of the ecological sensitivity analysis show that the most sensible zone lies in the centre of the wetland reserve, which can be set to the core protection area. The high sensibility zone is around the core protection area, which can be set to the buffer zone or experimental zone. The lowest sensibility zone is located in the east of the wetland reserve, which can be set to the demonstration area. The compared results of the two different methods show that the first method, the ecological unit method, can be used in case of comparative shortage of existing data. The ecological sensibility distribution is relatively explicit. The second method, the GIS method, can be used in case of the abundant Remote Sensing (RS) and geographic information systems (GIS) data. The analytical results are meticulous and objective. The ecological sensibility distribution is relatively implicit.

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Keywords: Ecological sensitivity analysis; GIS; Wetland

1. Introduction

Huixian wetland which belongs to Lacustrine wetland is currently the largest one of this type of wetlands in Guangxi and is also the typical wetland in karst topography of Guangxi. Huixian wetland is located in Lingui

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County and Yanshan District of Guilin, Guangxi. The wetland is located in east longitude 110°08'38"~110°16'57", north latitude 25°05'08"~25°08'34". Geographical location of Huixian wetland is shown in Fig. 1.

Since 1950s, with the increase of human activities and wetland reclamation, and with the lack of effective management and protection, the original wetland has been continuously undermined; the water has gradually been shrinking; and wetland ecosystems have been seriously damaged. At present, the large grassy areas around Jiutou Mountain and Fenghuang Mountain were opened up to about 2000 mu of farmland. The marshes around Dulong Pond, Jiutou Mountain, Fenghuang Mountain and Long Mountain are excavated to about 4200 mu of fish ponds. The status of land using in Huixian wetland reserve is shown in Fig. 2.

In recent years, there are more and more studies on Huixian wetland. With a series of remote sensing data in Huixian wetland reserve, Cai Desuo, Ma Zulu et al [1] used GIS technique to analyze the spatio-temporal evolution of the wetlands from 1969 to 2006. Li shijie, Cai Desuo et al [2] studied preliminarily on the environment changes record derived from sediment cores of Huixian karst wetland. Framework of Establishment of Health assessment
Program in Lijiang River Watershed Cai Desuo, Wang Beixin et al [3] studied the aquatic ecosystem health monitoring and evaluation system of the whole Lijiang River watershed.

Eco-environmental sensitivity evaluation is an important part of planning of Huixian wetland, which has a guiding role in ecological function zoning. There are a lot of researches on the evaluation of ecological environment [4-11].

This paper applies two methods to analyze the ecological sensitivity in Huixian wetland, and does comparative research of these two methods. The one method (the ecological unit method) is that the Huixian wetland reserve is divided into several ecological units according to different geographic condition and agricultural structure; then the main factors of ecological sensitivity are selected; Delphi [12] and Analytical Hierarchy Process (AHP) are applied to determine evaluation factors and the weight of each factor; and Index Accumulation Method (IAM) is adopted to evaluate the ecological sensitivity. The other method (the GIS method) is that using ecological sensitivity indexes and GIS spatial analysis module [13, 14], makes a comprehensive evaluation of the ecological sensitivity in Huixian wetland.

2. Methods and Applications

2.1. Method one: Ecological unit method

Ecological sensitivity is defined as the adaptability of ecological factors to the external pressure or external interference under the premise of no loss or reduction eco-environmental quality. The eco-sensitivity analysis is the analysis of regional eco-environment on the sensitivity of human activities and ecosystems resilience.

The ecological unit method of eco-sensitivity analysis is that at first, the Huixian wetland reserve is divided into several ecological units according to different geographic condition and agricultural structure; then the main factors of ecological sensitivity such as elevation, water, biodiversity, land use, road protection zone are selected; Delphi and Analytical Hierarchy Process (AHP) are applied to determine evaluation factors and the weight of each factor; at last, Index Accumulation Method (IAM) is adopted to evaluate the ecological sensitivity of each ecological unit.

2.1.1. The division of eco-sensitivity assessment units

The wetland reserve is divided into 5 geographical regions: northeast region, east region, southeast region, middle region and west region. Each region is divided into a number of ecological units as eco-sensitivity assessment units based on its socio-economic characteristics. The wetland reserve is divided into 11 eco-sensitivity assessment units, shown in Table 1. Different types of the units are divided based on existing agricultural structure. Fishery districts are those where primary industry is the main industry and fishery output accounts for more than 40% of primary industry; Agricultural districts are those where primary industry is the main industry and agricultural output accounts for more than 40% of primary industry; and others are mixing districts. The distribution of eco-sensitivity assessment units is shown in Fig. 3.

Table 1. Eco-sensitivity assessment units
| Number | Region   | Name              | Area (km²) | Percentage (%) |
|--------|----------|-------------------|------------|----------------|
| 1      | Northeast| Northeast Fishery District | 1.80       | 11.59          |
| 2      |          | Northeast Agricultural District | 0.66       | 4.24           |
| 3      | East     | East Mixing District | 1.34       | 8.66           |
| 4      | Southeast| Southeast Wetland District | 0.85       | 5.47           |
| 5      |          | Southeast Agricultural District | 0.41       | 2.64           |
| 6      | Middle   | Middle Mixing District | 0.96       | 6.20           |
| 7      |          | North Agricultural District | 1.59       | 10.24          |
| 8      |          | Middle Wetland District | 2.29       | 14.80          |
| 9      |          | South Agricultural District | 1.35       | 8.73           |
| 10     | West     | West Fishery District | 2.86       | 18.48          |
| 11     |          | West Agricultural District | 1.39       | 8.95           |

Fig. 3. Distribution of eco-sensitivity assessment units

2.1.2. Eco-sensitive factor selection and evaluation

The main factors of ecological sensitivity such as elevation, water, biodiversity, land use, road protection zone are selected. Delphi Method is applied to evaluate sensitivity value of each factor. The larger evaluation values the ecological units have, the higher ecological sensitivity they have. The indexes of evaluation are signified as follows: 9, extremely high sensitivity, the corresponding districts of the index are those where the ecological sensitivity is extremely high; 7, high sensitivity, the corresponding districts of the index are those where the ecological sensitivity is high; 5, medium sensitivity, the corresponding districts of the index are those where the ecological sensitivity is medium; 3, low sensitivity, the corresponding districts of the index are those where the ecological sensitivity is low; 1, non sensitivity, the corresponding districts of the index are those where the ecological sensitivity is extremely low. Eco-sensitive factor categories and ecological sensitivity indexes are shown in Table 2.
2.1.3. Comprehensive analysis of ecological sensitivity

Delphi Method and Analytical Hierarchy Process (AHP) are applied to determine the weight of each factor, as shown in Table 3. Index Accumulation Method (IAM) is adopted to evaluate the eco-sensitivity index of each unit, as shown in Table 4.

Table 3. Weights of factors

| Factors         | Elevation | Water | Land use | Biodiversity | Road protection zone |
|-----------------|-----------|-------|----------|--------------|----------------------|
| weights         | 0.1       | 0.4   | 0.2      | 0.2          | 0.1                  |

Table 4. Comprehensive sensitivity indexes of units
| No. | Units                | Elevation | Water | Land use | Bio-diversity | Road protection zone | Comprehensive indexes |
|-----|----------------------|------------|-------|----------|---------------|----------------------|------------------------|
| 1   | Northeast Fishery District | 7          | 7     | 7        | 5             | 7                    | 6.6                    |
| 2   | Northeast Agricultural District | 3          | 5     | 5        | 3             | 5                    | 4.4                    |
| 3   | East Mixing District    | 3          | 3     | 3        | 5             | 1                    | 3.2                    |
| 4   | Southeast Wetland District | 7          | 9     | 9        | 7             | 5                    | 8                      |
| 5   | Southeast Agricultural District | 5          | 7     | 5        | 3             | 5                    | 5.4                    |
| 6   | Middle Mixing District  | 1          | 5     | 5        | 5             | 5                    | 4.6                    |
| 7   | North Agricultural District | 7          | 7     | 5        | 3             | 5                    | 5.6                    |
| 8   | Middle Wetland District  | 7          | 9     | 9        | 7             | 5                    | 8                      |
| 9   | South Agricultural District | 7          | 7     | 5        | 3             | 5                    | 5.6                    |
| 10  | West Fishery District   | 9          | 5     | 7        | 5             | 1                    | 5.4                    |
| 11  | West Agricultural District | 7          | 5     | 9        | 3             | 1                    | 5.2                    |

2.1.4. Conclusions

Eco-sensitivity of ecological units in Huixian wetland reserve is in order of: Middle wetland district = Southeast wetland district > Northeast fishery district > South agricultural district = North agricultural district > Southeast agricultural district = West fishery district > West agricultural district > Middle mixing district > Northeast agricultural district > East mixing district. The distribution of ecological sensitivity in Huixian wetland is shown in Fig. 4.

![Fig. 4. Distribution of ecological sensitivity](image-url)
Units of extremely high sensitivity are Middle wetland district and Southeast wetland district. The districts of extremely high sensitivity belong to eco-environmental vulnerable areas. Once these districts are damaged, it will be difficult to restore them. The districts can be set to the core protection areas.

The unit of high sensitivity is Northeast fishery district. Units of Middle sensitivity are South agricultural district, North agricultural district, Southeast agricultural district, West fishery district, West agricultural district, Middle mixing district and Northeast agricultural district. The districts can be set to buffer or experimental areas.

The unit of low sensitivity is East mixing district. The district can be set to the demonstration area.

### 2.2. Method two: GIS method

According to the feature of Huixian wetland, main factors of ecological environment and operability of specific evaluation methods, vegetation, soil erosion and water pollution are selected as factors on the eco-environmental sensitivity evaluation.

#### 2.2.1. Sensitivity evaluation of vegetation

Vegetation sensitivity refers to sensitive grade of vegetation types by the surrounding environment. Based on category extract from satellite images, together with verification by on-site inspection, the map of vegetation types is obtained. Corresponding relationship between vegetation and sensitive grade is determined through seeking advice from experts. Indexes of vegetation sensitivity are shown in Table 5.

| Sensitivity  | Extremely high | High | Medium | Low | Non |
|--------------|----------------|------|--------|-----|-----|
| vegetation / | /              | Meadow, Reed | Shrub | Woodland | Others |
| Index        | 9              | 7    | 5      | 3   | 1   |

Areas of each sensitivity grades are shown in Table 6. The distribution of vegetation sensitivity in Huixian wetland is shown in Fig. 5.

| Grade | Area (km²) | Percentage (%) |
|-------|------------|----------------|
| High  | 2.02       | 13.0           |
| Medium| 4.83       | 31.2           |
| Low   | 1.07       | 6.9            |
| Non   | 7.58       | 48.9           |
2.2.2. Sensitivity evaluation of soil erosion

The ecological sensitivity evaluation of soil erosion is to evaluate sensitive degree of soil erosion by human activity in order to identify areas easy to occur to soil erosion. GIS and RS techniques are applied. The main factors of soil erosion: precipitation, soil texture and topography are selected for single-factor sensitivity analysis. The role of a single factor to soil erosion is reflected. The value of each factor is given by grade, shown in Table 7. Sensitivity indexes of soil erosion are calculated by the following formula.

$$SS_j = \left( \prod_{i=1}^{n} C_i \right)^{1/n}$$ (1)

where $SS_j$ is sensitivity index of soil erosion at spatial unit $j$, and $C_i$ is the value of sensitivity gradation of factor $i$.

Based on grading standard and GIS spatial analysis module, comprehensive sensitivity of soil erosion in Huixian wetland is divided into 3 grades: Medium sensitivity, Low sensitivity and Non sensitivity. The areas of 3 grades are shown in Table 8. The distribution of soil erosion sensitivity in Huixian wetland is shown in Fig. 6.

Table 7. Gradation indexes of sensitive factors of soil erosion

| Grade | Non sensitivity | Low sensitivity | Medium sensitivity | High sensitivity | Extremely high sensitivity |
|-------|----------------|----------------|--------------------|-----------------|--------------------------|
| Precipitation (mm) | ≤1200 | 1200-1300 | 1300-1400 | 1400-1600 | >1600 |
| Soil texture | Cobble, Gravel | Coarse sand, Fine sand | Loamy sand, Loam, Clay loam | Sandy loam, Silty clay, clay loam | Sandy silt, Silt |
| Topography(m) | 0-20 | 21-50 | 51-100 | 101-300 | >300 |
| Gradation value(C) | 1 | 3 | 5 | 7 | 9 |
| Grading standard(SS) | 1.0-2.0 | 2.1-4.0 | 4.1-5.0 | 5.1-6.0 | >6.0 |

Table 8. Areas of different grades
2.2.3. Sensitivity evaluation of water pollution

The sensitivity of water pollution refers to under natural rainfall conditions, the capacity of regional eco-system to pollution, i.e., under the normal rainfall conditions, the probability of occurrence of water pollution. It mainly depends on the regional non-point source pollution and the size of precipitation, and mainly reflecting the capacity of precipitation to dilute pollutants by the formation of surface runoff. The sensitive grades of water pollution are shown in Table 9.

Table 9. Sensitive grades of water pollution

| Grade     | Non | Low  | Medium | High  | Extremely high |
|-----------|-----|------|--------|-------|----------------|
| Runoff depth (mm) | >600 | 400-600 | 100-400 | 25-100 | <25            |
| non-point pollution degree | Non | Low   | Medium | High  | Extremely high |

Based on the statistics of multi-year mean regional precipitation and runoff and the status of non-point source pollution, the sensitivity of water pollution in Huixian Wetland is divided into 5 grades, shown in Table 10. The distribution of water pollution sensitivity in Huixian wetland is shown in Fig. 7.

Table 10. Areas of different grades
2.2.4. **Comprehensive evaluation of ecological sensitivity**

In order to evaluate the comprehensive sensitivity of vegetation, soil erosion and water pollution, the weight of each factor (vegetation, 0.35; soil erosion, 0.3; and water pollution, 0.35) is given. Indexes of comprehensive sensitivity are calculated by the following formula.

$$SI_j = \sum_{i=1}^{n} S_i \times W_i$$

where $SI_j$ is index of comprehensive sensitivity at spatial unit $j$, $S_i$ is the value of sensitivity gradation of factor $i$, and $W_i$ is the weight of factor $i$.

Based on grading standard and GIS spatial analysis module, comprehensive sensitivity of soil erosion in Huixian wetland is divided into 5 grades: Extremely high sensitivity, High sensitivity, Medium sensitivity, Low sensitivity and Non sensitivity. The areas of 5 grades are shown in Table 11. The distribution of soil erosion sensitivity in Huixian wetland is shown in Fig. 8.

### Table 11. Areas of different grades

| Grade         | Area ($km^2$) | Percentage (%) |
|---------------|---------------|----------------|
| Extremely high| 3.75          | 24.2           |
| High          | 7.36          | 47.5           |
| Medium        | 3.63          | 23.4           |
| Low           | 0.61          | 3.9            |
| Non           | 0.15          | 1.0            |

Fig. 7. Distribution of water pollution sensitivity
Fig. 8. Distribution of comprehensive sensitivity
3. Conclusions

The eco-environmental sensitivity evaluation is an important part of planning of Huixian wetland, which has a guiding role in ecological function zoning. This paper applies two methods to analyze the ecological sensitivity in Huixian wetland. The results of two methods are basically the same.

- The results of the ecological sensitivity analysis show that the most sensible zone is in the centre of the wetland reserve, which can be set to the core protection area.
- The high sensibility zone is around the core protection area, which can be set to the buffer zone or experimental zone.
- The lowest sensibility zone is in the east of the wetland reserve, which can be set to the demonstration area.

The compared results of the two different methods show as follows:

- The first method, the ecological unit method, can be used in case of comparative shortage of existing data. The second method, the GIS method, can be used in case of the abundant Remote Sensing (RS) and geographic information systems (GIS) data.
- The analytical results of GIS method are meticulous and objective.
- Using the ecological unit method in Huixian wetland, the ecological sensibility distribution is relatively explicit and simple.

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