Prediction and Assessment of Rainstorm Flooding Disasters Risk in Shanghai Metropolitan Area in 2050

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Abstract. Based on the theory of natural disaster risk, considering the natural environment and socioeconomic status comprehensively, with a target year of 2050, a risk assessment system and method for rainstorm flooding disasters risk in the Shanghai metropolitan area is constructed, and a division map of disaster risk is drawn. The results show that the regional differences in the risk of rainstorm flooding disasters in the Shanghai metropolitan area in 2050 are obvious. Hangzhou, Nantong, Ningbo, and Zhoushan in the east are high-risk areas of rainstorm flooding disasters. The medium-risk areas are mainly Shanghai, Huzhou, Changzhou, Wuxi, Jiaxing and other places. Suzhou, Jiaxing, Shaoxing and other places have lower risk indexes.

1. Introduction
In recent years, global warming and frequent extreme weather events have seriously affected human production and life, and have become important factors restricting social and economic stability and sustainable development. The strategic relationship between climate change, extreme weather and climate events, and related risk assessment and management, especially the establishment of a rainstorm flooding disasters assessment and management system, has become the focus of government disaster research in various countries.

Foreign scholars have carried out many researches on the risk of rainstorm flooding disasters. The research directions include. (1) Risk assessment of rainstorm flooding disasters based on historical disaster data[1]. (2) Selection of evaluation indicators based on the constituent factors of rainstorm flooding disasters, and use of geographic information system and other technologies to divide the rainstorm flooding disasters[2]. At the same time, Chinese scholars have used geographic information system technology, comprehensively evaluated and divided the rainstorm flooding disasters in Guangdong Province, Henan Province and other places, and achieved certain results[3, 4]. However, the current risk evaluation is mainly based on historical review and current situation evaluation analysis. Few scholars try to predict and evaluate future rainstorm flooding disasters risk. They do not pay enough attention to the time scale of disasters, which is difficult to guide the subsequent development and construction of cities. In the meanwhile, most of the analysis scales are analysis on a single province scale, and cross-region analysis is rarely performed.

The purpose of this paper is to establish a set of methods and systems for forecasting and evaluating rainstorm flooding disasters based on natural and socioeconomic data in the Shanghai metropolitan area, to accurately predict and evaluate the risk of rainstorm flooding disasters in the region in 2050, and to make spatial divisions for disaster warning and prevention, providing scientific basis for disaster and other work[5].
2. Materials and Methods

2.1. Study area overview
Shanghai metropolitan area is located in the center of the east coast of China. Most regions have a subtropical monsoon climate. The summer is hot and rainy here, and the winter is mild and has little rain. The annual average precipitation is between 800-1500mm, and the rainfall is unevenly distributed in the season. Its terrain is high in the southwest and low in the northeast, and is roughly a slope that slopes towards the yellow sea and the east China sea. The river system is dense, the rivers are numerous, the river network density is high, the Yangtze River radiates the entire metropolitan area, and the rivers such as Huangpu River and Qiantang River run through it. The area is vulnerable to severe floods. Through GIS analysis, basin distribution data and digital elevation data can be obtained (Figure 1, Figure 2).

2.2. Data sources
Based on the purpose of forecasting and evaluating the risk of rainstorm flooding disasters, the main sources of basic data used of my paper are: Meteorological data in Shanghai metropolitan area from National Meteorological Science Data Center(http://www.nmic.cn/data/), after replacing vacancy date, eliminating abnormal data, the appropriate daily precipitation data for the year 1995-2019 at the appropriate station were finally selected. The Shanghai metropolitan area administrative division map data is from National Earth System Science Data Center, National Science and Technology Infrastructure of China (http://www.geodata.cn). The GDEMDEM 30M digital elevation map of the Shanghai metropolitan area comes from the geospatial data cloud platform owned by the Computer Network Information Center of the Chinese Academy of Sciences(http://www.gscloud.cn/). The data of GDP density, population density, and soil type are from the Data Center of Resources and Environmental Sciences, Chinese Academy of Sciences. Data such as land cover types and river network density are derived from the MODIS series and Landsat series of data at NASA.

2.3. Principles and methods of forecasting and evaluating the risk of rainstorm flooding disasters

2.3.1. Rainstorm Flooding Disasters Risk Prediction and Evaluation Principles. The Rainstorm flooding disasters risk refers to the possible loss of people's lives, property, and economic activities caused by floods which are caused by short-term or long-term rainstorms in a given area within a given period of time. The risk of rainstorm flooding disasters is represented by the rainstorm flooding disasters risk index, which is a multi-factors comprehensive indicator[6]. By the disaster-causing factors (total economic value, population density, etc.), disaster-forming environment (ground
elevation, surface fluctuation, river network density, underlying surface type, soil type, etc.), hazard-affected body (total economic value, population density, etc.) and the capability of disasters prevention and reduction (regional fiscal revenue, traffic development level, etc.) and other factors play a comprehensive role, all of these factors determine the rain possibility and severity of flood disasters causing losses to human life and production in their areas.

Rainstorm flooding disasters prediction and assessment refers to the analysis of historical disaster data in a certain region, and the use of regression analysis, evolution simulation, simulation testing and other data processing methods to predict the spatial distribution and degree of the rainstorm flooding disasters risk index for this region in a future period.

2.3.2. Standardized Processing. Due to the different risk assessment factors of rainstorm flooding disasters, the feature scales of different dimensions of the original data are inconsistent. Although this paper cannot directly compare the factors, in order to eliminate the differences between the characteristics of each factor, this article needs to standardize the index of each factor, so that each factor date is distributed in the interval [0,1], the expression is

\[
Y_{ij} = \frac{X_{ij} - \min_{ij}}{\max_{ij} - \min_{ij}}
\]

when the date of \(X_{ij}\) in the formula as larger as better;

\[
Y_{ij} = \frac{\max_{ij} - X_{ij}}{\max_{ij} - \min_{ij}}
\]

when the date of \(X_{ij}\) in the formula as smaller as better.

2.3.3. Analytic Hierarchy Process. Analytic Hierarchy Process is a combination of qualitative decision-making method. For multi-factors calculations, this paper decomposes the relevant factors that affect the results into several levels and several factors. The various factors at the same level are based on the factors of the previous level. Factor weights are obtained by using judgment matrices. And finally, the combined weight is obtained.

2.3.4. Weighted Comprehensive Evaluation. The weighted comprehensive evaluation method comprehensively considers the degree of influence of various factors on the overall result, weights and integrates each specific indicator, and finally uses a numerical indicator to evaluate the overall result. The expression is.

\[
C_{ij} = \sum_{i=1}^{m} Q_i \omega_i
\]

Among the formula, \(C\) is the comprehensive weighted evaluation result, \(Q_i\) is the score of the i-th index, \(\omega_i\) is the weight of the i-th index, and \(m\) is the number of evaluation indexes.

2.3.5. Data Simulation. Based on historical data, this paper uses self-organizing mapping neural network, CA-Markov model and other algorithms to predict daily rainfall, land cover types, population density, GDP density, fiscal revenue, etc. with the goal of 2050. Predict the risk of rainstorm flooding disasters in the Shanghai metropolitan area in 2050[7].

Self-organizing mapping neural network is a non-intervention artificial neural network model that can cluster and classify high-dimensional meteorological change data to obtain circulation mode and evolution, that can reproduce extreme precipitation and simulate the annual variation of precipitation better.

The CA-Markov model is a comprehensive model that can effectively predict the spatial and temporal dynamics of spatial types, integrating Cellular Automata, Markov chains, and multi-criteria evaluation. Cellular Automata's neighborhood transformation principle and transfer may control the spatial pattern of the image change. At the same time, changes in surface cover types, population density, and GDP density are all spatial effects without aftereffects. And the time interval simulates
the change of the space type at a certain interval. The combination of the two can more effectively predict the type change without changing the limiting conditions. The CA-Markov module absorbs the characteristics of Markov chain and CA principle on the evolution of space-time. It can not only use remote sensing data, but also consider certain limiting conditions, so that the prediction ability of the model is more in line with the development of the socioeconomic system.

2.3.6. GIS Spatial Analysis. The geographic information system has powerful functions in the quantification, processing, and analysis of geographic remote sensing data, establishes the relationship between attribute data and spatial data, and uses related tools to achieve the purpose of multilevel spatial analysis. Geographic information system meteorological factor interpolation Krigings interpolation, landmark fluctuation calculation, slope calculation, inverse distance weight interpolation, spatial reclassification, interpretation of land cover types, spatial overlay analysis, natural discontinuity, etc., grid resolution is 500 * 500m, uniform use UTM-51N projection coordinate system. The natural discontinuity method is based on the uniqueness of the histogram, and uses statistical principles to determine the clustering distribution of factors, and classifies concentrated but discontinuous data to minimize the variance within the same level and maximize the difference between levels to achieve a reasonable division of data.

3. Results and Discussions

3.1. Index system for forecasting and assessing the risk of rainstorm flooding disasters in the Shanghai metropolitan areas

The reasons for the formation of rainstorm flooding disasters are complex, including both natural and social induced factors, as well as population, economic, and industrial production factors. Based on the theory of disaster risk assessment, this paper comprehensively considers the natural, economic and social factors of the Shanghai metropolitan area, and divides the evaluation factors into danger and vulnerability.

Generally, the greater the short-term precipitation, the longer the longest continuous rainfall days, the flatter the terrain, the lower the depression, the denser the river network, and the larger hardening area of the underlying surface, the greater the risk of rainstorm flooding disasters will be. At the same time, the greater the population density, the greater the GDP density, and the greater the proportion of cultivated land in a region, the higher the value exposed to the danger of rainstorm flooding disasters, and the greater the potential loss that may be suffered. Disaster prevention and reduction capabilities are mainly the ability to resist and recover from disasters. High regional fiscal revenue, high road density and dense road network can help to improve disaster resilience, which can reduce the degree of disaster losses. According to the sensitivity of various factors or types to the response to rainstorm flooding disasters, this paper uses the Delphi method to score them, makes a questionnaire and mails it to 9 experts in the industry, and adopts the clustering method to conduct a total of 2 consultations to determine weight of each factor (Table 1).

| First-level indicators | Secondary indicators | Tertiary indicators | Fourth level indicators | Weights |
|------------------------|----------------------|--------------------|------------------------|---------|
| Risk of rainstorm flooding disasters (0.750) | Danger | Disaster-causing factors (0.375) | Threshold precipitation | 0.250 |
| | | | Maximum continuous rain days | 0.125 |
| | | Disaster-forming environment (0.375) | Geographic factors | 0.125 |
| | | | River network density | 0.063 |
| | | | Buffer surface cover type | 0.062 |
| | | | Surface cover type | 0.125 |
| Vulnerability | Hazard-affected body | Population density | 0.050 |
3.2. Prediction of danger of Rainstorm Flooding Disasters in Shanghai Metropolitan Area.

Using the self-organizing map neural network to predict the daily precipitation series of Shanghai metropolitan area in 2050, the 60th percentile, 80th percentile, 90th percentile, 95th percentile and the 98th percentile of precipitation are classified. According to the principle that the higher the level of threshold precipitation and the longer the continuous rainfall days, the greater the impact on rainstorm flooding disasters, the paper grades scores of threshold precipitation (Table 2).

Table 2. Classification of danger of rainstorm flooding disasters.

| Threshold precipitation level | Percentile/% | The value of threshold precipitation/mm | The score of threshold precipitation level |
|------------------------------|-------------|----------------------------------------|------------------------------------------|
| 5                            | 100–98      | 273.33                                 | 1                                        |
| 4                            | 95          | 214.27                                 | 0.8                                      |
| 3                            | 90          | 156.33                                 | 0.6                                      |
| 2                            | 80          | 133.47                                 | 0.4                                      |
| 1                            | 60          | 59.39                                  | 0.3                                      |

According to Table 1, the index of danger of rainstorm flooding disasters in the Shanghai metropolitan area in 2050 was calculated and the risk division map of the risk of rainstorm flooding disasters was obtained.

In terms of the disaster-causing factors (Figure 3), the index of disaster-causing factors of the Shanghai metropolitan area is generally larger in the south than in the north and in the west than in the east. The index of disaster-causing factors has an arithmetic average of 0.157, a geometric mean of 0.150, and a median of 0.159. The distribution is relatively close. Use the natural discontinuity method to divide the index of disaster-causing factors, and divide the index from high to low into three levels: high, middle, and low. The area of the high-risk index area accounts for about 21% of the metropolitan area and the index is above 0.173, mainly in most areas of Ningbo, Zhoushan, and Hangzhou; the medium-risk index area accounts for about 12% of the metropolitan area, mainly in Shaoxing, Jiaxing, and Nantong; the low-risk index areas are mainly distributed in Suzhou and Wuxi.

In terms of the disaster-forming environment of the rainstorm flooding disasters (Figure 4), the index of disaster-forming environment in Shanghai metropolitan area is generally larger in the north than in the south and greater in the east than in the west, which is exactly the opposite of the distribution of the index of disaster-causing factors. The index of the disaster-forming environment has an arithmetic average of 0.203, a geometric mean of 0.195, and a median of 0.208. The distribution is relatively close, that is, the index is relatively concentrated. After grading the index, the analysis shows that the high-risk index area is mainly Suzhou, Changzhou, Hangzhou, Shaoxing and Shanghai, accounting for about 30% of the metropolitan area. The index is mainly distributed in...
[0.211,0.296]. The medium-risk index area is mainly Nantong, Wuxi and Jiaxing, accounting for about 25% of the metropolitan area. The southern metropolitan area is a low-risk area, accounting for about 44.3% of the metropolitan area. It should be noted that low-plain areas such as Shanghai, Hangzhou, and Suzhou, as well as river-dense areas along rivers and lakes along the river, have high disaster-forming environment indexes. Once severe rainstorms occur in these areas, floods may easily occur.

A comprehensive map of the danger of rainstorm flooding disasters risk can be obtained by combining the disaster-causing factors and the disaster-forming environment (Figure 5). The high-risk index regions are most of Hangzhou and Ningbo, and Suzhou, Wuxi, and Changzhou around Taihu Lake.

3.3. Prediction of the Vulnerability of Rainstorm Flooding Disasters in Shanghai Metropolitan Area.

The risk of vulnerability of rainstorm flooding disasters mainly reflects the sensitivity of the region's socioeconomic to heavy rain and flood disasters, and is determined by indicators such as population density, GDP density, arable land area, road network density, and fiscal revenue. Vulnerability indicators on the one hand reflect the socioeconomic development of the region, and on the other hand reflect the region's ability to help itself before, during and after the disaster.

From the perspective of hazard-affected body of rainstorm flooding disasters (Figure 6), the index is mainly in medium and high level, mainly distributed in Shanghai, Hangzhou, Suzhou, Wuxi, Changzhou, Nantong and Jiaxing. Nantong, Jiaxing and other places. The above areas are vulnerable to heavy losses in the face of heavy rains and floods, and the potential damage is severe.

Disaster prevention and resilience refers to the ability to resist disasters and to reduce losses when disasters strike. The dense road network can ensure the timely arrival of external rescue forces, ensure the transportation of materials in the area, and also serve as a disaster prevention axis to enhance the disaster prevention and resilience of the region. The disaster prevention and reduction capabilities of the Shanghai metropolitan area have been polarized (Figure 7). Suzhou, Changzhou, Shanghai, Hangzhou, and Wuxi have high-risk indexes, and disaster prevention, mitigation, and disaster relief capabilities are stronger. Huzhou, Nantong and Zhoushan have lower disaster prevention and reduction indexes due to their low road network density and low fiscal revenue.

A comprehensive map of the vulnerability of rainstorm flooding disasters risk can be obtained by integrating hazard-affected body and the capability of disaster prevention and reduction (Figure 8). The high-index areas are Nantong, Jiaxing, Shanghai, Hangzhou, and Changzhou. The medium-index areas are Ningbo, Suzhou, Huzhou and other places.

3.4. Prediction and Assessment of Rainstorm Flooding Disasters risk in Shanghai Metropolitan Area in 2050.

The risk of rainstorm flooding disasters is the result of the combined effects of danger and vulnerability. The rainstorm flooding disasters index is calculated as.

\[
RFRI = 0.375 \times DF + 0.375 \times DE + 0.125 \times HZ - 0.125 \times DPR
\]
In the formula: $RFRI$, $DF$, $DE$, $HZ$ and $DPR$ are the comprehensive risk index of rainstorm flooding disasters, disaster-causing factors, disaster-forming environment, hazard-affected body, and the capability of disaster prevention and reduction respectively. According to the formula 4, the index is comprehensively weighted and superimposed to obtain the rainstorm flooding disasters prediction and risk division map of the Shanghai metropolitan area in 2050 (Figure 9).

Figure 9. Risk Division Map of Rainstorm Flooding Disasters in Shanghai Metropolitan Area in 2050.

At the same time, the index of rainstorm flooding disasters is classified according to the natural discontinuity method (Table 3).

Table 3. Classification of rainstorm flooding disasters in Shanghai metropolitan area.

| Rainstorm flooding disasters | [0, 0.345] | [0.346, 0.405] | [0.405, 0.476] | [0.476, 0.599] |
|-----------------------------|------------|----------------|----------------|----------------|
| Level                       | Lower risk | Low risk       | Medium risk    | High risk      |
| Area ratio%                 | 21%        | 40%            | 30%            | 9%             |

The risk of rainstorm flooding disasters is generally distributed along rivers and lakes. The eastern index is greater than the western part, and the northern index is greater than the southern part. High-risk areas mainly include most areas of Changzhou Jintan District, Ningbo Haishu District, Hangzhou Shangcheng District, Haimen City, Nantong Chongchuan District, Hangzhou Xiacheng District, Hangzhou Jianggan District, Jiaxing Pinghu City, Ningbo Yinzhou District, and Jiaxing Haiyan County. Medium risk areas are widely distributed, such as Fenghua City, Wuxi Chong'an District, most part of Shanghai, Ningbo Zhenhai District, Jiaxing Haining District, Hangzhou Xiaoshan District, Suzhou Gusu District and Cixi City, etc. The land is widely distributed. The distribution of lower and low risk areas is relatively scattered, mainly in Tongxiang, Shanghai Pudong New Area, Huzhou Nanxun District, Qidong City, Ningbo Yinzhou District, Jiangyin City, Chun'an County, Hangzhou Yuhang District, Xinchang County and other places.

The medium and high risk areas account for more than 40% of the area of the Shanghai metropolitan area, indicating that in 2050, the Shanghai metropolitan area is more likely to be affected by rainstorm flooding disasters, which is likely to cause large losses. Relevant departments should focus on pre-disaster planning for disaster prevention and mitigation according to the natural regular of rainstorm flooding disasters, strengthen regional disaster prevention and regional disaster reduction cooperation, establish a comprehensive regional disaster prevention linkage system, rationally adjust layout of urban land, optimization of urban lifeline systems, and protection measures against storms, floods and other disasters.

4. Conclusions

(1) Based on the target year of 2050, using the historical meteorological data, socioeconomic data, and remote sensing data of the Shanghai metropolitan area as the basis, using neural network, CA-Markov
model and other methods to simulate relevant meteorological and socioeconomic data. Guided by the basic principles of disaster science and combined with the characteristics of the rainstorm flooding disasters in Shanghai metropolitan area, this paper constructs the rainstorm flooding disasters prediction and evaluation index system in Shanghai metropolitan area, which includes four factors: disaster-causing factors, disaster-forming environment, hazard-affected body and the capability of disaster prevention and reduction. The system has the characteristics of complex disaster assessment, scientific disaster prediction and comprehensive disaster impact assessment.

(2) From the results of risk zoning, it can be seen that the regional differences in the risks of rainstorm flooding disasters in the Shanghai metropolitan area in 2050 are obvious. Hangzhou, Nantong, Ningbo, and Zhoushan in the east are high-risk areas of rainstorm flooding disasters. These areas have high rainfall intensity and precipitation time. It is long and flat, distributed along the coast, and the river density is high. The medium risk areas are mainly Shanghai, Huzhou, Changzhou, Wuxi, Jiaxing and other places. Mild risk areas are mainly distributed in Suzhou, Jiaxing, Shaoxing and other places.

(3) Based on historical data, the paper tries to predict and partition the risk of future rainstorm flooding disasters in the Shanghai metropolitan area and obtains risk classification data. At the same time, remote sensing spatial data was used to improve the shortcomings of the average grid space display of the original research data, and a relatively detailed space displaying process was performed. However, there are still some difficulties to fully reflect the accurate and quantitative analysis of storm and flood disasters. First, the meteorological data are not comprehensive, and on the other hand, the storm and flood itself has considerable complexity. Therefore, it is necessary to continuously explore comprehensive data, optimize the evaluation method, and improve the evaluation system to provide guidance for urban construction and development.

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