Research on Risk Early Warning for the Cryogenic Freezing Rain and Snow Disaster

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Abstract. With the impact of global climate change on extreme weather and the rapid expansion of human activity range, the cryogenic freezing rain and snow disaster is becoming more frequent, bringing quite adverse effects on transportation, electric power and other industries, thus seriously affecting social and economic development and people's daily life. Implementation of risk early warning is one of the most effective means to prevent the cryogenic freezing rain and snow disaster. This paper, taking Guizhou Province as an example, studies the early warning technology and method for the cryogenic freezing rain and snow disaster based on the demand for prevention of the cryogenic freezing rain and snow disaster, and considering meteorological factors, topography, social economy, power transportation and other factors. On this basis, the weight of risk factors is determined by subjective weighting method, the risk early warning model for the cryogenic freezing rain and snow disaster based on AHP is constructed, and the four-level risk early warning indexes are determined. Trial application is realized in Guizhou Province.

Keywords: Cryogenic Freezing Rain and Snow Disaster, Risk, Early Warning, Guizhou

1. Introduction
Cryogenic Freezing Rain and Snow Weather are the phenomena of snow and ice as a result of snowfall (or sleet, graupel, ice particles, freezing rain, etc.) or low temperature after rainfall, which mainly occur in winter, but occasionally between autumn and winter as well as winter and spring. With the impact of global climate change on extreme weather and the rapid expansion of human activity range, the cryogenic freezing rain and snow disaster is becoming more frequent, bringing quite adverse effects on transportation, electric power and other industries, thus seriously affecting social and economic development and people's daily life. At the beginning of 2008, rare extreme cryogenic freezing rain and snow weather occurred in southern China, which lasted for a long time with large influence range, exerting huge influence on transportation, electric power, agriculture and ecosystem.

Implementation of risk early warning is one of the most effective means to prevent the cryogenic freezing rain and snow disaster, carrying out early warning by taking advantage of meteorological...
forecast data to analyze and judge the possibility of the cryogenic freezing rain and snow disaster and early release the information on areas where the cryogenic freezing rain and snow disaster may occur according to the early warning level, so as to enhance the public's defense awareness, remind the related industries such as electric power, transportation and agriculture to prepare for defense, and provide scientific basis for government departments at all levels to carry out disaster prevention, disaster resistance and relief work.

2. researched area and data source

2.1. Basic Information of Guizhou Province

Guizhou Province is located in the upper reaches of the Yangtze River and the Pearl River Basin, bounded by the Miaoling Mountains in the middle, the Yangtze River Basin in the north and the Pearl River Basin in the south. It is located in the northeast slope of the Yunnan-Guizhou Plateau, with an average altitude of about 1,100m. Guizhou Province is in the subtropical zone with a humid monsoon climate, where the winter wind is prevailing and cold air flows from the north to the south frequently, so it is prone to the cryogenic freezing rain and snow weather. The cold air is blocked by the Yunnan-Guizhou Plateau, and the raindrops in the upper warm wet air are transformed into cooling water droplets when passing through the lower cold air, then fall to the ground under the action of gravity and freeze rapidly, often forming the cryogenic freezing rain and snow weather.

2.2. Spatial-temporal Features Characteristics of the Cryogenic Freezing Rain and Snow Disaster in Guizhou Province

According to the data analysis of 84 meteorological stations from 1971 to 2008, the distribution of the cryogenic freezing rain and snow weather in Guizhou Province is more in the west, less in the east, more in the middle and less in the north and south. The annual the cryogenic freezing rain and snow weather exceeding 10 days in average are distributed between 25.5–27.5N, at area over 1,000m above sea level or relatively high. There are four centers of the cryogenic freezing rain and snow weather (the average annual sleet days are more than 30), which are distributed in an east-west band along 27°N at Weining (having annual average sleet days of 60.3 which are the most), Dafang, Kaiyang, Wanshan, etc. The cryogenic freezing rain and snow disaster in Guizhou Province mainly occur in Winter (December to the next February), accounting for 94.1% of the total station counting.

2.3. Data source

According to the causes of the cryogenic freezing rain and snow disaster and the main affected industries, and considering the application requirements of risk early warning for the cryogenic freezing rain and snow disaster, basic data such as meteorology, topography, land use and vegetation type, social economy, traffic roads and power line network are collected.

The basic geographic information data are 1: 50,000 and 1: 250,000 digital line data of the National Geomatics Center of China, which mainly include administrative boundaries, water systems, roads, geographical names and other geographical elements. The weather forecast products are GFS forecast data published by the National Centers for Environmental Prediction (NCEP) of the United States, which mainly include four selected variables including precipitation, wind speed, temperature and humidity. Land use and vegetation types are based on the data extracted from 30m satellite images, including arable land, forest land, shrubland, grassland, water and land for water conservancy facilities, glaciers and permanent snow, buildings (districts), other lands and marshes. The topography data are the SRTM digital elevation model data.
3. Risk early warning method for the cryogenic freezing rain and snow disaster

3.1. Identification of Risk Factors

According to the disaster-causing mechanism of the cryogenic freezing rain and snow disaster, based on the existing data conditions and considering the independence of each factor, the risk factors of cryogenic freezing rain and snow disaster are identified from three aspects: hazard, vulnerability and risk-bearing body.

The hazard of the cryogenic freezing rain and snow disaster mainly reflects the variation characteristics of the natural process of cryogenic freezing rain and snow disaster, embodies the natural attributes of the disaster of cryogenic freezing rain and snow, and is mainly the extreme meteorological factor in winter. Hazard is the direct cause of cryogenic freezing rain and snow disaster, which mainly includes factors such as low temperature, rain, snow and freezing degree. The risk-bearing body and vulnerability of cryogenic freezing rain and snow disaster reflect the social attribute of cryogenic freezing rain and snow disaster. The risk-bearing body is mainly the bearing object of the risk of cryogenic freezing rain and snow, and road traffic, electric power, population and property which are closely related to people's production and life are mainly considered. The vulnerability of cryogenic freezing rain and snow disaster is the ability to resist disasters, so it is expressed by the vulnerability degree according to the ability of disaster resistance and relief when freezing disaster occurs and the ability of recovery and reconstruction after disaster.

3.2. Quantification of risk factor weight

Analytic Hierarchy Process (AHP) is to take a complex multi-objective decision-making problem as a system, decompose the objective into multiple objectives or criteria, and then into several layers of multiple indexes (or criteria and constraints), and calculate the single hierarchical arrangement (weight) and the total hierarchical arrangement through the fuzzy quantitative method of qualitative indexes, which is a systematic method for optimizing decision-making of objectives (multiple indexes) and multiple schemes.

According to the different attributes of risk factors of cryogenic freezing rain and snow disaster, a hierarchical structure model is established from top to bottom. The upper elements dominate the lower ones, and elements controlled by the same index are parallel. After the hierarchical structure model is established, the membership relationship of different layers of elements is also determined. If the element $B_i$ of a certain hierarchical structure is taken as the standard and dominates the elements $C_1, \ldots, C_n$ in the lower structure, it is necessary to compare these elements in pairs to determine the importance of the order, and then mark them according to the quantitative table of 1~9 comparison scales proposed by Saaty, as shown in Table 1.

| Relative importance | Meaning |
|---------------------|---------|
| 1                   | Two factors are compared and they are of equal importance |
| 3                   | Two factors are compared and the former is of weak importance over the latter |
| 5                   | Two factors are compared and the former is of essential importance over the latter |
| 7                   | Two factors are compared and the former is of demonstrated importance over the latter |
| 9                   | Two factors are compared and the former is of absolute importance over the latter |
| 2, 4, 6, 8          | Intermediate value of the above two adjacent judgment factors |

Table 1. Meaning of Level 1 to Level 9 comparison scales
Single hierarchical arrangement refers to calculating the weight of the importance order of the elements at this layer dominated by a certain hierarchical structure element based on the constructed judgment matrix, which can be transformed into the problem of calculating the eigenvalue and eigenvector of the judgment matrix, that is, calculating the eigenvalue and eigenvector satisfying Equation (1) for the judgment matrix C.

\[ CW = \lambda_{\text{max}} \cdot W \]  

(1)

where, \( \lambda \) is the maximum eigenvalue of B; W is the eigenvector of \( \lambda \).

After obtaining the eigenvector of the matrix, it is necessary to check the consistency of the matrix. Saaty et al. define CI as the consistency index of B (judgment matrix), and when CI=0, B has complete consistency; the larger the CI is, the more serious the inconsistency of B is. See Equation 2 for the calculation.

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  

(2)

where, \( \lambda_{\text{max}} \) is the maximum eigenvalue of the judgment matrix; n is the order of the judgment matrix.

In order to judge the inconsistent range of matrix and find out the standard to measure the consistency index of B, Saaty et al. introduced the average random index RI, and its random average is shown in Table 2. The consistency ratio CR of the judgment matrix is calculated using Equation (3). If CR<0.1, the consistency of the judgment matrix is within acceptable range; if CR>0.10, it is unacceptable and needs to be reconstructed.

\[ CR = \frac{CI}{RI} \]  

(3)

where, CR is the consistency ratio of single hierarchical arrangement; CI is the consistency index of judgment matrix; RI is the average random index.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

The total hierarchical arrangement is to calculate the weights of all elements in a layer against its upper elements in terms of important order by using the results of all single arrangement in the same hierarchical structure. The calculation is generally carried out layer by layer from top to bottom, while the lowest total arrangement is the final weight of each element required. See Equation (4) for the calculation.

\[ W_i = \sum_{j=1}^{n} \sum_{i=1}^{m} W_i \times b_j \]  

(4)

where, \( W_i \) is the single hierarchical arrangement of elements at this layer; \( b_j \) is the total hierarchical arrangement of upper elements relative to \( W_i \); \( W_i \) is the total hierarchical arrangement of elements at this layer.
After getting the results of total hierarchical arrangement, it is also necessary to check the consistency of the results. Saaty et al. define CR as the consistency ratio of total hierarchical arrangement. When CR<0.1, the result of general sorting is acceptable, and see Equation (5) for the calculation.

\[
CR = \frac{\sum_{j=1}^{n} b_j CI_j}{\sum_{j=1}^{n} b_j RI_j}
\]

where, \(b_j\) is the weight of elements in judgment matrix B; \(CI_j\) is the consistency index of judgment matrix corresponding to \(b_j\); \(RI_j\) is the average random index of the judgment matrix corresponding to \(b_j\).

3.3. Risk Early Warning Model Construction and Early Warning Index Calculation

On the basis of the above-mentioned research on risk identification of the cryogenic freezing rain and snow disaster, this paper selects four factors, i.e. precipitation, temperature, wind speed and relative humidity as risk factors of the cryogenic freezing rain and snow disaster, and nine factors as risk-bearing body factors, i.e. population density, GDP per area, road network density, power grid density and substation density, passenger volume, freight volume, arable land area ratio and forest land area ratio. Restricted by data and information conditions, vulnerability indexes such as maximum wire icing thickness, ice melting technology, response speed, monitoring and early warning equipment and accident susceptibility are not considered.

The comprehensive risk value of the disaster of cryogenic freezing rain and snow disaster is taken as an early warning index, i.e., a quantitative index is used to represent the comprehensive result of disaster susceptibility and severity. The early warning index of the cryogenic freezing rain and snow disaster is calculated using the following equation, which is the sum of the products of each index and its weight.

\[
S = \sum_{i=1}^{13} W_i P_i, i = 1, \cdots, 13
\]

Where, \(W_i\) is the factor weight, \(P_i\) is the normalized value of 13 factors, and \(S\) is the comprehensive risk early warning index of the cryogenic freezing rain and snow disaster.

The early warning level shall be determined by multi-event calibration to determine the index value corresponding to each disaster level. The classification standard of early warning level includes four levels: perhaps, possible, probable, and prone to. Because the risk-bearing body index and vulnerability index are fixed values in a certain period of time, the extreme state of meteorological conditions is mainly set as the upper and lower boundary conditions of early warning index. The lower boundary conditions are: meeting the minimum precipitation in winter, the maximum temperature in winter, the maximum wind speed and the minimum humidity at the same time; the upper boundary conditions are: meeting the maximum precipitation in winter, the minimum temperature in winter, the minimum wind speed and the maximum humidity simultaneously. The upper and lower boundaries are taken as envelope lines, and four levels are set respectively by means of natural discontinuity or equal sample quantity discontinuity.

4. Application of risk early warning for cryogenic freezing rain and snow disaster in Guizhou Province

4.1. Early warning index calculation

Collect the meteorological data, natural resources data, traffic road data, electric power data, social and economic data and historical data of the cryogenic freezing rain and snow disaster in Guizhou Province, and make map of 13 factors, including precipitation, temperature, wind speed, relative
humidity, population density, GDP per area, road network density, power grid density and substation density, passenger volume, freight volume, arable land area ratio and forest land area ratio according to the grid size of 1km*1km.

Establish the hierarchical structure model according to the risk factors of the cryogenic freezing rain and snow disaster. The upper elements dominate the lower elements, and the elements dominated by the same index are parallel. After the establishment of the hierarchical structure model, if the elements of a certain hierarchical structure are taken as standard, they will dominate the elements in the lower structure, and these elements will be compared in pairs to determine the importance of the order, and then determine the weight of each index.

Fig. 1 Risk factors of the cryogenic freezing rain and snow disaster.

4.2. Analysis and verification of early warning results
The weather forecast data on January 28, 2018 is used as the input condition of the early warning model to obtain the risk early warning results of the cryogenic freezing rain and snow disaster in Guizhou Province. The early warning is for the next 24 hours, and the early warning level is divided into four levels, namely, IV (perhaps), III (possible), II (probable) and level I (prone to). The
comprehensive early warning results of the cryogenic freezing rain and snow disaster on January 28, 2018 were compared with the actual disaster situation in Guizhou Province to verify the early warning results. The result shows that the simulated prediction results are well consistent with the actual disaster situation.

4.3. Release of early warning information
CAP (Common Alerting Protocol) is a digital information format suitable for all kinds of alarm messages, which can be converted between data formats of various monitoring and early warning technologies. At present, CAP has been widely used in government authorities or organizations in many countries. China's national public emergencies early warning release system adopts this standard as the standard for describing and releasing early warning information. According to the characteristics of early warning information for the cryogenic freezing rain and snow disaster, this paper focuses on defining the sub-element attributes of early warning information elements, such as the category of early warning events, the level of early warning events, and the measures to be taken by early warning

5. Conclusion
This paper, taking Guizhou Province as an example, studies the early warning technology and method for the cryogenic freezing rain and snow disaster based on the demand for prevention of the cryogenic freezing rain and snow disaster, and considering meteorological factors, topography, social economy, power transportation and other factors. In this paper, the risk factors of the cryogenic freezing rain and snow disaster are identified from three aspects: hazard, risk-bearing body and vulnerability. On this basis, the weight of risk factors is determined by subjective weighting method, the risk early warning model for the cryogenic freezing rain and snow disaster based on AHP is constructed, and the four-level risk early warning indexes are determined. Trial application is realized in Guizhou Province. The early warning results of the cryogenic freezing rain and snow disaster in Guizhou Province on January 28, 2018 are compared with the actual disasters in Guizhou Province, which are well consistent. The predicted results can provide reference for the release of early warning information.

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