Sustainable Development of Property Insurance: A Risk Assessment and Fuzzy Evaluation Approach

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Abstract. Sustainability and informed decision-making are vital for real estate owners and the insurance industry. To support these goals, a risk assessment model was developed using ARIMA time series analysis to predict extreme weather events and classify areas into low, medium, and high-risk categories, assisting insurers in their decisions. An AHP-GIS site selection model was also implemented, utilizing spatial analysis to recommend optimal locations for real estate developers. Additionally, a community property protection model combines entropy weighting and fuzzy evaluation to establish protection tiers, aiding community leaders in formulating effective strategies. The ARIMA model reveals that increasing extreme weather in the U.S. raises insurance claims costs, prompting insurers to adjust risk assessments and premiums. The AHP-GIS model highlights the significance of economic factors (42.063%) in site selection, indicating that incorporating extreme weather and environmental considerations can enhance real estate sustainability. Ultimately, integrating these models fosters a proactive framework for building resilient communities and securing a sustainable future.

Keywords: Risk Assessment, Fuzzy Evaluation, Property Insurance.

1. Introduction

As global climate change intensifies, extreme weather events are becoming more frequent, significantly impacting property insurance [1] while posing major challenges to sustainability and decision-making. This issue is critical for real estate owners and the insurance industry as they confront these extreme weather risks [2]. In response, this research has developed a set of risk assessment models tailored for insurance companies, alongside optimized site selection and protection models for communities and real estate developers. The models categorize areas into low, medium, and high risk, helping insurance companies better identify underwriting risks, enhance risk management, and set building protection priorities. For communities and developers, a framework is provided to address the growing need for resilience.

Notably, the increasing frequency of extreme weather events [3] in regions like North America [4] and Australia [5] has placed unprecedented pressure on property owners and the insurance industry, driving the demand for effective response strategies. Therefore, to effectively develop and validate the models, this research has chosen to focus our study on continental North America and Australia. These regions have experienced significant extreme weather phenomena over the past few decades; the frequency and intensity of these events make them important cases for study. Moreover, both regions encompass a variety of climate types—from tropical to subarctic zones—featuring extreme weather under diverse climatic conditions. This diversity enhances the analysis, enabling the research to reveal the impact and behavior of extreme weather in different climatic contexts. Additionally, North America and Australia[6] have well-established meteorological monitoring systems with rich historical data, allowing for in-depth analysis and comparison. The maturity of the insurance markets in both regions also provides valuable data on loss assessments and claims, helping to understand the specific impact of extreme weather on the economy.

Given the urgent need to promote the sustainability of insurance companies, alleviate pressures on property developers, and prioritize building protection, the research presents research questions (RQs):

RQ1: How can insurers decide whether to offer policies in areas experiencing increasing extreme weather events?

RQ2: How can real estate developers determine where to build and develop properties that are more flexible, consciously designed, and capable of serving growing communities and populations?

RQ3: How can this research develop a conservation model for buildings based on their cultural, historical, economic, or public significance to determine protection priorities?

To address these RQs, this research has undertaken the following work: (1) This research used the ARIMA model [7] to predict extreme weather and developed a profit and loss model with insurance density data, enhancing risk assessment accuracy. The regional risk index was classified into low, medium, and high risk, supported by GIS visualizations for insurers [8, 9]. (2) By combining ArcGIS spatial analysis, AHP [10], and entropy weighting, this research analyzed insurance exposure to recommend optimal property locations for communities and developers. (3) This research created a protection framework using entropy weighting and fuzzy evaluation, categorizing buildings into priority levels to provide strategic protection recommendations for community leaders.

2. Problem Formulation

2.1. Problem Definition

The primary challenge is how to adjust property insurance to ensure the sustainability and long-term health of insurance companies. This involves determining the conditions under which properties should be insured, when to assume risk, and what actions property owners can take to influence these decisions. A model is needed to assist insurers in deciding whether to cover policies in regions increasingly affected by extreme weather events. Additionally, future real estate decisions must focus on constructing properties to adequately support the growing community and population. This raises questions about how and where real estate companies will build and develop to meet these objectives. Lastly, community leaders need a method for identifying buildings worthy of preservation due to their cultural, historical, economic, or public significance. A conservation model should be developed to guide community leaders in protecting these vital structures.

2.2. Problem Assumption

Given the backdrop of global climate change resulting in a rise in the frequency and intensity of extreme weather events, this research makes the following assumptions. Firstly, different regions exhibit varying levels of vulnerability and risk when it comes to extreme weather. Secondly, property owners determine whether to purchase insurance based on insurance policies, market conditions, costs, and risk management. Thirdly, property owners can impact insurance company decisions by implementing risk management and disaster reduction measures. Fourthly, evaluation indicators are independent of one another. Lastly, insurance models are capable of adapting to changes in the regional environment.

3. Methodology

3.1. Risk assessment model of insurance companies based on the ARIMA time series (RQ1)

The ARIMA time series model is used to predict the number and trend of future extreme weather events in a specific region to provide risk trend information for insurance companies.

$$y_t = \mu + \epsilon_t + \sum_{i=1}^{i} \theta_i \epsilon_{t-i}. \tag{1}$$

In order to reduce the effect of subjective judgment on fitting the ARMA model, this research relied on the AIC and BIC standards and selected the relatively optimal ARMA (p, q) model by referring to the AIC and BIC values of each ARMA model.

$$\begin{cases} AIC = 2k - 2\ln(L) \\ BIC = k\ln(n) - 2\ln(L) \end{cases}. \tag{2}$$

The financial balance of the insurance company is calculated through the profit and loss model, and the total insurance cost, claim rate, reinsurance cost and other factors are comprehensively considered to determine the insurance break-even ratio and to evaluate the profitability of the insurance company.

Total insurance cost=Net claims+Gross claims:

$$N_t = N_f + N_p. \tag{3}$$

Gross claims=Gross claims per policy×Number of policies:

$$N_p = N_a \times P. \tag{4}$$

$$\mathrm{q} = \frac{1}{(1+\mathrm{i})^{\mathrm{p}}}. \tag{5}$$

Claim rate =Number of reinsurance policies ×Disaster coefficient×Net loss:

$$N_c = Q \times P \times q. \tag{6}$$

Reinsurance cost=Number of reinsurance policies * Reinsurance premium per policy:

$$\mathrm{S} = \mathrm{P} \times \mathrm{Q}. \tag{7}$$

$$Q^* = S = N_t + N^c. \tag{8}$$

By combining equations (5) and (9), this research obtains equation (10). It represents the minimum breakeven output of the scheme; the higher its value, the weaker the risk resistance:

$$(k - T_b - T_v) \times K^* = C_f + C_v \times K^*. \tag{9}$$

$$K^* = \frac{C_f}{K - T_b - T_v - C_v}. \tag{10}$$

The break-even point of an insurance company can be expressed as:

$$S^* = (k - T_b - T_v) \times K^* = \frac{(k - T_b - T_v) \cdot C_f}{k - T_b - T_v - C_v}. \tag{11}$$

The Insurance Break-Even Ratio:

$$N^* = \frac{K^*}{K_d} \times 100\% = \frac{C_f}{(K - T_b - T_v - C_v) \cdot k_d} \times 100\%. \tag{12}$$

Spatial data analysis was conducted with ARIMA prediction results and profit and loss model data as the GIS data sources, dividing regional risk index levels, and dividing regions into low, medium and high-risk regions.

3.2. Location model based on AHP-GIS for real estate developers (RQ2)

Based on the Swiss Re Institute's analysis of insurance risk factors, this study evaluates environmental factors such as average sea level height (MsL), carbon dioxide concentration (CO2), and annual average temperature (MAT), along with economic factors like per capita GDP and the frequency of extreme weather events. A hierarchical analysis model is developed to assess how these factors influence community and real estate development strategies. Using the AHP model, this study constructs a judgment matrix to determine the weights of the four main indicators: extreme weather, environment, economy, and population.

Conducting a one-time verification:

$$CR = CI/RI. \tag{13}$$

3.3. Property Conservation Model for Community (RQ3)

Determine the set of evaluation factors, establish the set of evaluation levels, and establish high priority protection, priority protection, and consider protection.

Determine the set of evaluation factors:

$$U = \{u_1, u_2, u_3, \cdots, u_i\} \quad i = 1,2,3, \cdots, i. \tag{14}$$

U represents the set of factors affecting the evaluation object, represent specific influencing factors. The influencing factors determined in this question are:

$\mathrm{U} = \{\mathrm{u}_1, \mathrm{u}_2, \mathrm{u}_3, \mathrm{u}_4, \mathrm{u}_5\}$ = (historical, artistic, cultural, economic, social)

Determine the set of appraisal grade collections: Establish the evaluation set V through literature review, representing all possible evaluation results.

V = {high priority protection, priority protection, consider protection}

Establish the fuzzy relation matrix R:

$$\mathrm{R} = \begin{pmatrix} \mathrm{r}_{11} & \mathrm{r}_{12} & \cdots & \mathrm{r}_{1\mathrm{n}} \\ \mathrm{r}_{21} & \mathrm{r}_{22} & \cdots & \mathrm{r}_{2\mathrm{n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{r}_{\mathrm{m}1} & \mathrm{r}_{\mathrm{m}2} & \cdots & \mathrm{r}_{\mathrm{mn}} \end{pmatrix}. \tag{15}$$

$\mathrm{r}_{(\mathrm{j})}$ indicates the degree of membership of the evaluated object from factor u_i to the fuzzy subset of level v_i

Basic model of comprehensive fuzzy evaluation:

$$(\mathrm{b}_1, \mathrm{b}_2, \cdots, \mathrm{b}_\mathrm{m}) = (\mathrm{w}_1, \mathrm{w}_2, \cdots, \mathrm{w}_\mathrm{i}) \begin{pmatrix} \mathrm{F}_{11} & \mathrm{F}_{12} & \cdots & \mathrm{F}_{1\mathrm{m}} \\ \mathrm{F}_{21} & \mathrm{F}_{22} & \cdots & \mathrm{F}_{2\mathrm{m}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{r}_{\mathrm{i}1} & \mathrm{r}_{\mathrm{i}2} & \cdots & \Gamma_{\mathrm{im}} \end{pmatrix}. \tag{16}$$

B represents the comprehensive =evaluation result of all judgment factor $(\mathrm{b}_1, \mathrm{b}_2, \cdots, \mathrm{b}_\mathrm{m})$ represents the degree of membership corresponding to each appraisal grade, denotes fuzzy operation.

4. Result Analysis and Discussion

4.1. Result Analysis for insurance company (RQ1)

Data on monthly average temperatures since 1900 from the continental United States, located in North America, and Australia, located in Oceania, are selected to predict the monthly average temperatures for the next 10 years using the ARIMA model. The (p, d, q) values that best fit for ARIMA model predictions are (1,1,1) and (2,1,1) were obtained from stationary PCF and ACPF.

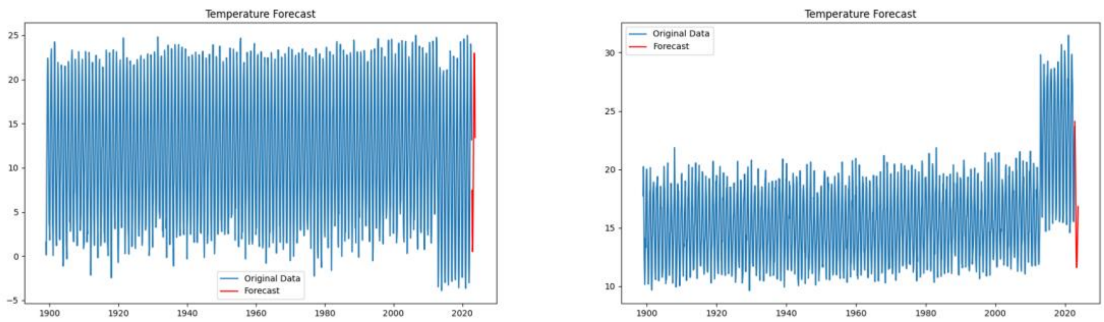

Figure 1: Time series result line chart

Figure 1 shows ARIMA model predictions for monthly average temps in the continental U.S. and Sydney. U.S. has more frequent and variable extreme temps; Sydney has stable but prolonged extreme weather with less variation. In insurance industry analysis, break-even model shows sensitivity of break-even point to expected loss ratio indicates risk assessment capability. Changes in break-even point relative to average policy cost reveal competition, tech investment, and management expense issues. Extreme weather raises claim costs, reducing insurers' profitability and solvency, leading to premium increases and affecting property insurance prevalence. Insurance companies adjust conditions, increasing consumer risk and prompting improvements in risk assessment models and management strategies.

4.2. Result Analysis for AHP-GIS Site Selection Model (RQ2)

Based on a large amount of literature records, we constructed the following judgment matrix, the following table1 :

Table 1: Judgment matrix

Index	Extreme weather	Environment	Economy	Population
Extreme weather	1	2	0.25	0.333
Environment	0.5	1	0.2	0.25
Economy	4	5	1	1
Population	3	4	1	1

Table1 shows the relative relationships between extreme weather, environment, economy, and population. Extreme weather has significant effects on the environment and population, but less economic impact. The environment and the economy are closely related, and the economy has the greatest impact on the extreme weather.

Table 2: Entropy and difference coefficient

Item	Information entropy value e	Information utility value d	Weight(%)
Annual mean Temperature	0.951	0.049	23.354
Annual sea level(cm)	0.9	0.1	47.181
Carbon dioxide Emissions	0.938	0.062	29.465

AHP weight calculations table2 show extreme weather contributes 12.885%, environmental factors 8.014%, economic considerations 42.063%, and population dynamics 37.038%. Maximum eigenvalue is 4.032 with a consistency ratio of 0.012, indicating acceptable consistency. To reduce subjectivity, entropy weight method is applied to evaluate environmental factors. Entropy values are calculated based on judgment matrix to reflect information disparity among indicators and allow weight adjustment. Finally, entropy-derived weights and AHP weights are combined to compute a comprehensive score for each option by multiplying criterion weights with evaluation values and aggregating results.

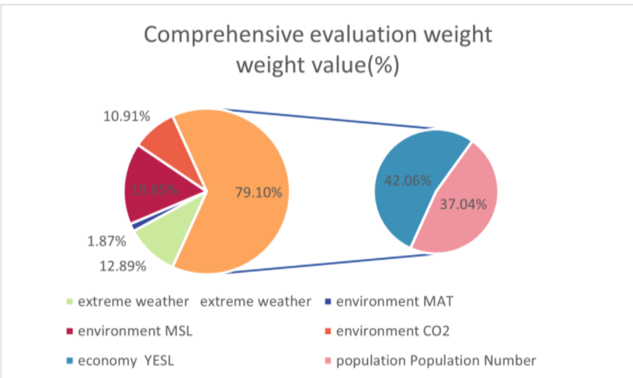

Figure 2: Comprehensive evaluation weight

In summary figure2, by considering extreme weather, environmental changes, economic feasibility, and population growth in their insurance models, real estate developers can enhance building quality, promote sustainability, and address community needs to ensure long-term project success and adapt to the evolving insurance industry.

4.3. Analysis of experimental results (RQ3)

Below is the process of referencing data from literature on representative historical buildings in Hancheng, incorporating it into the model for solution, and filtering through multiple indicators to ultimately determine the evaluation indicators. This research has organized and summarized this process, as shown in the table3 below:

Table 3: Index weight calculation

Index item	High protection	Priotity protection	Consider protection
History	0.42	0.36	0.22
Art	0.36	0.32	0.32
Culture	0.34	0.38	0.28
Economy	0.10	0.80	0.10
Society	0.48	0.28	0.26

The results of the weight calculation by the entropy method show that the weight of history is 10.965%, art is 27.866%, culture is 11.319%, economy is 28.702%, and society is 21.148%. Among them, the highest indicator weight is for economy (28.702%), and the lowest is for history (10.965%).

Table 4: Membership matrix calculation results

	High protection	Priotity protection	Consider protection
Membership degrss	0.278660904	0.287018353	0.278660904
Membership normalization	0.33	0.34	0.33

As shown in Table 4,this research conducts a fuzzy comprehensive evaluation of five indicators (history, art, culture, economy, society) and three appraisal levels (high priority for protection, priority for protection, consider for protection), utilizing the principal factor prominence type $M(\wedge, \vee)$ operator for research. Initially, using the evaluation indicator weight vector A and constructing a 5 x 3 weight judgment matrix R for analysis, this research obtains membership degrees for the three appraisal sets as 0.33, 0.34, 0.33, respectively. Hence, it can be known that the general weight is highest among the three appraisal sets, and through the maximum membership degree rule, the final comprehensive evaluation result is identified as priority for protection.

5. Conclusions

This study addresses the critical challenges posed by extreme weather events on the insurance and real estate sectors. By employing ARIMA time series models for risk assessment, this study identified trends in extreme weather that inform insurance companies' decision-making processes. The AHP-GIS location model provided insights into optimal property development strategies by evaluating environmental and economic factors. Additionally, the property conservation model highlighted the significance of cultural, historical, and economic indicators in prioritizing building protection. Overall, this study's integrated approach enhances the resilience of insurance firms and developers, ensuring sustainable practices in the face of increasing climate-related risks.

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