Evaluation of ecological sensitivity in Erhai Lake Basin, southwest China

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Abstract. In order to identify the ecological-sensitive region in Erhai Lake basin and to supply theoretical assistance for related eco-environmental protection planning, the ecological sensitivity in Erhai Lake basin was assessed and analysed based on the Geographic Information System (GIS), Remote Sensing (RS) and comprehensive-factor ecological sensitivity evaluation method. The results showed that the ecological sensitivity had the positive correlation relationship with terrain fluctuation but had the negative correlation relationship with vegetation coverage and the width of the waters buffer zone. The multifactorial comprehensive ecological sensitivity in Erhai Lake basin had the changing trend from the land to waters, which varied from low sensitivity, moderate sensitivity to high sensitivity. On the foundation of the above results, the waters buffer zone within 100 meters should be more paid attention to in the ecological protection planning. If the transition zone between waters and land was protected well, the waters buffer zone within 100 meters could play a great role in the ecological function of purification and remediation, and biodiversity conservation.

1. Introduction
Ecological environment is the foundation for organisms’ survival. With the rapid development of social economy, the disturbance degree of human beings’ activities to the ecological environment will also increase, and the deterioration of the ecological environment has become a common problem. It has been the research focus in domestic and foreign recently that how to balance the contradiction between rapid economic development and protection of ecological environment, to identify the ecological sensitivity region quickly and to formulate some environment protection plans based on the distribution characteristics of the ecologically sensitive regions [1-3].

Ecological sensitivity means that when the ecological environment is disturbed by human beings or the natural process, the ease of occurrence of ecological problems in ecological environment [4]. Generally, ecological sensitivity could be divided into five categories, which are insensitivity, low sensitivity, moderate sensitivity, high sensitivity and extreme sensitivity. The result from the analysis of ecological sensitivity is the significant basis for formulating environmental protection plans. Currently, the research point for ecological sensitivity is converted from single factor to multiple factors, from single-factor evaluation to multiple-factor evaluation methods. Moreover, the study object presents polymorphic development [5, 6].

The report of the 18th National Congress of the Communist Party of China (CPC) put forward the goal of building a beautiful China and raised the construction of ecological civilization to unprecedented heights. The 19th CPC put forward specific measures to accelerate the reform of the
ecological civilization system and to build a beautiful China. When President Xi Jinping inspected in Dali city, Yunnan province in January 2015, he pointed out that significant instruction that we must protect Erhai Lake. The Erhai Lake basin is an important support for breeding and growth of biological resources. It contains the Cangshan Erhai National Nature Reserve, and the national second-level key protected wild plant, golden buckwheat. With the development of social economy, the ecological function of Erhai Lake basin has been disturbed at certain degree. There are enormous researches concerned on Erhai Lake basin, whose point contained eutrophication of Erhai Lake [7], environmental pollution control [8], and the blue and green water flows induced by climate change [9]. However, there is only few researches on the point of ecological sensitivity for Erhai Lake basin. Therefore, in order to facilitate the work of eco-environmental in Erhai Lake basin and to supply some technological assistance for related plan, the evaluation of ecological sensitivity, whose index system consisted of land use type, terrain fluctuation, vegetation coverage and waters buffer zone, was evaluated in Erhai Lake basin.

2. Materials and methods

2.1. Study area
Erhai Lake is located in Dali Bai Autonomous Prefecture, Yunan province, China (Figure 1). It belongs to Lancang river system and is fault-block landforms [10]. Its watershed area is 2565 square kilometer (km²). There are 117 rivers, which are Miju river, Yongan river, luoshi river, Xier river and cangshan eighteen streams ect., and several lakes and reservoirs, which are Erhai Lake, Cibi Lake, Haixihai Reservoir, whose water is mainly from precipitation and snow melting, in Erhai Lake basin. For Erhai Lake basin, the average annual temperature is 15.5 degree Celsius, the annual rainfall varies from 1000 to 1100 millimeter (mm), and 95 percent rainfall is concentrated in the rainy season from May to October [11]. Cangshan Erhai National Nature Reserve is located in Erhai Lake basin, and this basin involves Dali City and Eryuan County, which consists of 16 towns, 167 village committees, and 33 communities. The north region of Erhai Lake basin, which involves six towns, is agriculturally developed area with only 30 percent urbanization. The south region of Erhai Lake basin, which contains 10 towns, is in 70 percent urbanization level. The cultivation in Erhai Lake basin is mainly rice, broad beans, rapeseed, and barley, etc., and the livestock breeding mainly includes pigs, cattle, sheep, and poultry, and the scattered breeding is dominant [12]. With the rapid development of society and economy, how to balance the contradiction between the use of water resources, water environmental protection and social-economic development in the Erhai Lake basin, and how to advance the ecological environmental protection work in Erhai Lake basin is one of the most important tasks in the entire Erhai Lake basin and even the country.

Figure 1. Location of study area.
2.2. Data sources
Landsat-8 operational land imager (OLI) remote-sensing image (spatial resolution 30 meters × 30 meters) and digital elevation model (DEM) data (spatial resolution 30 meters × 30 meters) both came from the Geospatial Data Cloud (http://www.gscloud.cn/). The software named ENVI5.3 was employed to obtain the land use type data of Erhai Lake basin from the remote-sensing images based on the neural network method in supervised classification. On the foundation of the dimidiate pixel model (DMP), the vegetation coverage in Erhai Lake basin was gotten from Normalized Difference Vegetation Index (NDVI) [13]. The software named Arcgis10.4 was employed to calculate the terrain fluctuations from DEM data. Moreover, the waters buffer zone data was calculated by Arcgis10.4 after the land use type data was vectorised by ENVI5.3.

2.3. Single-factor ecological sensitivity indicator system
The degree of the social-economic development, population, and natural resources, etc. should be taken into consideration in the comprehensive ecological sensitivity within basin scale. The land use type could explain the circumstance of social-economic development, and the proportion to the construction land and cultivated land in the entire basin could represent the circumstances of modern industry and agriculture. The results of the research conducted by Zhong J et al. [14] showed that there was the obviously negative correlation between the terrain fluctuation and the population density, so the terrain fluctuation could be selected to explain the feature of population distribution and human beings’ activity intensity. Vegetation is one of the important link between the waters and atmosphere, and it is the foundation of many organisms’ survival. Moreover, the vegetation holds the significant ecological function which is climate regulation as well as soil dan water conservation, and it is an integral part of natural resources. So, the vegetation coverage was employed to represent the circumstance of vegetation in basin scale within this research. The waters is the destination of the terrestrial hydrological process, and it carries important functions of social-economic development, water supply and drainage, and maintenance of biodiversity in the basin. Lake shore is the special band between waters and lands, and it could buffer pollution load induced by the hydrological process. Based on the above and related research [15-17], the four indexes (Table 1), which were land use type, terrain fluctuation, waters buffer zone, and vegetation coverage, were utilized to conduct the comprehensive-factor ecological sensitivity evaluation in Erhai Lake basin.

Table 1. Ecological sensitivity factor classification system table [5, 12].

| Index system               | Ecological sensitivity |
|----------------------------|------------------------|
| Land use type              | Insensitivity          |
| Construction land or unused land | Low sensitivity |
| Cultivated land            | Moderate sensitivity |
| Forest land                | High sensitivity       |
| Grassland                  | Extreme sensitivity    |
| Waters                     |                        |
| Terrain fluctuation        | 0-10m                  |
| 10m-20m                    |
| 20m-30m                    |
| 30m-40m                    |
| More than 40m              |
| Vegetation coverage        | More than 49%          |
| 39%-49%                    |
| 28%-39%                    |
| 16%-28%                    |
| 0-16%                      |
| Waters buffer zone         | More than 200m         |
| 100m-200m                  |
| 75m-100m                   |
| 50m-75m                    |
| Less than 50m              |
| Assignment                 | 1                      |
| 3                          |
| 5                          |
| 7                          |
| 9                          |

2.4. Comprehensive-factor ecological sensitivity index system
Based on the analytic hierarchy process, the indicator architecture layer was developed. Furthermore, on the foundation of the principle of five-point score and the importance of index factors in ecological sensitivity, the index factors were assigned values to. For example, 5 meant extremely significant, while the 1/5 meant the opposite. 4 meant strongly influential, and the opposite value was 1/4. 3 meant
obviously important, and the opposite value was 1/3. 2 meant slightly consequential, and the opposite value was 1/2. 1 means equally important [18] (Table 2).

Based on the index system and the results of principle of five-point score, the software named MATLAB2014a was employed to calculated the maximum eigenvalue ($\lambda_{\text{max}}=4.1076$) and consistency check index ($\text{CI}=(\lambda_{\text{max}}-n)/(n-1)=0.0359$). When judgement matrix order ($n$) equaled to four, the Stochastic consistency index (RI) was 0.90 [19]. The random consistency ratio (CR) was calculated as 0.0399, which was less than 0.01, so the matrix consistency was acceptable. The weight values of each index were 0.3132, 0.0714, 0.1522 and 0.4633 respectively after the eigenvectors of matrix was normalized (Table 2).

| Index system          | Land use type | Terrain fluctuation | Vegetation coverage | Waters buffer zone |
|-----------------------|---------------|---------------------|---------------------|-------------------|
| Land use type         | 1             | 4                   | 3                   | 1/2               |
| Terrain fluctuation   | 1/4           | 1                   | 1/3                 | 1/5               |
| Vegetation coverage   | 1/3           | 3                   | 1                   | 1/3               |
| Waters buffer zone    | 2             | 5                   | 3                   | 1                 |
| Weights               | 0.3132        | 0.0714              | 0.1522              | 0.4633            |

3. Results and discussions

3.1 Analysis of evaluation result of single-factor ecological sensitivity

3.1.1 Ecological sensitivity analysis Based on land use type. The Figure 2(a) showed that the area of construction land and unused land, cultivated land, forest land, grassland, and waters accounted for 6.87%, 21.82%, 57.81%, 4.00%, and 9.49% of the entire area of the Erhai Lake basin. There was the negative correlation between the human beings' activity intensity and ecological sensitivity. Regions, which hold high humans' activity intensity in Erhai Lake, focused on Dali Town, Xiaguan Town, Fengyi Town, and Haidong Town. The cultivated land concentrated in western regions of Erhai Lake, which consisted of Dali Town, Yinqiao Town, Wanqiao Town, and Xizhou Town, in the northern region of Erhai Lake, which was Shangguan Town, in the regions of Eryuan county, which consisted of Fengyu Town, Sanying Town, Dengchuan Town, and Cibihu Town. The results of single-factor ecological sensitivity based on land use data showed that there was mainly low and moderate sensitivity in Erhai Lake basin (Table 3).

3.1.2 Analysis of ecological sensitivity based on terrain fluctuation. As one of the key natural factors, terrain fluctuation has the significant impact on the human beings' spatial distribution. The circumstance of population density distribution has the direct impact on the ecological environment.
The greater terrain fluctuation was, the lower the population was, and the lower the intensity of human being’s disturbance was, the higher the ecological sensitivity was. The Figure 2 (b) showed that the area of terrain fluctuation within 0-10 m, 10m-20m, 20m-30m, 30m-40m, and above 40m in the entire Erhai Lake basin accounted for 31.59%, 22.98%, 19.36%, 12.59%, and 13.48%. The results of single-factor ecological sensitivity based on terrain fluctuation showed that the ecological sensitivity was dominant by insensitivity, low sensitivity, and moderate sensitivity in the entire basin, the proportion of the extremely sensitive area and the highly sensitive area was basically same, and they were located in the area around Cangshan mountain, which was on the west bank of Erhai Lake, and around Eryuan County.

![Legend](image1)

![Legend](image2)

![Legend](image3)

![Legend](image4)

**Figure 2.** Evaluation results of the singe-factor ecological sensitivity, (a) Land use type and its area ratio, (b) Terrain fluctuation and its area ratio, (c) Waters buffer zone and its area ratio, (d) Vegetation coverage and its area ratio.

3.1.3 Ecological sensitivity analysis based on waters buffer zone. Waters is important part of the ecological structure function in the basin, and it is also the destination of the terrestrial hydrological process. The waters in the basin undertake important functions of economic development, water supply and drainage, maintaining biodiversity, and providing landscape entertainment. The waters buffer zone is an important transition zone between land and waters, and it holds rich biological
diversity and has the dual biological characteristics of lands and waters. In the process of radiating from the waters to the lands, the smaller the buffer area is, the higher the ecological sensitivity is. The ecological sensitivity of the waters buffer zone and the band width of the buffer zone have the significant negative correlation. From Figure 2 (c), it can be observed that the area of the waters buffer zone of above 200m, 100m-200m, 75m-100m, 50m-75m, and less than 50m respectively accounted for 84.32%, 3.10%, 0.77%, 0.77%, and 11.04%. The single-factor ecological sensitivity evaluation results based on the waters buffer zone showed that the ecological sensitivity of Erhai Lake basin was mainly divided into insensitivity and extreme sensitivity, which accounted for 84.32% and 11.04% (Table 3). The extreme sensitivity area consisted of waters in Erhai Lake, West Lake, Cibi Lake, Haixihai Reservoir and the land area surrounding these waters within 50m.

Table 3. Evaluation results of single-factor ecological sensitivity and comprehensive ecological sensitivity in Erhai Lake Basin.

| Evaluation factors         | Insensitivity | Low sensitivity | Moderate sensitivity | High sensitivity | Extreme sensitivity |
|----------------------------|---------------|----------------|----------------------|------------------|--------------------|
|                            | Area ratio (%)|                |                      |                  |                    |
| Land use type              | 6.87          | 21.82          | 57.81                | 4.00             | 9.49               |
| Terrain fluctuation        | 31.59         | 22.98          | 19.36                | 12.59            | 13.48              |
| Waters buffer zone         | 84.32         | 3.10           | 0.77                 | 0.77             | 11.04              |
| Vegetation buffers         | 49.82         | 23.02          | 12.96                | 5.26             | 8.94               |
| Comprehensive ecological sensitivity | 0.27 | 38.17 | 49.45 | 3.30 | 8.82 |

3.1.4 Analysis of ecological sensitivity based on vegetation coverage. Vegetation is an important link between the soil, water body and the atmosphere, and it is the basis for the survival of surface organisms in the watershed. From Figure 2 (d), it can be observed that the vegetation coverage was above 49%, 39%-49%, 28%-39%, 16%-28%, and 0-16%, which accounted for 49.82%, 23.02%, 12.96%, 5.26%, and 8.94% respectively. The ecological sensitivity results of Erhai Lake basin based on single-factor of vegetation coverage indicated that Erhai Lake basin was mainly insensitive and low sensitive. The extremely sensitive region accounted for 8.94% of the entire basin (Table 3), and it was mainly dominant by Erhai Lake, West Lake, Cibi Lake, and Haixihai Reservoir.

Figure 3. Evaluation result of the comprehensive-factor ecological sensitivity.
3.2. Analysis of evaluation result of comprehensive-factor ecological sensitivity

Taken the social-economic development, terrain feature, water resources feature and vegetation characteristics into the consideration, the evaluation of comprehensive-factor ecological sensitivity in Erhai Lake was conducted. The Figure 3 showed that the region areas of insensitivity, low sensitivity, moderate sensitivity, high sensitivity, and extreme sensitivity regions accounted for 0.27%, 72.60%, 15.83%, 1.76%, and 9.54% of the entire Erhai Lake basin area separately (Table 3). The ecological sensitivity varied from low sensitivity, moderate sensitivity to extreme sensitivity when the spatial location varied from lands to waters.

4. Conclusions

The evaluation of single-factor ecological sensitivity, whose index system contained land use type, terrain fluctuation, waters buffer zone, and vegetation coverage separately, was investigated. Moreover, the Analytic Hierarchy Process was selected to calculate the weights of each indexes. Furthermore, the Geographic Information System was introduced to conduct the spatial overlay analysis to calculate the comprehensive-factor ecological sensitivity in Erhai Lake basin. The result was as follows:

- The ecological sensitivity in Erhai Lake basin showed the negative correlation with human activity intensity, vegetation coverage, and the bandwidth of waters buffer zone. However, it had the positive correlation with terrain fluctuation. Therefore, the regions which held low human beings’ activity, low vegetation coverage or high terrain fluctuation, the waters or its buffer zone with low bandwidth could be classified as high or extreme sensitivity.
- The ecological sensitivity was dominant by waters buffer zone. For the reason that the waters and the 100 meters’ bandwidth of waters buffer zone was the region, which was high or extreme sensitivity, the region in 100 meters’ bandwidth of waters buffer zone should be paid more attention to in Erhai Lake basin within the eco-environmental protection plan.
- The evaluation results of comprehensive-factor ecological sensitivity showed that the ecological sensitivity in Erhai Lake basin had a trend of polarization that the low sensitivity region accounted for 72.60 percent of the entire Erhai lake basin region, while the extreme sensitivity region only accounted for 9.24 percent. The ecological sensitivity varied from low sensitivity, moderate sensitivity to extreme sensitivity when the spatial location varied from lands to waters.

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