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Protection model based on value assessment and vulnerability curve

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Abstract: Extreme weather has become one of the most serious challenges to humans' lives, its increasingly frequent occurrences affect the preservation and protection of many cultural buildings, to judge the cultural and historical value of a cultural building and its vulnerability to extreme weather, so as to further realize its preservation and protection. This paper establishes the historical and cultural value evaluation model and the vulnerability curve of cultural heritage buildings based on the AHP-Field method, Mann-Kendall test and quintile regression respectively. Taking Fujian Tulou as an example, we obtained the historical and cultural evaluation system and the vulnerability curve affected by heavy rain, and comprehensively considered the relationship between the two, and obtained comprehensive measures to protect Fujian Tulou buildings. Make feasible suggestions on how to protect ancient buildings in the case of heavy rain and provide reference for the evaluation and protection of other regions.

1. Introduction

With global warming, extreme weather is occurring with increasing frequency and is transforming from a classic black swan event to a gray rhino event. The increasing number of extreme weather events globally have resulted in significant economic losses. To cope with the losses caused by extreme weather, insurance companies have developed insurance for some buildings, real estate, etc. for property protection. Among many buildings, cultural relics, as buildings of great significance, how to assess their historical and cultural value and protect them in extreme weather is particularly important in terms of culture and economy.

For a long time, there have been many studies on the evaluation of building value and the establishment of regional vulnerability curves caused by precipitation. Gerrote J combined the flood disaster matrix generated from flood data with the vulnerability matrix of cultural heritage at the regional scale [1]; Rui Figueiredo with the help of the flood disaster data provided by the National Environmental Information System, they constructed a risk model, heritage exposure model and vulnerability model, and quantified the risk indicators and drew them into a risk map [2]; TERASHIMA Y uses contingent valuation method(CVM)to calculate the cultural value of the coastal area [3]; Yu Tingting systematic analysis of the disaster factors of flood disaster in Fujian province --the time and space of rainstorm Characteristics, construct the rainstorm-flood disaster vulnerability curve [4]; Saraswati Thapa couples the flood risk analysis with the vulnerability of tile houses and rough houses, the most important building system along the river channel. Establish vulnerability and vulnerability functions based on the measured submerged water depth [5].

However, at this stage, most studies separate value assessment from vulnerability assessment, and less study the historical and cultural value and vulnerability of buildings in the same area. This article mainly focuses on the ancient building right of Fujian Tulou, evaluates its historical and cultural value and builds a vulnerability curve affected by precipitation. It comprehensively considers both and puts forward protective suggestions.

2. The basic fundamental of model

2.1 The structure of AHP method

In multi-criteria decision-making, the importance of each criterion may be different, and it is difficult to directly determine the weight of each criterion through subjective judgment. Therefore, we chose the AHP-Field [6] method. This method provides a systematic and quantitative way to determine the weights, based on expert judgment and comparison, which makes the decision more scientific and reliable.

(1) standardized layer

First, through the Delphi method, several experts' opinions were solicited and discussed repeatedly by the expert group, and the judgment matrix was constructed by comparing the guideline-level indicators pairwise on a scale of 1-9.

Calculate the geometric mean of each scale data of each line in the judgment matrix, record it, and then standardize it. The standardized processing formula is as follows:

$$w_i^{'} = \frac{w_i}{\sum w_i} \tag{1}$$

Where w_i means rating of indicator

The calculated according to the formula is the contribution rate of the index corresponding to the upper target, namely the weight.

Then the judgment matrix was tested for consistency, according to Eq. (2-4):

$$A\omega = \lambda_{\max} A \tag{2}$$

$$CI = \frac{(\lambda - n)}{(n-1)} \tag{3}$$

$$CR = \frac{CI}{RI} \tag{4}$$

Where A is scoring matrix, λ is maximum eigenvalues of the comparison matrix, CI is coincidence indicator, n is matrix row number.

When CR < 0.1, we consider that the consistency of the standardized horizontal judgment matrix passes the test.

(2) indicator layer

The same method was used to compare the indicator layers of each criterion layer in pairs and to construct the corresponding judgment matrices. By calculation, the judgment matrices at the indicator level all pass the consistency test.

2.2 The structure of Mann-Kendall test

The original hypothesis H_0 is that the time series data (X_1... , X_n), are n independent, identically distributed samples of random variables: the alternative hypothesis H1 is a bilateral test that the distributions of X_k and X_j are not the same for all k, j≤n, and k≠j, and the statistic S of the test is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} Sgn(X_j - X_k) \tag{5}$$

$$Sgn(X_j - X_k) = \begin{cases} +1, (X_j - X_k) > 0 \\ 0, (X_j - X_k) = 0 \\ -1, (X_j - X_k) < 0 \end{cases} \tag{6}$$

Where *S* is a normal distribution with mean 0 and variance $V_{ar}(S)$.

$$V_{ar}(S) = \frac{n(n-1)(2n-5)}{18} \tag{7}$$

When n>10, the standard normal system variables are calculated by the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{V_{ar}(S)}}, \ S > 0 \\ 0, \ S = 0 \\ \frac{S+1}{\sqrt{V_{ar}(S)}}, \ S < 0 \end{cases} \tag{8}$$

In a bilateral trend test, the original hypothesis is not accepted if |Z|≥Z1-α/2 at a given α confidence level, indicating that there is a significant upward or downward trend in the time series data at the α confidence level. For the statistic Z, greater than 0 is an upward trend and less than 0 is a downward trend.

The significance level *α* is a concept in hypothesis testing that refers to the probability or risk that one rejects the original hypothesis when it is correct. It is the value of the probability of a recognized small probability event a, which must be determined prior to each statistical test, and is taken to be *α* = 0.1. This indicates that the decision to accept the original hypothesis, when made, has a 90% probability of being correct. *α*= 0.1 has a z-value for a two-sided test of 1.645.

When the Mann-Kendall test is further used to test for sequence mutations, the test statistic differs from Z above by constructing an order column:

$$S_K = \sum_{i-1}^{k} \sum_{j}^{i-1} \alpha_{ij} \quad (k = 2,3,4,\ldots,n) \tag{9}$$

$$\alpha_{ij} = \begin{cases} 1 \ X_i > X_j \\ 0 \ X_i < X_j \end{cases} \quad 1 \le j \le i \tag{10}$$

Define statistical variables:

$$UF_k = \frac{[S_k - E(S_k)]}{\sqrt{Var(S_k)}} \quad (k = 1,2,\ldots,n) \tag{11}$$

$$E(S_k) = \frac{n(n+1)}{4} \tag{12}$$

$$V_{ar}(S_k) = \frac{n(n-1)(2n+5)}{72} \tag{13}$$

Where UF_k is the standard normal distribution

Given the significance level α, if $|UF_k|>U\alpha/2$, then it indicates that there is a significant trend change in the series, the time series x is arranged in reverse order, and then calculated according to the above equation, while making:

$$UB_k = -UF_k \quad k = n, n-1, \ldots, 1 \tag{14}$$

2.3 The theory of quantile regression

Quantile regression modeling involves dividing the dependent variable into a certain number of quartiles and then examining the regression impact relationship for each quartile.

1) Determination of quartiles

In a quantile regression model, the choice of quantile needs to be determined first. Commonly used quantiles include 0.5 (median), 0.25, 0.75 and so on. These quantiles can reflect the distribution of the dependent variable at different levels.

2) Build a model

Based on the selected quantile, a quantile regression model can be constructed. Specifically, for a given independent variable X and dependent variable Y, we can build the following model:

$$Q(\tau|X) = \beta_0(\tau) + \beta_1(\tau) X \tag{15}$$

Where $Q(\tau|X)$ denotes the τ-quantile of Y at a given value of X. $\beta_0(\tau)$ and $\beta_1(\tau)$ are model parameters that can be estimated by least squares or other methods.

3. Results

3.1 The results of AHP-Field method

To realize the evaluation of the cultural and historical value of cultural relics and buildings and the evaluation of their risk levels, this paper selects the Earthen Building in Fujian Province as the evaluation object. On the one hand, earthen buildings use special construction methods and materials, which are difficult to repair once damaged. On the other hand, the Fujian region is often affected by typhoons and hurricanes. These extreme weather conditions may pose a serious threat to the structural stability and building integrity of earthen buildings. The above two conditions meet the requirements of the area we are evaluating.

Based on the current situation of Fujian Tulou in the form of scoring the evaluation factors of the 8 indicator layers, according to AHP method and Field method, the field method index scores are indicated by the ”√” in Table 1, the final score is calculated by weighting the score, as shown in Table 1:

Further, by finding the relevant index data of the Tulou Ancient Building Complex in Fujian Province, the data is normalized. After weighted calculation, a comprehensive score of cultural historical value can be obtained.

Table 1: Expert scoring and weighting results

Criterion layer	Guideline layer score	Expert scoring	Indicator layer	Indicator layer score
Cultural value 0.340	1.59	√ 4 3 2 1	Regional Culture 0.23	1.15
		5 √ 3 2 1	Spiritual values 0.11	0.44
Historical value 0.386	1.75	√ 4 3 2 1	Historical background 0.29	1.45
		5 4 √ 2 1	Heritage value 0.10	0.3
Economic value 0.181	0.6	5 √ 3 2 1	Business value 0.12	0.48
		5 4 3 √ 1	Tourism value 0.06	0.12
Community significance 0.093	0.3	5 4 √ 2 1	Human Values 0.08	0.24
		5 4 √ 2 1	Planning Layout 0.02	0.06

3.2 Analysis of Mann-Kendall test

To establish a vulnerability curve, this study first used the Mann-Kendall method to conduct trend analysis and mutation test of rainstorm volume in Fujian Province. The results are shown in Figure 1:

From the results of the MK test, there was a significant increase in rainfall between 2005 and 2006, followed by a gentle change between 2006 and 2007. However, there was a significant decrease in rainfall between 2007 and 2012, and from 2012 to 2015, the decreasing trend flattened out again. Then, the precipitation increased significantly from 2015 to 2016, and the increasing trend slowed down from 2016 to 2019. From 2019 to the statistical deadline of 2020, there was a slight decrease. Therefore, we take 2007 and 2019 as the sudden changes in rainfall reduction and increase, respectively.

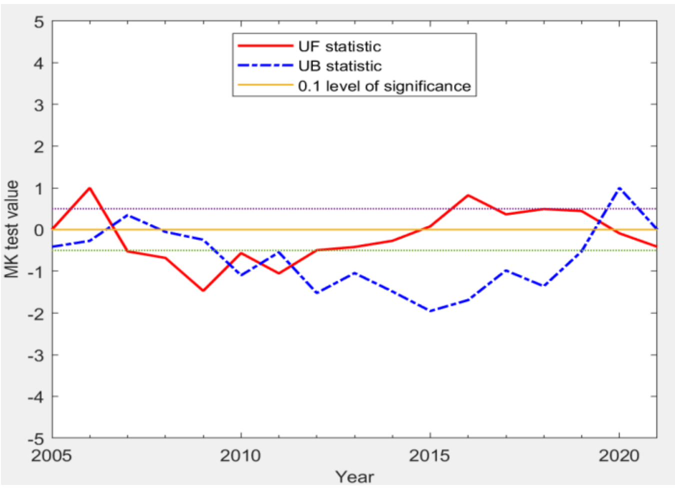

Figure 1: The vulnerability curve fit in fig

3.3 The result of quantile regression

We looked for data on the annual rainstorm volume, affected crop area in Fujian Province for vulnerability assessment. We take the annual rainstorm volume as the independent variable and the affected crop area as the dependent variable and establish a quarter fitting curve with a centiles of 0.45. The results are shown in Figure 2:

From the vulnerability fitting curve, the vulnerability of Tulou is not highly affected by the local environment.

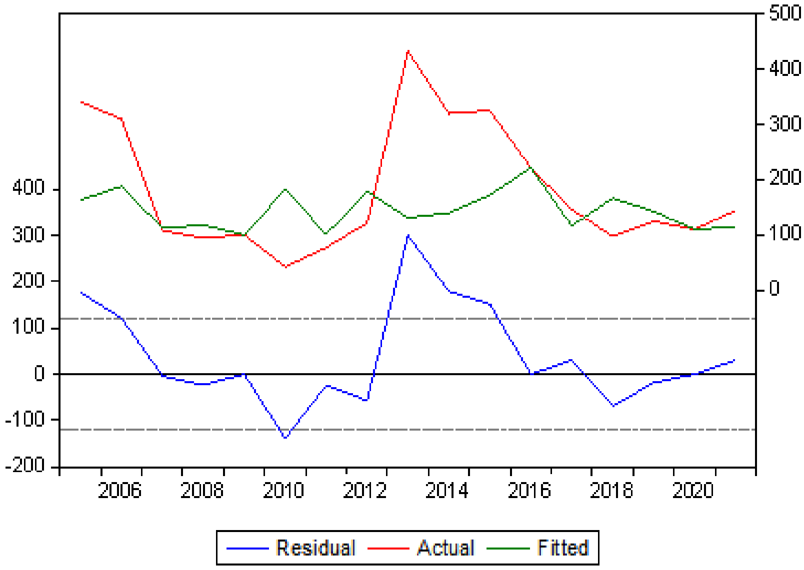

Figure 2: The MK test results in fig

Because Fujian Tulou has a certain historical and cultural value and is less affected by local precipitation and rainstorms, we adopt In-situ protection. The specific measures are as follows:

1) Maintaining and restoring heritage in situ to preserve its original historical and cultural values.

2) Various measures, such as the construction of protective walls and reinforcement of structures, are taken to ensure that heritage can exist safely in the local environment.

3) Develop management plans and policies to ensure that the heritage is managed and protected in the local environment.

4. Conclusions and outlooks

This study intends to evaluate the historical and cultural value of historical cultural relics and their vulnerability under extreme weather conditions. Using the AHP-Field method, MK test and quintile regression to establish a historical and cultural value evaluation model and vulnerability curve, based on this modeling Fujian earth buildings, we can get the conclusion that they have a certain historical and cultural value and that their damage is not affected by heavy rain in Fujian. Based on this, protection suggestions for on-site protection are given to provide reference for how to protect other regions and types of buildings under the influence of extreme weather.

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