Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 5506388, 12 pages
https://doi.org/10.1155/2022/5506388

Research Article

Spatial Analysis on the Vulnerability of Tourism Economic System Based on BP Neural Network: The Guangdong-Hong Kong-Macao Greater Bay Area (GBA)

Yiming Deng

School of Economics and Commerce, Guangdong University of Technology, Guangzhou, 510520, China

Correspondence should be addressed to Yiming Deng; 3119008694@mail2.gdut.edu.cn

Received 6 May 2022; Accepted 1 July 2022; Published 18 July 2022

Academic Editor: Zaoli Yang

Objective. To carry out the research on the vulnerability evaluation and influencing factors of the tourism economic system is the objective requirement of formulating the scientific development strategy of the tourism economy and improving the quality of regional tourism development. *Methods*. Based on the vulnerability analysis of tourism economic system based on BP neural network (BPNN), this paper takes the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) as the research object and selects 14 index data. The mean and standard deviation of the calculated weight values are used to formulate evaluation criteria for the tourism system. *Results*. The BP neural network (BPNN) model was used to predict the distribution law of vulnerability data within the standard range of the Greater Bay Area after 2020, obtained the spatial distribution law of vulnerability in the geographic structure distribution of the Greater Bay Area, and determined the vulnerability analysis framework and evaluation method. *Conclusion*. The cities in the Greater Bay Area should first pay attention to the industrial structure; increase financial investment; enhance the attractiveness of tourist destinations, in-depth development of tourism resources, and rational design of tourism products; help reduce the vulnerability of the tourism economic system; and improve regional self-recovery capabilities.

1. Background of the Study

Vulnerability theory is used by relevant international organizations, governments, and scholars at home and abroad. With the in-depth understanding of vulnerability theory, vulnerability theory has been extensively used in other fields, such as ecology, climate, politics, and economy, since vulnerability has gradually developed into a theory involving interdisciplinary research [1]. Tourism economic vulnerability is one of the development branches, and the tourism industry is a sensitive and vulnerable industry. The COVID-19 epidemic has caused a great impact on the tourism industry. In the strategic context of regional tourism cooperation, building the GBA into an international first-class bay area suitable for tourism is one of the key objectives at present. Depending on the document, the GBA is positioned as a high-quality life circle suitable for living, employment, and tourism. The healthy development of tourism can promote the overall economic transformation and upgrading, improved comprehensive competitiveness, and brand image building of the GBA city cluster. As a type of regional economy, the bay area economy is of great importance and has great development potential. Opening up embodies the essence of the bay area economy, which can be highlighted by the mobility of tourism. On this premise, if we can use the vulnerability theory to establish a BP neural network prediction model, build the vulnerability evaluation index system of the tourism economic system through the two dimensions of tourism destination to predict the future trend, divide the evaluation criteria of the two major dimensions according to the expected conclusion, and analyze in combination with the spatial location of the GBA city cluster that each region should actively adjust

the industrial structure according to the actual situation and promote the development of industrial structure in the diversified direction, so as to reduce the sensitivity and vulnerability of tourism economic system [2].

Existing studies on vulnerability theory mainly focus on the in-depth research on vulnerability from different perspectives. At the beginning, it mainly concentrates on the research in the fields of natural ecological disaster vulnerability, ecosystem vulnerability, and climate change. With the in-depth research, the connotation of vulnerability theory has gradually expanded to other fields, such as the economy and politics [3]. In the study of vulnerability from the perspective of natural disasters, after Clements put forward the ecological transition zone, the academic research on the vulnerable ecological environment was gradually carried out, and Zhao Xueyan put forward countermeasures and recommendations on the ecological environment construction in Hexi region with respect to ecological vulnerability. As for the research on vulnerability from the perspective of climate change, Pandey investigated the impact of rapid climate change in the Himalayas region of Nepal sensitive to climate on the social ecosystem. Huang Yingchao systematically expounds the impact of climate change vulnerability on the change of elements in China's food production system. As for vulnerability research from the perspective of economy and politics, Papathoma-Kohle et al. used vulnerability theory to assess the impact of natural disasters on the economic system in case of extreme emergencies. Boyle WC believed that vulnerability is the capability of society, economy, politics, and environment to defend the disturbances of a series of potential danger. Wang Zhaofeng studied the construction of vulnerability measurement indicator system of the tourism economy. Zhao Xueyan et al. put forward countermeasures and recommendations for the construction of ecological environment in Hexi region on the basis of vulnerability evaluation of ecological environment in Hexi region. Huang Yingchao, a domestic scholar, systematically expounded the influence of various elements in China's grain production system and their interaction on the fluctuation of grain production. Xiaohong Yuet and research ability assessment indicator system (VAIS), including the tourism economic sensitivity and respondent, are modified and established in this paper according to the collected data [4].

In the 1970s, the occurrence of the energy crisis severely impacted and affected the development of the world tourism industry. Under this background, the international tourism community began to pay attention to the vulnerability of the tourism economy [5]. Foreign scholars' research on tourism economic vulnerability is mostly from the perspective of tourism crisis management, analyzing the causes of tourism economic vulnerability and the recovery and management of the tourism economy after encountering a crisis [6–9]. The research on fragility in China started relatively late. At first, scholars mainly focused on natural fragility [10, 11], ecological fragility [12–14], social fragility, and other single systems for analysis. With the deepening of vulnerability research, the focus of scholars has gradually shifted to complex system vulnerabilities, such as natural-social system vulnerability [15], social-ecological system vulnerability [16], human-land system vulnerability [17], human-sea system vulnerability [18], and human-environment system vulnerability [19]. In recent years, domestic scholars have been paying more attention to the vulnerability of the economic system, gradually changing from the focus on urban economic system vulnerability [20], marine economic system vulnerability research [21], transition to tourism economic system vulnerability research [22], and so on. Judging from the existing research results, the research on the vulnerability of the tourism economic system is mainly based on case studies of typical tourist destinations or tourist cities, and the content involves the measurement and evaluation of the vulnerability of the tourism economic system [23], the evolution of the temporal and spatial pattern [24] and analysis of influencing factors [25], and so on. But in general, the current domestic research on the vulnerability of the tourism economic system is still relatively weak, lacking a unified tourism economic system vulnerability research framework and comprehensive evaluation system, and the vulnerability research method is based on the set pair analysis method [26], principal component analysis method, TOPSIS method, and obstacle degree model [27], and some new methods are urgently needed to enrich the research.

This paper takes the GBA as the research object and draws on the relevant literature at home and abroad. It first constructs the tourism evaluation indicator system and uses the BPNN prediction model to evaluate and predict the GBA city cluster. This paper studies the two major dimensions of the tourism economy in the GBA and obtains the spatial distribution characteristics of the GBA city cluster from the perspective of vulnerability according to the positive and negative correlation between them. For the economic vulnerability theory, there are some laws and phenomena at a certain time and space. The vulnerability of the tourism economy is to study the rationality of the development mode of the tourism industry in the GBA in the future and pay attention to the laws and characteristics of the economy, environment, and sustainable development. Among them, the economic leap of the GBA is the basic condition for the survival and development of the tourism industry. Due to the two major characteristics, i.e., sensitivity and response capability, of the tourism economy in the vulnerability theory, the capability of the tourism economic system of a specified region to resist the risk is measured by the said two characteristics. Therefore, studying the spatial distribution law of the tourism economic vulnerability of the GBA city cluster can deal with the irresistible factors of tourism development in the future.

2. Study Design

2.1. Study Object. The study object is located in the GBA city cluster. Based on the vulnerability theory and the actual situation of the GBA, this paper selects the sensitivity, response capability, and vulnerability of the tourism indicator system. In terms of sensitivity, the paper selects seven macroeconomic basic indicators: the proportion of total tourism revenue in the GDP, the proportion of inbound

tourists in total tourists, the proportion of inbound tourism revenue in total tourism revenue, GDP growth rate, consumer price index, urban registered unemployment rate, and the percentage of employees in tertiary industry in total employees. As for the response capability, this paper selects indicators from per capita GDP, the growth rate of tourism revenue, the ratio of catering and lodging industry, the total retail sales of social consumer goods, the length of road transportation lines, the total investment in environmental pollution control, and the employees of environmental protection institutions. Vulnerability is taken from the ratio of two major dimensions. The formula reflects that there is a positive or negative correlation between sensitivity and response capability when a regional tourism economic system is facing risks [28]. (Table 1).

2.2. Data Collection

2.2.1. Indicator System. 2.2.2. Data Source. The data will be mainly from the official statistical yearbook of cities and regions in the GBA in 2021. The data are collected from the original data in the authoritative documents of the official statistical bureaus of major cities with a well-established indicator system.

3. Study Analysis

3.1. The Entropy Method Used to Calculate the Data Weight

3.1.1. Data Processing. In the evaluation of the tourism economic system in the GBA, the weight of the selected indicators will directly affect the objectivity of the data, and then affect the evaluation results [29]. Therefore, there are many ways to de-subjectivize the original data, among which the two most commonly used methods are subjective weighting method and objective weighting method; subjective weighting method generally includes the analytic hierarchy process (AHP), expert scoring method, and other methods. Its advantage is that it is easy to obtain indicators and has strong operability while its disadvantage is that it is too subjective without certain scientific rigorousness. Objective weighting method is to determine the weight through the connection degree of the original data displayed by the indicator system, including the entropy method and factor analysis method. The core point of the objective weighting method is information entropy. The greater the information entropy, the greater the degree of disorder of information, and the higher the degree of objectivity of the data. On the contrary, the smaller information entropy means the lower degree of disorder of information and the higher degree of subjectivity. Therefore, by using the entropy method to process objective original data, we can determine the degree of objectivity of information and avoid the error caused by subjective factors [30]. Therefore, this paper obtains objective and real data by querying the official statistical data of the GBA city cluster and uses the entropy method to determine the indicator weight. The steps of calculating data weight by the entropy method are the following:

Step 1. *Dimensionless processing of the original data.* In the statistics of the original data, there are differences in the unity and magnitude of the data, so it may be difficult to make the data comparison. In order to avoid the influence of these differences on the data in the evaluation process, the original data are generally subject to dimensionless processing first so that the data fall within the range of 0 to 1. According to the selected indicators and vulnerability impact degree, they are divided into P (positive indicator) and N (negative indicator). See Table 2 for the processing results.

$$\begin{aligned} \text{Postive indicator}: X_{ij}' &= \frac{X_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}}, \\ \text{Negative indicator}: X_{ij}' &= \frac{\max\{X_j\} - \{X_{ij}\}}{\max\{X_j\} - \min\{X_j\}}. \end{aligned} \tag{1}$$

Step 2. *Data translation.* After dimensionless processing, 0 may appear in some data. In order to avoid the impact on the consequence formula, the overall dimensionless data can be translated to the right by a small number, thus avoiding the difficulty of subsequent calculation caused by 0. At the same time, translation of a negligible small number has little impact on other data as shown in Table 3.

Step 3. *Calculation of the probability of data translation.* X_{ij} represents the sum ratio of the objects in group j to the jth indicator in each group i object. The formula is

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}. \tag{2}$$

Step 4. *Calculation of the entropy of the jth indicator.* As mentioned above, the greater the entropy, the more confused the amount of information, the greater the weight, and the higher the degree of objectivity reflected. In particular, it should be noted that "ln" is a natural logarithm and it is in the closed interval of (see Tables 4 and 5).

Step 5. Calculation of the difference coefficient of the jth indicator, which means that the larger the difference coefficient, the more important the indicator [31].

$$g_j = 1 - e_j. \tag{3}$$

Step 6. *Calculation of the data weight.* The formula for calculating the weight of the jth indicator is as follows:

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j}, \quad j = 1, 2, \ldots\ldots, m. \tag{4}$$

3.1.2. Evaluation Model. In the vulnerable system theory used in this paper, sensitivity and response capability are related to vulnerability. In a literal sense, sensitivity is the response speed of the city's tourism industry in the face of external interference, which shows the sensitivity of the city

Table 1: Vulnerability evaluation indicator system of tourism economic system in the GBA.

Target layer	Criteria layer	Code	Name and unit of indicator	Indicator nature	Indicator significance
Evaluation index of tourism economic vulnerability	Sensitivity	V_1	Proportion of total tourism revenue in GDP (%)	+	Economic dependence on tourism industry
		V_2	Proportion of inbound tourists in total tourists (%)	+	Attraction to inbound tourism
		V_3	Proportion of inbound tourism revenue in total tourism revenue (%)	+	Dependence on inbound tourism
		V_4	GDP growth rate (%)	−	Reflect the local economic development level
		V_5	Consumer price index	+	The impact of rising prices on residents' consumption
		V_6	Urban registered unemployment rate (%)	+	Unemployment rate
		V_7	Percentage of employees in tertiary industry (%)	−	Employability formed by the development of tourism economy
	Response capability	J_1	Per capita GDP (RMB)	+	Macroeconomic basis of tourism economic development
		J_2	Growth rate of tourism revenue (%)	−	Tourism economic growth
		J_3	Proportion of revenue of catering and lodging enterprises (%)	−	Regional accommodation reception capacity
		J_4	Total retail sales of social consumer goods (RMB)	−	Regional consumption reception capacity
		J_5	Length of road transportation line (km)	+	Transportation reception capacity
		J_6	Total investment in environmental pollution control (RMB)	+	Degree of environmental support for tourism development
		J_7	Personnel of environmental protection institutions (person)	+	Ability to deal with the negative impact of tourism development

Table 2: Dimensionless results of sensitivity indicator of tourism economic system.

City	V1	V2	V3	V4	V5	V6	V7
Guangzhou	0.001	0.773	0.958	0.065	0.156	0.931	0.001
Shenzhen	0.687	0.904	0.944	0.059	0.250	0.938	0.325
Foshan	0.927	0.993	0.997	0.083	0.125	0.942	0.454
Dongguan	0.843	0.992	0.980	0.091	0.063	1.000	0.590
Zhuhai	0.640	0.836	0.927	0.000	0.250	0.961	0.273
Huizhou	0.702	1.000	1.000	0.084	0.125	0.965	0.533
Zhongshan	0.828	0.974	0.991	0.084	0.156	0.938	0.538
Jiangmen	0.900	0.917	0.946	0.073	0.001	0.958	0.539
Zhaoqing	0.725	0.987	0.997	0.061	0.125	0.938	0.668
Hong Kong	1.000	0.001	0.001	0.196	1.000	0.001	1.000
Macao	0.549	0.858	0.104	1.000	0.156	0.938	0.968

Source: Ministry of culture and tourism of the People's Republic of China.

to external impact and destruction in a certain period of time to a certain extent; response capability is the tourism economic recovery capability after the city is disturbed by external interference. The two restrict each other and jointly affect the system vulnerability of urban areas. Specifically, when the urban tourism economic system faces external interference, it has strong sensitivity, weak response capability, and high vulnerability. On the contrary, when the system is faced with external interference, it has low sensitivity, higher response capability, and lower vulnerability. Therefore, urban system vulnerability is positively correlated with sensitivity and negatively correlated with response capability. Based on this, the vulnerability evaluation model formula is as follows [32]:

$$Ri = \frac{\mathrm{Vi}}{\mathrm{Ji}}, \tag{5}$$

where Ri is the evaluation indicator of system vulnerability, Vi is the evaluation indicator of system sensitivity, and Ji is the evaluation indicator of system response capability. The system sensitivity evaluation indicator refers to the weighted sum of the product of the dimensionless value of sensitivity and the weight of corresponding indicators, and the system response capability evaluation indicator refers to the

Table 3: Dimensionless results of response capability indicator of tourism economic system.

City	J1	J2	J3	J4	J5	J6	J7
Guangzhou	0.704	0.313	0.506	0.986	0.386	0.995	0.001
Shenzhen	0.612	0.000	0.287	0.987	0.496	0.001	0.113
Foshan	0.782	0.673	0.346	0.996	0.649	0.986	0.825
Dongguan	0.865	0.277	0.000	0.995	0.659	1.000	0.530
Zhuhai	0.664	0.173	1.000	1.000	0.927	0.988	0.840
Huizhou	0.948	0.678	0.552	0.999	0.071	0.987	0.974
Zhongshan	0.943	0.962	0.325	0.999	0.837	0.998	0.943
Jiangmen	0.960	1.000	0.199	1.000	0.334	1.000	0.904
Zhaoqing	1.000	0.745	0.103	1.000	0.001	0.997	1.000
Hong Kong	0.001	0.113	0.502	0.987	0.594	0.759	0.165
Macao	0.370	0.406	0.453	0.001	1.000	0.990	0.872

Source: Ministry of culture and tourism of the People's Republic of China.

Table 4: Information entropy of tourism economic system sensitivity indicator.

V1	V2	V3	V4	V5	V6	V7
0.954	0.959	0.932	0.678	0.803	0.960	0.930

Table 5: Information entropy of tourism economy response capability indicator.

J1	J2	J3	J4	J5	J6	J7
0.947	0.888	0.901	0.960	0.909	0.959	0.907

weighted sum of the product of the dimensionless value of response capability and the weight of corresponding indicators (see Table 6).

3.1.3. Evaluation Criteria. Because of the diversity of the theoretical indicator system of tourism economic vulnerability, there are no corresponding classification criteria in the world at present. Based on the review of many papers and literature, this paper selects a relatively simple classification method. The vulnerability indicator of the tourism economic system of cities and regions in the GBA is divided into three levels (low, moderate, and high), representing three different evaluation criteria.

3.1.4. Evaluation Results. In order to describe the distribution difference of tourism economic vulnerability among cities and regions in the GBA, the mean $X = 1.014$ and standard deviation $S = 0.448$ of vulnerability in the GBA are used as the basis for classification and evaluation criteria [33]. The vulnerability degree is divided into three interval ranges in Table 7: low vulnerability, moderate vulnerability, and high vulnerability. The specific division method is that low vulnerability area falls within the range of $0 < R' < X\text{-}S$, moderate vulnerability area falls within the range of $X\text{-}S < R' < X$, and high vulnerability area falls within the range of $X < R < X + S$ (see Table 8 for details).

Table 6: Weight value of comprehensive indicator of tourism economic system.

Indicator	Information entropy	Indicator weight
V1	0.954	0.035
V2	0.959	0.031
V3	0.932	0.052
V4	0.678	0.245
V5	0.803	0.150
V6	0.960	0.030
V7	0.930	0.053
J1	0.947	0.040
J2	0.888	0.085
J3	0.901	0.076
J4	0.960	0.030
J5	0.909	0.069
J6	0.959	0.031
J7	0.907	0.071

3.2. Study and Analysis Based on BP Artificial Neural Network Model

3.2.1. Neural Network Fitting Training. The input layer and output layer of the BP neural network toolbox are 2 and 1, respectively, representing three groups of data samples in the GBA, and the hidden layer is placed at 3. For 11 cities and regions in the GBA, dimensionless processed sensitivity data samples, response capability data samples, and expected value samples of vulnerability data calculated by the evaluation model are subject to the fitting training. The whole training process is divided into two parts. The first part is data training, that is, randomly select groups of existing data samples for training. The data samples are from the sensitivity statistics and response capability statistics of the cities and regions in the GBA in 2021. Groups are selected according to the standard data as the expected target value for training, and the standard data are calculated from the vulnerability evaluation model formula according to the two dimensions, such as sensitivity and response capability. The second part is the test sample. The BP neural network model will be tested according to the training results. In case of great error, it will be transmitted back to the feedforward input layer for repeated training and constantly correct the

Table 7: Evaluation criteria grade of vulnerability of tourism economic system in the GBA.

	Low vulnerability	Moderate vulnerability	High vulnerability
GBA evaluation criteria	0, 0.565	0.565, 1.014	1.014, 1.463

Table 8: Comprehensive indicator evaluation value of tourism economic system.

Region	Sensitivity V	Responsiveness J	Vulnerability R
Guangzhou	0.141	0.181	0.781
Shenzhen	0.199	0.119	1.675
Foshan	0.207	0.279	0.740
Dongguan	0.205	0.203	1.007
Zhuhai	0.178	0.302	0.589
Huizhou	0.205	0.273	0.751
Zhongshan	0.212	0.331	0.641
Jiangmen	0.185	0.288	0.642
Zhaoqing	0.205	0.244	0.843
Hong Kong	0.287	0.154	1.861
Macao	0.400	0.246	1.628

data sample error to get the data closest to the expected value sample, thereby finally getting the fitting test result [34].

According to the indicator system constructed by the GBA city cluster and the actual situation, there is no evident correlation between the tourism economic system and various indicators. In mathematical language, it is a nonlinear functional relation, and it is impossible to find a one-to-one functional mapping relation. In order to facilitate the research, the relevant data as collected and summarized of the GBA city cluster in 2020 are divided into two groups: the sensitivity indicator data and response capability indicator data in the tourism economic system vulnerability evaluation indicator system of the GBA city cluster in 2020 and the vulnerability indicator data calculated by the evaluation model formula, which is used as the reference sample for fitting the expected value of the data [35]. Firstly, unified relevant data of cities and regions in the GBA in 2020 are imported as the input layer for BP neural network toolbox fitting training, and the fitting process is completed after the best training results are obtained through multiple training. It can be seen from Figure 1 that the error of the training set always varies within the range of 0.0000001–1 when the BP neural network model trains the sample data, and the verification set and test set also fall within this range. The best point of the model training results is that at the point of the error of 0.0004, the error range of most of the fitted data and expected data is controlled within 0.0004. Figure 2 shows the error distribution of the training set, verification set, and test set. It can be seen that most of the errors of the three data sets are distributed within the range of −0.01751 to 0.01752, with a few data sets scattering in other ranges. Figure 3 shows the correlation between data fitting and expected value, expressed by the correlation coefficient R. If it is close to 1, the correlation coefficient R indicates good data fitting. On the contrary, if the data are closer to 0, it means that the data fitting is poorer. Figure 4 can be seen that the correlation coefficients of the training set, verification set, and test set are above 0.99, infinitely close to 1, which means good accuracy, falling within the required range of fitting error, and satisfactory sample results. Therefore, it can ensure the establishment of the BP neural network model and high accuracy of the indicator system as well as the accuracy of data training to a certain extent [36]. The fitting process results are given in Table 9.

3.2.2. Prediction Results of Vulnerability Indicators of the GBA City Cluster and Regions Predicted by BP Neural Network. Upon completion of the fitting, the indicator data of 11 cities in the GBA are reimported into the trained model, the predicted value is obtained through the fitted linear function relation, and then the expected predicted value of the vulnerability indicator is obtained from the predicted value of each indicator data with the evaluation model formula. Finally, the prediction results of the vulnerability indicator of the GBA city cluster and regions are obtained as shown in Table 10.

3.2.3. Spatial Distribution of the Vulnerability of Tourism Economic System in the GBA Based on BP Neural Network. According to the vulnerability prediction indicator of the tourism economic system, the vulnerability of the tourism economic system is divided into three levels: low, moderate, and high. According to the prediction data sample analysis of the BP neural network model, the average value of the vulnerability indicator of the tourism economic system of cities and regions in the GBA is 0.874, indicating that the tourism economic system in the GBA is in a state of moderate vulnerability on the whole. According to the statistical analysis of the number of cities and regions, there are 7 cities in the low vulnerability range and moderate vulnerability range, accounting for 72.72% of the total number of cities and regions in the GBA. The total number of cities in the high vulnerability range is 3, accounting for 27.27% of the total number of the GBA. The prediction data results show that the number of cities with tourism economic system vulnerability in the GBA presents the distribution characteristics more in the middle and less at the bottom [37]. In terms of spatial distribution, most of the cities with moderate vulnerability in the tourism economic system are concentrated in the middle and periphery of the GBA, showing the distribution characteristics of "C"-type encirclement. Cities with low vulnerability are surrounded by the "C" type in the city cluster with moderate vulnerability in the GBA while the cities with high vulnerability are at the bottom of the GBA. On the whole, the vulnerability of the tourism economic system in the GBA has an agglomeration effect.

(1) *City with low vulnerability: Shenzhen.* According to the original indicator data of the constructed tourism

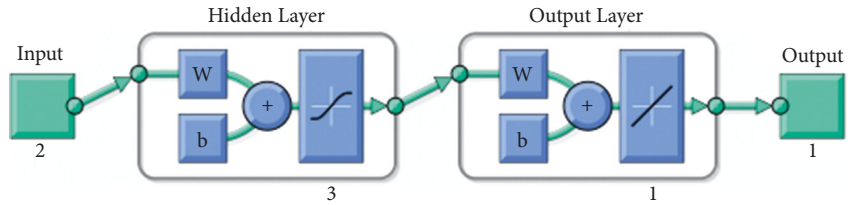

Figure 1: Structural diagram of BP neural network model.

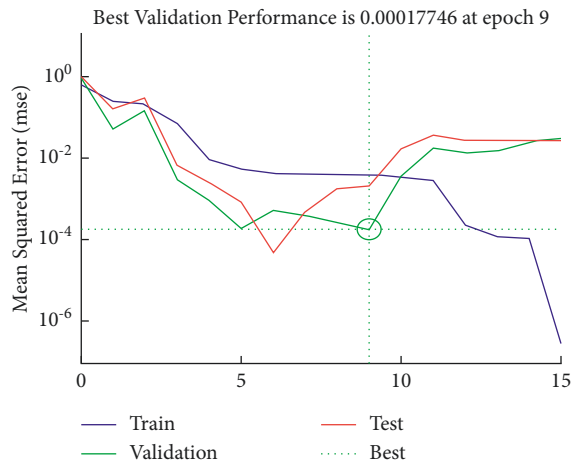

Figure 2: Training fitting curve of BP neural network training set, verification set, and test set.

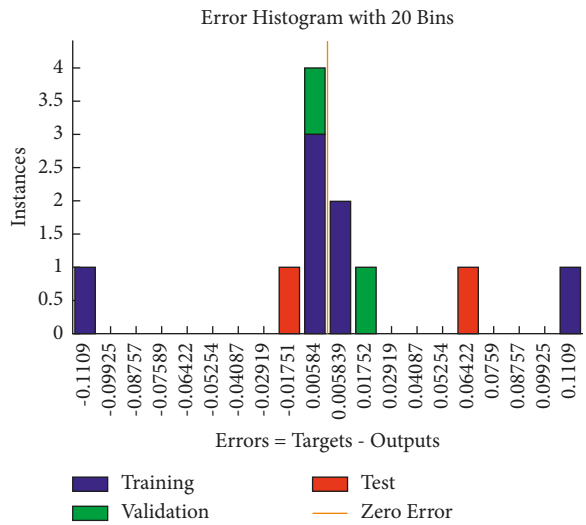

Figure 3: Error distribution diagram of BP neural network model training and fitting process.

economic vulnerability indicator system in the GBA [38], V1 (the proportion of tourism revenue in GDP in Shenzhen) is not high, only at 5%, indicating that the main economic structure of Shenzhen does not depend on tourism, and J1 (per capita GDP) ranks third in the GBA, indicating that there is also a strong support for the recovery of tourism economy despite of the impact of the COVID-19 epidemic. Another factor is sanitation. As Shenzhen J6 (total investment in environmental pollution control) ranks first in the GBA, another important factor affecting the tourism industry is the environmental conditions of tourism destinations. It is obvious that the Shenzhen municipal government's significant investment in environmental maintenance plays a significant role in the current operation of the tourism industry and the recovery after fighting risks. Similarly, the J7 indicator (number of personnel of environmental protection institutions) plays the same role as the J6 indicator (total investment in environmental pollution control) in Guangzhou alone. Shenzhen J2 (growth rate of tourism revenue) is −19%. As one member of the city cluster of the GBA, Shenzhen has the smallest impact compared with other cities in the GBA in spite of the negative growth of tourism revenue in the face of the COVID-19 epidemic. To sum up, according to the system of this paper and in combination with the original data of indicators, this paper explains the reasons why Shenzhen has low vulnerability.

(2) *Cities with moderate vulnerability: Foshan, Dongguan, Zhuhai, Huizhou, Zhongshan, Jiangmen, and Zhaoqing.* According to the results predicted by the BP neural network model, the order from high to low is Dongguan > Zhaoqing > Huizhou > Foshan > Zhongshan > Jiangmen > Zhuhai. From the sorting order, we can know that the maximum value among cities with moderate vulnerability in the GBA is 1.004, the predicted vulnerability indicator of Dongguan, the minimum value among cities with the minimum is 0.713, the predicted vulnerability indicator of Zhuhai, and the average vulnerability indicator among city cluster with moderate vulnerability is 0.803. It can be seen that the reasons why Dongguan ranks first among the city cluster with moderate vulnerability are mostly that Dongguan ranks first among all cities by its excessively large J3 indicator (the proportion of revenue of catering and lodging enterprises). Tourism is closely related to catering and lodging enterprises. The chain reaction arising from the COVID-19 epidemic may cause two of the five major elements of catering, lodging, travel, shopping, and entertainment of Dongguan tourism industry to be directly paralyzed. Looking at other indicators, Dongguan has the moderate vulnerability on average. Zhuhai is the city with the lowest indicator within the range of moderate vulnerability. Influenced by the culture of Hong Kong and Macao

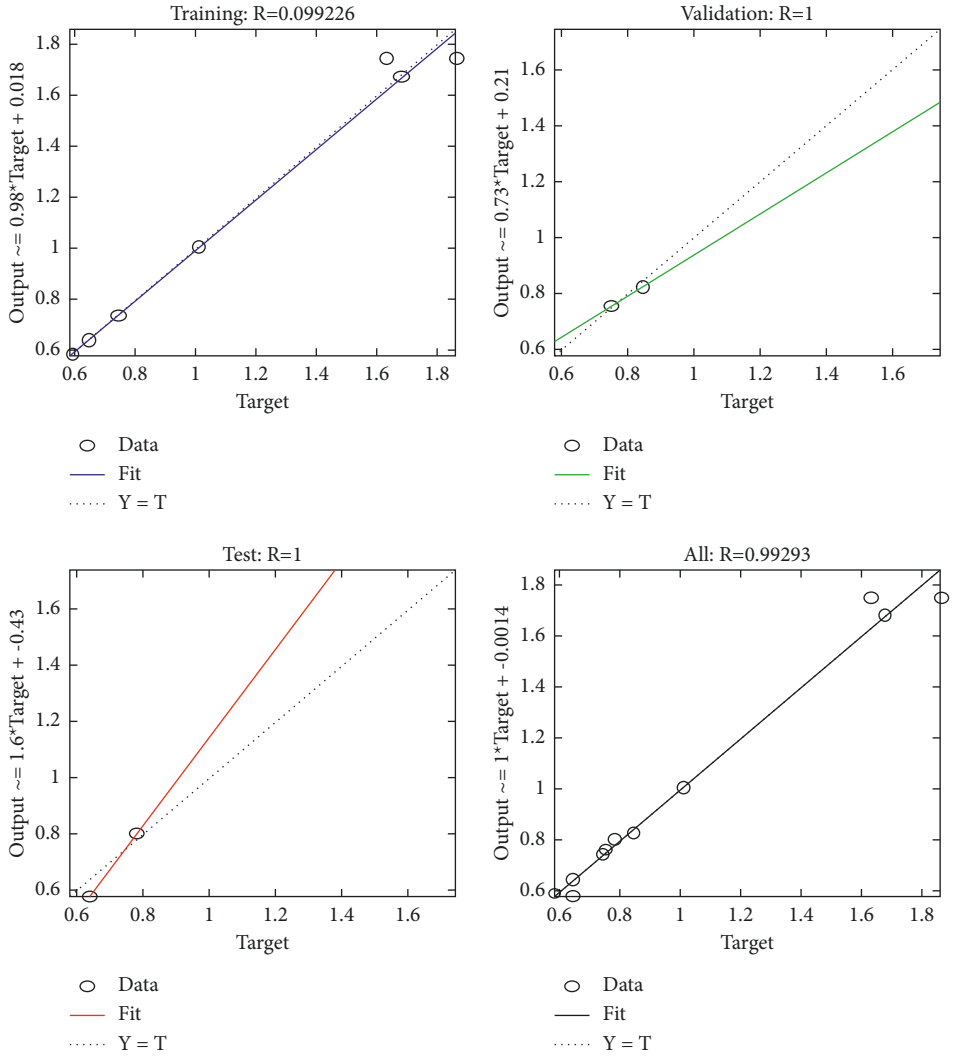

Figure 4: Training fitting correlation coefficient of BP neural network model.

Table 9: Training fitting results of BP neural network model.

City	V	J	R
Guangzhou	0.141	0.181	0.768
Shenzhen	0.199	0.119	2.039
Foshan	0.207	0.279	0.746
Dongguan	0.205	0.203	1.009
Zhuhai	0.178	0.302	0.591
Huizhou	0.205	0.273	0.751
Zhongshan	0.212	0.331	0.644
Jiangmen	0.185	0.288	0.630
Zhaoqing	0.205	0.244	0.843
Hong Kong	0.287	0.154	1.861
Macao	0.400	0.246	1.627

Table 10: Prediction results of BP neural network model.

City	V	J	R
Guangzhou	1.245	0.972	1.281
Shenzhen	0.986	1.523	0.548
Foshan	1.008	1.311	0.769
Dongguan	1.001	0.997	1.004
Zhuhai	0.977	1.369	0.713
Huizhou	1.002	1.286	0.779
Zhongshan	1.026	1.339	0.766
Jiangmen	0.970	1.338	0.725
Zhaoqing	1.004	1.161	0.865
Hong Kong	1.334	1.108	1.204
Macao	1.009	1.170	1.863

and the tourism industry and culture of Zhuhai in the coastal area that cannot be overlooked, Zhuhai ranks last in the range of moderate vulnerability mainly because its service sector is performing well [39]. From the original data, it can be seen that in terms of the indicator V7 (percentage of employees in the tertiary industry), Zhuhai is only behind Guangzhou and Shenzhen and the only city with V7 exceeding 50% in the GBA except the first-tier cities including Guangzhou and Shenzhen. In addition, due to its J1 (per capita GDP) ranking top and V1 (the proportion of total tourism revenue to the GDP) with a low proportion, J6 (total investment in environmental pollution control), and J7 (the total

number of personnel of environmental protection institutions), Zhuhai ranks last in terms of its prediction result of BP neural network model in the city cluster with moderate vulnerability. Except for cities ranking medium between Dongguan and Zhuhai, the difference of vulnerability indicator is small, basically floating within the range of 0.716–0.865, not more than 0.149 up or down, which means generally stable.

(3) *Cities with high vulnerability: Guangzhou, Hong Kong, and Macao.* The prediction results of the BP neural network model show that Guangzhou, Hong Kong, and Macao are the only three cities with high vulnerability in the GBA. The ranking order from top to down is Macao > Guangzhou > Hong Kong. Macao ranks first in terms of the vulnerability indicator in the GBA city cluster. It is a city with high vulnerability. Though covering a small area and boasting a small population, Macao has developed the tourism industry, giving its own advantages. It connects with Zhuhai, Guangdong Province geographically. Gongbei pass has facilitated the development of tourism in Hong Kong and Macao before. As for tourism resources, Macao boasts rich cultural resources. The intersection of Chinese and Western cultures has left many places of interest and cultural customs in Macao [40]. In addition, the most important point is that Macao's developed gambling industry is an important factor to attract a large number of tourists, and such tourists attracted by the casino have also driven Macao's tourism industry, making Macao a tourist attraction, covering from tourism to accommodation, jewelry, nightclub, and other entertainment venues [41]. The highly developed tourism industry in Macao has been severely affected by the COVID-19 epidemic. According to the original data of the tourism indicator system constructed in this paper, although Macao V1 (the proportion of tourism revenue to the GDP) is only 6.14%, other related industries of Macao relying on tourism have been greatly implicated, resulting in a chain reaction. The original data V4 (the growth rate of Macao's GDP) declines sharply, by 56%. As a direct result, Macao's GDP fell by half compared with that in the previous year. The original data also show that the GDP of Macao and Hong Kong in the context of COVID-19 epidemic achieved negative growth, which is not optimistic.

The difference in the predicted vulnerability value between Guangzhou and Hong Kong is 0.07, and in terms of vulnerability, two cities are basically close to each other. Guangzhou is rich in tourism resources. It has not been only natural tourism resources but also rich cultural tourism resources. Recently, Guangzhou is gradually integrating the cultural tourism industry and providing a series of tourism products in line with Guangzhou culture, such as Guangzhou Creative Industry Park, Butterfield & Swire's Godowns & Wharf, Urban Imprint Park, and other tourism and cultural products [42]. In addition, the slogan "Cuisine in Guangzhou" has attracted tourists from all over the country and even overseas to come to Guangzhou to taste delicious food. Therefore, it can be seen that Guangzhou not only has developed the manufacturing industry but also have great development potential for its tourism industry. From the original data, it can be seen that the V1 indicator of Guangzhou (the proportion of total tourism revenue to GDP) rank first, with a value of 10.7%, accounting for the largest share among the GBA city cluster. The same V2 indicator (the proportion of inbound tourists to total tourists) is second only to Hong Kong, and the value of J2 indicator (the growth rate of tourism revenue) is −39.8%. The data show that Guangzhou has shown high vulnerability due to the strong impact of the COVID-19 epidemic on the tourism industry; Hong Kong's economy is supported by four major industries: finance, industry and commerce, trade and logistics, and tourism, which are the four pillars of Hong Kong's economy [43]. Among them, Hong Kong is known as a "shopping paradise" and attracts tourists from all over the world by means of its unique local culture, including those who rely in mainland China. Since the opening of Hong Kong customs, which is the same as Macao, the number of tourists from mainland China visiting Hong Kong has been on the rise. In addition, Hong Kong's perfect tourism industry management regulations have greatly improved the experience of tourists visiting Hong Kong. It can be seen from the original data table that the value of Hong Kong's V1 indicator (the proportion of total tourism revenue to GDP) is 2.39%, which is roughly the same as that of Macao. Industries related to tourism have suffered major economic trauma due to the strong impact of the COVID-19, resulting in a negative growth of −5.5% in Hong Kong's V (the growth rate of GDP). Compared with Macao, Hong Kong's industrial structure is more diversified than that of Macao. After the outbreak of the COVID-19 epidemic, the decline in GDP is far less serious than that of Macao. To sum up, in the three cities, due to the impact of the COVID-19 epidemic on their highly developed tourism industry which involves a wide range of related industries, their advantages have turned into defects. Therefore, it is necessary to consider whether the cities can set out to restore the tourism industry at present and after the finish of the COVID-19 epidemic.

4. Conclusion and Recommendations

4.1. Findings of the Study

(1) On the whole, the tourism economic system of the GBA is moderately vulnerable. According to the number of cities, the spatial distribution shows the characteristics of more in the middle and less at the bottom. The statistical analysis of the magnitude of the data also shows that the moderately vulnerable city cluster is featured by the distribution outside the GBA, a "C" type surrounding internal cities, with cities with low vulnerability and those with high vulnerability in the middle and bottom of the GBA area, respectively.

(2) In the analysis of the prediction data of the vulnerability of the tourism economic system in the GBA, it is also found that the distribution of "agglomeration effect" among cities with moderate vulnerability and the overall tourism economic vulnerability in the GBA are balanced without obvious differences.

(3) In the detailed analysis of cities and regions in the GBA, the diversification of industrial structure is the main factor affecting the vulnerability of the tourism economic system in the GBA and an important prerequisite for maintaining the stability of the tourism economic system in the long run.

4.2. Contribution of the Study. The vulnerability of the tourism economic system in the GBA reflects the sustainable development capability of a region's tourism economy. The lower the vulnerability, the higher the sustainable development level of the tourism economy in the region. Otherwise, the higher the vulnerability, the lower the sustainable development level of tourism economy in the region. The results predicted with the above BP neural network model show that the instability of the tourism economic system shown by the city with high vulnerability at the bottom is extremely vulnerable to the impact of external risks, resulting in the decline of the economy of the whole region, which indicates that the city cluster with high vulnerability will become a crisis while it has developed tourism industry in case of any risk. In short, we need to adjust the vulnerability of the tourism economy in the GBA. First, we must have a correct understanding of vulnerability. Only when we understand the vulnerability can we better solve the vulnerability issue.

4.3. Practice Enlightenment

(1) We should establish and improve the tourism industry system. All cities in the GBA should first pay attention to the industrial structure. Optimizing the tourism industrial structure is the main factor for the analysis of the vulnerability of the tourism economy in the GBA, and the important prerequisite for maintaining the long-term stability of the tourism economic system is the structure of industrial diversification. Of the indicators, the proportion of inbound tourists in the total number of tourists and the annual growth rate of tourism revenue impose the greatest impact on the analysis of the vulnerability of the tourism economic system. The specific suggestions and countermeasures are as follows: to develop the tourism infrastructure manufacturing industry and optimize the structure of the tourism industry. The revenue from the tourism infrastructure manufacturing industry can drive the development of relevant industries, offer a great number of jobs, and solve the employment issue to a certain extent. Even the development of the tourism infrastructure manufacturing industry may not directly improve the cultural tourism industry. It can promote the adjustment and optimization of the tourism industry structure and drive the upgrading of related industries so as to achieve the purpose of optimizing the tourism industry structure. The tourism industry involves an excessively broad scope. Specifically, in addition to tourism enterprises, the tourism also the cooperation between many other links in its industry. So, the government should introduce relevant policy systems.

(2) We should increase financial investment. We should promote the innovation in the tourism industry, establish and improve the financial guarantee mechanism, and ensure the investment budget of fiscal departments at all levels for the construction of cultural tourism. We should reduce tax burden pressure. We should treat the utility bills of tourism enterprises in the same way as those of industry, offer tax reduction and subsidy for the investment of enterprises entering the tourism industry, and promote the rapid development of the tourism industry by adjusting tax rates and other policies [44]. We should adjust the structure of the tourism industry and offer relevant support and gradually reduce the government investment with the continuous improvement of the rate of return in the future. At the same time, according to the promotion effect of the tourism industry on the regional economy, we should give investors corresponding returns and rewards in turn. The perfection of the tourism industry system plays a strong role in promoting the optimization of the internal structure of the tourism economic system. It is a powerful measure and also the fundamental guarantee for reducing the vulnerability of the tourism economic system.

(3) We should enhance the attraction of tourism destinations, deeply develop tourism resources, and reasonably design tourism products to help reduce the vulnerability of the tourism economic system and improve the self-recovery capability of the region. Therefore, improving tourism attraction is one of the effective measures to reduce the vulnerability of the tourism economic system in a region. To protect the tourism environment, first of all, a development factor of the tourism industry is dependent on the tourism environment. At the same time, the development of tourism in the GBA is also affected by external factors, such as economic foundation, transportation foundation, basic public infrastructure, and ecological environment. In terms of ecological environment, the quality of tourism ecological environment may directly affect the entire

tourism economy of the GBA and have a considerable impact on the vulnerability of the tourism system. Therefore, a good ecological environment in an area is conducive to the self-recovery of a regional tourism economic system and the reduction of regional sensitivity, and improving the capability to resist external risks while reducing vulnerability is a solution to the sustainable development of a regional tourism economic system.

In a word, the economic development environment can provide a foundation for the GBA's tourism economic system in terms of regional economic growth, adjustment and optimization of tourism industrial structure, and establishment and improvement of tourism management regulations so as to promote the sustainable development of the GBA's tourism economic system and improve the GBA's capability to deal with risks. In the vulnerability evaluation indicator system of the tourism economic system, residents' consumption level, GDP growth rate, per capita GDP, and the proportion of tertiary industry in the GDP are the comprehensive embodiments of the capacity to support the GBA's economy. In three aspects, we should have a correct understanding of the vulnerability issue, adjust and optimize the tourism industry system, and improve the tourism environment so as to put forward the countermeasures and recommendations for the vulnerability issue in the GBA.

4.4. Limitations of the Study. The evaluation indicator system of this paper only selects a few indicators, and the samples are not rich enough. Compared with the real problem research, this paper is not scientific and rigorous, and the data analysis is not perfect. It cannot be fully and truly reflect the issue of urban vulnerability. The real reasons for the vulnerability of various regions of the GBA have not been explored.

Data Availability

All the data have been included in the article.

Conflicts of Interest

The author declares no conflicts of interest.

Acknowledgments

The paper was supported in part by (1) Co-construction project in 2020 of the 13th five-year plan for the development of philosophy and Social Sciences in Guangzhou (serial number: 2020GZGJ102) and (2) "Building Guangdong-Hong Kong-Macao Greater Bay Area" and "supporting Shenzhen to build a leading demonstration area of socialism with Chinese characteristics" of Guangdong philosophy and Social Sciences Planning Special Project (serial number: GD20SQ07).

References

[1] X. Guo, Q. Zhang, and Y. Li, "Study on the economic system vulnerability of small and medium-sized tourism cities along the "the Belt and Road" -- A case study of Dunhuang City," *Economic Survey*, vol. 32, no. 4, p. 6, 2015.

[2] L. Cheng, *Study on the Harmonious Development of Stakeholders in Vulnerable Ecotourism Areas*, Sichuan University Press, Chengdu, China, 2008.

[3] Q. Zhao, *Functional Zoning and Ecological Vulnerability Assessment of Soil and Water Conservation in Shanxi Province*, Shandong Agricultural University, Tai'an, China, 2014.

[4] X. Yu, H. Xu, and S. Wang, "Vulnerability assessment and spatiotemporal differentiation of provinces tourism economic system based on the projection pursuit clustering model," *Discrete Dynamics in Nature and Society*, vol. 2021, Article ID 4330728, 12 pages, 2021.

[5] F. Li, "Study of vulnerability measurement of Chinese tourism economic system:Based on SPA," *Tourism Science*, vol. 27, no. 1, pp. 15–28, 2013.

[6] G. Patrick, "Assessing the economic vulnerability of small island developing states and the least developed countries," *Working Papers*, vol. 46, no. 5, pp. 828–854, 2010.

[7] M. Csete, T. Pálvölgyi, and G. Szendrő, "Assessment of climate change vulnerability of tourism in Hungary," *Regional Environmental Change*, vol. 13, no. 5, pp. 1043–1057, 2013.

[8] S. L. Perchnielsen, "The vulnerability of beach tourism to climate change: an index approach," *Climatic Change*, vol. 100, no. 3-4, pp. 579–606, 2010.

[9] D. Scott, J. Dawson, and B. Jones, "Climate change vulnerability of the US northeast winter recreation: tourism sector," *Mitigation and Adaptation Strategies for Global Change*, vol. 13, no. 5-6, pp. 577–596, 2008.

[10] L. R. Tan, K. Chen, and J. Wang, "Assessment on storm surge vulnerability of coastal regions during the past twenty years," *Scientia Geographica Sinica*, vol. 31, no. 9, pp. 1111–1117, 2011.

[11] X. W. Shi, Z. X. Guo, and Y. Zhang, "A review of research on vulnerability to storm surges," *Progress in Geography*, vol. 35, no. 7, pp. 889–897, 2016.

[12] P. X. Li and J. Fan, "Regional ecological vulnerability assessment of the guangxi xijiang river economic belt in southwest China with VSD model," *Journal of Natural Resources*, vol. 29, no. 5, pp. 779–788, 2014.

[13] D. J. Zhang, H. Gao, and J. Yang, "Assessment for the ecological vulnerability of Nansihu Wetland based on GIS technology," *Resources Science*, vol. 36, no. 4, pp. 874–882, 2014.

[14] J. H. Lin, G. J. Hu, and X. H. Qi, "Ecological environmental vulnerability and its driving forces in urban agglomeration in the Fujian Delta region," *Acta Ecologica Sinica*, vol. 38, no. 12, pp. 4155–4166, 2018.

[15] S. E. Zhou, M. J. Zhang, and S. J. Wang, "Assessment of vulnerability in naturalsocial system in Hexi,Gansu," *Resources Science*, vol. 40, no. 2, pp. 452–462, 2018.

[16] J. Chen, X. J. Yang, S. Yin, K. Wu, M. Deng, and X. Wen, "The vulnerability evolution and simulation of the social-ecological systems in the semi-arid area based on the VSD framework," *Acta Geographica Sinica*, vol. 71, no. 7, pp. 1172–1188, 2016.

[17] L. X. Zhang, X. J. Yang, and J. Chen, "Vulnerability assessment and mechanism of human-land systems in the Han Dynasty Chang'an large relic area," *Resources Science*, vol. 37, no. 9, pp. 1848–1859, 2015.

[18] B. Li, Z. L. Han, C. Z. Sun, and Q. Di, "Spatial and temporal vulnerability analysis of the human-sea resource environment of the Bohai Rim Region," *Resources Science*, vol. 34, no. 11, pp. 2214–2221, 2012.

[19] P. Chen and X. L. Chen, "Summary on research of coupled human-environment system vulnerability under global environmental change," *Progress in Geography*, vol. 29, no. 4, pp. 454–462, 2010.

[20] Y. R. Yang, S. J. Wang, and X. H. Chen, "Dynamic evolution and control approaches of petroleum city's economic system vulnerability: a case study of Daqing City," *Scientia Geographica Sinica*, vol. 35, no. 4, pp. 456–463, 2015.

[21] F. Peng, Z. L. Han, and J. Yang, "Time-space differentiation of the vulnerability of marine economy systems in China's coastal area based on BP neural networks," *Resources Science*, vol. 37, no. 12, pp. 2441–2450, 2015.

[22] F. Su, Y. Chen, and P. Y. Zhang, "Vulnerability assessment of tourism city's economic system based on the set pair analysis: a case study of Zhoushan City," *Scientia Geographica Sinica*, vol. 33, no. 5, pp. 538–544, 2013.

[23] F. Li, N. Q. Wan, and B. L. Shi, "The vulnerability measure of tourism industry based on the perspective of "environment-structure" integration: a case study of 31 provinces in mainland China," *Geographical Research*, vol. 33, no. 3, pp. 569–581, 2014.

[24] F. Jia, H. Miao, Y. X. Kong, and G. Yirui, "Evaluation on system vulnerability of regional tourism economy in Ningxia," *Journal of Ningxia University (Humanities & Social Sciences Edition)*, vol. 38, no. 4, pp. 409–414, 2017.

[25] P. Yin, S. G. Liu, and P. L. Duan, "Analysis on the vulnerability and obstacle indicators in island type tourism destination: Take Zhoushan City for example," *Economic Geography*, vol. 37, no. 10, pp. 234–240, 2017.

[26] Y. B. Lu, X. D. Li, and X. P. Zhao, "Tourism economic system's vulnerability assessment of Hotan Prefecture in Xinjiang," *Areal Research and Development*, vol. 36, no. 1, pp. 120–124, 2017.

[27] B. Y. Lu, Q. Z. Ming, and X. Y. Guo, "Vulnerability evaluation,influencing factors and coping strategies of tourism economic system in Frontier provinces: a case study of Yunnan," *Journal of Yunnan Normal University (Natural Sciences Edition)*, vol. 38, no. 5, pp. 66–74, 2018.

[28] K. Tang, *Study on the Economic System Vulnerability and Sustainable Development of Tourism Cities*, Yunnan Normal University, Kunming, China, 2017.

[29] H. Jisheng, H. Ren, and W. Jing, "BP neural network stock price prediction based on adaptive genetic algorithm optimization," *Henan Science*, vol. 35, no. 2, p. 6, 2017.

[30] L. Dai, *Study on Social Ecosystem Vulnerability of Rural Tourism Destination Based on Household Survey*, Zhengzhou University, Zhengzhou, China, 2017.

[31] W. Wen, *Study on the Prediction of Product Quality Conformity Rate Based on Improved BP Neural Network*, South China University of Technology, Guangzhou, China, 2014.

[32] Q. Ma, *Evaluation of marine Ecological Environment Security in Zhejiang Province Based on BP*, Zhejiang Ocean University, Zhoushan, China, 2019.

[33] C. Li and J. Fan, "Study on the prediction of ecotourism volume in Taibai Mountain based on BP neural network," *Protection Forest Science and Technology*, vol. 6, p. 3, 2013.

[34] X. Fang, *Study on the Characteristics of Economic Connection and Spatial Structure of the GBA City Cluster*, South China University of Technology, Guangzhou, China, 2019.

[35] G. Weng and Q. Zhang, "Study on the vulnerability evaluation of tourism economic system in western regions," *Commercial Research*, vol. 7, p. 8, 2015.

[36] M. Liu and W. Qianmei, "Study on spatial differentiation of vulnerability of tourism economic system in China's border areas," *Resource Development & Market*, vol. 37, no. 9, p. 7, 2021.

[37] Q. Zhang, *Study on the Vulnerability of Economic System of Small and Medium-Sized Tourism Cities*, Lanzhou University, Lanzhou, China, 2014.

[38] S. Liu, *Study on Economic Vulnerability of Specialized Tourism Cities*, Yunnan University, Kunming, China, 2019.

[39] Z. Zhu and B Tang, "Study on the economic vulnerability of tourism dependent cities-a case study of Macao Special Administrative Region," *Special Zone Economy*, vol. 10, p. 3, 2018.

[40] B. Xia, Q. Fu, and H. Xu, "Application of mathematical method in economic field -- Prediction of tourism demand by fitting linear equation method," *Financial Theory and Teaching*, vol. 96, no. 4, pp. 45-46, 2008.

[41] X. Xia, "Vulnerability assessment of tourism economic system in the core area of the Silk Road Economic Belt," *Discrete Dynamics in Nature and Society*, vol. 2022, no. 5, Article ID 4330728, 2022.

[42] Q. Zhang, *Study on the Vulnerability Evaluation of Tourism Economic System in Western Region*, Yanshan University, Qinhuangdao, China, 2014.

[43] M. Deery, "Journal of hospitality and tourism management," *Journal of Hospitality and Tourism Management*, vol. 52, p. 18, 2011.

[44] T. Li, *Study on the Vulnerability of Agricultural Regional Socio-Economic System in Hainan Island*, Hainan Normal University, Haikou, China, 2020.