International Journal of Environmental Technology and Management

ISSN online: 1741-511X - ISSN print: 1466-2132
https://www.inderscience.com/ijetm

Evaluation method of ecological vulnerability of scenic spots based on entropy weight TOPSIS model

Jiong Li

DOI: 10.1504/IJETM.2022.10048774

Article History:

Received:	24 November 2021
Accepted:	14 February 2022
Published online:	30 November 2022

Evaluation method of ecological vulnerability of scenic spots based on entropy weight TOPSIS model

Jiong Li

Zhoukou Vocational and Technical College,
Zhoukou 466000, China
Email: jiongli@36haojie.com

Abstract: In order to solve the problem of poor accuracy of traditional ecological vulnerability assessment methods, an ecological vulnerability assessment method of scenic spots based on entropy weight TOPSIS model is proposed. Firstly, it analyses the natural environment and conditions of the scenic spot, determines the ecological vulnerability evaluation index of the scenic spot, and constructs the evaluation index system through spatial principal component analysis. Then, the evaluation indexes are standardised and graded according to the ecological vulnerability index of scenic spots. Finally, the weight of ecological vulnerability index is calculated by using entropy weight TOPSIS model, and the ecological vulnerability index is determined. After building the ecological vulnerability assessment model of scenic spots, input the ecological vulnerability indicators into the model and output the assessment results. The results show that the accuracy of this method is as high as 0.98.

Keywords: evaluation factor; entropy weight TOPSIS model; ecological vulnerability; evaluation method.

Reference to this paper should be made as follows: Li, J. (2023) 'Evaluation method of ecological vulnerability of scenic spots based on entropy weight TOPSIS model', *Int. J. Environmental Technology and Management*, Vol. 26, Nos. 1/2, pp.14–26.

Biographical notes: Jiong Li received his MA in Tourism Management Department from the Guangxi Normal University in 2014. He is currently a Lecturer in the Zhoukou Vocational and Technical College. His research interests include tourism enterprise management and tourism culture.

1 Introduction

Ecological vulnerability refers to the ability of the ecosystem in a region to cope with the interference of other external factors. It includes two aspects: one is to respond to external changes, and the other is to restore the ability to a complete ecosystem (Zhu et al., 2019). Today, with the rapid economic development, scenic spots continue to provide people with a variety of tourism services. With the increasing number of tourists, the ecological environment of scenic spots has also been impacted to a certain extent. The tourist plant landscape and soil in the scenic spot have been damaged by tourists, and the human waste in the scenic spot has gradually increased (Xie et al., 2019; He et al., 2019). These behaviours have seriously affected the ecological stability of the scenic spot.

Therefore, it is necessary to evaluate the ecological vulnerability of scenic spots, determine the key factors affecting the ecological environment of scenic spots, and maintain the sustainable development of scenic spots. Therefore, relevant researchers have done a lot of research and achieved some results.

Guo et al. (2019b) proposed a comprehensive evaluation method of ecosystem vulnerability in the Yangtze River Estuary, which uses GIS technology to obtain the geographical environment information of the Yangtze River Estuary, realises the stratification of ecosystem vulnerability indicators according to the spatial principal component analysis method, classifies the ecosystem vulnerability, and makes a comprehensive evaluation according to the indicators. The content of this method can analyse the trend of ecological vulnerability, however, there are some differences between the evaluation results and the actual values. Xu et al. (2018) introduced the dprism conceptual framework into the eco-environmental vulnerability assessment system, obtained multiple assessment levels of the ecosystem in the upper reaches of Minjiang River, obtained the basic information of the ecosystem in the upper reaches of Minjiang River, calculated the eco-environmental value, and realised the vulnerability analysis of the ecological environment in the upper reaches of Minjiang River. This method can obtain the temporal and spatial change law of the ecological environment in the upper reaches of Minjiang River; however, the accuracy of ecological environment vulnerability assessment is poor. Xu et al. combined RS technology with GIS technology to improve the comprehensive evaluation method of ecosystem vulnerability proposed by Shuwen and Qiu (2019) comprehensively evaluate the ecological environment vulnerability of the Yangtze River Delta, use the spatial principal component analysis method to realise the spatial division of the regional environment of the Yangtze River Delta, and use GIS technology to match geographic information with spatial information one by one, The comprehensive evaluation of environmental ecosystem vulnerability in the Yangtze River Delta is completed by calculating the weight of ecosystem vulnerability index. This method can realise the evaluation of ecological environment vulnerability from multiple angles, but the evaluation efficiency is poor.

Therefore, based on the entropy weight TOPSIS model, this paper designs an ecological vulnerability assessment method of scenic spots, constructs the TOPSIS model, establishes the ecological vulnerability assessment index system of scenic spots in X province, obtains the ecological vulnerability assessment factors, and uses the entropy weight method to optimise the ecological vulnerability assessment results of scenic spots, so as to realise the ecological vulnerability assessment of scenic spots. The ideas of this paper are as follows:

Firstly, the natural environment and conditions of scenic spots are analysed, and the ecological vulnerability assessment indicators of scenic spots are determined, including: selecting elevation, population density, proportion of cultivated land and GDP density and constructing the assessment index system through spatial principal component analysis;

Then, the evaluation indexes are standardised and graded according to the ecological vulnerability index of scenic spots.

Finally, the weight of ecological vulnerability index is calculated by using entropy weight TOPSIS model, and the judgement matrix is constructed by analytic hierarchy process to determine the relative importance of the index and determine the ecological vulnerability index; On this basis, the ecological vulnerability assessment model of scenic spots is constructed, and the ecological vulnerability indicators are input into the model to output the assessment results.

2 Study on the construction and classification of ecological vulnerability evaluation index system of scenic spots

2.1 Construction of ecological vulnerability evaluation index system of scenic spots

In order to realise the accurate assessment of ecological vulnerability of scenic spots and improve the ecological environment quality of scenic spots. In this paper, firstly, the evaluation indexes affecting the ecological vulnerability of scenic spots are selected, and the evaluation index system is constructed.

1 Index selection. Analyse the natural environment and conditions of the scenic spot, refer to the existing research results on the ecological vulnerability of the scenic spot and other similar natural areas, and start from the current situation of the ecological environment of the scenic spot, scientifically and objectively select five factors such as elevation, population density, proportion of cultivated land and GDP density to build the ecological vulnerability evaluation index system of the scenic spot (Guo et al., 2019a).

2 Process data. Collect data according to the selected five factors, transform the data into a unified Albers projection and wgs-1984 coordinate system by coordinate and projection transformation; all grid data processing is 1 km × 1 km grid; in order to eliminate the influence of different dimensions of each factor, each evaluation index factor is quantified and graded before comprehensive evaluation, and processed into the standardised value of [0, 10] interval change (Wu et al., 2019).

3 Establish evaluation model. The establishment of evaluation model is the key step and important link of this paper. Through spatial principal component analysis, calculate the ecological vulnerability index and comprehensive ecological vulnerability index of scenic spots, and comprehensively evaluate and analyse the overall ecological vulnerability degree of scenic spots and the vulnerability characteristics of counties and regions on the basis of the classification of ecological vulnerability evaluation results (Zhang, 2021).

4 Spatial correlation analysis. Spatial correlation analysis is a universal and effective analysis method in geography. It mainly represents the spatial correlation and distribution characteristics of objective things and is expressed by corresponding statistical indicators (Yan et al., 2019). The constructed evaluation index system is shown in Table 1.

In the process of constructing the index system, analyse the natural environment and conditions of the scenic spot, and determine the ecological vulnerability assessment indicators of the scenic spot, including: select the elevation, population density, proportion of cultivated land and GDP density, and study the technical route of the article according to the determined indicators.

Table 1 Evaluation index system of ecological vulnerability of scenic spots

Sub target layer	*Criterion layer*	*Index layer*
Ecological sensitivity	Terrain factor	Altitude
		Slope
	Land factor	Soil erosion intensity
		Landscape diversity index
	Meteorological factors	Average annual temperature
		Annual precipitation
Ecological resilience		Dryness
		Vegetation coverage
Ecological pressure	Population activity pressure	Population density
		Proportion of cultivated land
Economic activity pressure		GDP density

2.2 *Classification of ecological vulnerability indicators of scenic spots*

According to the above determined ecological vulnerability assessment indicators of scenic spots, in order to improve the effectiveness of the assessment, it is necessary to grade the ecological vulnerability indicators of scenic spots. By classifying the ecological vulnerability index, we can have a more intuitive and clear understanding of the overall situation of ecological vulnerability of scenic spots (Dossou et al., 2021).

Before classification, the vulnerability index calculated above shall be standardised, and the calculation formula is as follows:

$$S_i = \frac{\text{EVI}_i - \text{EVI}_{\text{min}}}{\text{EVI}_{\text{max}} - \text{EVI}_{\text{min}}} \times 10 \quad (1)$$

In formula, S_i indicates the vulnerability index normalised values, EVI_i, EVI_{max}, EVI_{min} represent the original, maximum and minimum values of the vulnerability index, respectively.

According to the characteristics of ecological vulnerability of scenic spots (Zhu and Wang, 2019), the standardised ecological vulnerability index of scenic spots is classified according to five classification standards such as '< 2.0', '2.0 ~ 4.0', '4.0 ~ 6.0', '6.0 ~ 8.0' and '≥ 8.0'. The specific classification results are shown in Table 2.

In the construction and grading of the ecological vulnerability evaluation index system of scenic spots, analyse the natural environment and conditions of scenic spots, determine the ecological vulnerability evaluation indexes of scenic spots, and construct the evaluation index system through spatial principal component analysis. On this basis, the evaluation indexes are standardised and graded according to the ecological vulnerability index of scenic spots, lay the foundation for follow-up evaluation (Raheem et al., 2019).

Table 2 Classification standard of ecological vulnerability of scenic spots

Vulnerability	*Grade*	*Standardised value of ecological vulnerability index*	*Ecological characteristics*
Micro vulnerability	I	< 2.0	The ecosystem structure and function are reasonable and perfect, the pressure is small, the ecosystem is stable, the ability to resist external interference and self recovery is strong, there are no ecological abnormalities, and the ecological vulnerability is low.
Mild vulnerability	II	2.0~4.0	The structure and function of the ecosystem are relatively complete, the pressure is small, the ecosystem is relatively stable, the ability to resist external interference and self recovery is strong, there are potential ecological abnormalities, and the ecological vulnerability is low.
Moderately vulnerable	III	4.0~6.0	The ecosystem structure and function can be maintained, the pressure is close to the ecological threshold, the ecosystem is relatively unstable, sensitive to external interference, weak self recovery ability, a small number of ecological abnormalities and high ecological vulnerability.
Severe vulnerability	IV	6.0~8.0	There are defects in ecosystem structure and function, great pressure, unstable ecosystem, strong sensitivity to external interference, difficult recovery after damage, many ecological abnormalities and high ecological vulnerability.
Extremely vulnerable	V	≥ 8.0	The ecosystem structure and function are seriously degraded, under great pressure, the ecosystem is extremely unstable, extremely sensitive to external interference, it is very difficult to recover after damage, or even irreversible, ecological anomalies occur in a large area, and the ecological vulnerability is very high.

3 Evaluation method of ecological vulnerability of scenic spots based on entropy weight TOPSIS model

3.1 Weight calculation of ecological vulnerability assessment of scenic spots

Based on the above determination of the ecological vulnerability assessment indicators of scenic spots, in order to realise the ecological vulnerability assessment of scenic spots, this paper uses the entropy weight TOPSIS model to evaluate. Entropy weight TOPSIS model can obtain effective evaluation results by assigning the objective indexes of research objectives and comprehensively and hierarchically evaluating the research objects through TOPSIS model (Griffiths et al., 2019). Therefore, this paper uses this method to evaluate the ecological vulnerability of scenic spots and improve the evaluation effect. The entropy weight TOPSIS model transforms the spatial data parameters in the ecological environment into a comprehensive index of ecological environment vulnerability, and replaces it into the entropy weight TOPSIS assessment model to realise ecological vulnerability assessment (Yu et al., 2020). The specific process is as follows:

The correlation coefficient matrix R was calculated using the standardised data:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ r_{p1} & r_{p2} & \cdots & r_{pp} \end{bmatrix} \quad (2)$$

In the formula, r_{ij} $(i, j = 1, 2, \ldots, p)$ is the correlation coefficient of the original variable with.

Calculate the correlation coefficient matrix to calculate the eigenvalues and the eigenvectors (Liu and Yang, 2019); the correlation coefficient matrix calculates the eigenvalue λ_i and the eigenvector e_i; the eigenequation $\lambda|I - R| = 0$ is solved, the eigenvalues are obtained, and the results are performed in permutation.

$$\lambda_1 \geq \lambda_2 \geq \cdots \lambda_p \geq 0 \quad (3)$$

Eigenvectors corresponding to eigenvalues e_i $(i = 1, 2, \ldots, p)$.

The contribution rate and cumulative contribution rate of each principal component are calculated (Cowood et al., 2019; Hu et al., 2019) as follows:

- Contribution rate:

$$Y_i = \lambda_k \Big/ \sum_{i=1}^{p} \lambda_i \quad (4)$$

- Cumulative contribution rate:

$$X_i = \sum_{j=1}^{k} \left(\lambda_j \Big/ \sum_{i=1}^{p} \lambda_i \right) \quad (5)$$

In formula, Y_i represents the contribution, X_i represents the cumulative contribution, λ_i represents the eigenvalues.

The load of each main component (Chang et al., 2021) is calculated as follows:

$$I_{i,j} = \sqrt{\lambda_i}\, e_{i,j} \, (i, j = 1, 2, \ldots, p) \quad (6)$$

In the formula, *Local Moran's I* represents the local Moran index:

$$m = \left(\sum_{j=1, j \neq i}^{n} x_j^2 \right) \Big/ (n-1) - x^{-2} \quad (7)$$

According to the calculation of the weight of the ecological vulnerability assessment index of the above scenic spots, the ecological vulnerability risk and vulnerability index are calculated respectively. Calculation formula:

$$X = \omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_n x_n \quad (8)$$

In the formula, $\omega_1, \ldots, \omega_n$ is the weight value of the vulnerability index; n as the number of indicators; $x_1, x_2, \ldots, x_n$ as the vulnerability assessment index.

From the above formula (8), it can be seen that the accuracy of index weight affects the ecological vulnerability assessment of scenic spots. Therefore, this paper uses analytic hierarchy process to calculate the ecological vulnerability index, and the specific steps are as follows:

Step 1 Build analytic hierarchy process structure.

Step 2 Construct judgement matrix. Compare two indicators in the same level to obtain the relative importance of each indicator, and quote the appropriate scaling method (see Table 3) to complete the construction of judgement matrix. Set $A = a_{ij}$, where a_{ij} represents the comparison results of the i index relative to the first index.

Table 3 1–9 scale method

Index I is better than index J	a_{ij}
Extremely important	9
Strongly important	7
Obviously important	5
Slightly important	3
Equally important	1
Slightly unimportant	1/3
Obviously unimportant	1/5
Strongly unimportant	1/7
Extremely unimportant	1/9

Step 3 Calculate the index weight. Here, the square root method is used to calculate the weight of each factor. The basic principle is as follows: firstly, the product of each line element is obtained, and then on the basis of this, the n-th square root of the product of each line is obtained. Finally, the vector is normalised to obtain the weight vector and eigenvalue.

Step 4 Check the consistency of the judgement matrix.

Step 5 Single level sorting and total level sorting.

3.2 Realisation of ecological vulnerability assessment of scenic spots

Based on the weight calculation of the ecological vulnerability index of scenic spots determined above, the weight is further determined by entropy method to realise the ecological vulnerability assessment. Entropy method is a method to determine the index weight by the judgement matrix composed of the evaluation index value under objective conditions. It can eliminate the subjectivity of the weight of each factor as far as possible and make the evaluation results more in line with the reality.

According to the definition of entropy, with m feasible schemes and n evaluation indicators, the entropy of the ecological vulnerability evaluation index of tourist attractions can be determined as:

$$H = -\frac{1}{lnn} \sum_{i=1}^{m} f_{ij} lnf_{ij} \tag{9}$$

$$f_{ij} = \frac{b_{ij}}{\sum_{j=1}^{n} b_{ij}} i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{10}$$

To make lnf_{ij} make sense, it generally needs to be assumed that when $f_{ij} = 0$, $f_{ij}lnf_{ij} = 0$. But when $f_{ij} = 1$, the lnf_{ij} is also equal to zero, which is obviously impractical and goes against the meaning of the entropy, so it needs to be corrected and defined as:

$$f_{ij} = \frac{1 + b_{ij}}{\sum_{j=1}^{n} \left(1 + b_{ij}\right)} \tag{11}$$

The entropy power of the evaluation index W:

$$f_{ij} = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}, W = \left(w_j\right)_{1\times n}, \sum_{j=1}^{n} w_j = 1 \tag{12}$$

According to the formula (12) calculation, when the index entropy value $H_j \to 1$ (j = 1, 2, …, n), according to the entropy right principle, if the entropy difference of different indicators does not mean much, it means that the amount of useful information is basically the same, based on this, the ecological vulnerability evaluation model of tourist attractions is constructed as follows:

$$w_j = \frac{\sum_{k=1}^{n} H_k + 1 - 2H_j}{\sum_{j=1}^{n} \left(\sum_{k=1}^{n} H_k + 1 - 2H_j\right)}, W = \left(w_j\right)_{1\times n} \tag{13}$$

Equation (13) is met $\sum_{j=1}^{n} \omega_j = 1, 0 \le \omega_j \le 1(j, k = 1, 2, ..., n)$.

In formula, w_j represents the ecological vulnerability assessment results of tourist attractions and H_k represents the correction factors.

In the realisation of ecological vulnerability assessment of scenic spots, the weight of ecological vulnerability index is calculated with the help of entropy weight TOPSIS model, and the ecological vulnerability risk and vulnerability index are calculated; On this basis, the ecological vulnerability assessment model of scenic spots is constructed, the ecological vulnerability indicators are input into the model, and the assessment results are output (Guo et al., 2020).

4 Experimental analysis

4.1 Experimental scheme design

In order to verify the effectiveness of this method, a comparative method is used to verify the effectiveness of this method. In the experiment, taking a famous scenic spot in a certain place as the research object, the scenic spot covers an area of about 300 square metres. The business hours of the scenic spot are from 8 a.m. to 7 p.m., which is an excellent place for viewing. According to the facilities and planning in the scenic spot, its environmental vulnerability is analysed and studied. Before the experiment, the ecological vulnerability index of the scenic spot is determined due to the large number of tourists accepted by the scenic spot. Therefore, there is a serious problem of man-made damage, which is taken as the point for experimental analysis. The relevant parameters in the experiment are shown in Table 4.

Table 4 Experimental parameters

The degree of ecological vulnerability of scenic spots/m^2	100
Artificial environmental pollution area/m^2	80
Acceptance person/day	1000
Evaluate the range of accurate coefficients	[0, 1]

In the selection of experimental parameters, the selected parameters meet the indicators of ecological vulnerability assessment, and the length of the initial parameters is selected after multiple treatments.

4.2 Experimental index design

In the experiment, the vulnerability and vulnerability index of scenic spots, the area of risk grade and the accuracy of evaluation are taken as the experimental indicators. In the experiment, this method, dprism framework evaluation method, RS and GIS evaluation method and GIS evaluation method are compared to verify the effectiveness of this method.

4.3 Analysis of experimental results

4.3.1 Calculation results of vulnerability and vulnerability index of scenic spots

The vulnerability and vulnerability index of scenic spots in X province are calculated by entropy weight TOPSIS model, and the results are shown in Table 5.

Table 5 Calculation results of vulnerability and vulnerability index of scenic spots

Target layer	*Criterion layer*	*Sub-criteria layer*	*Tertiary indicators*
Risk index of scenic spots 0.6154	Vulnerability 0.6444	Disaster causing factor	Precipitation 0.8564
		Pregnant disaster environment	Terrain 0.6589
			River network 0.7564
	Vulnerability 0.5787	Disaster bearing body	Population 0.5644
			Economics 0.4535

Table 6 Ecological vulnerability and vulnerability index of scenic spots

Project	*Index*
Vulnerability index	0.6559
vulnerability index	0.7455

According to the weight, the vulnerability and vulnerability index of scenic spots in X province are obtained, as shown in Table 6.

4.3.2 Area statistics of ecological vulnerability risk level of scenic spots in X province

The ecological vulnerability risk level of each scenic spot in X province is statistically calculated, and compared with the actual results and the results calculated and processed by three traditional methods (dprism framework evaluation method, RS and GIS evaluation method and GIS evaluation method), so as to judge the effectiveness of this method. Table 7 shows the risk level area of each scenic spot in X province.

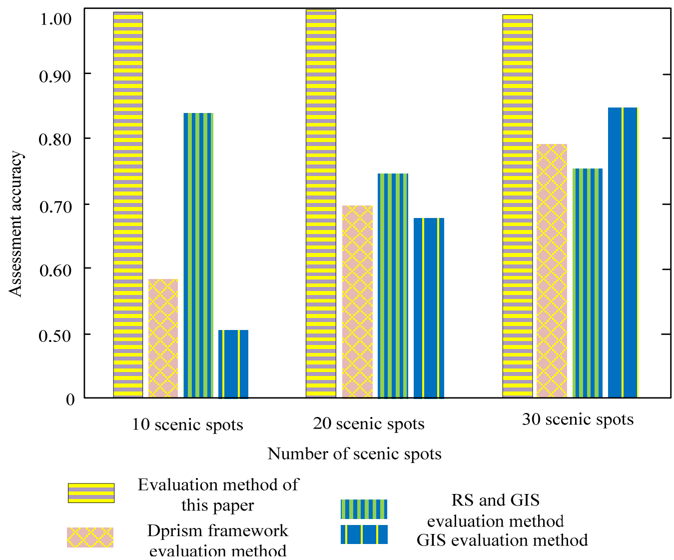
Table 7 Vulnerability risk grade area of scenic spots in X province (unit: 10,000 square kilometres)

Grade	*Actual area*	*Paper method*	*Dprism framework evaluation method*	*RS and GIS evaluation method*	*GIS evaluation method*
High-risk	3.45	3.45	3.80	3.00	2.56
Medium risk	6.32	6.33	5.98	6.01	5.93
Low risk	2.87	2.87	2.98	3.86	3.65

According to Table 7, the actual area of tourist attractions in X province with high ecological vulnerability level is 34,500 square kilometres, the area calculated by dprism framework assessment method is 38,000 square kilometres, the area calculated by RS and GIS assessment method is 30,000 square kilometres, and the area calculated by GIS assessment method is 25,600 square kilometres, the area calculated by this method is 34,500 square kilometres; the actual area of tourism scenic spots in X province with medium ecological vulnerability level is 63,200 square kilometres, the area calculated by dprism framework assessment method is 59,800 square kilometres, the area calculated by RS and GIS assessment method is 60,100 square kilometres, the area calculated by GIS assessment method is 59,300 square kilometres, and the area calculated by this method is 63,300 square kilometres; the actual area with low risk ecological vulnerability level of scenic spots in X province is 28,700 square kilometres, the area calculated by dprism framework evaluation method is 29,800 square kilometres, the area calculated by RS and GIS evaluation method is 38,600 square kilometres, the area calculated by GIS evaluation method is 36,500 square kilometres, and the area calculated by this method is 28,700 square kilometres. Compared with three traditional flood risk assessment methods based on dprism framework assessment method, RS and GIS assessment method and RS and GIS assessment method, the risk grade area obtained by using the entropy weight TOPSIS Model in this paper is closer to the actual results. This proves that the risk assessment method in this paper has higher accuracy and the assessment results are more accurate, which provides a reliable decision-making basis for the ecological vulnerability risk prevention of scenic spots, and can effectively reduce the impact and damage caused by the risk of scenic spots.

In order to further verify the effect of different methods on the ecological vulnerability assessment of scenic spots in X province, the assessment accuracy results are as follows.

Figure 1 Evaluation accuracy under different methods (see online version for colours)



According to the analysis of Figure 1, the accuracy of ecological vulnerability assessment is constantly changing due to the different number of scenic spots. When the number of scenic spots is 10, the accuracy of ecological vulnerability assessment based on dprism framework assessment method is 0.58, the accuracy of ecological vulnerability assessment based on RS and GIS assessment method is 0.84, the accuracy of ecological vulnerability assessment based on GIS assessment method is 0.51, and the accuracy of ecological vulnerability assessment based on this method is 0.99. When the number of scenic spots is 30, the accuracy of ecological vulnerability assessment based on dprism framework assessment method is 0.78, the accuracy of ecological vulnerability assessment based on RS and GIS assessment method is 0.76, the accuracy of ecological vulnerability assessment based on GIS assessment method is 0.84, and the accuracy of ecological vulnerability assessment based on this method is 0.98. The accuracy of ecological vulnerability risk assessment of this method has been higher than that of other methods, which shows that the ecological vulnerability assessment result of this method is more accurate.

5 Conclusions

This paper puts forward the ecological vulnerability assessment method of scenic spots based on entropy weight TOPSIS model, constructs the entropy weight TOPSIS model, obtains the ecological vulnerability assessment factors of scenic spots according to the entropy method, and introduces the ecological vulnerability assessment results of scenic spots to calculate, so as to realise the ecological vulnerability assessment of scenic spots. The following conclusions are drawn through experiments:

1 The vulnerability and vulnerability index calculated by the design method are consistent with the actual results, and have a certain reliability.

2 The accuracy of ecological vulnerability assessment using the designed method is 0.98. The accuracy of ecological vulnerability risk assessment of this method has been higher than that of other methods, which shows that the ecological vulnerability assessment result of this method is more accurate.

References

Chang, H., Pallathadka, A. and Sauer, J. (2021) 'Assessment of urban flood vulnerability using the social-ecological-technological systems framework in six US cities', *Sustainable Cities and Society*, Vol. 68, No. 1, pp.762–786.

Cowood, A.L., Young, J. and Dowling, T.I. (2019) 'Assessing wetland climate change vulnerability for wetland management decision support using the hydrogeological landscape framework: application in the Australian Capital Territory', *Marine and Freshwater Research*, Vol. 70, No. 2, pp.66–78.

Dossou, J.F., Li, X.X. and Sadek, M. (2021) 'Hybrid model for ecological vulnerability assessment in Benin', *Scientific Reports*, Vol. 11, No. 1, pp.16–25.

Griffiths, S.P., Kesner-Reyes, K. and Garilao, C. (2019) 'Ecological assessment of the sustainable impacts of fisheries (EASI-Fish): a flexible vulnerability assessment approach to quantify the cumulative impacts of fishing in data-limited settings', *Marine Ecology Progress Series*, Vol. 625, No. 29, pp.89–113.

Guo, B., Luo, W. and Zang, W. (2020) 'Spatial-temporal shifts of ecological vulnerability of Karst Mountain ecosystem-impacts of global change and anthropogenic interference', *Science of The Total Environment*, Vol. 741, No. 75, pp.239–256.

Guo, J., Zhen, W. and Ren, J. (2019a) 'Ecological vulnerability analysis of alpine and poor mountainous areas based on entropy weight Grey correlation method – a case study of Haidong City, Qinghai Province', *Bulletin of Soil and Water Conservation*, Vol. 39, No. 3, pp.197–205.

Guo, M., Han, J. and Shi, Y. (2019b) 'Ecological environment vulnerability assessment based on dprism conceptual framework – taking the upper reaches of Minjiang River as an example', *Computing Techniques for Geophysical and Geochemical Exploration*, Vol. 41, No. 1, pp.128–134.

He, Y., Yuan, Y., Wang, T., Zhang, H. and Chen, Y. (2019) 'Comprehensive assessment of ecosystem vulnerability in the Yangtze River Estuary based on GIS', *Journal of Ecology*, Vol. 39, No. 11, pp.3918–3925.

Hu, X-D., Hu, K-H. and Zhang, X-P. (2019) 'Quantitative assessment of the impact of earthquake-induced geohazards on natural landscapes in Jiuzhaigou Valley', *Journal of Mountain Science*, Vol. 16, No. 2, pp.441–452.

Liu, Y. and Yang, X. (2019) 'Aquaculture area extraction and vulnerability assessment in Sanduao based on richer convolutional features network model', *Journal of Oceanology and Limnology*, Vol. 37, No. 6, pp.153–166.

Raheem, N., Cravens, A.E. and Cross, M.S. (2019) 'Planning for ecological drought: Integrating ecosystem services and vulnerability assessment', *Wiley Interdisciplinary Reviews: Water*, Vol. 12, No. 3, pp.1352–1364.

Shuwen, L.V. and Qiu, L. (2019) 'National vulnerability assessment system based on correlation analysis', *Science and Wealth*, Vol. 32, No. 3, pp.57–66.

Wu, W., Chen, J. and Ye, R. (2019) 'Vulnerability assessment of urban socio-ecological systems in coastal zones under the influence of typhoons: big data perspective', *Acta Ecologica Sinica*, Vol. 39, No. 19, pp.7079–7086.

Xie, Z., Li, X., Jiang, D., Yang, B., Lin, S. and Chen, S. (2019) 'Spatial management and control countermeasures of Zhujiajian Island based on island ecological vulnerability simulation', *Chinese Journal of Applied Ecology*, Vol. 30, No. 8, pp.2783–2792.

Xu, Q., Huang, M., Lu, P. and Li, R. (2018) 'Comprehensive assessment of eco-environmental vulnerability in the Yangtze River Delta based on RS and GIS', *Research of Environmental Sciences*, Vol. 24, No. 1, pp.58–65.

Yan, X., Cai, R. and Guo, H. (2019) 'Vulnerability assessment of mangrove ecosystem in Dongzhai port, Hainan under the background of climate change', *Journal of Applied Oceanography*, Vol. 38, No. 3, pp.338–349.

Yu, R., Liang, L. and Su, X. (2020) 'A driver based framework for vulnerability assessment of the poverty stricken areas of Funiu Mountain, China', *Ecological Indicators*, Vol. 113, No. 3, pp.196–209.

Zhang, Y. (2021) 'Ecological vulnerability assessment in Western China – an exploratory study of 45 cities in Western China', *Statistics & Information Forum*, Vol. 16, No. 8, pp.74–84.

Zhu, Q. and Wang, M. (2019) 'Ecological vulnerability assessment on Changbai Mountain National Nature Reserve and its surrounding areas, Northeast China', *The Journal of Applied Ecology*, Vol. 30, No. 5, pp.1633–1641.

Zhu, Q., Zhou, W. and Jia, X. (2019) 'Ecological vulnerability assessment on Changbai Mountain National Nature Reserve and its surrounding areas, Northeast China', *Chinese Journal of Applied Ecology*, Vol. 30, No. 5, pp.1633–1641.