Risk assessment of urban flood disaster in Jingdezhen City based on analytic hierarchy process and geographic information system

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Abstract. The research of urban flood risk assessment and management are of great academic and practical importance, which has become a widespread concern throughout the world. It’s significant to understand the spatial-temporal distribution of the flood risk before making the risk response measures. In this study, the urban region of Jingdezhen City is selected as the study area. The assessment indicators are selected from four aspects: disaster-causing factors, disaster-pregnant environment, disaster-bearing body and the prevention and mitigation ability, by consideration of the formation process of urban flood risk. And then, a small-scale flood disaster risk assessment model is developed based on Analytic Hierarchy Process(AHP) and Geographic Information System(GIS), and the spatial-temporal distribution of flood risk in Jingdezhen City is analysed. The results show that the risk decreases gradually from the centre line of Changjiang River to the surrounding, and the areas of high flood disaster risk is decreasing from 2010 to 2013 while the risk areas are more concentrated. The flood risk of the areas along the Changjiang River is the largest, followed by the low-lying areas in Changjiang District. And the risk is also large in Zhushan District where the population, the industries and commerce are concentrated. The flood risk in the western part of Changjiang District and the north-eastern part of the study area is relatively low. The results can provide scientific support for flood control construction and land development planning in Jingdezhen City.

1. Introduction
The urbanization in China has been carried forward by leaps and bound, from 18.96% in 1979 to 53.7% in 2013. However, the development also brings a series of problems, for example, the rapid increase of impermeable surfaces changes the urban water cycle process [1], which leads to the increase of extreme precipitation events, the ground runoff, and eventually the urban flood risk [2]. The urban flood disaster is becoming more and more severe, which is recognized as a choke point that restricts the sustained and healthy development of economic society [3]. As a member of the Yangtze River Economic Belt and the city-cluster in the middle of Yangtze River, Jingdezhen City is in a pivotal position in the development of Jiangxi Province. However, Jingdezhen has long been suffering from floods due to its special geographical location and historical reasons. With the advance of city construction, it’s necessary to evaluate flood risk to provide basic support for city development in Jingdezhen City.

The risk assessment of urban flood disaster is a process of using the assessment method to quantify...
the impact or loss caused by flood disaster. Many studies have been done in flood risk assessment, using historical disaster data, scenario analysis, Remote Sensing(RS) and Geographic Information System(GIS), assessment index system [4]. The research of historical disaster data is carried out by means of mathematical statistics, by analyzing the disaster results rather than analyzing the influencing factors of floods. This method is simple. However, it’s necessary to add new disaster data to ensure the reliability [5]. The risk assessment based on the scenario analysis is carried out from the perspective of future scenarios, which overcomes the imprecise of the assessment from the aspect of disaster influence factors. However, it requires high modelling ability for disaster simulation [6-8]. The risk assessment approach combined RS and GIS usually analysis the spatial risk based on RS data, basic data and related socio-economic data [9]. However, the current spatial scale is large [10, 11]. The method based on assessment index system is commonly used in urban flood risk assessment. Generally, the index system is established from four aspects: disaster-causing factors, disaster-pregnant environment, disaster-bearing body, disaster prevention and mitigation ability [12-14]. Although lots of important findings have been obtained in this field, most of the current research have been done in the city regions with administrative boundaries. There are few studies on the risk assessment of small-scale floods in urban space [15-17].

Based on the theory of disaster system, considering the danger of disaster-causing factors, the sensitivity of disaster-pregnant environment, the vulnerability of disaster-bearing body, the ability of disaster prevention and mitigation from the formation process of flood disaster risk in Jingdezhen City, this paper puts forward the risk assessment index system of urban flood disaster in the small scale, constructs the risk assessment model based on the analytic hierarchy process method and analyses the spatial-temporal variation characteristics of flood disaster risk in urban region of Jingdezhen City with GIS. It provides a scientific support for making the urban flood emergency plan and strengthening the comprehensive risk management.

2. Study area
Jingdezhen City is located in the northeast of Jiangxi Province, China (see figure 1). The main river in Jingdezhen City is Changjiang River, the main tributaries are the South River and the West River. The distribution of precipitation in Jingdezhen City is extremely uneven during the year. The average precipitation during April-June is accounted for about 46% of annual precipitation, during July-September is accounted for about 22.1% of the year and during October-March is accounted for 31.8% of the precipitation. Further, Jingdezhen City is often plagued by flood disaster. According to the flood disaster in June 9, 2016, there are 528.7 thousand people affected and the direct economic losses was about $0.62 billion. There are still some problems in flood risk management in Jingdezhen City, such as lack of risk awareness and weak urban drainage facilities.

![Figure 1. Study area-Jingdezhen central city.](image-url)
3. Materials and methods

3.1. Formation process of urban flood risk
The urban flood risk is influenced by four aspects: disaster-causing factors, disaster-pregnant environment, disaster-bearing body, and the prevention and mitigation ability (see figure 2). The rainfall intensity in Jingdezhen is large, so there is a high probability of floods. The density of river network is large, which leads to the increasing of the sensitivity of the disaster environment. Besides, the density of urban population is large, most of the economic output concentrates in the urban region. So the vulnerability of the disaster-bearing bodies is high. Lastly, the operation of the drainage pumping station is not guaranteed and the design of the rainwater drainage is not reasonable, which result in the reduction of the disaster prevention and mitigation ability.

![Figure 2. The formation process of urban flood disaster risk.](image)

3.2. Risk assessment indicators
Based on the formation process of flood disaster in Jingdezhen City, the risk assessment index system of urban flood disaster is constructed from four above aspects, and 12 indicators are selected.

Precipitation is the most important factor of urban flood disaster [18], especially the short-term heavy rainfall has a greatest threat to the flood. Therefore, the average monthly precipitation, the maximum daily precipitation, the maximum continuous precipitation and the maximum continuous precipitation days were selected. Secondly, the terrain elevation and river network were selected to assess the environmental sensitivity of disaster. Through the actual investigation, it was found that terrain and topography will affect the runoff of rainfall in the ground, and the environmental sensitivity was stronger in areas closer to the river. GDP per 100 square meters, population density and land use types were selected to assess the vulnerability of the disaster-bearing body. Furthermore, in view of the medical level, drainage ability and other factors can reflect the impact of disaster prevention and mitigation on flood risk. So the radiation range of hospital, drainage pumping station and drainage pipeline are selected.

3.3. Data preparation and pre-processing
The meteorological data, population density data and gross domestic product (GDP) were collected from Jingdezhen Statistical Yearbook 2009-2013. The data were purchased from the Jingdezhen Statistical Bureau. The river network data and drainage pipeline location map were collected from Jingdezhen’s Water Conservancy Bureau. The topographic (SRTM 90 m resolution) data were collected from NASA website (http://srtm.cgiar.org /SELECTION/inputCoord.asp)*. The land use type data is the Planning of land use map in Jingdezhen City. The map comes from the official website of Jingdezhen Planning Bureau. The hospital and the drainage pumping station location data come
from the field investigation.
Precipitation indicators, population density indicators and GDP per 100 square meters’ indicators use different methods for standardization as follows:

Positive indicators:

\[ a = 0.1 + \frac{I - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}} \times (0.9 - 0.1) \]

Negative indicators:

\[ a = 0.1 + \frac{I_{\text{max}} - I}{I_{\text{max}} - I_{\text{min}}} \times (0.9 - 0.1) \]

Where \( a \) is standardized data between 0.1 and 0.9. The \( I \) is the raw data. \( I_{\text{max}} \) and \( I_{\text{min}} \) refer to the maximum and minimum of the original data respectively. The data of the land use type is standardized by the analytic hierarchy process. More specifically, calculate the weight value of the four types of land use, and then judge from its weight value to determine the impact of the four types of land on the vulnerability of the disaster-bearing body.

DEM elevation data were reclassified by geometric interval classification method to determine the influence of different categories in this paper. The results are showed in table 1.

**Table 1.** The influence degree of terrain elevation.

| Terrain elevation | <20 | 20~40 | 40~60 | 60~80 | 80~100 | >100 |
|-------------------|-----|-------|-------|-------|--------|------|
| Standard deviation|     |       |       |       |        |      |
| Value             | 0.4 | 0.5   | 0.6   | 0.7   | 0.8    | 0.9  |

The sensitivity of the disaster-pregnant environment was determined by the distance between the river and area. Therefore, the results for influence degree of river network are shown in table 2.

**Table 2.** The influence degree of river network.

| River network | <100 | 100~200 | 200~500 | 500~1000 | >1000 |
|---------------|------|---------|---------|----------|-------|
| Distance(m)   |      |         |         |          |       |
| Value         | 0.4  | 0.5     | 0.6     | 0.7      | 0.9   |

**Table 3.** The influence degree of disaster prevention and mitigation ability.

| Medical Institutions | <50 | 50~200 | 200~500 | 500~1000 | 1000~2000 | >2000 |
|----------------------|-----|--------|---------|----------|-----------|-------|
| Distance(m)          |     |        |         |          |           |       |
| Value                | 0.9 | 0.8    | 0.7     | 0.6      | 0.5       | 0.4   |

| Drainage Pumping Station | <50 | 50~100 | 100~200 | 200~500 | 500~1000 | >1000 |
|--------------------------|-----|--------|---------|---------|----------|-------|
| Distance(m)              |     |        |         |         |          |       |
| Value                    | 0.9 | 0.8    | 0.7     | 0.6     | 0.5      | 0.4   |

| Drainage Pipe Line       | <1  | 1~2    | 2~5     | 5~10    | 10~20    | >20   |
|--------------------------|-----|--------|---------|---------|----------|-------|
| Distance(m)              |     |        |         |         |          |       |
| Value                    | 0.9 | 0.8    | 0.7     | 0.6     | 0.5      | 0.4   |

Distance is an important indicator to access the disaster prevention and mitigation ability. The closer to the hospital, drainage pumping station, and the pipe line, the stronger the disaster prevention
and mitigation ability [19-21]. The results of influence degree are shown in table 3.

3.4. Risk assessment model of urban flood
In this paper, 50 representatives from water authority department, planning department and land management department conducted a questionnaire survey. The AHP (analytic hierarchy process) method is used to get the importance of each factor, then the weights of the various indicators is calculated. The results are shown in table 4.

| Table 4. The weight of each index. |
|-----------------------------------|
| **Object hierarchy** | **Rule hierarchy** | **Weight** | **Index hierarchy** | **Weight** |
| Flood Disaster Risk Assessment Index System | Disaster-causing factors | 0.332 | Average monthly precipitation | 0.184 |
| | | | Maximum daily precipitation | 0.268 |
| | | | Maximum continuous precipitation | 0.350 |
| | | | Maximum continuous precipitation days | 0.198 |
| | Disaster-pregnant environment | 0.241 | Terrain elevation | 0.493 |
| | | | River network | 0.507 |
| | Disaster-bearing body | 0.287 | GDP per 100 square metres | 0.122 |
| | | | Population density | 0.320 |
| | | | Type of land use | 0.558 |
| | Disaster prevention and mitigation ability | 0.140 | Medical institutions | 0.190 |
| | | | Drainage pumping station | 0.412 |
| | | | Drainage pipeline | 0.398 |

In this paper, the comprehensive risk value (R) is defined as a function of disaster-causing factors (D), disaster-pregnant environment (S), disaster-bearing body (V) and disaster prevention and mitigation ability (C). The assessment model is as follows:

\[ R = \sum_{i=1}^{S} w_i q_i \]

\[ q_i = \sum_{j=1}^{N} w_j q_j \]

Among them, \( w_i \) is the weight of item \( i \) in rule hierarchy. \( q_i \) is the index value of each rule hierarchy. \( w_j \) is the index weight of item \( j \) in each rule hierarchy. \( q_j \) is the index value of item \( j \) in each rule. \( N \) is the number of influencing factors.

4. Result and analysis

4.1. Analysis the danger of disaster-causing factors
The changes of annual rainfall from 2009-2013 are showed in figure 3. It shows that the precipitation increases from January to June. The precipitation was concentrated in June, July and August, however the value of the extreme point is fluctuating in different year. The precipitation is particularly concentrated in June and August when the flood disasters is most likely to happen.

As seen in figure 4, the total amount of monthly precipitation is constantly fluctuating from 2009 to 2013, and the extreme points of the remaining three sub-indicators appear in different years. Besides, the extreme points of the longest continuous precipitation days and the maximum precipitation in one
day are in 2012, while the extreme point of the longest continuous precipitation is in 2011. It’s also found that the smaller the factor value, the greater the danger and the largest danger of disaster-causing factors are in 2011.

### Figure 3. Monthly precipitation in Jingdezhen City (During 2009-2013).

### Figure 4. The changes of the precipitation in Jingdezhen City (During 2009-2013).

#### 4.2. Analysis the sensitivity of disaster-pregnant environment

It is seen that the environmental sensitivity of Jingdezhen city is with high spatial variation (see in figure 5). The sensitivity is lower in the north and higher in the south. On the other hand, the sensitivity of the river network is the highest, and is gradually weakening from the central line of the river network to the areas along the river.

#### Figure 5. Sensitivity of the disaster-pregnant environment.

#### 4.3. Analysis the vulnerability of disaster-bearing body

As seen in figure 6, the vulnerability of the eastern city is stronger than that of the western city, and the vulnerability of the areas along Changjiang River is strong. More specifically, the vulnerability of the Zhushan District is stronger than the Changjiang District. The vulnerability in Fuliang County is small because of the small population density and small gross production value, the vulnerability is small.

#### Figure 6. Vulnerability of disaster-bearing body.

#### 4.4. Analysis the disaster prevention and mitigation ability

As seen in figure 7, the disaster prevention and mitigation ability in the northeast of the city is stronger, and it decreases gradually from the northeast to the southwest. There are obvious differences between the east and the west of Jingdezhen City. The flood disaster risk is small because the medical institutions and drainage pumping stations are gathered in the eastern part of the city.
4.5. The spatial-temporal variation analysis of urban flood risk

The spatial-temporal variation of flood disaster risk in Jingdezhen City has significant differences (see in figure 8). From the view of space, the characteristics included differences in flood risk characteristics, direction characteristics and volatility characteristics. From the view of time, the area of high flood disaster risk decreased year by year, while flood disaster risk value became larger in some local areas.

Figure 7. Disaster prevention and mitigation ability.

Figure 8. Risk Zoning Map in Jingdezhen City (2010-2013).
4.5.1. **Spatial variation analysis.** The flood risk of areas along Changjiang River as well as central and north-eastern of urban is larger. From the view of the local urban region, it has the greater risk along the east and west coast of Changjiang River. The maximum flood risk areas are the narrow river bank between Changjiang River and Zhushan District. Furthermore, the risk of flood disaster has a changing tendency from east to west divided by Changjiang River. The flood risk in Zhushan District is the largest, followed by Changjiang District.

Taking the centreline of Changjiang as the dividing line, the flood risk presents a spatial distribution characteristic which extends from the centre line of Changjiang River to the surrounding, meanwhile, the risk value of flood disaster is gradually decreasing.

The fluctuation of flood risk value in Zhushan District is the largest. And the west and southwest of Jingdezhen urban areas have higher terrain, smaller population density and GDP, the flood risk value fluctuates less.

4.5.2. **Temporal variation analysis.** Flood risk shows a downward trend in time, increased from 0.572–0.757 in 2010 to 0.637–0.812 in 2013. The minimum of the flood risk values are 0.572, 0.582, 0.603, 0.637 in 2010, 2011, 2012 and 2013 respectively. Further speaking, it can be concluded that the risk of high flooding area was decreasing year by year, at the same time, the peak value of flood risk value was decreasing too.

Flood risk in the eastern part of the urban region was becoming smaller, while the risk was increasing in the northwest and north of the city, and the change of flood risk in the east and west coast of Changjiang was smaller. From 2010 to 2011, the main change happened in the northeast of Jingdezhen City, called Fuliang County. Its amount of area of low flood risk was becoming larger, and the southern flood disaster risk became smaller. From 2011 to 2012, the value of flood risk reduced in the area between Changjiang and Zhushan District. Meanwhile, the risk value of western urban region increased slightly. From 2012 to 2013, although there was little change in the areas with high risk of flood disaster, the risk areas were more concentrated, and the risk of flood disaster decreased in other areas of the city.

5. **Conclusion and discussion**

The risk assessment of urban flood disaster is studied in this paper. Based on the understanding of the formation process of urban flood disaster risk, the indicators of danger, sensitivity, vulnerability, prevention and mitigation are constructed in this paper. The weight of those indicators was calculated by using the analytic hierarchy process. And then a small-scale flood disaster risk assessment model was developed based on AHP and GIS. Finally, the spatial and temporal distribution of flood risk in Jingdezhen was analyzed.

The results showed that the flood risk of Jingdezhen was decreasing year by year from 2010 to 2013, and the risk of flood disaster was diverse on the spatial distribution. Changjiang District and Zhushan District were had high environmental sensitivity because of the low terrain and intensive rivers. There were lots of commercial facilities and residential areas in both banks of Changjiang River which indicates high vulnerability. Inevitably, the flood disaster risk along the Changjiang River was the maximum. The flood risk of the city was decreasing when it diffused from the Changjiang River to the surrounding. The flood disaster risk in west and south of Changjiang District was small, so did the northeast of Fuliang County.

Although sufficient analysis has been done based on the urban flood risk formatting in this paper, there are also part of the important influence factors are out of consideration. It would be better to assess the risk of urban flood in dynamic concept and method. The spatial-temporal variation analysis of the flood risk in whole Jingdezhen City would be studied in the near future.

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