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Research and Application of Lightning Disaster Risk Assessment of Gas Station

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Abstract: In order to scientifically guide gas stations to implement the main responsibility of lightning disaster prevention, the corresponding lightning disaster risk assessment model and multi-level indexes weight evaluation method are explored. The analytic hierarchy process (AHP) is used to establish the indexes judgment matrix of each layer, the maximum characteristic root of the matrix is calculated and the consistency test is carried out, and the weight of each index is obtained. Based on the lightning location monitoring data of Shanghai in recent 12 years (2009 ~ 2020) and the data obtained from field visits and surveys, the lightning disaster risk index of each gas station is calculated. According to the classification method, the risk level and higher risk factors of each station are determined, and targeted suggestions are put forward to guide gas stations to take effective measures to prevent or reduce the risk of lightning disaster.

1. Introduction

At present, meteorological authorities at all levels are pushing forward the meteorological disaster risk census, and the China Meteorological Administration (CMA) has explicitly requested to improve meteorological disaster risk assessment and early warning service capabilities. As one of the most serious natural disasters, the frequency, likelihood and extent of lightning disaster are related to the breeding environment, disaster-causing factors and the characteristics of the disaster-bearing body itself. Domestic scholars have done a lot of research on lightning activity patterns, causes of disasters, and risk assessment. Zhang Guocai critically analyzed the expression of risk degree and risk assessment model based on the scientific connotation of natural disaster risk [1]; Zeng Jinquan et al. conducted a risk assessment study of regional lightning hazard risk based on the prior causative factors from the perspective of the prior risk assessment of lightning hazard [2-8]; Gu Yuan et al. analyzed the spatial and temporal distribution characteristics of cloud-to-ground lightning in Zhejiang Province from 2007 to 2018 based on the observation data of the lightning location system, and assessed the risk of cloud-to-ground lightning density and intensity as a disaster-causing factor [9]; Liu Pingying et al. formed a vulnerability risk zoning of lightning disaster in Kunming based on lightning location monitoring data and lightning disaster compilation data [10]. These studies provide a research basis for regional risk analysis of lightning disaster, but there is a lack of targeted and specific technical guidance for relevant units that need to assume the main responsibility for meteorological disaster defense. This paper explores the individual application of lightning disaster risk evaluation in 120 gas stations in Shanghai, based on the principles of natural disaster analysis, refers to the technical guidelines of lightning disaster risk zoning, selects the hazard of the causative factor, the exposure of the hazard-bearing body, and the vulnerability of the hazard-bearing body as the main analysis factors, establishes the lightning hazard risk evaluation model, uses the Analytic Hierarchy Process to determine the weight of the sub-indicators at all levels [11-13], uses the 2009-2020 Shanghai lightning location data, combines with the site survey and visit data, and calculates the lightning hazard risk indicator, and finally the lightning hazard risk level is classified according to the hierarchical statistical method, and targeted response suggestions are made to each gas station.

2. Data Source and Analysis Method

2.1. Data Source

With the longitude and latitude coordinates of each gas station measured on site as the center of the circle and 2 km as the radius, the lightning positioning monitoring data from 2009 to 2020 were extracted from the Shanghai lightning monitoring network, and a total of 113,466 valid cloud-to-ground lightning data were obtained from 120 gas stations, including the occurrence time, longitude and latitude coordinates, and lightning current amplitude of the cloud-to-ground lightning.

Other information and data of the disaster-bearing bodies involved were obtained from on-site surveys and visits of gas stations.

2.2. Analysis Methods

(1) Analytic Hierarchy Process (AHP): a multi-objective decision analysis method that combines qualitative and quantitative analysis methods, comparing and judging the importance degree between two indicators with reference to expert ratings, establishing a judgment matrix, and obtaining the weights of the importance degree of each factor by calculating the maximum eigenvalue of the judgment matrix, the corresponding eigenvector, and conducting consistency tests [14].

(2) Normalization method: for indicators with different magnitudes, normalization is carried out to achieve standardization. The calculation formula is:

$$D_{\mathrm{i}} = 0.5 + 0.5 \times \frac{A_{\mathrm{i}} - \mathrm{Min}}{\mathrm{Max} - \mathrm{Min}} \tag{1}$$

Where, D_{i} denotes the normalized value of the ith data, $\mathrm{A_i}$ denotes the ith data, and Max and Min are the maximum and minimum values in the same group of data, respectively.

(3) Grading statistics method: commonly used in statistics, the lightning disaster risk indicator is divided into 5 regions, which are very low, low, medium, high and very high. Firstly, all the calculated risk indices are sorted, in a small to large order, and every 24 are divided into one group, for a total of 5 groups. Finally, the average of the maximum value derived from the comparison of the nth group (n=1,2,3,4) and the minimum value derived from the comparison of the (n+1)th group (n=1,2,3,4) is recorded as the maximum value of the n'th level (n=1,2,3,4) and also the minimum value of the (n+1)'th level (n=1,2,3,4), as shown in formula (2).

$$\mathrm{n}'_{\mathrm{max}} = (\mathrm{n}+1)'_{\mathrm{min}} = 0.5 \times [\mathrm{n}_{\mathrm{max}} + (\mathrm{n}+1)_{\mathrm{min}}] \tag{2}$$

3. Establishment of Risk Assessment Model

3.1. Indicator Factor and Weighting Coefficients

The disaster generating factors can be roughly divided into disaster-causing factors, disaster-inducing environment and disaster-bearing body. According to the lightning hazard principle and the characteristics of the assessment target, the lightning hazard risk evaluation model for gas stations in Shanghai city determines the indicator factors to be considered and is divided into three indicator layers, with three indicator factors in the first layer, three groups of ten indicator factors in the second layer, and two indicator factors in the third layer (Figure 1).

Based on the Analytic Hierarchy Process, the indicators associated with the same layer are compared two by two using the 1~9 scaling method to determine the relative importance of each indicator (expert scoring combined with self-perception) and give the corresponding ratio (see Table 1); all scales form the judgment matrix A, and the maximum eigenvalue $\lambda_{\max}$ and the corresponding eigenvector W are obtained by solving the maximum eigenvalue of the judgment matrix A the weight coefficients of the indicators associated with the same layer. When the order of the judgment matrix A is greater than or equal to 3, the consistency test is required.

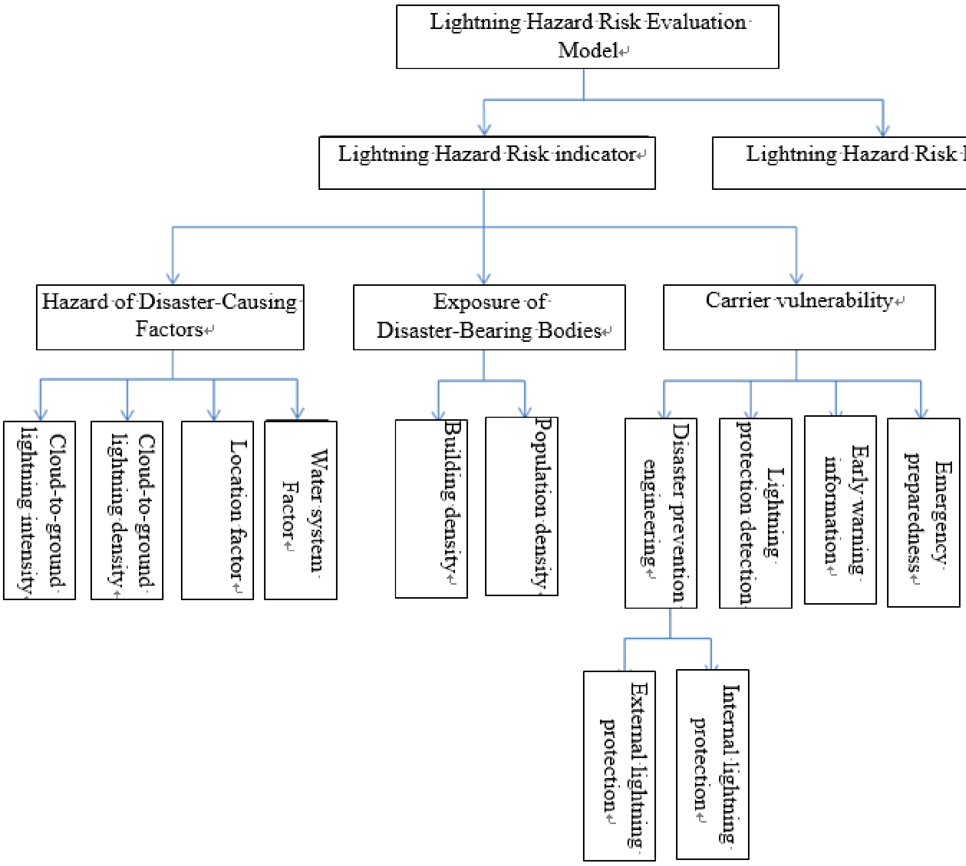

Figure 1: Lightning hazard risk evaluation model

Table 1: Table values for the scale method

Scale	Meaning
$a_{ij} = 1$	Indicator a_i has the same importance as indicator a_j
$a_{ij} = 3$	Indicator a_i is slightly more important than indicator a_j
$a_{ij} = 5$	Indicator a_i is significantly more important than indicator a_j
$a_{ij} = 7$	Indicator a_i is highly more important than indicator a_j
$a_{ij} = 9$	Indicator a_i is extremely more important than indicator a_j
$a_{ij} = 2,4,6,8$	Between scales
$a_{ii} = 1$(i=1~n)	/
Reciprocal	$a_{ji} = 1/a_{ij}$

The 1st layer indicators are hazard of disaster-causing factor, exposure of disaster-bearing body and vulnerability of disaster-bearing body, and the judgment matrix obtained from two comparisons is: $A=\begin{bmatrix} 1 & 3 & 1/3 \\ 1/3 & 1 & 1/5 \\ 3 & 5 & 1 \end{bmatrix}$. After calculation, the maximum eigenvalue of this matrix is $\lambda_{\max}$=3.039, $\mathrm{C.R.} = 0.037 \leq 0.1$, and the consistency meets the requirements. Determine the 1st layer indicator weight eigenvector as $W_1=\begin{bmatrix} 0.261 \\ 0.106 \\ 0.633 \end{bmatrix}$.

The indicator of the 2nd layer is divided into 3 groups.

The 1st group of the 2nd layer indicators are cloud-to-ground lightning intensity, cloud-to-ground lightning density, location factor and water system factor, and the judgment matrix obtained from two comparisons is: $A=\begin{bmatrix} 1 & 1/5 & 3 & 3 \\ 5 & 1 & 5 & 7 \\ 1/3 & 1/5 & 1 & 1/2 \\ 1/3 & 1/7 & 2 & 1 \end{bmatrix}$. After calculation, the maximum eigenvalue of this matrix is $\lambda_{\max}$=4.217， $\mathrm{C.R.} = 0.080 \leq 0.1$, and the consistency meets the requirements. Determine the 1st group of the 2nd layer indicator weight eigenvector as $W_{2.1}=\begin{bmatrix} 0.203 \\ 0.615 \\ 0.079 \\ 0.103 \end{bmatrix}$.

The 2nd group of the 2nd layer indicators are building density and population density, and the judgment matrix obtained from two comparisons is: $A=\begin{bmatrix} 1 & 1/3 \\ 3 & 1 \end{bmatrix}$. The matrix order is less than 3, and there is no need to test the consistency. Same as below. Determine the 2nd group of the 2nd layer indicator weight eigenvector as $W_{2.2}=\begin{bmatrix} 0.250 \\ 0.750 \end{bmatrix}$.

The 3rd group of the 2nd layer indicators are disaster prevention engineering, lightning detection, early warning information and emergency preparedness, and the judgment matrix obtained from two comparisons is: A=$\begin{bmatrix} 1 & 5 & 5 & 3 \\ 1/5 & 1 & 2 & 1/2 \\ 1/5 & 1/2 & 1 & 1 \\ 1/3 & 2 & 1 & 1 \end{bmatrix}$. After calculation, the maximum eigenvalue of this matrix is $\lambda_{\max}$=4.175, $\mathrm{C.R.} = 0.065 \leq 0.1$, and the consistency meets the requirements. Determine the 3rd group of the 2nd layer indicator weight eigenvector as $W_{2.3}$=$\begin{bmatrix} 0.567 \\ 0.136 \\ 0.117 \\ 0.180 \end{bmatrix}$.

The 3rd layer indicators are hazard of disaster-causing factor, exposure of disaster-bearing body and vulnerability of disaster-bearing body, and the judgment matrix obtained from two comparisons is: A=$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$. Determine the 3rd layer indicator weight eigenvector as W_3=$\begin{bmatrix} 0.500 \\ 0.500 \end{bmatrix}$.

3.2. Risk Level Classification

After determining the weight coefficients of all indicator factors, the lightning hazard risk indicator values of all gas stations can be obtained by calculating and applying the hierarchical statistical method to divide the risk indicator into 5 regions, which are very low, low, medium, high and very high.

First, all the risk indicator values are sorted in a manner from smallest to largest; then, all the indicator values are divided into 5 groups in equal order (if the complete grouping is not possible then the remaining data are grouped into the 5th group); finally, the average of the maximum value derived from the comparison of the nth group (n = 1, 2, 3, 4) and the minimum value derived from the comparison of the (n + 1)′th group is recorded as the maximum value of the nth level (n = 1, 2, 3, 4) and the minimum value of the (n + 1)′th level, that is:

$$n'_{\max} = (n+1)'_{\min} = [n_{\max} + (n+1)_{\min}]/2 \qquad \text{……(3)}$$

The thresholds of the five regions can be determined by calculating from Formula (3).

4. Case Study

Taking a gas station as an example, a total of 881 lightning flashes were monitored in the past 12 years, and all the lightning current amplitude data were sorted in order from lowest to highest, and the cloud-to-ground lightning intensity was calculated according to Formula (4) based on the threshold interval grading in Table 2.:

$$L_n = \sum_{(i=1)}^{5} \left(\frac{i}{15} \times F_i\right) \qquad \text{……(4)}$$

Where, i is the lightning current amplitude level, F_i is the lightning current amplitude for i level of the number of cloud-to-ground lightning frequency.

Table 2: Classification of lightning current amplitude

Level	Percentile (P) interval	Threshold
Level 1	P≤60%	I≤17.2935kA
Level 2	60%<P≤80%	17.2935kA<I≤30.0669kA
Level 3	80%<P≤90%	30.0669kA<I≤40.9005kA
Level 4	90%<P≤95%	40.9005kA<I≤50.4714 kA
Level 5	P>95%	I>50.4714 kA

Cloud-to-ground lightning density is calculated according to Formula (5):

$$\mathrm{L_d} = \frac{\sum_{i=1}^{5} \mathrm{F_i}}{(\pi\times4)\times12} \qquad \text{……(5)}$$

Building density is calculated according to Formula (6):

$$\mathrm{D_s} = \frac{\mathrm{A_b}+\mathrm{A_s}}{\mathrm{A_g}} \qquad \text{……(6)}$$

Where: A_b is the floor area of the business room, A_s is the floor area of the canopy, and A_g is the total floor area of the gas station.

Population density is calculated according to Formula (7):

$$\mathrm{D_p} = \frac{\mathrm{N_w}+\mathrm{N_g}}{\mathrm{A_g}} \qquad \text{……(7)}$$

Where: N_w is the number of working population, N_g is the number of foreign population (number of fuel guns in the station * 1.5)

The values of the above four indicator factors are normalized according to Formula (1). The other 8 indicator factors are location factor, water system factor, disaster prevention engineering, lightning detection, warning information, emergency preparedness, external lightning protection and internal lightning protection, and the corresponding values are selected qualitatively according to the preset Table 3.

Table 3: Values of indicator factors of a gas station

Indicator factor	Numeric	Weighting
Cloud-to-ground lightning intensity (normalized)	0.7297	0.2.3
Cloud-to-ground lightning intensity (normalized)	0.6938	0.615
Location factor	0.25	0.079
Water system factor	1	0.103
Building density (normalized)	0.7783	0.250
Population density (normalized)	0.7664	0.750
Disaster prevention engineering	0.65	0.567
Lightning protection detection	0.8	0.136
Early warning information	0.8	0.117
Emergency preparedness	0.8	0.180
External lightning protection	0.8	0.500
Internal lightning protection	0.5	0.500

The calculated risk indicator R_D of the gas station is 0.3297.

After completing the calculation of the risk indicator of 120 gas stations, the risk indicator of all gas stations was ranked to determine the grade, and the four indicators normalized to determine the grade were also ranked separately. Finally, it was concluded that the risk indicator rank of the gas station was high. Among all the indicator factors, the cloud-to-ground lightning intensity and cloud-to-ground lightning density are medium, and the building density and population density are very high. Combined with the distribution of water systems in the vicinity of the station, it is recommended that the station should, on the basis of good daily lightning protection, be particularly strengthened by paying attention to early warning information, strengthening emergency preparedness rehearsals.

5. Summary

This paper uses analytic hierarchy process, normalized processing, and hierarchical statistics to construct a lightning hazard risk evaluation model and evaluation approach applicable to gas stations, explore the quantitative calculation of indicator weights, clarify the lightning hazard risk classification scheme, and finally demonstrate the practical application of the evaluation model and evaluation approach through case studies to provide scientific, effective, and targeted guidance recommendations for gas stations.

The literature research base, expert argumentation and evaluation provide a solid theoretical foundation for this paper, but the final model construction inevitably has some subjective judgment and the coverage of the research object is insufficient. With the further depth of the study, coming to the further expansion of the research scope, the evaluation model will be further improved in the future, and the settings of some formulas, indicators and coefficients need to be revised or modified.

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References

[1] ZHANG Guocai. Risk assessment and zoning method for meteorological disasters. Beijing: China Meteorological Press (in Chinese), 2010, 12-20.

[2] Zeng Jinquan, Feng Zhenzhen, Zhang Yefang et al. Regional Lighting Disaster Risk Assessment Model and Its Application. Meteorological Science and Technology, 2017, 45(1): 178-182.

[3] Wang Shuyi, Zou Shanyong, Wang Jianjian. Quantification Methods of Evaluation Index System for Lightning Risk Assessment in Dalian. Meteorological Science and Technology, 2016, 44(3): 510-516.

[4] Wang Min, Kong Shangcheng, Wang Xiuying. Vulnerability and Regionalization of Lightning Disasters in Eastern Qinghai, Meteorological Science and Technology, 2018, 46(2): 412-417.

[5] Chen Liutong, Long Shuang, Yu Haiyang et al. Research on Risk Zoning of Lightning Disaster in Hebei Province, Journal of Catastrophology, 2019, 34(3): 189-195.

[6] Cheng Xiangyang, Xie Wusan, Wang Kai et al. Method research of the risk zoning of thunder and lightning and its application over Anhui Province. Journal of the Meteorological Sciences, 2012, 32(1): 80-85.

[7] Li Jingxiao, Hu Haibo, Fan Rong, et al. Impact of lightning monitoring and warning on lightning risk assessment. Journal of the Meteorological Sciences, 2013, 33(6): 678-684.

[8] Chen Yu, Wang Lei, Yang Chao, et al. Temporal-spatial distributions of lightning and prediction of lightning strike risk comprehensive index over Dalian Area. Journal of the Meteorological Sciences, 2017, 37(6):832-838.

[9] Gu Yuan, Zhang Weibin, Cui Xuedong. Analysis of CG Lighting Characteristics and Disaster-Causing Risk in Zhejiang Province, Meteorological Science and Technology, 2021, 49(4): 654-661.

[10] Liu Pingying, Zhang Tengfei, Zhou Qingqian et al. Analysis of the causes of lightning disasters in Kunming City from 2006 to 2016 and vulnerability risk Zoning. Journal of the Meteorological Sciences, 2018, 38(6): 824-831.

[11] Cai Zhongzhou, Hu Yanan, Jin Xin. Risk Zoning of Regional Lightning Disaster in Xining Based on Analytic Hierarchy Process Model. Chinese Agricultural Science Bulletin, 2020, 36(15): 74-80.

[12] Guo Jinyu, Zhang Zhongbin, Sun Qingyun, Study and Applications of Analytic Hierarchy Process. China Safety Science Journal, 2008, 18(5): 148-153.

[13] Deng Xue, Li Jia-ming, Zeng Hao-jian et al. Research on Computation Methods of AHP Weight Vector

and Its Applications. Mathematics In Practice and Theory, 2012, 42(7): 93-100.

[14] Ye Yao-jun, Wang Shou-jun, Wei Lei et al. Approximate computation on the maximum eigenvalue of matrixs. Journal of Henan Agricultural University, 2001, 35: 69-71.