Analysis on Comprehensive Risk Assessment for Urban Fire: The Case of Haikou City

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Abstract

This paper first defines the term “urban fire risk” by referring to both the definition of “risk” in U.N.’s “International Strategy for Disaster Reduction” which was enacted in 2004 and the features of urban fire. Secondly, this paper presents a comprehensive analysis on the urban fire risk from the respects of risk of fire accidents in urban areas, urban vulnerability and urban anti-fire capability. Based on the analysis, the Analytic Hierarchy Process (AHP) is employed in this paper to establish an urban fire risk assessment system, which includes 3 first-level indicators, 13 second-level indicators and 48 third-level indicators. With the data on fire accidents and fire statistics in the past as the basis, this paper applies the Gray Correlation Degree Method to set up the Weight Coefficient of the system and quantify the indicators mentioned above, and finally, this paper applies what has been discussed above to the case of Haikou, capital city of Hainan province, P.R. China. In the city’s chosen 17 sub-districts and 1 town, fire risk assessments are conducted, and the values of risk of fire accidents in urban areas, urban vulnerability, anti-fire capability and comprehensive fire risk in the mentioned selected areas are computed and identified.

Keywords: urban areas; fire risk; assessment; analysis

1. Introduction

With the program of building Hainan into an international tourism island being promoted into a national strategy, Hainan province, the southern-end province in the country, is witnessing a new development stage. Haikou, the capital city of the province, is accordingly experiencing a period of rapid and new development. In this context, the population density in Haikou is expected to increase, buildings will be highly concentrated, and the distribution of the road traffic and energy facilities will be more complex. Moreover, with the rapid economic development, Haikou city will be confronted with more and more sources of risks, even some serious risks. The statistics about fire accidents in Haikou city between the year of 2000 and 2009 suggests that the fire accidents in this city tend to be more happenings, more destructive and more complicated. In this context, the fire risks assessment is quite significant in urban fire planning and the making of fire regulations, which is a guarantee in promoting the coordinated social and economic development in the city of Haikou.

2 Risk assessment for urban fire

2.1 Definition of fire risk

By referring to the definition of “risk” in U.N.’s “International Strategy for Disaster Reduction” in 2004, this paper presents...
a definition of “urban fire risk”: the possibility of damage to people’s life safety, property loss and threatening of public security, caused by the interaction between the fire accidents and urban vulnerability, and the possibility of negative consequences or likely loss such as the breaking up of economic activities and environmental destruction. The comprehensive urban fire risk evaluation, with city as the basic unit for evaluation, includes fire hazard in urban areas, urban vulnerability and anti-fire capability.

2.2 Risk analysis of urban fire

2.2.1 Analysis of risk in urban fire accidents
The statistics of China’s fire accidents indicate that the more probable the factors such as urban electricity, gas pipe network, flammable and explosive chemical materials cause fire to happen in urban areas, the higher the urban fire risk will be, and accordingly the more risky the fire accidents are.

2.2.2 Analysis of urban vulnerability
Meteorological factors and the breaking out of fire are closely related. Among these meteorological factors, Related Humidity, rainfall and wind speed are directly related factors. With the speeding up of urbanization process, both urban economy and population experience remarkable development, and the modern buildings are more and more concentrating. In this context, once the fire accidents break out, especially serious fire accidents, life and economic loss as well as social and political impacts will be brought about, which will hinder the sustainable social and economic development. Thus, the more vulnerable the city is, the higher the risk will be.

2.2.3 Analysis of urban anti-fire capability
Generally speaking, the more investment in fire is made, the more proper the measures to prevent and control fire are taken, and the more convenient the traffic is, the more capable we will be in preventing and controlling the fire, and the lower the urban fire risk will be. This paper holds that the capability of anti-fire should be determined by the following factors: construction of fire stations, water supply for fire, communication for fire, lanes for firefighting, fire equipment, fire forces, medical services for fire, input in fire, fire training and distant monitoring of urban fire.

2.3 Development of fire risk evaluation system
By referring to the risk theory and Studies on Urban Fire Security Evaluation Indicators System compiled by Fire Bureau, Ministry of Public Security, the State Council of the P. R. China and taking into full account of the impacts of persons, materials, management and environment on urban fire security, and the interrelation between the evaluated targets in Haikou city, this paper employs Analytic Hierarchy Process (AHP) to initially establish 3 first-level indicators, 13 second-level indicators and 48 third-level indicators for evaluating urban fire risks. The first-level indicators include risk of urban fire, urban vulnerability and urban anti-fire capability. 13 second-level indicators include risk of fire accidents in the past, potential fire risk, meteorological factors, features of city, high risky building, infrastructure of public fire, input in fire, warning against fire, training program, relief capability in emergency, monitoring, evacuation, safety of building. 48 third-level indicators includes: number of fire happening per 10 thousand persons, fire deaths per 10 thousand persons, fire loss per 100 million yuan of GDP, number of human-caused fire accidents, number of the secondary fire disaster of other disaster, the gasification of fuel, the density of gas pipeline network, unit density of flammable and explosive chemical materials, power consumption, relative humidity, rainfall, wind speed, population density, density of economy, high building density, density of underground buildings, density of people concentration area, density of key units with high risk of fire, number of fire stations per 10 thousands persons, number of fire brigade wagon per 10 thousands persons, number of respirator for fire fighters, number of equipment for Emergency rescue, density of fire water, coverage of fire hydrant, the percentage of good-condition hydrant, up-to-standard rate of fire accidents warning 119, up-to-standard rate of special lines for fire, rate of equipping wireless communication facilities for fire, density of road network, proportion of funding for fire in financial expenditure, automatic facilities perfectness in buildings, coverage of fire distant supervision, the up-to-standard rate of fire safety management in crowded place, the setting up of course on fire in primary and middle school, number of fire education and training per 10 thousand persons, rate of training for fire-related personnel, number of fire publicity in community, the penetration rate of fire training, number of fire volunteers per 10 thousand persons, number of fire fighters per 10 thousand persons, the 7.5 minutes response in the area under a fire brigade’s control, number of hospital bed per 10 thousand persons, number of supervisor against fire per 10 thousand persons, number of police supervising fire per 10 thousand persons, rectification ratio of potential fire accident, number of square or park per 10 thousands persons, fire-break rate of buildings, fireproof endurance rate of buildings.

3 Risk assessment of urban fire

3.1 Methods for the risk assessment of urban fire
At present, the methods used in evaluating risk are mainly Delphi Method, Analytic Hierarchy Process (AHP), Fuzzy
Mathematics Comprehensive Judgment and Gray Correlation Degree Method. Since the Gray Correlation Degree Method is based on the objective historical data to compute the index between indicators, and finally quantify the weight coefficients with some formulas, this paper thus employs this method.

3.2 Risk assessment of urban fire

3.2.1 To construct basic data sheet

The columns in the data sheet present the indicators in risk evaluation, constituting the sequence of number

\[ X_j = \{X_1, X_2, X_3, \ldots, X_n\} \quad (j=1, 2, 3, \ldots, n) \]

Since 48 third level evaluation indicators have been established in this paper, thus \( n=48 \).

3.2.2 To handle data

1. To quantify the data. Among the indicators in risk evaluation system, there might be both quantitative indicators and qualitative ones. The qualitative indicators need to be quantified so as to calculate the value of risk.

2. The Umpolung of data. Some indicators in the system and the comprehensive risk for urban fire are in either positive or negative relation. With the application of the theorem of “gray correlation inverse image-processing”, the value of multiplicative inverse which is in negative relation to comprehensive fire risk is computed, and then we transform the indicators with negative relation into positive one.

3. Sequence transformation of data. By transforming the sequence, the values of all evaluation indicators are transformed into undimensionalized data which is roughly close in terms of order of magnitude so that they can be compared. This paper employs a mean-based data transformation method, that is, the value of each column divides the mean value of each column.

3.2.3 To calculate correlation degree

1. If we take sequence \( X_1 \) as reference sequence, according to the formula

\[ \Delta_{ij} (k) = |X_i (k) - X_j (k)| \quad (k=1, 2, \ldots, n) \]

we use reference sequence to minus other column, and select the absolute value of the result, then we finally get absolute difference sequence.

2. By comparing the absolute difference sequence, we can get \( \Delta_{\text{min}} \) and \( \Delta_{\text{max}} \). In the formula of correlation coefficient:

\[ \xi_{ij} (k) = \frac{\Delta_{\text{min}} + \rho \Delta_{\text{max}}}{\Delta_{ij} (k) + \rho \Delta_{\text{max}}} \]

\( \rho \) is distinguishing coefficient, its value is [0,1]. Its value only determines the value of correlation coefficient \( \xi_{ij} \), it does not affect the order of correlation. Its value normally is 0.5. In order to get value of the absolute sequence, we have to compare the correlation coefficients of the reference sequence \( X_1 \) with relation to the sequence of number \( X_j \).

3. Based on the formula of relation degree, we can get the relation degree of comparative sequence \( X_j \) to reference sequence as follow:

\[ r_{ij} = \frac{1}{n} \sum_{k=1}^{n} \xi_{ij} (k) \]

In this formula, “n” represents the number of relation degree of comparative sequence \( X_j \) to reference sequence \( X_1 \).

4. Following the calculation procedures mentioned above, we change the reference sequence one by one, and we get the correlation values of all Fibonacci Sequences, and finally get relational matrix \( R \) \((n \times n)\). R here refers to diagonal elements which are valued 1. Based on this, we can calculate the mean \( \bar{r}_i \) of all rows in the relational matrix \( R \) \((n \times n)\).

3.2.4 The calculation of weight coefficient

Based on the formula \( \omega_i = \bar{r}_i / \sum_{i=1}^{n} \bar{r}_i \), we can get the values of weight coefficients \( \omega_i \) for all indicators in the system.

3.2.5 The quantification of risk evaluation indicators for urban fire

In the urban fire risk evaluation system, the criteria for establishing indicators and the value for each indicator are different
for different targeted districts. To ensure the generality of the evaluation method, a five-grade evaluation method is employed to grade all indicators and quantify them based on the actual situation in each district. They are graded in the way of scoring according to their relationships with the urban fire risk. Different criteria will be referred to for different evaluation indicators.

For those indicators with positive relation to the urban fire comprehensive risk, such as “the fire accident rate per 10 thousand persons”, five grade ranging from the lowest value to the highest value will be set up according to the population density in the district and the number of actual fire accidents, and accordingly, giving 1,2,3,4,5 as undimensionalized value. It just reverses for those evaluation indicators with negative relation to the comprehensive urban fire risk. Similar grading criteria is established for all the underlying index in the evaluation system, and the final values for these indicators are obtained in the target district by comparing the actual values of all evaluated districts.

3.2.6 Calculation of the value at risk of urban fire

Based on the weighted coefficient of indicators and the criteria for quantification corresponding to the actual indicators of the evaluated districts, we get the weighted sum, and finally we get the values at risk of urban fire, urban vulnerability, anti-fire capability and comprehensive fire risks.

3.2.7 The case of Haikou city

(1) The identification of areas to be evaluated. The major functions of city mainly concentrate in the districts administrated directly by the city government, and all key aspects of city can find their expressions in these districts, while the towns governed by the city government are not the major players. That is why the author of this paper mainly selects the data about the districts instead of towns, specifically, 17 sub-districts and 1 town of Haikou city.

(2) Results of comprehensive urban fire risk evaluation. Based on the weight coefficients (value for urban fire risk is 0.1845, value for city vulnerability is 0.187, value for city anti-fire capability is 0.7949) of Haikou city’s comprehensive fire evaluation indicators and the criteria of quantification, the sum of the weight is obtained, and accordingly the values of the above-mentioned items in the targeted sub-districts are identified (see table one for details). Among the 18 evaluated sub-districts in Haikou, the sub-districts administrated by Xiuying sub-district office, Jinyu sub-district office and Jinmao sub-district office are highest in terms of fire risk, while the sub-districts administrated by Zhongshan sub-district office and Boai sub-district office are lowest. The sub-districts under Datong sub-district office, Jinyu sub-district office and Jinmao sub-district office are relatively high with regard to urban vulnerability while Fucheng Town is the lowest in the same aspect. For anti-fire capability, Fucheng Town, Lantian sub-district office and Bailong sub-district office do a very good job. The ranking of value of comprehensive fire risk is as follows (from the highest to the lowest): Fucheng Town, Jinyu sub-district office, Jinmao sub-district office, Haifu Road sub-district office, Baoxi sub-district office, Datong sub-district office, Lantian sub-district office, Haidian sub-district office, Binhai sub-district office, Haiken sub-district office, Boai sub-district office, Baisha sub-district office, Remin Road sub-district office, South Heping Road sub-district office, Guoxing sub-district office, Zhongshan sub-district office, Haixiu sub-district office and finally Xiuying sub-district office. According to the evaluation result, Fucheng town is the highest among the evaluated districts in terms of comprehensive urban fire risk, while Zhongshan sub-district is the lowest in this regard. The facts also prove that this evaluation result is matched with the actual situation in urban fire risk in the city of Haikou.

Table one: values of risk of fire accidents, urban vulnerability, anti-fire capability and comprehensive fire risk

| Sub-district | Risk of fire accident | Urban vulnerability | Anti-fire capability | Comprehensive fire risk |
|--------------|-----------------------|---------------------|---------------------|------------------------|
| Xiuying      | 0.51647965            | 0.44090486          | 1.49155446          | 2.44893897             |
| Haixiu       | 0.43630106            | 0.44124952          | 1.65880078          | 2.53635136             |
| Zhongshan    | 0.28998824            | 0.58542504          | 1.71339084          | 2.58880412             |
| Binhai       | 0.49378374            | 0.60600023          | 1.82961589          | 2.92939986             |
| Datong       | 0.35280893            | 0.79096599          | 1.83923365          | 2.98300857             |
4 Conclusions

4.1 The applicability of the gray correlations degree method
The Gray Correlation Degree Method employed in this paper gives equal weight to each evaluation indicators, which enable people to select these indicators in an objective manner. Thus the obtained values of weight coefficient are objective. The research findings suggest that the gray correlations degree method can be applied in risk evaluation for urban fire.

4.2 The weight value
The weight value shows that as far as Haikou city is concerned, anti-fire capability is the most important factor in ensuring the fire safety. Urban vulnerability ranks the second and urban fire risk the last (this ranking is based on the result of weighted sum). As we know that fire generally break out accidentally, we thus need to strengthen the anti-fire capability building so as to lower the risk of fire and ensure the fire safety of the city.

4.3 Analysis of comprehensive risk for fire
By computing a large number of the collected data about the urban fire, the values of urban fire risk, urban vulnerability, anti-fire capability and the comprehensive risks of the 17 sub-districts and 1 town are obtained. The conclusion of this paper is that the comprehensive fire risk is generally high in Haikou city, it is therefore necessary to speed up and strengthen the infrastructure for fire prevention and control.

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