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Construction of Early Warning System for Tourism Environment Carrying Capacity of Cultural Heritage Sites under Low Carbon Economy

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Abstract: With the development of tourism, cultural heritage has become a new hot spot in tourism. Tourism not only improves citizens' awareness of cultural heritage protection, but also provides financial, technical and environmental advantages for the protection of cultural heritage. However, on the other hand, the contradiction between the development of tourism service industry and the protection of cultural heritage become increasingly prominent, and the continuous development of tourism is putting more and more pressure on the protection of cultural heritage. In addition, due to the increase in tourists and environmental issues such as global warming caused by pollution from greenhouse gas emissions, people's production and living conditions are facing severe and unprecedented challenges. Coupled with the fragility of the environmental system of tourist attractions in cultural heritage sites, this paper intended to study and establish a tourism environment early warning system that could accommodate the carrying capacity of cultural heritage on the basis of low-carbon economy. The active monitoring and dynamic early warning simulation of the tourism environmental capacity in the future period has become an urgent and major need for cultural heritage tourism scenic spots. After the research and experiment of this paper, taking a cultural heritage site as the research object, the forest coverage rate of the scenic spot reflecting the natural ecological environment capacity in terms of tourism environment was more than 80%. The air quality was always excellent and the standard rate of ornamental water quality was 100%. The economic and environmental capacity early warning index showed a linear upward trend, with an average annual increase of 102%. The social and environmental capacity early warning index showed a mild downward trend.

1. Introduction

People's demand for tourism has grown dramatically as a result of the social economy's rapid expansion, which further supports the industry's positive growth. However, there are significant issues in the cultural heritage tourism living environment due to the recent short-term and large-scale trend of tourism environmental management. These issues include the devastation of the ecological environment system, the misuse of tourism resources, and the ongoing overabundance of tourist attractions. Future growth initiatives and the carrying capacity of the tourism environment are unavoidable trends. In order to accomplish objectives, implement sustainable control measures, and advance cultural heritage tourism, an early warning system for cultural heritage tourism is developed using the theoretical underpinnings of tourism environmental carrying capacity and early warning systems. Timely early warning systems are also constructed, and current and future tourism environmental carrying capacities are predicted.

This paper made the case that the early warning report on the heritage tourism environment was intended to stop the system's development from going from orderly to disorderly, based on an analysis of other changes in time and space of the heritage protection tourism environment system. This paper discussed the issue of damage to the tourism environment caused by tourism activities from various perspectives, suggested the use of advanced early warning principles and methods to optimize the comprehensive system of tourism environment in cultural heritage sites, and exhaustively and methodically promoted evaluation projects and early warning research in the early stage to promote the harmonious development of tourism surrounding environment and cultural heritage.

2. Literature Review

The tourism environment of cultural heritage sites has attracted much attention, more and more people are interested in it and many scholars have done a lot of research. Su R explained a cultural political economy "framework" for explaining heritage tourism in urban contexts. Based on the relational view of the interconnectedness of social relations, he emphasized the seriousness of cultural symbols and economic politics in the co-composition of social practices and characteristics of urban heritage tourism [1]. Giuliani F conducted a disaster risk analysis of the Italian historic center, and took into account the value of cultural heritage assets, as well as proposed a qualitative method for heritage-oriented risk assessment [2]. In her analysis of museum buildings' status as heritage institutions, Mosquera-Perez C found that restoration and the conversion of foreign galleries into museums were of special importance [3]. The carrying capacity of Gerasa, one of the Dekapolis cities in Jordan, was evaluated by A A M. A mathematical model for determining carrying capacity was used in the study's methodology, and it was altered in the ArcGIS 10.2 environment [4]. According to Pioppi B, maintaining the cultural heritage masterpieces of tourism and local sociocultural identity while providing thermal comfort conditions for outdoor residents was crucial within the framework of the urban resilience problem [5]. These studies are all targeted, but the research in the direction of low-carbon economy is insufficient.

Environmental protection is a concern that people must deal with as the population base grows, and people are also becoming more and more aware of the environment's carrying capacity. Li X N developed a thorough index system of soil environmental carrying capacity by examining the input-output flux in order to comprehend the influence of soil environmental carrying capacity on pollutants and human activities, effectively prevent the escalation of soil pollution, and control soil environmental risks [6]. According to Wang S, socioeconomic growth could only be deemed sustainable when the ecosystem was functioning at its typical carrying capacity [7]. Wang J Y created a three-layer structure for the aquatic environment carrying capacity evaluation index system based on the DPSIRM model's development [8]. Resource and Environmental Carrying Capacity (RECC), in Zhang F's opinion, is a crucial pillar for cities' long-term growth. Given China's growing urbanization, a precise assessment of RECC was crucial [9]. Zhou X felt that it was essential to create an efficient Reward and Punishment Mechanism (RPM) for areas within the watershed based on the performance of Water Resources Environmental Carrying Capacity

(WRECC) because of the pollution discharge, overuse of water resources, and significant regional imbalances [10]. However, in many studies, the construction of the early warning system of tourism environment carrying capacity was not very in-depth and comprehensive. Therefore, combined with the current environmental form, this paper would study the construction of an early warning system for the tourism environment carrying capacity of cultural heritage sites under the low-carbon economy.

3. Environmental Carrying Capacity Early Warning Method

3.1 Tourism Environment of Cultural Heritage Sites under the Low-carbon Economy

In addition to being a new form of travel that has emerged in line with the trend of low-carbon economic growth, low-carbon tourism is also a reaction to the tourism industry's low-carbon economic development [11]. The low-carbon economy identifies the path for low-carbon tourist development and has significant ramifications for its realization in terms of the growth of tourism resources, patterns of consumption, and patterns of behavior.

There are three important characteristics of a low-carbon economy, as shown in Figure 1.

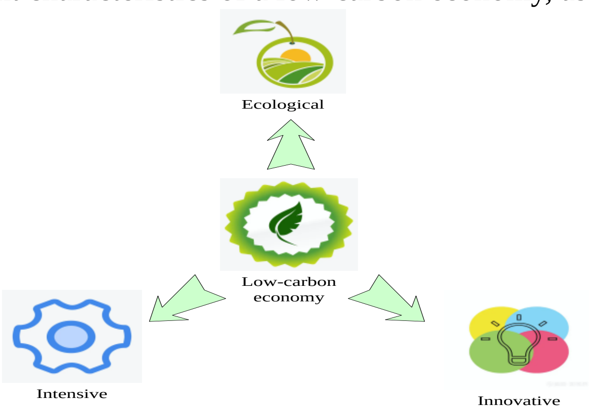

Figure 1. Three characteristics of a low-carbon economy

The first is innovation: It includes not only technological innovation, continuous development and innovation of low-carbon technologies, but also institutional innovation and concept innovation. From the ideological point of view, it is necessary to have a new understanding and transformation of the development mode and create a positive environment for the development of low-carbon economy through policy and system innovation; the second is ecological: Carbon emissions are reduced to protect the ecological environment; the third is intensiveness: Different from the traditional extensive development mode, the road of "low energy consumption, low pollution and low emission" is an important path choice for developing a low-carbon economy. On the basis of these three lows, the efficiency of economic development and energy efficiency are continuously improved to promote rapid and sustainable economic development [12].

The low-carbon concept is integrated into the whole process of tourism resource development and construction, which is the key link and important prerequisite for realizing low-carbon tourism. This paper adopts the human-society-economic-environmental structure and divides the sustainable development system of world heritage tourism into three stages [13-14].

3.2 Quantitative Evaluation of Early Warning Indicator System

(1) The basic steps of the coefficient of variation method

With an a-year sample and b specific measurement indicators, a $a \times b$-order matrix can be obtained from the sample data. y_{ij} represents the observed value of the i th evaluation object on the j th indicator.

The mean $\overline{y_j}$ and standard deviation S_j of each indicator are calculated:

$$\overline{y_j} = \frac{1}{a}\sum_{i=1}^{a} y_{ij}, j = 1,2,\cdots,b \tag{1}$$

$$S = \sqrt{\frac{1}{a}\sum_{i=1}^{a}(y_{ij} - \overline{y_j})^2}, j = 1,2,\cdots,b \tag{2}$$

The coefficient of variation U_j for each indicator is calculated:

$$U_j = \frac{S_j}{y_j}, j = 1,2,\cdots,b \tag{3}$$

Finally, the coefficient of variation is normalized to obtain the weight of each indicator ω_j:

$$\omega_j = \frac{U_j}{\sum_{j=1}^{b} U_j} \tag{4}$$

(2) Determination of indicator weights

The judgment matrix is constructed according to the quantified value of the importance of each indicator [15]. The general expression of the judgment matrix is as follows: In the formula, n_{ij} represents the importance of the i th factor to the j th factor, and n_{ij} and n_{ji} have a reciprocal relationship, that is, $n_{ij} = \frac{1}{n_{ji}}$.

$$N = (n_{ij})_{m \times m} = \begin{bmatrix} n_{11} & n_{12} & \cdots\cdots & n_{1m} \\ n_{21} & n_{22} & \cdots\cdots & n_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ n_{m1} & n_{m2} & \cdots\cdots & n_{mm} \end{bmatrix} \tag{5}$$

According to the constructed judgment matrix, the following methods are used to calculate the eigenvalues and eigenvectors of the judgment matrix.

$$\overline{u_1} = \sum_{j=1}^{m} \frac{n_{ij}}{\sum_{i=1}^{m} n_{ij}}, i, j = 1,2,\cdots,m \tag{6}$$

The vector $\overline{u} = [\overline{u_1}, \overline{u_2}, \cdots, \overline{u_n}]^T$ is normalized, and the resulting $u = [u_1, u_2, \cdots, u_n]^T$ is the desired eigendirection:

$$u = \frac{\overline{u_i}}{\sum_{j=1}^{m} \overline{u_j}}, i = 1,2,\cdots,m \tag{7}$$

The calculation of the largest eigenvalue of the matrix is as follows:

$$\zeta_{\max} = \sum_{i=1}^{m} \frac{(NU)_i}{mu_i} \tag{8}$$

(3) Hierarchical single ordering and consistency check

The first-level classification refers to calculating the weight value of the importance order of all factors of this level relative to the previous level factors according to the table [16]. In order to check the consistency of the matrix, the consistency index GI and the consistency ratio GR are also calculated.

$$GI = \frac{\zeta_{\max} - m}{m-1} \tag{9}$$

$$GR = \frac{GI}{RI} \tag{10}$$

When $GR < 0.1$, it means that the judgment matrix has satisfactory consistency, otherwise it needs to be adjusted. Among them, RI is the random consistency index.

3.3 Construction of Early Warning System for Tourism Environment Carrying Capacity of Cultural Heritage Sites

(1) Basic steps of early warning

Clarifying the warning's meaning, identifying its source, evaluating the warning sign, determining the warning's level of severity, and removing the warning patient are the five fundamental processes of the early warning system. Finding the source of the warning and evaluating warning signs is a qualitative or quantitative examination of the indicators and elements of early warning status. The fundamental requirement of early warning is to make the warning's meaning clear. Warning the degree of warning is the final form of early warning output, and eliminating the warning patient is to use the early warning mechanism to pre-control the warning situation.

Clarifying the warning means clarifying the object of monitoring and early warning and determining the police situation. It mainly includes two aspects: warning element and warning limit. The warning element refers to the indicators that constitute the police situation, and the warning limit refers to the safety limit of the police situation element. According to the severity of the police situation, the police limit can be divided into different levels [17].

(2) Quantitative evaluation model of each component of early warning indicators

In the process of calculating the actual early warning index, a comprehensive evaluation of the early warning index value of the tourism environment capacity should be carried out [18]. The quantitative calculation model of the comprehensive index value of the tourism environment early warning ability of cultural heritage sites can be obtained:

$$C = f_1 * E + f_2 * R + f_3 * F + f_4 * P \tag{11}$$

Among them, C is the comprehensive index value of early warning of tourism environment carrying capacity, and E is the early warning index of tourism ecological environment carrying capacity, as well as f_1 is the weight value. R is the early warning index of tourism space environmental carrying capacity, and f_2 is the weight value, as well as F is the early warning index of environmental carrying capacity of tourism economic facilities. f_3 is the weight value, and P is the early warning index of social psychological carrying capacity, as well as f_4 is the weight value.

The natural ecological environment that constitutes the tourism environment system has certain self-generating functions. For example, air and water have self-cleaning functions, and this self-cleaning ability determines the size of the pollution absorption capacity [19]. The tourism ecological environment capacity of cultural heritage sites refers to the number of tourists allowed under the condition that the ecological environment is not destroyed, and its formula is:

$$E = \min(W, A, S) \tag{12}$$

In the formula, W is the water environment carrying capacity of cultural heritage sites:

$$W = \frac{\text{Daily sewage treatment capacity (volume/day)}}{\text{Daily sewage production per capita (amount/person-day)}} \tag{13}$$

A is the urban atmospheric environment carrying capacity:

$$A = \frac{\text{Regional atmospheric environment capacity}}{\text{Per capita waste gas production}} \tag{14}$$

S is the carrying capacity of solid waste in cultural heritage sites:

$$S = \frac{\text{Daily processing capacity of solid waste (volume/day)}}{\text{The amount of solid waste generated per capita per day (amount/person-day)}} \tag{15}$$

The ability of tourists to accept people in a certain period of time (such as one day) due to the spatial and temporal nature of tourists' visits to tourism resources is called the resource space carrying capacity R:

$$R = \frac{\text{Daily turnover rate} * \text{Total area of resource space}}{\text{Standard area of basic space per capita}} \tag{16}$$

The ability of the tourism economy to provide for the fundamental needs of visitors, such as food, shelter, transportation, and clothes, also determines the capacity of the tourism environment. Prior research findings indicate that the hotel's bed space, water supply, power supply, and transportation capacity—generally excluding inventory supply and non-essential supplies—are the four primary determinants of economic facilities' capacity [20-21].

4. Experiment and Evaluation on the Early Warning System of Tourism Environment Carrying Capacity of Cultural Heritage Sites

4.1 Experiment of the Early Warning System of Tourism Environment Carrying Capacity

This paper takes the tourism environment of a cultural heritage site as the research object, and constructs an early warning system for the carrying capacity of the tourism environment. The cultural heritage site has been favored by tourists in recent years. According to statistics, since its trial operation in 2015, the number of tourists has remained at around 3 million each year. By the end of 2021, it has received a total of 22.55 million tourists, and the changing trend of the number of tourists received is shown in Figure 2:

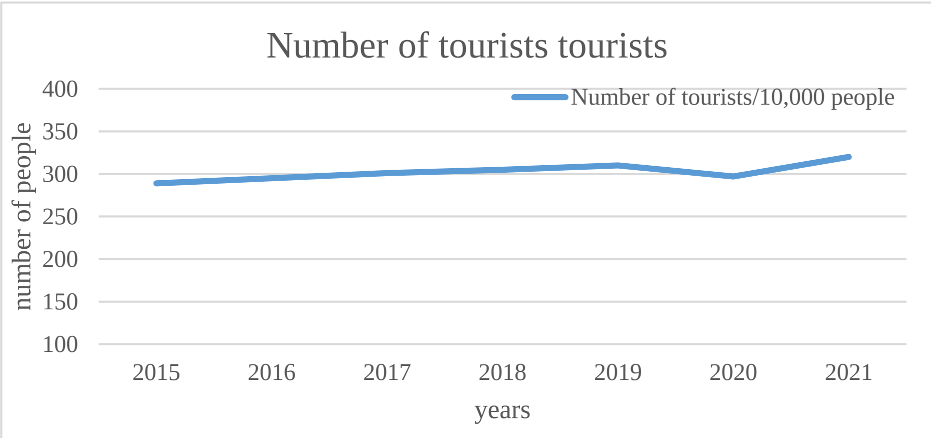

Figure 2. Tourist reception of a cultural heritage site from 2015 to 2021

At the same time, according to the field survey of scenic spots during the summer vacation (August 2020) and the results of the questionnaire survey of tourists, male tourists accounte for 49.3% and female tourists accounte for 50.7%, which is basically balanced; tourists aged 25-58 accounte for the highest proportion.

Based on the development status of cultural property tourism and the availability of data, the early warning indicator system is appropriately adjusted, and the early warning indicator system for cultural property tourism environmental capacity is determined as shown in Table 1.

Table 1. The early warning index system and weight of the tourism environment carrying capacity of the cultural heritage site

Tourism Environment Carrying Capacity Early Warning System		Weights		Variable name	Weights	Direction
	Ecological environment carrying capacity	0.2644	Scenic area tourable area ratio / %	Y_1	0.1698	+
			Appropriate time to visit/day	Y_2	0.0512	+
			Forest cover rate/%	Y_3	0.0311	+
			Ornamental water quality compliance rate / %	Y_4	0.0091	+
			Excellent air quality rate/%	Y_5	0.0032	+
	Economic environment carrying capacity	0.4536	Domestic wastewater treatment rate/%	Y_6	0.023	+
			Solid waste treatment rate/%	Y_7	0.0441	+
			Water supply capacity/10,000m^3	Y_8	0.0398	+
			Parking capacity/m^3	Y_9	0.1044	+
			Catering Capacity/Number of Seats	Y_{10}	0.0132	+
			Accommodation capacity/number of rooms	Y_{11}	0.1569	+
			Traffic carrying capacity/vehicle	Y_{12}	0.0722	+
	social environment carrying capacity	0.2819	Attractiveness of landscape resources/%	Y_{13}	0.0451	+
			Tourist Satisfaction Index / %	Y_{14}	0.0462	+
			Travelling ratio/%	Y_{15}	0.0161	-
			Number of scenic spot service personnel/person	Y_{16}	0.0872	+
			Ticket price/yuan	Y_{17}	0.0873	-

Table 1 shows the proportion of tourism environmental capacity in the natural environment, economy and social fields.

At the case site, the early warning indicator values in 2021 and 2022 are forecasted on a rolling basis, that is, each early warning indicator value in the first three years is used to predict the value in the fourth year until the accuracy requirements are met by analogy, and the execution steps are shown in Table 2.

Table 2. Execution steps of network early warning prediction model

Steps	input layer	output layer	type
1	$Y_{m2015}Y_{m2016}Y_{m2017}$	Y_{m2018}	training and testing samples
2	$Y_{m2016}Y_{m2017}Y_{m2018}$	Y_{m2019}	
3	$Y_{m2017}Y_{m2018}Y_{m2019}$	Y_{m2020}	
4	$Y_{m2018}Y_{m2019}Y_{m2020}$	Y_{m2021}	
5	$Y_{m2019}Y_{m2020}Y_{m2021}$	Y_{m2022}	prediction sample

The network adjustment results of the early warning evaluation model constructed by BP neural network can be used to evaluate the tourism environment capacity. According to Table 2, the early warning guarantee and early warning coverage rate of tourism environmental capacity in the case area are shown in Table 3.

Table 3. Warning boundaries for early warning

Years	2015-2020				
Alert status	Weak load area	Growth area	Health area	Optimum load area	Overload area
Natural ecosystems	<0.0788	[0.0788,0.1442)	[0.1442,0.2790)	[0.2790,0.3481)	≥0.3481
Economic environment	<0.1750	[0.1750,0.2701)	[0.2701,0.4593)	[0.4593,0.5525)	≥0.5525
Social environment	<0.2093	[0.2093,0.2315)	[0.2315,0.2771)	[0.2771,0.2994)	≥0.2994
Years	2015-2022				
Tourism environment	<0.1671	[0.1671,0.2070)	[0.2070,0.2855)	[0.2855,0.3251)	≥0.3251
Alert	Serious policeI	Light policeI	No police	Light policeII	Serious policeII

4.2 Experimental Results and Evaluation of the Tourism Environmental Carrying Capacity Early Warning System

After formula operation, the early warning index of the early warning subsystem of the tourism environment carrying capacity of the cultural heritage site from 2015 to 2021 is obtained as shown in Figure 3:

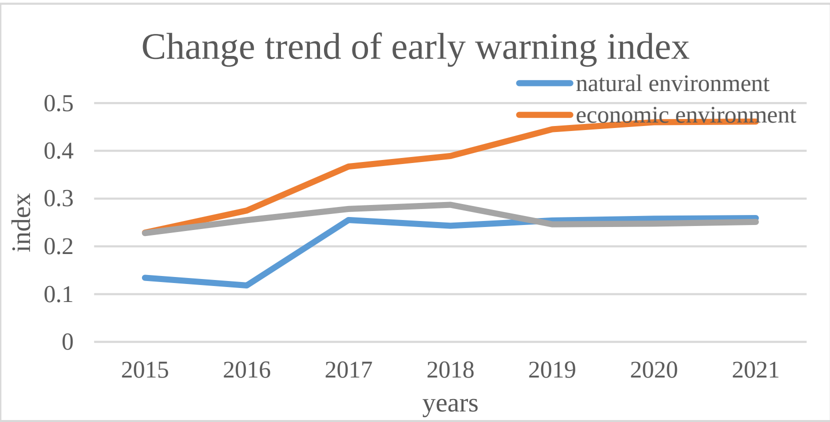

Figure 3. The early warning index of the early warning subsystem of the tourism environmental carrying capacity of the cultural heritage site from 2015 to 2021

According to Figure 3, the early warning index of the natural ecological environment showed a significant increase and decrease twice in 2016 and 2017, and it showed a downward trend from 2015 to 2016, reaching the lowest in 2016. 2015-2016 was in the development and construction period. Due to the construction of many tourist facilities, the water quality compliance rate and forest coverage rate of scenic spots have declined, and the ecological environment capacity has weakened.

5. Conclusions

This paper systematically studies this concept, based on tourism research and theoretical status quo of tourism environment capacity and early warning environment capacity evaluation index system early warning. Combined with the real situation of cultural heritage, a specific analysis of its tourism environment carrying capacity was carried out. In this paper, the early warning system was used to conduct a comprehensive early warning evaluation of the tourism environment carrying capacity of a cultural heritage site and forecast the short-term trend of tourism development of the cultural heritage site. However, the current research on the carrying capacity of cultural heritage sites is not very mature. According to different research objects, the determination model of the capacity limit of tourism environment is not yet clear. How to scientifically avoid the intervention of subjective factors is one of the difficulties in the study of tourism environment capacity. Therefore, the environmental tourism evaluation index system in this paper needs to be further improved.

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