The Urban Rain-flood Risk Division Based on the Cloud Model and the Entropy Evaluation Method—Taking Changzhou as an Example

Chengcheng Yu 1, Mengyu Liu 1, Xukan Xu 1,2 and Yanwen Shi 1
(1College of Business Administration, Hohai University, Changzhou, 213022)
(2Institute of Statistics and Data Science, Hohai University, Changzhou, 213022)

Abstract: In order to improve cities’ non-engineering measure capacity to cope with rain-flood disasters and provide emphasis for government’s flood protection, the urban rain-flood risk division was studied. The cloud model can be used to deal with qualitative and quantitative transformation and adapt to randomness and fuzziness of urban rain-flood risk evaluation. By taking Changzhou as a research object, 3 criterion layers, including hazard inducting environment, hazard-affected body and disaster-inducing factors and 11 indexes were selected. The cloud model and entropy evaluation method were chosen to evaluate the urban rain-flood risks. Besides, ArcGIS software was used to draw the urban rain-flood risk division map of Changzhou. The findings showed that regions with the higher rain-flood risk grade included most of areas in Jintan District and Xinbei District, some areas in Wujin District and Zhonglou District. The corresponding flood protection measures should be taken.

1. Introduction
The rain-flood disaster is the common natural hazard of China and brings the huge threats to industrial production and residents of China. In recent years, the waterproof areas in cities are constantly increasing, while the coping capacity of the rain-flood disaster is also weakening [1]. Besides, with the urban development, the population density is increasing and social economic development is also enhancing. The losses on our cities caused by the rain-flood disaster are enhancing day by day. By taking the catastrophic flood disaster of Changzhou in 2015 as an example, the rainfall intensity during the flood period was 200 years per time. Until June 27, 2015, the number of victims in Changzhou was 64792. 10029 people were arranged in urgency. The direct economic losses were up to 420 million. The water level of Changzhou section in the canal hit a new high.

In order to reduce the hazards of urban rain-flood disaster, it is extremely necessary to study the urban rain-flood risk division. For this reason, domestic and overseas scholars have done lots of studies. For example, Blaikei et al [2] described the correlation between resource utilization and natural disaster from the perspective of interaction among hazard inducing environment, disaster-inducing factors and hazard-affected body. Miao Qilong [3] et al used ArcGIS analysis technology with fuzzy comprehensive evaluation to compile the risk division map of heavy rain flood disaster in Hangzhou. Yin Jie et al [4] regarded Pudong New Area as the research object and established the risk assessment model from three aspects, including evaluation of disaster-inducing factors, vulnerability analysis and...
exposure analysis. Wang He et al. introduced the cloud model into the rain-flood risk evaluation, selected 6 relevant indexes, and obtained Jingdezhen’s risk grade in recent years.

On the basis of the above research foundation, the author in this thesis regarded towns and streets of Changzhou as the research units, selected three criterion layers (including vulnerability of hazard inducing environment, vulnerability of hazard-affected body and dangerousness of disaster-inducing factors), and evaluated the rain-flood risk grade of each research unit based on the entropy evaluation method and cloud model. By virtue of ArcGIS, the author drew the urban rain-flood disaster division map of Changzhou, helping the government to take protective measures and rectify flood-control projects with pertinence and emphasis.

1. The Formation Mechanism Analysis of Extreme Rain-flood Disaster in Cities

The rain-flood disaster refers to the flood damage formed by the high grade of rainfall. When the hazard-affected body of rain-flood is a city, it is called as the urban rain-flood disaster. Integrating with the previous studies, the author defined the urban rain-flood as follows: in certain time, rare rainfall exceeds the bearing capacity of the cities and results in the significant influences on people, objects, production and life in cities. The formation mechanism is shown in Figure 1.

![Fig.1 The Formation Mechanism Diagram of Urban Extreme Rain-flood](image)

It could be observed from the Figure 1 that extreme rain-flood was formed by disaster-inducing factors, hazard inducing environment and hazard-affected body, which interact and restrain each other.

2. Methods and steps

2.1 Data

Data used in this thesis included 5min rainfall data of 187 Changzhou hydrometric stations in 2015-2017, Changzhou statistical yearbooks, Changzhou drainage maps, Changzhou DEM data, Changzhou land use maps and Changzhou road network maps. By virtue of ArcGIS, 11 indexes of towns and streets in Changzhou required by the study were collected, including plant coverage data, river network density, average elevation, average gradient, population density, gross regional domestic product density, road network density, agricultural acreage, daily rainfall, annual average rainstorm days and maximum 24h rainfall.

2.2 Normal cloud model

In order to solve fuzziness and randomness in uncertainty, the academician in Academy of Engineering in China—Professor Li Deyi proposed the theory of cloud model in 1995. The cloud model used expectation (Ex), entropy (En) and hyper entropy (He), combined with randomness and fuzziness in uncertainty, and completed the mapping transformation between uncertain qualitative concept and quantitative concept. The specific steps of the cloud model were shown as follows:

1) The normal random number $En = NORM(En, He^2)$ was generated, where $En$ was the expectation value, while $He^2$ was the variance.
2) The normal random number \( x' = NORM[Ex, (En')^2] \) was generated, where \( Ex \) was the expectation value and \( En' \) was the variance.

3) \( \mu = \exp \left[ -\frac{(x' - Ex)^2}{2En'} \right] \) was calculated.

4) \( (x', \mu) \) was any cloud droplet in the domain.

5) Steps 1-4 have been repeated until \( N \) cloud droplets were generated. \( N \) was the established cloud droplet.

\( N \) cloud droplets obtained were drawn on the coordinate system to generate the corresponding cloud model. The x-coordinate was the value of the indexes, while the y-coordinate was the membership value. By taking the vegetation coverage as an example, the corresponding cloud model generated by the normal cloud model was shown in Figure 2.

![Figure 2](image.png)

**Fig.2 The Cloud Model Map of Vegetation Coverage Index Attaching to the Risk Grade**

### 3. The Urban rain-flood risk division based on the cloud model and entropy evaluation method

#### 3.1 Construction of the index system

In this thesis, the urban rain-flood risk grade was chosen as the evaluation target layer. It could be observed from the formation mechanism of the urban rain-flood disaster, the urban rain-flood disaster was caused by the interaction among the disaster-inducing factors, hazard inducing environment and hazard-affected body. The criterion layers in this thesis included the dangerousness of disaster-inducing factors, vulnerability of hazard inducing environment and vulnerability of hazard-affected body. 11 subordinated indexes were selected as the indexes on the criterion layers.

#### 3.2 Weight confirmed by entropy evaluation method

The entropy evaluation method was used to confirm the weight value of each index objectively, obtaining the weight vector \( W = \{w_1, w_2, ..., w_n\} \). The weight value of each index was shown in Table 1.

| Indexes                                | Weight   |
|----------------------------------------|----------|
| Vulnerability of hazard inducing environment | Vegetation coverage | 0.0585 |
|                                        | River network density | 0.0666 |
|                                        | Average elevation   | 0.2349 |
|                                        | Average gradient    | 0.1345 |
| Vulnerability of hazard-affected body  | Population density  | 0.0931 |
### 3.3 Confirmation of the index grade in the criterion layers

In this thesis, the natural break method was used to divide each criterion layer into five grades: high risk areas, sub-high risk areas, middle risk areas, sub-low risk areas and low risk areas. By taking vegetation coverage as an example, the vegetation coverage of towns and streets in Changzhou was 0.10%-65.29%. According to the natural break method, each grade interval was confirmed as [0.10, 5.30], [5.31, 15.26], [15.27, 25.20], [25.21, 39.24], and [39.25, 65.29].

Based on the cloud model theory, the numerical characteristics of the index grade standards were calculated as follows:

\[
Ex_j = \frac{I_{jmin} + I_{jmax}}{2} \quad (1)
\]

\[
En_j = \frac{I_{jmax} - I_{jmin}}{6} \quad (2)
\]

\[
He_j = 0.5 \quad (3)
\]

Among which, \( I_{jmin} \) was the lower bound of a grade, while \( I_{jmax} \) was the upper bound of a grade.

According to the cloud model theory, three digital characteristics of different grades in each criterion layer were calculated, including Expectation(\( Ex \)), entropy(\( En \)) and hyper entropy(\( He \)).

Based on the vegetation coverage, each grade’s digital characteristics of this index included (2.7000,0.8667,0.5), (10.2850,1.6583,0.5), (20.2350,1.6550,0.5), (32.2250,2.3383,0.5) and (52.2700,4.3400,0.5), respectively.

### 3.4 The cloud model calculation

According to the theory of the cloud model, \( En_j \) was the expectation and \( He_j^2 \) was the variance. The normal random number \( En_j \) was generated. Then, the membership of the index value on the given criterion layer belonged to the membership \( \mu_j \) of the grade \( n_j \).

\[
\mu_j = \exp[-\frac{(x-Ex_j)^2}{2En_j}] \quad (4)
\]

With the purpose reduce errors and repeatedly calculate N times, the average value \( d_{ij} \) was considered as the element in the membership matrix. \( d_{ij} \) was the membership value that \( i^{th} \) index belonged to the \( j^{th} \) grade. The membership between each grade and each grade was combined to constitute in the \( m \times n \) order membership matrix \( D \).

By taking Niutang Town as an example, according to the index value of each criterion layer in Niutang Town, normal cloud generator algorithm was used to calculate the membership between each index and each grade. The membership matrix for the vulnerability of the hazard inducing environment in Niutang Town was shown in Table 2:

| Dangerousness of disaster-inducing factors | Gross regional domestic product density | 0.1573 |
|------------------------------------------|----------------------------------------|--------|
|                                          | Road network density                   | 0.1365 |
|                                          | Agricultural acreage                   | 0.0717 |
|                                          | Daily rainfall                         | 0.0085 |
|                                          | Annual rainstorm days                  | 0.0133 |
|                                          | Maximum 24h rainfall                    | 0.0251 |
Table 2: The membership matrix of the normal cloud model—Niutang Town

| Criterion layers | Index                        | Low risk areas | Sub-low risk areas | Middle risk areas | Sub-high risk areas | High risk areas |
|------------------|------------------------------|----------------|--------------------|-------------------|---------------------|----------------|
|                  | Vegetation coverage         | 0.4361         | 0.649              | 0.8263            | 0.9898              | 0.8525         |
|                  | River network density       | 0.1679         | 0.4431             | 0.7214            | 0.1621              | 0.0124         |
|                  | Average elevation           | 0.0048         | 0.1079             | 0.5454            | 0.984               | 0.6663         |
| Vulnerability of | Average gradient(°)         |                |                    |                   |                     |                |
| hazard inducing  |                              |                |                    |                   |                     |                |
| environment      |                              |                |                    |                   |                     |                |

3.5 Risk evaluation

Based on Niutang Town, $W$ conducted fuzzy transformation for $D$ to obtain the fuzzy subset $C$ on the evaluation set, obtaining the fuzzy subset $C = W \cdot D = \{0.0997, 0.1570, 0.3109, 0.4123, 0.3981\}$. According to the maximum principles of membership, it is corresponding to the 4th grade, namely urban rain-flood risk grade of Niutang Town was the sub-high risk area.

The cloud model and entropy evaluation method were used to obtain the risk grade of towns and streets in Changzhou. ArcGIS was used to draw the rain-flood division map of Changzhou, as illustrated in Figure 3.

Fig.3 The Rain-flood Risk Division Map of Changzhou

It could be observed from the rain-flood risk division map of Changzhou that the regions with the high rain-flood risk grade in Changzhou included most of areas in Jintan District and Xinbei District and some areas in Wujin District and Zhonglou District. Relevant departments and people should take flood control measures and try to reduce hazards of rain-flood disaster on production, life and property safety as many as possible. Meanwhile, the government should enlarge the investment in flood control project construction in these areas and enhance the capacity to cope with rain-flood disaster.

4. Conclusions

On the basis of analyzing the formation mechanism of the urban extreme rain-flood disaster, 3 criterion layers(including hazard inducing environment, hazard-affected body and disaster-inducing factors) and 11 subordinated indexes were selected to construct the index system of the urban rain-flood risk division. The tool of entropy evaluation method was used to confirm the weight of indexes on different criterion layers objectively. The cloud model was used to calculate the
membership matrix and conduct the fuzzy transformation, obtaining the rain-flood disaster risk grade of towns and streets. Moreover, ArcGIS was used to draw the rain-flood risk division map of Changzhou. The findings showed that the regions with the higher rain-flood risk grade included most of areas in Jintan District and Xinbei District and some areas in Wujin District and Zhonglou District. Corresponding flood control measures should be taken.

The cloud model was used in the urban rain-flood risk division to greatly adapt to the self-randomness and fuzziness of the urban rain-flood risks and solve the shortcoming that the traditional evaluation method couldn't solve the uncertainty of evaluation index. The cloud model was introduced into the urban rain-flood risk division, providing the valuable experience for the study on relevant aspects. Meanwhile, this provided the emphasis for the governmental departments to take protective measures and rectify flood control projects, showing the application value and promotion value.

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References:

[1] Zhang Dong, Yan Denghua and Wang Yicheng, et al., the Urban Inland Inundation Risk Evaluation and Comprehensive Response Research Progress[J], Science of Disaster, 2014, 29(1): 144-149.

[2] Blaikie P M, Cannon T, Davis I, et al. At risk: natural hazard, people vulnerability and disasters [M]. London: Rout-ledge, 1994: 147-167.

[3] Miao Qilong and Chen Xin, the Rainstorm Flood Disaster Risk Division[J], Resources and Environment of the Yangtze River Basin, 2012, 21(2): 164-167.

[4] Yin Jie and Yin Zhan’e, the Rainstorm Inland Inundation Disaster Risk Evaluation of Urban Communities Based on GIS[J], Geography and Geographic Information Science, 2009, 25(6): 93-94.

[5] Wang He, Liu Gaofeng, and Wang Huimin, the Urban Extreme Rain-flood Risk Evaluation Based on the Cloud Model[J], Water Conservancy Economy, 2014, 32(2): 15-18.

[6] Wang He, Liu Gaofeng and Wang Huimin, the Urban Extreme Rain-flood Disaster Warning Study Based on the Cloud Model[J], Water Conservancy Economy, 2014(4): 15-18.

[7] Liu Changxian, Liu Deyi and Du Ci, the Statistical Analysis of the Normal Cloud Model[J], Information and Control, 2005, 34(2): 236-239.

[8] Zhang Qiuwen, Zhang Yongzhi and Zhong Ming, the Multi-level Fuzzy Comprehensive Evaluation of Reservoir-induced Earthquake Based on the Cloud Model[J], Water Conservancy Economy, 2014, 45(1): 87-95.

[9] Li Deyi, Liu Changyu and Du Ci, the Artificial Intelligence of Uncertainty[J], Journal of Software, 2004, 15(11): 1583-1594.

[10] Wei Guanghui and Ma Liang, the Regional Water Resource Carrying Capacity Evaluation Based on the Normal Cloud Model[J], Water-saving Irrigation.