Hazard evaluation of mountain flood disaster based on multi-source remote sensing information—a case study in city of rain, Ya'an

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Abstract. Because the hazard of flood disaster is mainly related to the natural attribute of flood disaster, this paper makes full use of multi-source remote sensing information to reflect the meteorological and underlying surface conditions in Ya'an City, constitutes an evaluation index system according to selecting the rainfall, runoff depth, the basin storage capacity, elevation, slope and water system, from the two aspects of disaster-inducing factors and disaster-pregnant environment; trains historical flood occurrence sites by using BP neural network, obtains the weights of each research index; overlays analysis each index according to the index model, based on the GIS technology; and obtains the torrential flood hazard distribution map of Ya'an City as well as comparing it with the occurrence sites of historical flood disasters. The results show that the flood hazard level is the highest in the eastern part of Ya'an, the lowest level area of the flood hazard is the southern part. The evaluation results well reflect the actual situation of regional flood spatial distribution, which can provide a scientific basis for the development of reasonable flood control and disaster mitigation planning in Ya'an City.

1. Introduction

Flood disaster is current one of the natural disasters that have brought huge losses to human. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) indicates that global warming is occurring and will continue in the future due to the increased human emissions [1]. Resulting in natural system variation and frequent extreme climate, this will greatly affect the frequency, intensity, spatial extent, duration of flood disasters and increase the flood risk in some areas. In China, the mountain basin area covers for about two-thirds of the national land area, and the population accounts for about one third of the total population of the country. The losses caused by mountain torrents are particularly serious, which has become a significant factor restricting the sustainable development of mountain economy and society. In order to avoid and reduce the disaster loss from the source, it is necessary to evaluate the risk of mountain flood disaster scientifically.

From the perspective of disaster system theory, the risk of flood disaster refers to the damage caused by flood to the natural environment and human society to a certain extent, with two attributes of nature and society. Hazard evaluation is the basis of risk assessment, which involves the natural attributes of flood disasters. In brief, it analyzes flood disasters from two aspects: disaster-inducing factors (causes of flood) and disaster-pregnant environment (natural environment for flood disasters)
Research on regional flood risk assessment has always been a hotspot, and methods of historical flood, Hydro-hydraulic model and index are often adopted [3]. Historic flood method is simple in calculation, but difficult in data acquisition, and the consistency of data statistics is difficult to ensure. Therefore, hydrological frequency calculation method is often adopted to calculate the recurrence period [4-5]. The hydro-hydraulic method can calculate the flow, possible flood inundation scope, depth and other elements through mathematical simulation of flood by means of hydrological and hydraulic models, and has high calculation accuracy, but needs to observe precipitation, flow, water level and other data, limiting its application in mountain watershed [6-7]. With the development of GIS and RS technology, index method is more commonly used evaluation methods in recent years, which has low data requirements and is suitable for flood assessment in non-data regions. The most intuitive method of index method is to extract flood inundation scope and depth indicators based on remote sensing images, usually used for rapid extraction of hazard areas and assessment of post-disaster losses in sudden flood disasters [8-9]. Huang Shifeng et al. [10] used the natural geomorphology of the Liaohe River Basin as the research object, and used the river network density index to characterize the underlying surface conditions of the basin, and analyzed its relationship with flood hazard. As the occurrence of flood is affected by many factors, it is more reasonable to use a variety of indicators to obtain comprehensive indicators through weighting. Thus, analytic hierarchy process, fuzzy comprehensive evaluation, grey clustering, entropy weight method, random forest, artificial neural network [11-13] and other methods are often used to judge the weight. However, there are great uncertainties in analytic hierarchy process, fuzzy comprehensive evaluation and grey clustering. Moreover, when using entropy weight method, even small differences will lead to entropy weight change exponentially when the entropy value tends to 1, so that certain indexes are endowed with unreasonable weight. With the development of artificial intelligence technology, object evaluation based on machine learning algorithm, such as random forest, artificial neural network, etc. has become the trend of future development.

In this paper, GIS technology and multi-source remote sensing information such as satellite precipitation, digital elevation, land cover and soil type are applied to the Ya'an area where the data is lacking. Taking the natural attribute characteristics of flood disaster as the target and the actual flood occurrence sites as the training data of BP neural network, hazard evaluation of mountain flood disaster is carried out in Ya'an administrative region to improve the reliability of hazard map. In order to provide a scientific basis for the flood control and disaster reduction and disaster assessment in Ya'an City.

2. The research methods

2.1 BP neural network
Back Propagation Neural Network [14] is a multi-level feedforward Network trained according to the algorithm of error reverse transportation, which is one of the most widely used Neural networks nowadays. BP neural network has strong mirroring capability with sigmoid hidden layer and linear output layer. The main operational steps are :(1) provide training examples to the network, i.e. learning samples, including input and expected output; (2) determine the allowable error between the actual output and the expected output of the network. Change all the connection weights in the network so that the output produced by the network is closer to the expected output until a certain allowable error is met.

Through calculation, the calculation formula for the weight adjustment of the BP learning algorithm with the three-layer feedforward network is obtained as follows:

\[ \nabla w_{jk} = \eta(d_k - o_k)a_k(1 - o_k)y_j \]  
\[ \nabla v_{ji} = \eta(\sum_{k=1}^{n} o_k^0 w_{jk})(1 - y_j)x_i \]

In the formula, \( W \) is weight matrix between the hidden layer and the output layer; \( V \) is weight
matrix between the input layer and the hidden layer; the constant \( \eta \in (0,1) \) indicates the proportional coefficient; \( d_i, o_k \) are the expected output vector and the output layer output vector; \( x_i, y_j \) are the input vector and the hidden layer output vector; For the output layer: \( j = 1,2,L,m; \ \ k = 1,2,L,l; \) For the hidden layer: \( i = 0,1,2,L,n; \ \ j = 1,2,L,m. \)

2.2 Construction of evaluation index system

It is difficult for flood disaster to make unified quantitative analysis due to its complicated formation conditions and numerous influencing indexes. This paper considers that each impact index can be analyzed separately and classified according to its influence degree on flood disaster. Then, each index is superimposed with corresponding weight value, using the spatial overlay function of GIS system, analyzing comprehensively the influence of each factor on flood hazard, so as to make the analysis result more reliable.

The basic conditions for the formation of flood disasters include disaster-inducing factors and disaster-pregnant environment, reflecting the natural properties of floods. Disaster-inducing factors are the causes of flood, such as rainfall, water conditions of river, etc. Disaster-pregnant environment refers to the natural factors that form floods, such as topography and landforms, soil vegetation and so on. According to local conditions and the actual situation of flood in Ya'an City, the following indicators are selected:

(1) Disaster-inducing factors

Rainfall and runoff depth are selected as the indicators of disaster-inducing factors: Ya’an City is a mountainous city, and its floods belong to mountain torrents. Mountain torrents, as a strongly destructive surface runoff, are mainly caused by heavy rainfall. At the same time, the runoff depth is commonly used to measure the size of surface runoff. The greater the runoff depth is, the greater the possibility of flood disasters is.

(2) Disaster-pregnant environment

The basin storage capacity, elevation, slope and water system are selected as disaster-pregnant environmental indicators: the basin storage capacity represents maximum soil moisture content in the basin, and the smaller the value is, the lower the upper limit of soil moisture content is, the easier surface runoff is to form, and the greater the impact on flood hazard is. Topography and landforms are important factors for the formation of flood disasters. The probability of flood disasters is higher in low-lying and Middle-Mountain areas than in high-lying areas such as hills. However, in areas with relatively flat mountains, once torrential rain occurs, the accumulated water will wash down along the mountains to plain areas due to lack of obstacles, easily outbreak of mountain torrents. River network system is another important factor affecting flood disasters. The closer to the river system, the stronger the water-collecting capacity is, the weaker the seepage capacity is, the higher the hazard of mountain torrent disasters is.

3. Survey of research areas

Ya’an City is located in the western margin of the Sichuan Basin, in the middle reaches of the Qingyi River, in the upper reaches of the Yangtze River, east to Chengdu, west to Ganzi, south to Liangshan, and north to Aba. It is known as “Western Sichuan Throat”, “Tibet Gateway” and “National Corridor”. The topography is high in the southwest and low in the northeast, belonging to low-lying and middle-mountain zone (as shown in Figure 1). The city covers an area of 15,000 square kilometers and administers 6 counties and 2 districts with a total population of 1.53 million. Known as "Rain City" and "Sky Leak", most of the county's annual rainfall of 1000-1800 millimeters above, an average annual rainfall of about 1800 millimeters, is relatively more rainfall area in Sichuan province. In addition, its main rivers: both Dadu River and Qingyi River belong to Minjiang River system, with nearly 100 tributaries, and are located near Longmenshan fault zone, prone to geological disasters and rainstorm floods and other disasters. In the past five years, Ya’an City has suffered several major floods. In July 2013, after the Lushan earthquake, the Longxi River basin in Yucheng district suffered
extraordinary flood in more than 50 years. On July 7 and 8 of the same year, the accumulated rainfall of Shangli town in Yucheng district reached 221.8 millimeters, causing flash floods. On August 27, 2017, Ya’an City was hit by torrential rain and mountain torrents, flooding many parts of the country.

4. Data and processing

4.1 Data sources

The specific description of each data is shown in Table 1.

| Category                        | Data name                        | Data source                                      | Data description                                                                 |
|---------------------------------|----------------------------------|--------------------------------------------------|----------------------------------------------------------------------------------|
| Disaster-inducing factors       | TRMM 3B43 satellite rainfall     | NASA in USA                                      | Global grid data of monthly rainfall of 0.25°×0.25° from 1998 to 2016             |
|                                 | Isogram of annual average runoff depth | Sichuan hydrological bureau                       | Synchronous series from 1956 to 2000                                              |
|                                 | Land cover UMD                   | University of Maryland, USA                      | Global land cover grid data of 1 km                                               |
| Disaster-pregnant environment   | Soil type                        | International Food and Agriculture Organization, FAO | Global soil type grid data of 1 km                                                 |
|                                 | Digital elevation model, DEM     | Geospatial data cloud http://www.gscloud.cn/     | 30m DEM based on the latest STRM V4.1 data mosaic and collation                   |
|                                 | Historic flood sites in Ya’an City | Flood and drought control command of Sichuan Provincial People's Government /Network information collection | 79 points for flood and drought control command and 10 points for network collection, specific to villages. |

4.2 Data processing

4.2.1 Standardized processing. Due to the different data download sources, different measurement units and large variation range, it is not conducive to neural network learning and training, so it is necessary to standardize data to eliminate its dimension. The specific algorithm is as follows:

\[ X = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \]  

(3)

In the formula, \( X \) is the standard value of the index; \( x_i \) is the actual value of a certain index; \( x_{\max} \), \( x_{\min} \) is the maximum and minimum value of the index respectively.

4.2.2 Natural breakpoint classification method. In order to reflect the degree of impact of various indicators on flood hazard, this paper uses the natural breakpoint classification method to classify each index. The classification principle is to reduce the difference in the level and increase the difference among the levels. The calculation formula is as follows:

\[ SSD_{i-j} = \sum_{k=1}^{j} (A[k] - mean_{i-j})^2, (1 \leq i < j \leq N) \]  

(4)

In the formula, \( A \) is an array (the length of the array is N); \( mean_{i-j} \) is the average in each level.
The standardized indicators are divided into five levels using equation (4), and the classification is as shown in Table 2:

| Level          | Very low | Low    | Medium | High    | Very high |
|----------------|----------|--------|--------|---------|-----------|
| Rainfall       | 90-100   | 100-106| 106-117| 117-126 | 126-146   |
| Runoff depth   | 254.28-690.1 | 690.15-1029.0 | 1029.98-136 | 1369.82-175 | 1753.97-213 |
| The basin storage capacity | 5 | 98 | 9.82 | 3.97 | 8.13 |
| Elevation      | 488-1250 | 1250-1926 | 1926-2624 | 2624-3461 | 3461-5700 |
| Slope          | 0-12.69  | 12.69-23.11 | 23.11-32.55 | 32.55-42.96 | 42.96-82.99 |
| Hazard         | 0.239-0.400 | 0.400-0.467 | 0.467-0.529 | 0.529-0.607 | 0.607-0.826 |

4.2.3 Index processing. (1) Rainfall index. Torrential rain is usually an important cause of mountain torrents in Ya’an City. At present, ground precipitation stations and radar are the main methods to obtain rainfall data. Precipitation station observation, as one of the most direct precipitation measurement method, is relatively mature, the most widely applied, in terms of a single measurement point, it has strong accuracy. However, because of the limitations of station distribution and observation scope, especially influenced by the complex mountainous terrain, it can not reflect the large-area spatial distribution and intensity change of rainfall. Moreover, most rainfall interpolation methods tend to produce too smooth rainfall curves, which underestimate the impact of spatial variability, such as the estimation of rainstorm value. The products of TRMM satellite precipitation are characterized by wide coverage (50°S-50°N), good accuracy and high spatial resolution (0.25°×0.25°). Among them, the products of 3B43 month precipitation are significantly correlated with the observation data of ground meteorological stations. Therefore, this paper selects the monthly data of TRMM satellite precipitation during the period of 1998-2016 for 19 years, and uses MATLAB software to calculate the average annual rainfall. According to the principle that the greater the rainfall is, the higher the flood hazard is, the layer is divided into five levels by the natural breakpoint classification method, and the distribution map of the impact degree of rainfall on flood hazard is shown in Figure 2.

(2) Runoff depth index. In this paper, the runoff depth contour of Ya’an City is drawn on the basis of the multi-year average annual runoff depth contour map of Sichuan Province. The iterative finite difference interpolation technology is used to interpolate it into the grid surface, which is divided into 5 levels after standardized processing, the distribution map of the impact degree of runoff depth on flood hazard is shown in Figure 3.

(3) The basin storage capacity index. According to statistics in 2019, the vegetation coverage rate in Ya’an City reaches 64.77%, and runoff process of the whole city is greatly affected by vegetation. The basin storage capacity can be calculated by the plant root depth and field capacity listed in Formula (5). The plant root depth is determined by determining vegetation types in the study area, according to the standard table of root depth of different land cover types [15] (as shown in Table 3). There are 8 kinds of FAO soil numbers in this study area: 4351, 4287, 4329, 3085, 3963, 4270, 3967, 4269. According to the proportion of FAO soil type particles provided by Yamanashi University (as shown in Table 4) and the soil triangle provided by USDA [16], the soil types in this study area can be divided into three types, namely, sandy clay loam, clay and loam. The field capacity corresponding to different soil types is found in Table 5 [15]. Then, the basin storage capacity is obtained. As it is inversely proportional to the flood hazard, the distribution map of the basin storage capacity is obtained by subtracting the grid value from the maximum value and dividing levels, as shown in Figure 4.

\[
M = W_m \times F_r
\]  

(5)

In the formula, \(M\) is the basin storage capacity; \(W_m\) is the field capacity; \(F_r\) is the plant root depth.
Table 3. Root depth for various land cover types.

| UMD land cover classification | Evergreen coniferous forest | Mixed forest | Woodland | Forest steppe | Dense thickets | Grassland | Arable land |
|------------------------------|----------------------------|--------------|----------|---------------|---------------|-----------|-------------|
| Root depth/m                 | 1.0                        | 1.25         | 1.125    | 0.997         | 0.872         | 0.651     | 0.578       | 0.75         | 0.75         |

Table 4. Soil particle proportion of each FAO soil type in the study area.

| Soil particle ratio | FAO soil number | Clay% | Sand%   | Silt% | USDA soil type      |
|---------------------|----------------|-------|---------|-------|----------------------|
|                     | 4351           | 23.3  | 55.628  | 21.072| sandy clay loam     |
|                     | 4287           | 41.3  | 39.91   | 18.89 | clay                 |
|                     | 4329           | 30.62 | 46.42   | 24.9  | sandy clay loam     |
|                     | 3085           | 39.699| 38.059  | 22.275| clay                 |
|                     | 3963           | 25.245| 45.022  | 29.733| loam                |
|                     | 4270           | 40.96 | 44.32   | 14.8  | clay                 |
|                     | 3967           | 26.75 | 51      | 22.25 | sandy clay loam     |
|                     | 4269           | 43.03 | 42.6    | 14.44 | clay                 |

Table 5. Field capacity for various USDA soil type.

| USDA soil type | Field capacity | USDA soil type | Field capacity |
|----------------|----------------|----------------|----------------|
| Sand           | 0.08           | Sandy clay loam| 0.27           |
| Loamy sand     | 0.15           | Silt clay loam | 0.36           |
| Sandy loam     | 0.21           | Clay loam      | 0.34           |
| Silt loam      | 0.32           | Sandy clay     | 0.31           |
| Silty sand     | 0.28           | Silty clay     | 0.37           |
| Loam           | 0.29           | Clay           | 0.36           |

(4) Elevation and slope indexes. In GIS, topographic elevation is expressed by DEM, and topographic variation degree is often expressed by slope. The influence of elevation and slope on flood hazard is negatively correlated, so it is necessary to convert it into positive correlation, and then classify it to obtain the distribution map of its influence on flood hazard, as shown in Figure 5 and 6.

(5) Water system index. The spatial analysis function of GIS is used to hydrologic analysis DEM to get the flow accumulation, and the water system with the flow accumulation of no less than 15000 is taken as the main water system in the study area. Then, the buffer analysis of the water system is conducted according to the buffer width listed in Table 6 after comprehensively considering the different impacts of river grade and topographic variation on flood hazard. This paper establishes the two-level buffer. According to the principle of buffer formation, the impact degree of buffers on flood hazard at all levels is quantified: the magnitude of the first-level buffer is 0.9, the magnitude of the
second-level buffer is 0.7, and the magnitude of the non-buffer is 0.5. The distribution map of the influence of water system on flood hazard is shown in Figure 7.

Table 6. River buffer width values at all levels.

| River rank          | Absolute elevation (m) |
|---------------------|------------------------|
| 488-1249            | 1249-1925              |
| 1925-2623           | 2623-3459              |
| 3459-5700           |                        |
| Trunk stream        | 3000                   |
| First-level buffer  |                        |
| First-level river   | 2500                   |
| Second-level others | 1500                   |
| Second-level buffer |                        |
| First-level river   | 6000                   |
| Second-level others | 3000                   |

Table 7. Weights of indexes.

| Index         | Rainfall | Runoff depth | The basin storage capacity | Elevation | Slope | Water system |
|---------------|----------|--------------|----------------------------|-----------|-------|-------------|
| Weight        | 0.321    | 0.114        | 0.125                      | 0.163     | 0.134 | 0.143       |

\[
P = R \times \alpha + E \times \beta + H \times \gamma + S \times \varepsilon + W \times \delta + M \times \lambda
\]  

(6)

In the formula, \( P \) is flood hazard index; \( R \) is rainfall index; \( E \) is runoff depth index; \( H \) is elevation index; \( S \) is slope index; \( W \) is water system index; \( M \) is the basin storage capacity index; \( \alpha, \beta, \gamma, \varepsilon, \delta, \lambda \) are weights of each index respectively.

From Figure 8, it can be seen that the flood hazard in the eastern region of Ya’an City is higher than that in the western region, while the flood hazard in the northern and central regions is higher than that in the southern region. Through the analysis of the test samples, 75.6% is located in the area with high and very high flood hazard, and 92.7% is located in the area with medium or above flood hazard, which better reflects the actual spatial distribution of flood in Ya’an City. The very high-hazard areas account for 10.7% of the total area, including Mingshan District in the east of Ya’an City, Dachuan Town, Baosheng Township, Yuquan Township and Longmen Township in Lushan County, as well as Shangli Town, Zhongli Town, Bifengxia Town, Fengming Township, Beijiao Town, and Daxing Town in the north of Yucheng District. These areas belong to low and middle mountain zone, located in the middle reaches of the Qingyi River, with gentle topography, high rainfall and developed water system. The basin storage capacity in Mingshan District is low, which is more likely to form surface runoff, about 22.5% of the historical flood occurrence points concentration distribution in the area. The high-hazard areas account for 20.7%, including the southern of Lushan County, the southern of Yucheng District, the Zishii Township and surrounding townships of Tianquan County, the surrounding areas of Yingjing County, Lingguan Town of Baoxing County, etc., which concentrate 42.7% of
historical occurrence flood points. The medium-hazard areas account for 33.2%, mainly located in the northern and central regions of Ya’an City. Low and very low hazard areas account for 35.4%, mainly located in Hanyuan County and Shimian County in the south of Ya’an City, most regions of which are in the high mountain, belonging to the Dadu River Basin, with low rainfall and the lowest flood hazard compared to other districts and counties from Figure 8. However, the urban section of trunk stream of Dadu River and the lower reaches of first-level rivers which are Tianwan River, Nanya River and Liusha River, are low-lying, have medium flood hazard and distribute many historical flood occurrence points. The results shown in Table 8 are obtained by using zonal statistics of GIS.

Table 8. Hazard ranking and the proportion of different hazard levels in each district (county) (%).

| Hazard ranking of district (county) | Very low | Low | Medium | High | Very high |
|-----------------------------------|----------|-----|--------|------|-----------|
| Mingshan District (1)             | -        | -   | -      | 5.166| 94.834    |
| Lushan County (2)                 | -        | 0.176| 17.414 | 31.750| 50.660    |
| Yucheng District (3)              | 0.104    | 0.519| 16.390 | 54.979| 28.008    |
| Tianquan County (4)               | -        | 3.045| 47.182 | 46.364| 3.409     |
| Yingjing County (5)               | 1.587    | 17.949| 54.884 | 24.481| 1.099     |
| Baoxing County (6)                | 0.139    | 16.011| 65.889 | 17.090| 0.870     |
| Hanyuan County (7)                | 39.379   | 50.100| 10.220 | 0.301| -         |
| Shimian County (8)                | 45.553   | 47.091| 7.107  | 0.249| -         |

6. Conclusion
(1) On the basis of summarizing previous research results, selecting rainfall, runoff depth, the basin storage capacity, elevation, slope and water system factors are as evaluation indexes to build an evaluation index system. BP neural network is used to learn and train samples combined with the actual flood occurrence points to get the weight of each evaluation index, according to which, superimposing the index factors on the GIS platform, so as to obtain the hazard distribution map of flood in Ya’an City. Finally, the analysis results are compared with historical flood sites, and the research shows that the consistency is good.

(2) In terms of the hazard distribution map, high-hazard areas of flood are mainly concentrated in the east of Ya’an City. The highest-hazard areas are in the east of Lushan County and Yucheng District and most of Mingshan District. Some of these three administrative regions belongs to post-disaster reconstruction areas, which will aggravate the impact of flood disasters. So corresponding countermeasures for flood control and disaster reduction should be done well.

(3) TRMM satellite rainfall of 0.25°×0.25° in this paper has a large spatial scale, and is still insufficient spatial difference description of rainfall in mountainous areas, as well as lacking of description of topo-short-term heavy rainfall. The surface rainfall of smaller spatial scale should be considered. In addition, this article also ignores the impact of hydraulic structures such as reservoir, dam, dike and so on. The above shortcomings hope to be improved in future research.
Figure 1. Geographical location of Ya’an City.

Figure 2. Rainfall impact map.

Figure 3. Runoff depth impact map.

Figure 4. The basin storage capacity impact map.
Figure 5. Elevation impact map.
Figure 6. Slope impact map.
Figure 7. Water system buffer map.
Figure 8. Flood hazard map.

Reference
[1] ZHAO Zongci, LUO Yong, WANG Shaowu, et al. (2015) Science issues on global warming. J. Journal of Meteorology and Environment, 31(01):1-5.
[2] WANG Shaoyu, LIU Jia. (2012) Multi-attribute dynamic evaluation of urban flood disaster vulnerability. J. Advances in Water Science, 23(3): 334-340.
[3] MAO Dehua, HE Zilin, HE Xiguang, et al. (2009) Review and prospect of research on flood risk analysis at home and abroad(I): status quo of research on risk analysis of flood hazard. J.
Journal of Natural Disasters, 18(01): 139-149.

[4] Archer D R, Parkin G, Fowler H J. (2017) Assessing long term flash flooding frequency using historical information. J. Hydrology Research, 48(1): 1-16.

[5] SUN Zhangli, ZHU Xiufang, PAN Yaozhong, et al. (2017) Flood Risk Analysis: Progress, Challenges and Prospect. J. Journal of Catastrophology, 32(3): 125-130, 136.

[6] Manfreda S, Samela C, Gioia A, et al. (2015) Flood-prone areas assessment using linear binary classifiers based on flood maps obtained from 1D and 2D hydraulic models. J. Natural Hazards, 79(2): 735-754.

[7] Gusyev M, Gädeke A, Cullmann J, et al. (2016) Connecting global - and local - scale flood risk assessment: a case study of the Rhine River basin flood hazard. J. Journal of Flood Risk Management, 9(4): 343-354.

[8] QI Shuhua, SHU Xiaobo, Daniel Brown, et al. (2015) Flooding hazard mapping for Poyang Lake Region with remote sensing and water level records. J. Journal of Lake Sciences, 21(5): 720-724.

[9] Rosser J F, Leibovici D G, Jackson M J. (2017) Rapid flood inundation mapping using social media, remote sensing and topographic data. J. Natural Hazards, 87(1): 103-120.

[10] HUANG Shifeng, XU Mei, CHEN Deqing. (2001) GIS-based extraction of drainage network density and it's application to flood hazard analysis. J. Natural Hazards, 2001(04): 129-132.

[11] LIU Rui. (2016) A Study on Modeling of Flood Risk Evaluation Based on Bayesian Networks. D. East China Normal University.

[12] LAI Chengguang, CHEN Xiaohong, ZHAO Shiwei, et al. (2015) A flood risk assessment model based on Random Forest and its application. J. Journal of Hydraulic Engineering, 46(1): 58-66.

[13] Kourgialas N N, Karatzas G P. (2017) A national scale flood hazard mapping methodology: The case of Greece–Protection and adaptation policy approaches. J. Science of the Total Environment, 601: 441-452.

[14] WANG Lei. (2014) Principle, classification and application of artificial neural network. J. Science & Technology Information, 2014(03): 240-241.

[15] YUAN Fei. (2006) Hydrological Processes Modeling Considering the Effect of Vegetation. D. Hohai University.

[16] Rawls W L, Ahuja L R, Brakensiek D L. (1993) Infiltration and soil water movement, In: Maidment, D.R.(Eds)Handbook of hydrology, New York: McGraw-Hill Inc, 5.1-5.51.