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Hazard Analysis of Severe Convective Weather in Guangdong Province, China

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Abstract: In the present study, a hazard model of severe convective weather was constructed on the basis of meteorological observational data obtained in Guangdong Province between 2003 and 2015. In the analysis, quality control was first conducted on the severe convective weather data, and the kriging method was then used to interpolate each hazard-formative factor. The weights of which were determined by applying the coefficient of variation method. The results were used to establish the hazard-formative factor model of severe convective weather. The cities showing the greatest hazards for severe convective weather in Guangdong Province include Yangjiang, Dongguan, Foshan, Huizhou, Jiangmen, and Qingyuan.

Key words: severe convective weather; quality control; weight; hazard-formative factor; hazard

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1 INTRODUCTION

Severe convective weather, which mainly includes thunderstorm gales with gusts ⩾17.2 m s^{-1}, hail, tornadoes, and short-term heavy rainfall ⩾20 mm h^{-1}, is one of the main meteorological disasters occurring in Guangdong Province during the annually first rainy season [1].

The hazard-formative factors of typhoons and rainstorms have attracted significant research attention. For example, Wang et al. [2] calculated the agricultural effects under various risk levels by analyzing the storm-hazard and environmental vulnerability factors. Other studies analyzed the risks of typhoon hazard factors and the vulnerability of disaster-tolerant systems in China [3–10].

Several previous studies analyzed the hazards of severe convective weather. Zhao et al. [11] examined the influence of topography on factors of lightning risks. In addition, Cao et al. [12] generated a final zoning map by analyzing the risk levels of disaster-inducing factors as well as the exposure and vulnerability of disaster-bearing bodies.

At present, no zoning maps exist for the four main types of severe convective weather in China. An essential component in hazard analysis of severe convective weather is the quality control of data, which requires numerous case studies and analysis periods. However, little analysis has been conducted on this topic in China owing to insufficient data for study. The hail and tornado datasets used in the present study were obtained from a manual observation database with no need for quality control. However, the quality of the hourly precipitation and wind data were controlled by checking the temporal, spatial, and factor consistencies and climate boundary values, as well as manual observation. Although weight determination of the formative factors of severe convective weather hazards is also crucial in such research, no quantitative method for this process has been proposed. Therefore, in the present study, the weights of hazard-formative factors of severe convective weather are quantitatively and objectively determined according to meteorological observational data obtained in Guangdong Province between 2003 and 2015. In particular, the risks associated with the hazard-formative factors of severe convective weather in Guangdong Province are evaluated to provide scientific references for meteorological warnings and forecasting. In addition, the results of this study are expected to be helpful in making decisions on disaster prevention and mitigation measures.

2 DATA AND METHODS

2.1 *Data description*

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The observational data of national and regional meteorological stations recorded between 2003 and 2015 were used in this study. This information includes hail and tornado datasets obtained from a manual observation database with no need for quality control, and thunderstorm gale and short-term heavy rainfall data sets obtained from a historical hourly meteorological observation database from the Climate Center of Guangdong Province. The quality control methods of the hourly precipitation and wind data include temporal, spatial, and factor consistency checks, climate boundary value checks, and manual checks.

2.2 *Method description*

2.2.1 WEIGHT DETERMINATION

(1) Determination of hazard-formative factors

Because short-term heavy rainfall, thunderstorm gales, hail, and tornadoes are the main hazard-formative factors for severe convective weather in Guangdong Province, these four factors were adopted accordingly in the present study.

Short-term heavy rainfall is defined as a precipitation event with cumulative rainfall ⩾20 mm h^{-1}. However, precipitation events with 3 h cumulative rainfall amounts ⩾50 mm and ⩾100 mm are also prone to cause disasters in Guangdong Province. Thus, precipitation cases with rainfall ⩾20 mm h^{-1}, ⩾50 mm $3h^{-1}$, and ⩾100 mm $3h^{-1}$ were adopted in this study as indicators for short-term heavy rainfall.

In this study, a thunderstorm gale was defined as a severe wind weather event with gusts reaching up to level 8, or ⩾17.2 m s^{-1}. Thus, severe wind events with gusts ⩾17.2 m s^{-1}, ⩾24.5 m s^{-1}, and ⩾32.7 m s^{-1} were adopted as three indicators for thunderstorm gales.

The hail and tornado events were analyzed according to the frequency obtained from the manual observation database. Therefore, no indicators were set for these events.

(2) Normalization of hazard-formative factors

To eliminate the effects of different units and to facilitate calculation, the aforementioned hazard-formative factors were quantified into a non-vector index between 0 and 1 by using the following formula:

$$D_{ij}=\frac{A_{ij}-\min_i}{\max_i-\min_i}, \quad (1)$$

where D_{ij} is the normalized value of the i th index in the j zone, A_{ij} is the ith index in the j zone, and $\min_i$ and $\max_i$ are the minimum and maximum values of the i th index, respectively.

(3) Weight determination

The coefficient of variation method, which objectively uses the information contained in each index to calculate the weight, was adopted in this study to determine the weights of the hazard-formative factors. In this evaluation index system, although indices with greater differences in value are more difficult to achieve, they can better reflect differences in the parameters to be evaluated.

Owing to the different dimensions of each index in the evaluation index system, direct comparison of the difference degree is not appropriate. To eliminate the influence of the different dimensions of each evaluation index, it is necessary to use the coefficient of variation of each index to measure the difference degree of each index value. The variation coefficient formula of each index is

$$V_i=\frac{\sigma_i}{\bar{x}_i}(i=1, 2, L, n), \quad (2)$$

where V_i is the coefficient of variation (coefficient of standard deviation) of the i th index, σ_i is the standard deviation of the i th index, and $\bar{x}_i$ is the mean value of the i th index.

The weight of each index is

$$W_i=\frac{V_i}{\sum_{i=1}^{n} V_i} \quad (3)$$

Table 1 shows the standard deviation, mean value, and coefficient of variation of each hazard-formative factor, where R1, R2, and R3 are precipitation events with ⩾20 mm h^{-1}, ⩾50 mm $3h^{-1}$, and ⩾100 mm $3h^{-1}$ cumulative rainfall, respectively; W1, W2, and W3 are the severe wind weather events with maximum gusts reaching levels 8, 10, and 12, respectively; H and T represent hail and tornado events, respectively.

Table 1. Weights of hazard-formative factors.

Index	R1	R2	R3	W1	W2	W3	H	T	Sum
Standard deviation	0.2019	0.0941	0.0589	0.1071	0.0559	0.0961	0.0898	0.0781	—
Mean value	0.3009	0.0716	0.0110	0.0701	0.0210	0.0093	0.0129	0.0115	—
Coefficient of variation	0.6711	1.3145	5.3536	1.5277	2.6624	10.3130	6.9789	6.8083	35.6295
Weight	0.0188	0.0369	0.1503	0.0429	0.0747	0.2895	0.1959	0.1911	1.000

2.2.2 HAZARD MODEL CONSTRUCTION

The model of the hazard-formative factors of severe convective weather was constructed according to the weights calculated above. The results were used to develop the integrated model of the hazard-formative factors of severe convective weather in Guangdong Province as

$$IDRI = D_{R1}*W_{R1} + D_{R2}*W_{R2} + D_{R3}*W_{R3} + D_{W1}*W_{W1} + D_{W2}*W_{W2} + D_{W3}*W_{W3} + D_H*W_H + D_T*W_T, \quad (4)$$

where IDRI is the integrated hazard index of severe convective weather; D_{R1}, D_{R2}, and D_{R3} are the normalized hazard indices of three types of short-term heavy rainfall, respectively; D_{W1}, D_{W2}, and D_{W3} are the normalized hazard indices of three types of thunderstorm gale, respectively; D_H and D_T are the normalized hazard indices of hail and tornado, respectively; and W corresponds to the weight of each hazard-formative factor.

2.2.3 SPATIAL INTERPOLATION

The kriging method was adopted in this study to determine the weights of the hazard-formative factors. This method is a regression algorithm for the spatial modeling and prediction (interpolation) of random process or random fields based on the covariance function [13]. Kriging is a typical statistical algorithm that has been applied in such fields as geography, environmental science, and atmospheric science.

3 RESULTS

On the basis of the hazard model of severe convective weather described in Section 2.2.2 and the weights of the four hazard-formative factors derived in Section 2.2.1, normalization processes were performed to obtain the hazard index of severe convective weather in Guangdong Province (Fig. 1). The hazard indices are the highest in Yangjiang, Dongguan, Foshan, Huizhou, Jiangmen and Qingyuan.

The distributions of cases with rainfall ≥20 mm h^{-1}, ≥50 mm $3h^{-1}$, and ≥100 mm $3h^{-1}$ after normalization are shown in Figs. 1, 2, and 3, respectively; those of cases with gusts ≥17.2 m s^{-1}, ≥24.5 m s^{-1}, and ≥32.7 m s^{-1} after the normalization are shown in Figs. 4, 5, and 6, respectively; and those of hail and tornado cases after normalization are shown in Figs. 7 and 8, respectively.

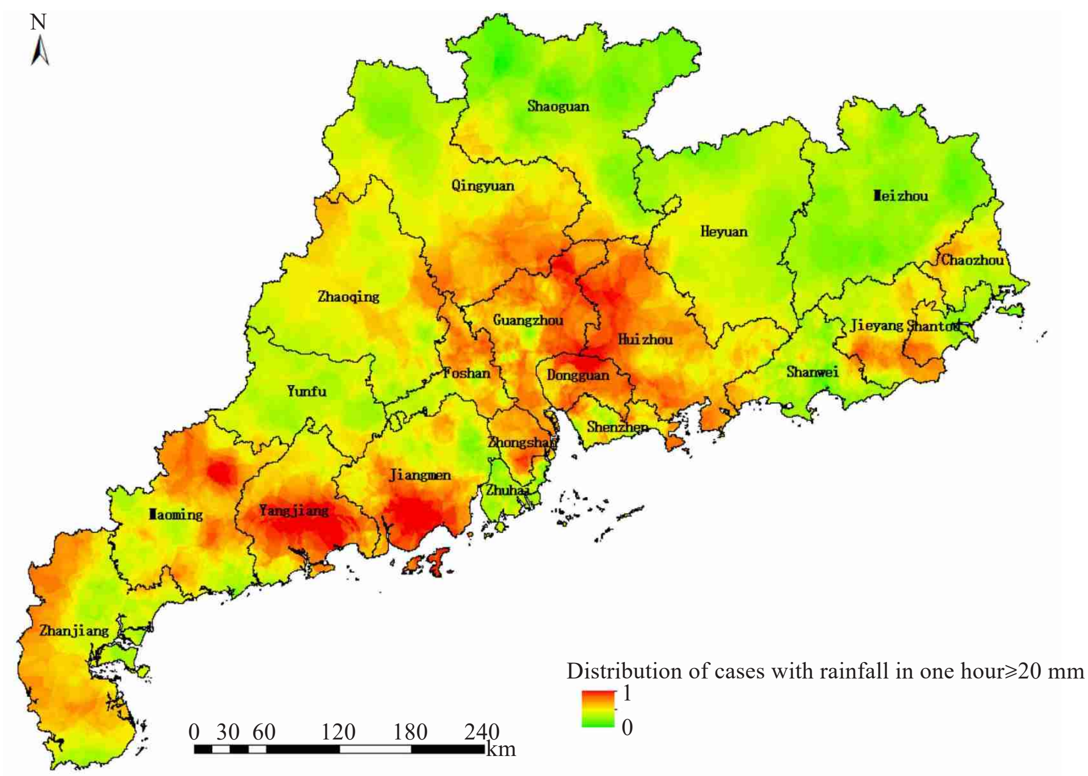

Figure 1. Distribution of cases with rainfall ≥20 mm h^{-1} in Guangdong Province after normalization.

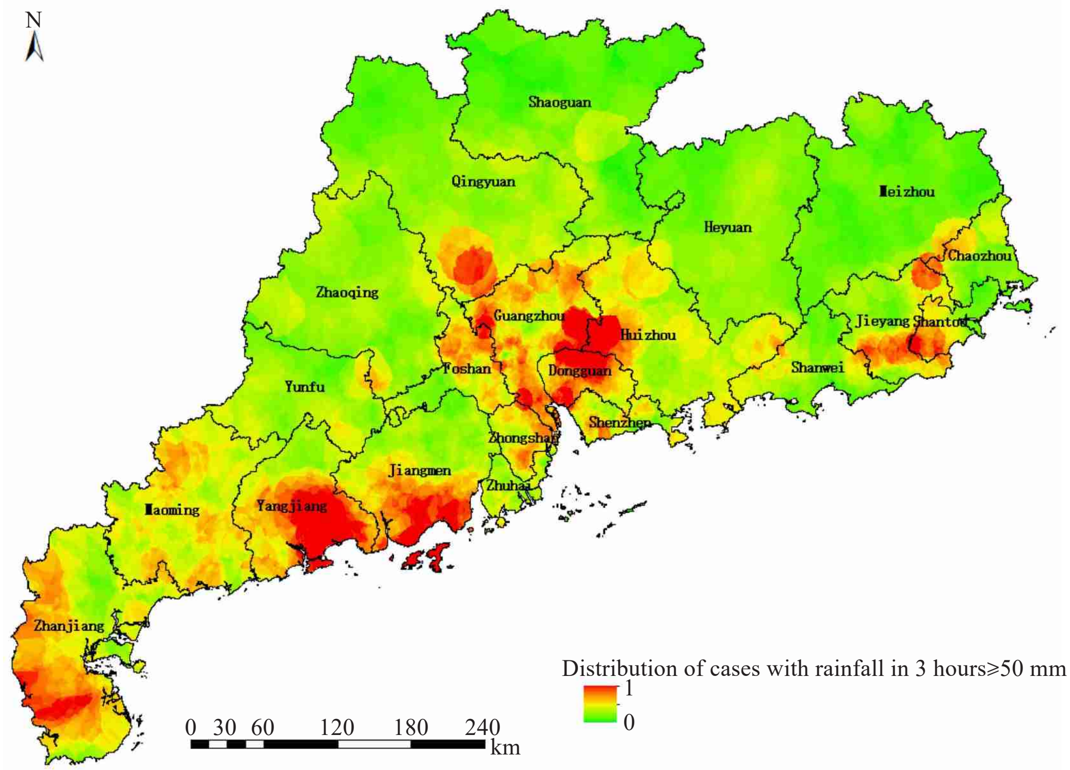

Figure 2. Distribution of cases with rainfall ≥50 mm $3h^{-1}$ in Guangdong Province after normalization.

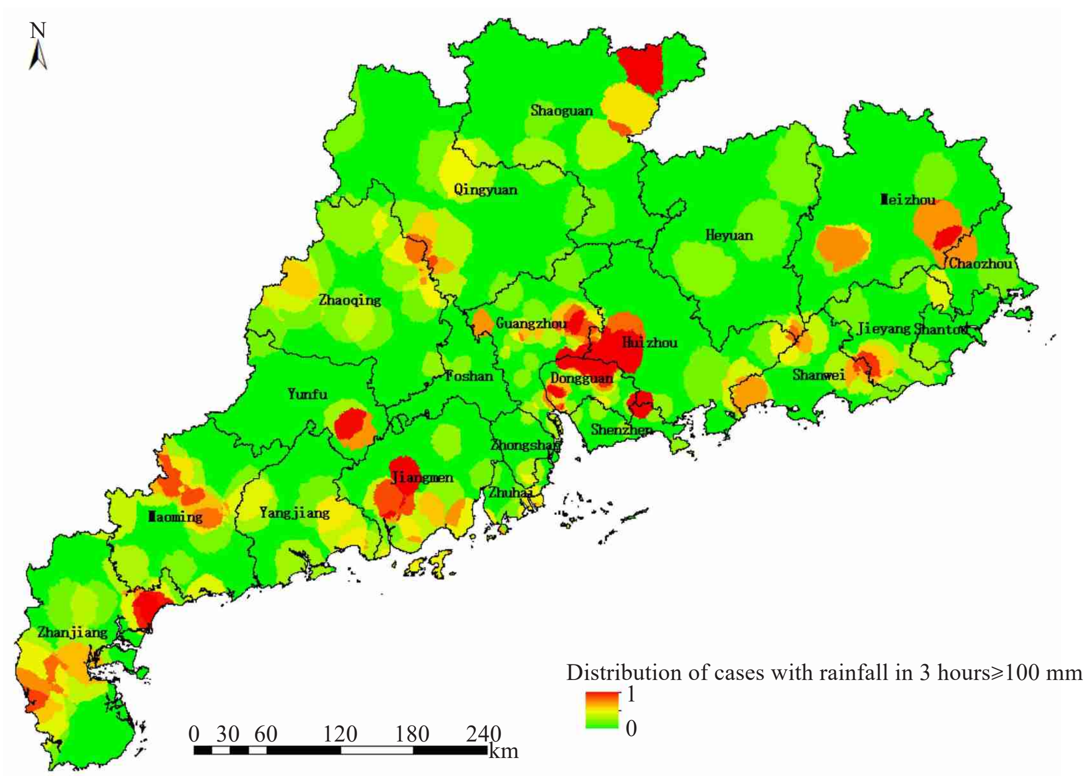

Figure 3. Distribution of cases with rainfall ≥100 mm $3h^{-1}$ in Guangdong Province after normalization.

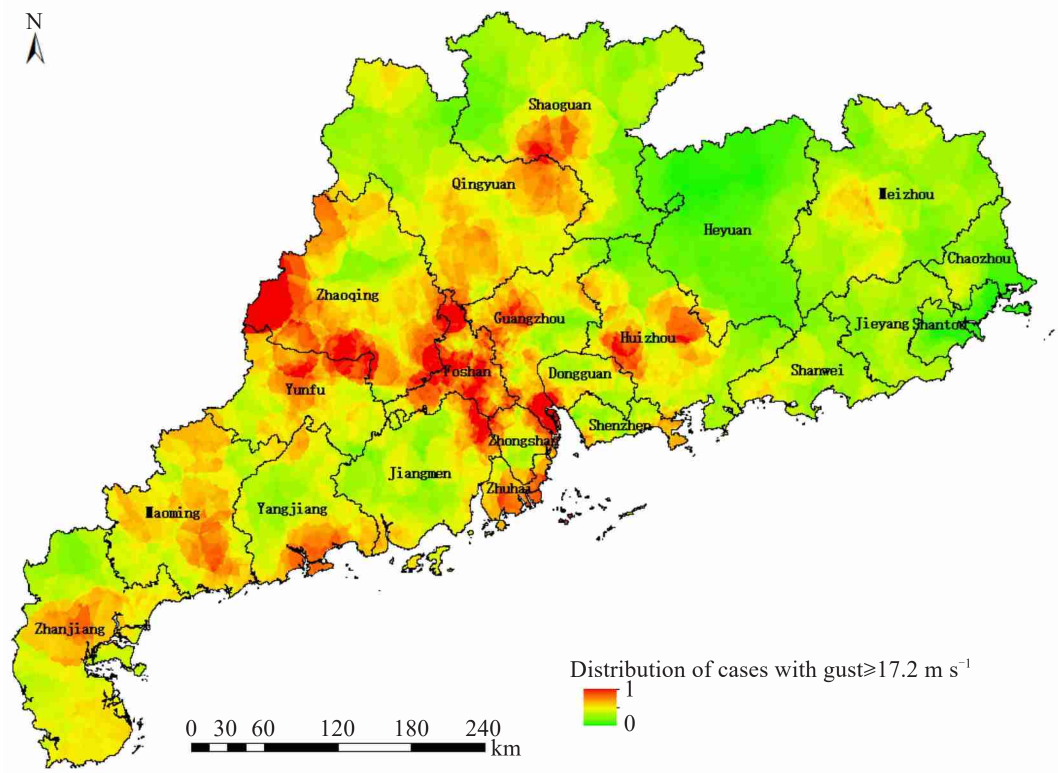

Figure 4. Distribution of cases with gusts ≥17.2 m s^{-1} in Guangdong Province after normalization.

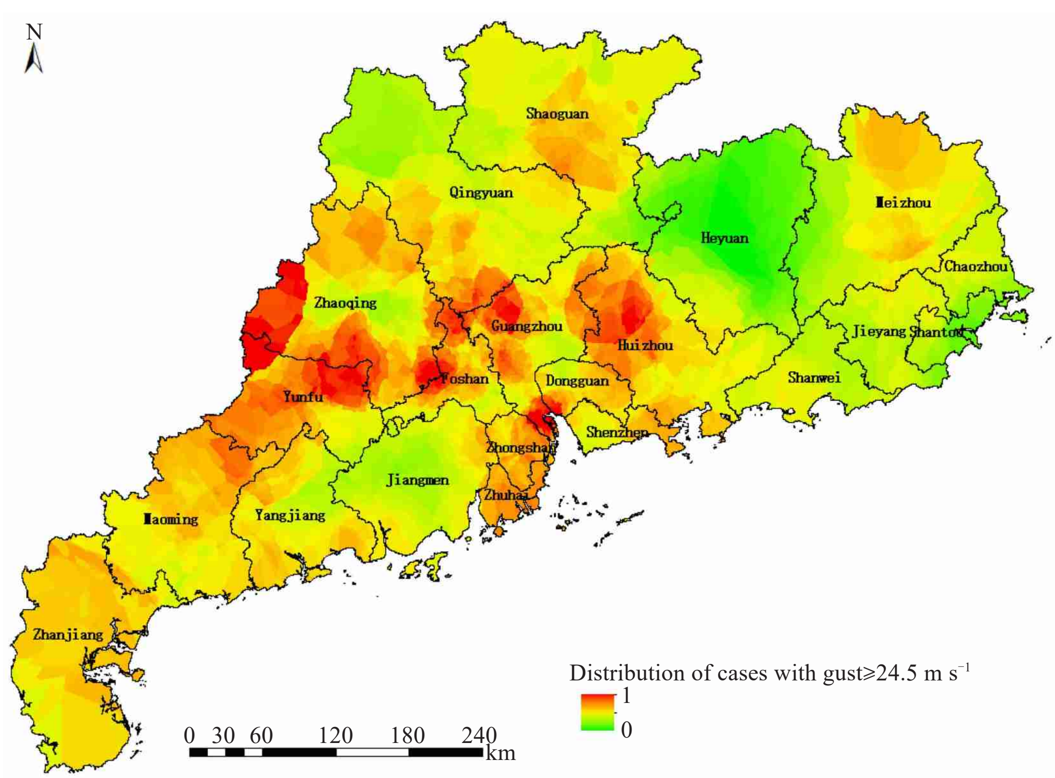

Figure 5. Distribution of cases with gusts ≥24.5 m s^{-1} in Guangdong Province after normalization.

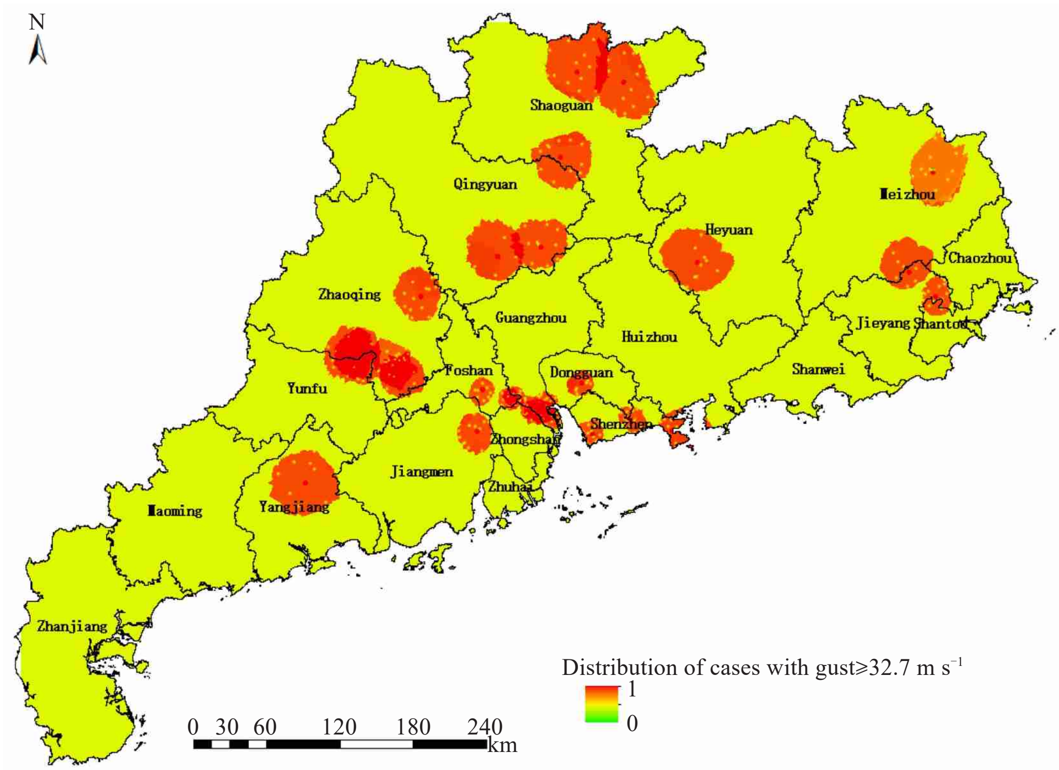

Figure 6. Distribution of cases with gusts ≥32.7 m s^{-1} in Guangdong Province after normalization.

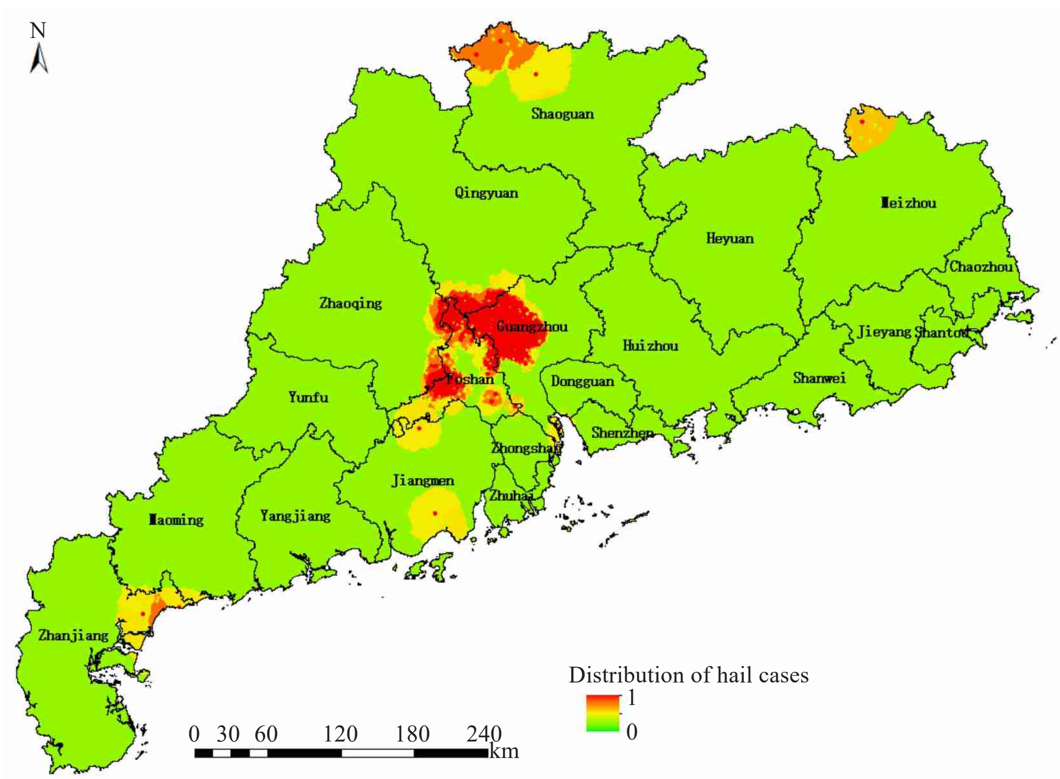

Figure 7. Distribution of hail cases in Guangdong Province after normalization.

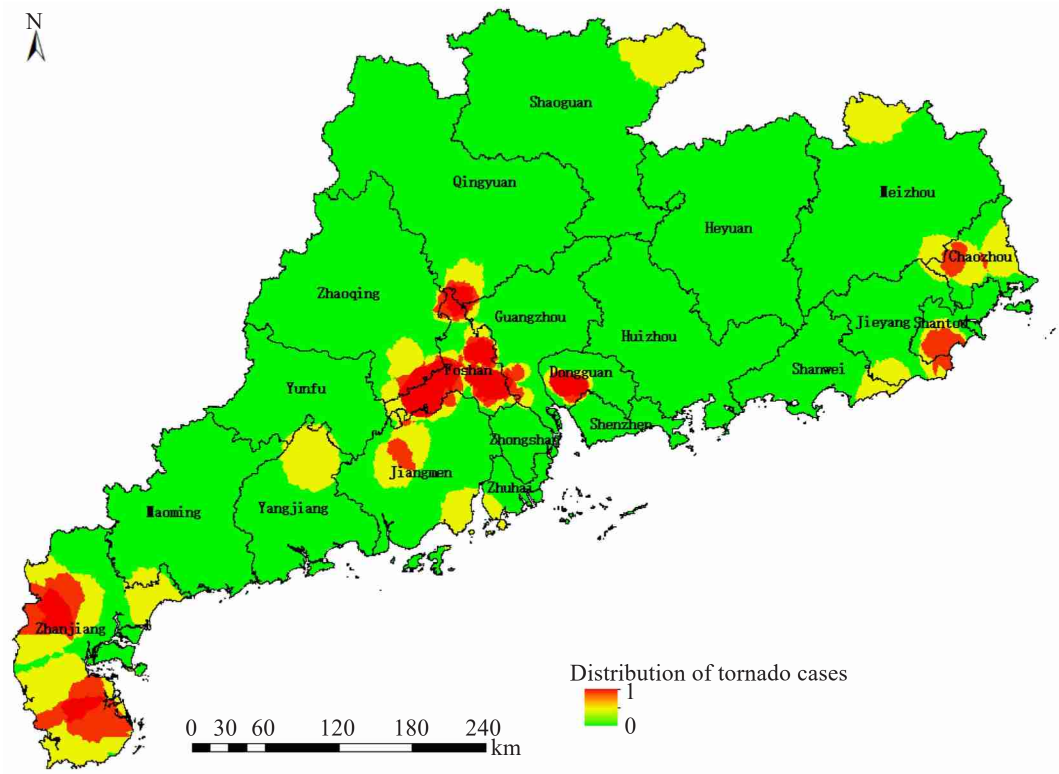

Figure 8. Distribution of tornado cases in Guangdong Province after normalization.

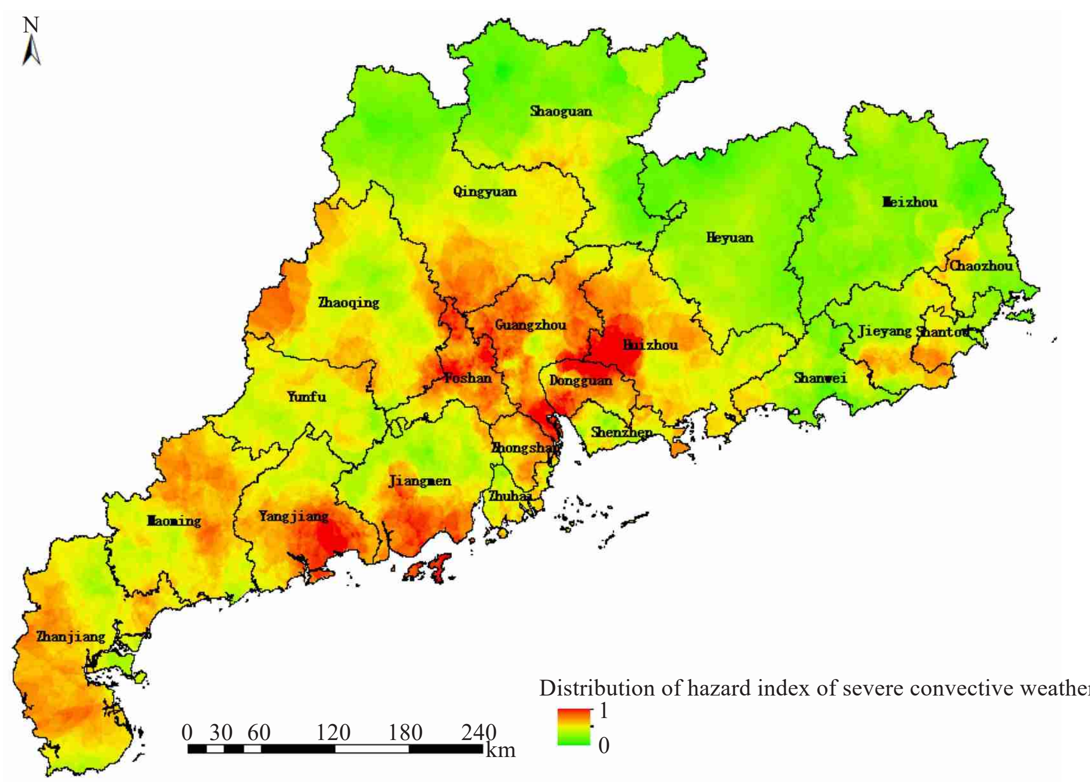

Figure 9. Distribution of the normalized hazard index of severe convective weather in Guangdong Province.

4 CONCLUSIONS

Data quality control is the most important factor in hazard analysis of severe convective weather. The quality control methods used for hourly data of precipitation and wind include checking for temporal, spatial, and factor consistency, climate boundary values, and manual observation. Such methods are not necessary for hail and tornado data because these events are recorded mainly by manual observation.

The hazard-formative factors adopted in this study include precipitation cases with rainfall ⩾20 mm h^{-1}, ⩾50 mm $3h^{-1}$, and ⩾100 mm $3h^{-1}$; severe wind weather events with gust ⩾17.2 m s^{-1}, ⩾24.5 m s^{-1}, and ⩾32.7 m s^{-1}; and hail and tornado events. The weights of these factors were determined by applying the coefficient of variation method, which objectively uses the information contained in each index to calculate the weight.

The weight of each hazard-formative factor of severe convective weather was used to establish a hazard model of severe convective weather, which was then employed to calculate the hazard index of severe convective weather in Guangdong Province. The cities showing highest risk for severe convective weather include Yangjiang, Dongguan, Foshan, Huizhou, Jiangmen, and Qingyuan.

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