

Regional Building Value Assessment under Extreme Weather Based on HEN Assessment Model

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Abstract. The frequent occurrence of extreme weather events has caused significant losses around the world, which has drawn attention to property sustainability. In order to better evaluate the value of regional buildings under the influence of extreme weather, this paper proposes a HEN evaluation model. First of all, this paper selects three first-level indicators: humanity, economy and nature, and extends this to 10 second-level indicators. Secondly, this paper proposes different data normalization methods for different types of indicators, and uses three methods to determine the weight from a combination of subjective and objective perspectives. Finally, this paper proposes the building value index (BVI) and applies the model to 50 states in the United States. In addition, this paper divides BVI into five value levels, and proposes different levels of protection measures according to the value levels.

Keywords: Analytic Hierarchy Process, Entropy Weight Method, K-means, Building Value Index.

1. Introduction

“We must address the climate crisis and the crisis of inequality to ensure that no one is left behind.”
- Professor Celeste Soro, Secretary-General of the World Meteorological Organization.

In today's world, extreme weather occurs more and more frequently, bringing major challenges and disturbances to human society. Extreme weather events are an important manifestation of climate change and have become a crisis affecting property owners and insurance companies. In recent years, climate change has made weather more unpredictable, and the frequency and intensity of extreme weather events such as floods and droughts have shown a clear upward trend [1]. These events include extreme high and low temperatures, precipitation, storms, floods and droughts, the occurrence of which not only affects natural ecosystems but also brings huge economic, social and environmental losses to human society. Studies have shown that economic losses and damages caused by floods, hurricanes, etc. are increasing year by year [2].

Natural disasters are becoming more frequent and expensive, and insurance companies are facing huge challenges. In some areas affected by extreme weather, insurance companies may not or are unwilling to insure [3]. This could lead to district leaders facing difficult decisions regarding properties of cultural or regional significance. As a regional leader, it is particularly important to identify buildings in the region that should be preserved because of cultural, historical, economic, or regional significance and to take appropriate steps to protect these buildings.

To this end, this paper proposes a model for assessing the value of regional buildings, taking into account extreme climates. First, this paper selects three indicators: humanity, economy and nature, and expands it to 10 secondary indicators. Then, this paper adopts different normalization methods for different types of indicators, and uses three weight determination methods to determine the joint weight from a combination of subjective and objective perspectives. Finally, the buildings of different value levels are clustered and divided according to the calculation results. And different levels of protection measures are proposed according to different levels.

2. HEN evaluation model

2.1. Indicator selection

The valuation of a building and the level of protection required are primarily intertwined with human, economic and natural factors. Therefore, this paper chooses to investigate from the above three aspects. In order to estimate the value of buildings more accurately, this paper carefully examines many official indicators and synthesizes insights from the relevant literature. Finally, this paper extracted a set of 10 highly representative secondary indicators. The specific description and indicator selection are shown in Table 1. In order to simplify the evaluation, the indicators selected in this paper are all indicators centered on the building and radiating to the area where it is located.

Table 1. System of indicators.

First-level indicator	Second-level indicator
Humanity (H)	Tourist arrivals (H ₁)
	Community significance (H ₂)
	Number of scenic spots (H ₃)
	Population (H ₄)
Economy (E)	GDP per capita (E ₁)
	Tourism revenue share (E ₂)
	Number of colleges and universities (E ₃)
Nature (N)	Extreme climate index (N ₁)
	Temperature change trend (N ₂)
	Forest coverage (N ₃)

2.1.1. Humanities indicators

H1. Tourist arrivals

The quantity of tourists serves as a pivotal metric for gauging the magnitude of tourism activities, providing a reflection of the region's allure and popularity. A heightened tourist count in a region typically signifies heightened attractiveness, often attributable to its cultural richness and the historical significance embodied in its buildings.

H2. Community significance

Community significance is a crucial indicator that underscores the importance of a building within the local community. When a building frequently serves as a venue for community events like celebrations, assemblies, or classes, its significant functional value for the community. Such structures may holds evolve into symbols of the community, playing a pivotal role in fostering community cohesion and identity. In addition, buildings may be carriers of community history and culture. It witnesses the development and changes of the community or reflects the specific cultural traditions of the community [4].

To quantitatively assess the community significance of a building, this paper utilizes public interest and evaluations of the neighborhood building as metrics. This involves gauging the number of searches associated with the neighborhood building keyword on Google Trends for the specific area, subsequently assigning a rating based on the obtained results.

H3. Number of scenic spots

This indicator captures the diversity of buildings within a given area. Typically, scenic spots feature historical sites and other significant structures. The greater the number of scenic spots, the more likely they are to attract tourists, resulting in increased foot traffic. This heightened visitor influx enhances both the utilitarian and aesthetic values of buildings, emphasizing their functional and ornamental significance.

H4. Population

The population size of an area is often correlated with the city's size and level of development. In densely populated regions, buildings tend to experience higher frequency of use, potentially resulting in increased demands for their protection. Larger populations in a given area often coincide with

greater cultural diversity, contributing to a richer and more diverse cultural value associated with the buildings within that region.

2.1.2. Economic indicators

E1. GDP per capita

Per capita GDP is an important indicator to measure the level of economic development and affluence of a region. The stronger the economy of an area usually means the higher the value of buildings in that area is likely to be.

E2. Tourism revenue share

This indicator reflects the economic contribution of tourism to a region. The higher the proportion of tourism revenue, it means that this area tends to rely more on the benefits brought by tourism resources such as important buildings, which means that the greater the importance of buildings in this area.

E3. Number of colleges and universities

This indicator reflects the educational resources available in a region. Colleges and universities play a pivotal role as conduits for producing skilled individuals who, in turn, contribute significantly to creating economic value for society. Furthermore, due to the prolonged construction timelines of certain universities, campus buildings often exhibit a diverse range of architectural styles, witnessing the evolution of eras. This imparts considerable historical and artistic value to these structures [5].

2.1.3. Natural indicators

N1. Extreme climate index

Karl et al. (1996) first defined a climate extreme index (CEI) for the contiguous United States, comprehensively considering indicators such as extreme temperature and precipitation, and analyzed the temporal changes of the index [6]. The extreme climate index is a metric that quantifies the frequency and intensity of extreme climate events, providing insight into the impact of extreme weather conditions on a specific region. The higher the extreme climate index, the more severe the climate conditions and the higher the likelihood and intensity of damage to buildings, which requires regional leaders to increase investment and intensity and strengthen protective measures.

N2. Temperature change trend

This indicator reflects the climate change in a region. A larger temperature trend results in a greater temperature difference, leading to varying degrees of additional internal forces within the building structure [7]. When these forces surpass a certain threshold, the structure may undergo deformation, develop cracks, or even fail. This directly impacts the normal usage performance and structural safety of buildings.

N3. Forest coverage

This indicator offers insight into the natural environment of a region. Elevated forest coverage signifies a healthier natural environment in the area. Higher forest coverage often acts as a buffer against the impact of extreme climates, mitigating damage to buildings. Consequently, the urgency for building protection is typically reduced in regions with higher forest coverage.

2.2. Data normalization

2.2.1. Maximum, minimum, and dispersion normalization method

For some benefit indicators, Indicators such as GDP per capita, tourism index and number of tourists, the maximum normalization method is used.

$$f(x) = \frac{x}{x_{\max}} \quad (1)$$

For cost indicators, such as forest cover, the minimum normalization method is adopted.

$$f(x) = 1 - \frac{x}{x_{\max}} \quad (2)$$

For indicators with optimal values, the median normalization method can be employed. This method ensures that the normalized value is higher when the original value of the indicator approaches the optimal value. The formula for median normalization is as follows:

$$f(x) = \begin{cases} \frac{x_{\max} - x}{x_{\max} - x_0}, & x_0 \leq \frac{x_{\max} - x_{\min}}{2} \\ \frac{x_{\min} - x}{x_{\min} - x_0}, & x_0 > \frac{x_{\max} - x_{\min}}{2} \end{cases} \quad (3)$$

2.2.2. Membership function

Membership function is a mathematical tool used to characterize fuzzy sets, indicating the "true degree" of an element belonging to a certain fuzzy set. This paper adopts this approach for the standardization of fuzzy indicators such as community significance levels. First, these indicators are graded into 5 levels, and then normalized and quantified through membership functions. The higher the level, the greater the value of this indicator. Calculated as follows:

$$f(x) = \begin{cases} \frac{1}{1 + \frac{a}{(x-b)^2}}, & 1 \leq x < 3 \\ \ln x + d, & 3 \leq x \leq 5 \end{cases} \quad (4)$$

2.2.3. Sigmoid function

If the data are unrestricted in their range or lack threshold limitations, the sigmoid function emerges as a suitable choice, given its capacity to map any real number to the interval (0,1).

$$f(x) = \frac{1}{1 + e^{-r(x-x_{\min})}} \quad (5)$$

Here, r is used to control the rise rate of the function.

2.3. Weight determination

2.3.1. Analytic hierarchy process

The essence of the analytic hierarchy process lies in the systematic structuring of problems under analysis, employing a subjective assignment evaluation approach [8]. To gauge and assess the building value index of a given area, this paper considers three principal indicators: human, economic, and natural, which further extend to 10 secondary indicators. A hierarchical chart is then constructed based on the previously identified indicators. Subsequently, judgment matrices for both the main indicators and each group of secondary indicators are formulated, taking into account the Google search index.

The utilization of the Google search index in this context is significant, as it partially reflects the level of public attention to various aspects at a specific moment, thereby introducing an element of objectivity into the judgment process. In the final step, the weights for each indicator are calculated, and a consistency test is conducted. The resulting weight for each index determined by this method is denoted as ω_{j1} .

2.3.2. Coefficient of variation method

In the comprehensive evaluation of multiple indicators, it becomes imperative to allocate weights to each indicator, reflecting their relative significance within the entire evaluation system. The fundamental principle behind the coefficient of variation method lies in the notion that indicators

exhibiting greater variation should be accorded higher weights due to their increased discriminatory capacity [9]. However, it is important to note that the effectiveness of the coefficient of variation method may be compromised when applied to datasets with minimal variability. The steps for calculating the weight of the coefficient of variation are as follows:

Step1 Data normalization (This part of the work has been done above)

Step2 Calculate the mean and standard deviation of each indicator:

$$\mu_j = \frac{1}{n} \sum_{i=1}^n b_{ij}, j = 1, 2, \dots, m. \quad (6)$$

$$\sigma_j = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (b_{ij} - \mu_j)^2}, j = 1, 2, \dots, m. \quad (7)$$

Here, b_{ij} is the normalized data.

Step3 The variation coefficient and weight of each indicator are calculated:

$$CV_j = \frac{\sigma_j}{\mu_j} \quad (8)$$

$$\omega_j = \frac{CV_j}{\sum_j CV_j} \quad (9)$$

The weights of each indicator calculated by this method are denoted as ω_{j2} .

2.3.3. Entropy weight method

The entropy weight method stands as a prevalent objective evaluation approach, extensively employed in multi-attribute decision problems [10]. Rooted in the concept of information entropy, this method calculates the weight of each evaluation index to quantify its contribution to the decision-making result. The process for computing weights using the Entropy Weight method unfolds as follows:

Step1 Data normalization (This part of the work has been done above)

Step2 Calculate information entropy:

$$e_j = - \frac{\sum_{i=1}^n \ln b_{ij} \cdot b_{ij}}{\ln n} \quad (10)$$

Here, b_{ij} is the normalized data.

Step3 Calculate the weight:

$$w_j = \frac{1 - e_j}{\sum_i (1 - e_j)} \quad (11)$$

The weights of each indicator calculated by this method are denoted as ω_{j3} .

2.3.4. Combination weight

By employing the three aforementioned methods, this paper derives three distinct weights (ω_{j1} , ω_{j2} , ω_{j3}) for each indicator. To enhance the accuracy of the model and strike a balance between subjective and objective evaluations, this paper opts for the mean of these three weights as the final weight for each index. This approach is selected with the aim of minimizing potential errors in the evaluation process.

$$\omega_j = \frac{\omega_{j1} + \omega_{j2} + \omega_{j3}}{3} \quad (12)$$

2.4. The establishment of HEN evaluation model

Given the interconnection of building value with humanity, economy, and nature, this paper has devised the HEN evaluation model. This model introduces the BVI as a quantitative metric to depict the value of buildings in a specific area, indicating the extent to which protective measures are warranted.

Furthermore, based on the chosen database, the BVI values are categorized into five intervals through K-means clustering. This segmentation results in the classification of building value into five distinct levels.

Following the preceding steps, this paper has identified the data sources for each indicator along with their respective calculation methods. The weights for each index are ultimately determined through the normalization of diverse data and the integration of both subjective and objective weighting methods. The weights assigned to the H, E, and N indicators are considered as the degree of influence these three indicators have on the BVI. In essence, the greater the weight, the more significant the impact of the corresponding indicators on BVI.

Building upon this foundation, this paper introduces a rational and innovative formulation for the calculation of the Building Value Index (BVI):

$$BVI = 100 \cdot (\omega_H \cdot H + \omega_E \cdot E + \omega_N \cdot N) \quad (13)$$

Similarly, based on the same lines, this paper constructs the formulas for H, E, and N:

$$\begin{cases} H = \omega_{H_1} \cdot H'_1 + \omega_{H_2} \cdot H'_2 + \omega_{H_3} \cdot H'_3 + \omega_{H_4} \cdot H'_4 \\ E = \omega_{E_1} \cdot E'_1 + \omega_{E_2} \cdot E'_2 + \omega_{E_3} \cdot E'_3 \\ N = \omega_{N_1} \cdot N'_1 + \omega_{N_2} \cdot N'_2 + \omega_{N_3} \cdot N'_3 \end{cases} \quad (14)$$

3. Results

3.1. The final results of the weights of each indicator

This paper selects the 50 states in the United States as the research target and collects relevant data on ten indicators from various official websites in the United States, and brings them into the above model. The final joint weight we obtained is in the Figure 1.

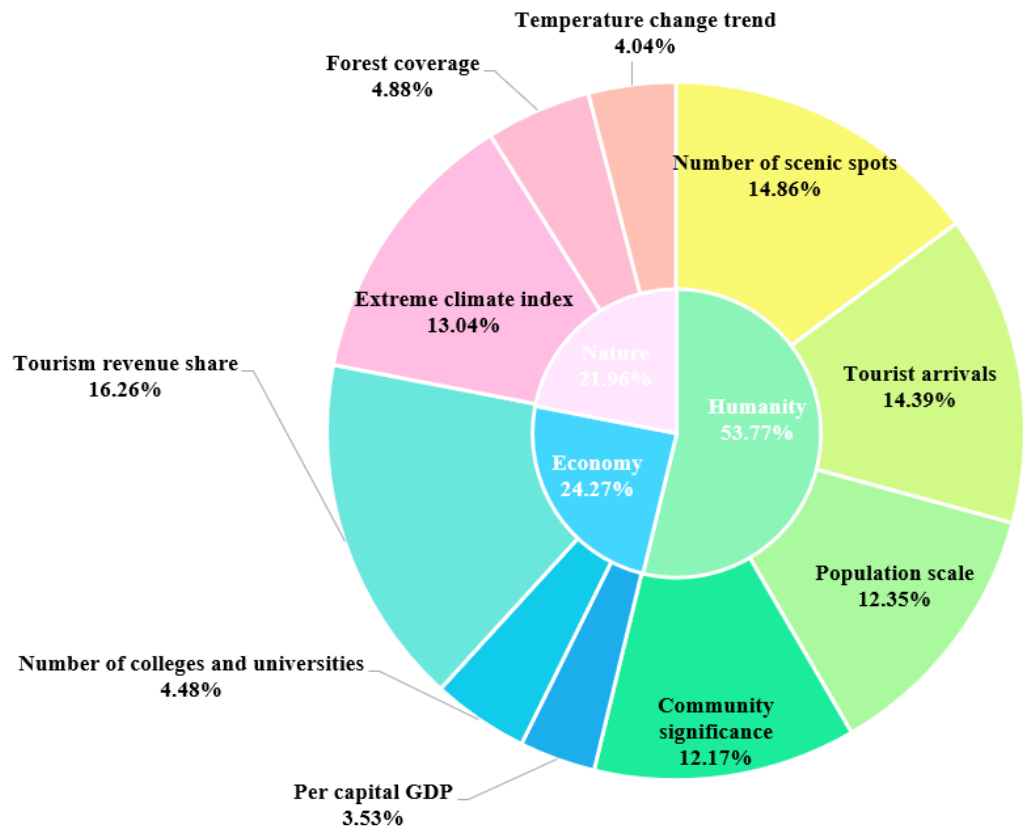


Figure 1. The combination weight diagram of each indicator

As can be seen from Figure 1, the major category of humanistic indicators has the largest weight, which reflects that people pay more attention to the historical and cultural value and regional significance brought by buildings.

3.2. Analysis based on building value index

The HEN evaluation model is applied to the dataset comprising the 50 selected US states, resulting in the computation of BVI values for each location, as illustrated in the Figure 2.

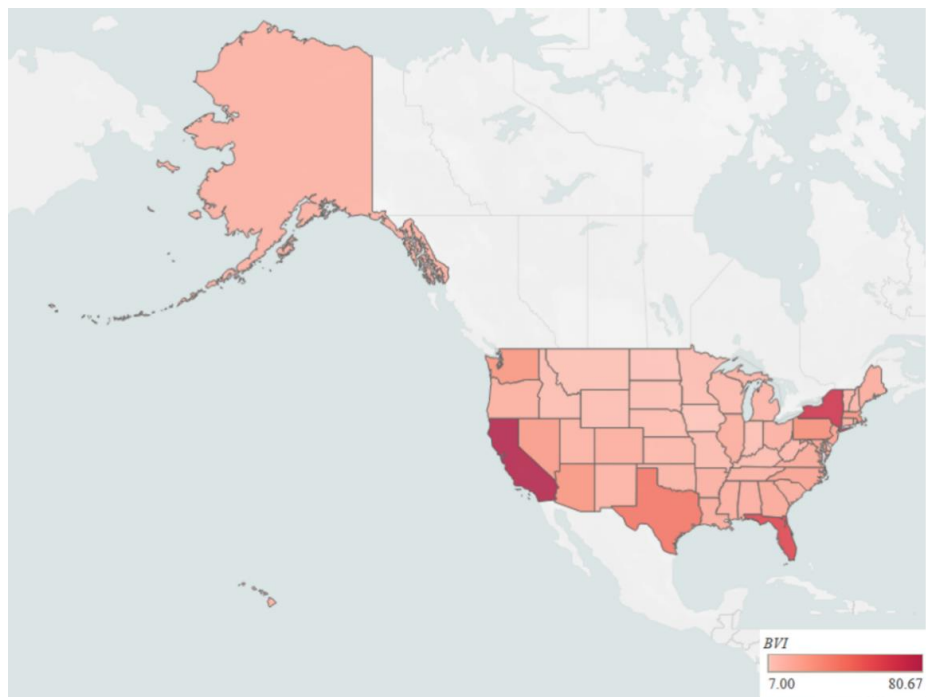


Figure 2. Distribution of BVI values for the 50 states of the United States

Subsequently, employing k-means clustering, all locations are categorized into five groups based on the magnitude of their BVI values. These groups are defined as follows: Level I: Very Low, Level II: Low, Level III: Medium, Level IV: High, and Level V: Very High. The detailed classification is presented in Table 2.

Table 2. Division of building importance

Level	I	II	III	IV	V
Importance degree	very low	low	Medium	high	very high
BVI	<20	20~40	40~55	55~70	>70

As evident from the provided table, the BVI values for specific locations serve as a basis for assessing the importance of buildings in those areas. Depending on the degree of importance, it becomes feasible to determine the appropriate level of protective measures needed to safeguard the buildings. The classification of building importance based on BVI values is as follows:

I (Very low): Ordinary buildings with low cultural, historical, and economic value. No additional protection measures are deemed necessary.

II (Low): Buildings of some economic or community significance. Consideration may be given to retrofits or renovations to meet community needs or enhance economic value while preserving its original character.

III (Medium): This category encompasses buildings with greater historical, cultural, or community value. In addition to routine conservation measures, the installation of an information board may be considered to introduce its historical and cultural background, thereby raising public awareness and respect.

IV (High): Buildings falling into this category may represent significant historical sites or cultural symbols. Apart from rigorous conservation measures, initiatives such as education and publicity campaigns should be contemplated to enhance public historical awareness and cultural literacy.

V (Very high): Buildings with exceptionally high historical, cultural, economic, or community value. Besides implementing the most stringent protection measures, consideration should be given to inclusion in national or local protection lists. There may even be a possibility to apply for international-level protection, such as World Heritage status.

4. Conclusion

In today's world, extreme weather occurs more and more frequently, bringing major challenges and disturbances to human society. In recent years, the frequency and intensity of such incidents have shown a clear upward trend. Its occurrence not only affects the natural ecosystem, but also brings huge economic, social and environmental losses to human society. In some areas affected by extreme weather, insurance companies may not or are unwilling to insure. This could lead to district leaders facing difficult decisions regarding properties of cultural or regional significance. To this end, this paper proposes a regional building value assessment model that considers extreme climates. First of all, this paper selects three indicators: humanities, economy, and nature, and expands them into 10 secondary indicators. Then, this paper uses different normalization methods for different types of indicators, and uses three weight determination methods to determine the joint weight from a combined subjective and objective perspective. Finally, the buildings of different value levels are clustered and divided based on the calculation results. In addition, this paper applies the assessment model to the 50 states in the United States and proposes different levels of protection measures based on the final clustering results. It is worth mentioning that the indicators selected in this paper are well representative, and the evaluation model constructed thereby has good robustness and adaptability and can be applied to various regions in the world.

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