Journal of Geoscience and Environment Protection, 2022, 10, 84-93
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Regionalization and the Method for Risk Grading for Flash Flood Disaster in Tibet Region

**Yangzong Ciren[1]*, Nima Ji[2]**

[1]College of Atmospheric Sciences, Nanjing University of Information Science and Technology, Nanjing, China
[2]Tibet Climate Center, Tibet Meteorological Bureau, Lhasa, China
Email: *15289103761@126.com

**How to cite this paper:** Ciren, Y. Z., & Ji, N. M. (2022). Regionalization and the Method for Risk Grading for Flash Flood Disaster in Tibet Region. *Journal of Geoscience and Environment Protection, 10,* 84-93.
https://doi.org/10.4236/gep.2022.105007

**Received:** April 6, 2022
**Accepted:** May 23, 2022
**Published:** May 26, 2022



## Abstract

Flash flood is one of the major meteorological disasters on the Tibet Plateau (TP). Flash flood risk regionalization based on the theory of flash flood occurrence risk is the essential basis for relative risk management. The flash flood risk regionalization and the high-resolution grid mountain flood risk level in TP is carried out by using ArcGIS with the indicators of rainfall, days of heavy rain, vegetation cover, slope, relative elevation difference, river network density, population density, average GDP and traffic density. The areas with high mountain flood risk are mainly located in the middle and downstream of Yarlung, the Nujiang River Valley, the Jinsha River and Lancang River Basin. Besides, the results of flash flood disaster risk regionalization were tested by using historical flash flood disaster data and calamity census data. The disasters occurred in high-risk and sub-high-risk regions are accounted for 73%. Flash floods that cause casualties and economic losses of more than 100,000 CNY (Chinese Yuan) occurred in high-risk areas. Flash flood risk assessment may provide reference for the prevention and control of geological disasters in TP, improve disaster prevention and mitigation capabilities, reduce the hazards of flash floods to social development.

## Keywords

Tibet, Flash Flood, Risk Regionalization, Vulnerability Assessment, Flash Flood Prevention

## 1. Introduction

Flash flood is the disaster caused by rainfall in mountainous areas, with the characteristics of suddenness, concentrated water, great destructive power, often accompanied by geological disasters such as debris flow and landslide, which pose a major threat to the national economy and people's lives and property. Tibet Plateau is the main body of the Qinghai-Tibet Plateau, the largest plateau in the world. The TP has high and steep slopes, fragile ecological environment and poor living conditions. Restricted by the terrain, the residents are mostly located in river valleys with relatively flat terrain and convenient transportation. Highway traffic is often constructed along rivers, which is particularly susceptible to flash flood and derivative geological disasters. In rainy season, the phenomenon of highways being destroyed due to flash flood often occurs, which seriously affects traffic safety and capacity, and greatly restricts economic development (Cui et al., 2015). For example, due to a sudden flash flood caused by continuous rainfall, a steel bridge in Bayi District, Nyingchi City, 318 National Highway of Sichuan-Tibet Highway was destroyed on August 17, 2015, resulting in traffic interruptions for more than half a month. On July 28, 2014, the 25-meter-long Gedang Highway XiXi Steel Bridge was completely destroyed by flash flood and debris flow. Traffic interruption brought great inconvenience to local people's lives. Flash flood disaster risk regionalization can provide a basis for scientifically analyzing the disaster-causing factors and providing appropriate prevention and control measures, which is important basis for flash flood disaster risk management.

Domestic scholars have carried out a lot of work for different regions. Huang et al. (2015) studied the risk assessment model of flash flood disaster in Yao'an River Basin in Qingyuan City, Guangdong Province, and made a regionalization map of flash flood disaster and vulnerability and risk. Took the Tiaoshi Town, Banan District, Chongqing as the research scope, Lin et al. (2015) constructed a flash flood danger regionalization index system in mountain towns, obtained the flash flood hazard comprehensive index and carried out the comprehensive risk region. Similarly, Yue et al. (2015) completed the mountain flood disaster risk assessment, vulnerability and mountain flood disaster risk regionalization map in the upper reaches of Minjiang River by combining analytic hierarchy process with Delphi method to determine the weights. Gao et al. (2015) took Huangshan Scenic Area as the research object to explore the applicability of the relatively closed regional flash flood disaster risk regionalization method. Xu et al. (2015) and Liu et al. (2015) produced flash flood risk regionalization maps of Jiangxi and Hainan based on DEM data and DEA method respectively. Studying the calculation and division method of mountain flood disaster risk map in the mountainous regions lacking data in north China, Liu et al. (2013) provided reference for risk analysis of mountain flood disaster in the regions lacking data in north China. By combining high-precision DEM, small watershed ditch measurement and heavy rain flood survey data, Yang et al. (2013) discussed the division method and implementation steps of flash flood disaster risk areas in small watersheds in Beijing. The characteristics, causes and prevention measures of flash flood disasters in Hunan Province are also analyzed and corresponding suggestions for prevention and control are made (Zeng et al., 2004). Practice has shown that flash flood disaster risk regionalization can provide a reference decision-making of flash flood disaster prevention and mitigation.

In the context of global warming, extreme precipitation occurs more frequently in TP. Therefore, the threat of flash flood disasters is increasing (Qiangba et al., 2015). Due to economic and technological backwardness, relatively low level of education, insufficient awareness of disaster risk and its prevention and reduction, lacking of professionals in TP, it is in urgent need of improving disaster risk prevention capabilities. Due to the difficulty of field monitoring and the lack of data, there are few analysis reports on flash flood risk regionalization in TP. This paper attempts to use meteorological disaster risk theory to establish a flash flood risk regionalization in TP to provide a reference for flash flood prevention and mitigation.

## 2. Data and Method

### 2.1. Data

The precipitation data used in this paper is the daily precipitation observation of 38 meteorological stations in the whole region provided by the Information Network Center of the Meteorological Bureau of the TP Autonomous Region, due to the vast territory of TP and the sparse distribution of meteorological observation stations, the precipitation data of THE CMORPH (CPC MORPHing technique) is used as a supplement to the precipitation observation. Previous research shows that this data can remedy defects for the lack of ground rainfall observation in the plateau area and has a certain reference value in vocational work (Lin et al., 2016). The DEM data used is ASTER GDEM V2 data with spatial resolution of 30 meters comes from the International Science Data mirror website of the International Scientific Data Service Platform, Computer Network Information Center, CAS (http://www.gscloud.cn). The vegetation coverage data is the 1:4 million vegetation distribution map, which is from the Cold and Arid Regions Science Data Center (Hou et al., 1979, http://westdc.westgis.ac.cn/). The geographical data of villages, roads and administrative divisions in TP come from the National Geomatics Center of China (http://ngcc.sbsm.gov.cn/). The adopted socio-economic data is the China kilometer grid GDP and population distribution data set provided by the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, which is from the Global Change Research Data Publishing (Fu et al., 2014, http://geodoi.ac.cn/).

### 2.2. Risk Regionalization Method

#### 2.2.1. Data Standardization

Due to different data sources and large differences in dimensions and orders of magnitude, the indicators need to be uniformized, standardized to the [0, 1] interval, and converted into dimensionless scalars:

$$D_{ij} = \frac{A_{ij} - \min_i}{\max_i - \min_i}$$

where subscript $i$ represents the $i_{th}$ indicator and j represents the $j_{th}$ value; $D_{ij}$ is the standardized result, $A_{ij}$ is the original indicator value. $\min_i$ and $\max_i$ are the minimum and maximum values of the $i_{th}$ indicator, respectively.

#### 2.2.2. Risk Regionalization Method

According to meteorological disaster risk theory (Zhang et al., 2010), risk = hazard ($H$) × vulnerability ($V$). Among them, hazard refers to the degree of disasters obtained from the natural attributes of disasters (including terrain, climatic conditions, etc.), and the weighted cumulative model is adopted for hazard assessment, that is:

$$H = \sum_{i=1}^{n} W_i X_i$$

$H$ represents the disaster hazard index, $X_i$ is the standardized value of each assessment index, and the flash flood risk indicators include: rainfall, number of hard rain days, land use, vegetation cover, slope, relative height difference and river network density. $W_i$ is the weight coefficient of each indicator, which is scored by experts and calculated by analytic hierarchy process (**Figure 1**).

Vulnerability is the assessment of the extent to which the disaster bearing body is affected by flash flood. The loss and hazard caused by flash flood are largely determined by vulnerability. According to the damage of flash flood disasters to the national economy and people's lives and property, the vulnerability indicators include: population density ($A$), GDP ($B$) and traffic line density ($C$). The vulnerability assessment index $V$ is calculated by $V = (A + B + C)/3$. Due to the serious imbalance of population and economic development in TP, the following treatment is adopted:

$$V' = 1 + \left(V - \min(V)/(\max(V) - \min(V)\right) * 0.5$$

as the final vulnerability assessment index.

#### 2.2.3. Index grade division

Since some indicators are not presented in digital form, they are reassigned

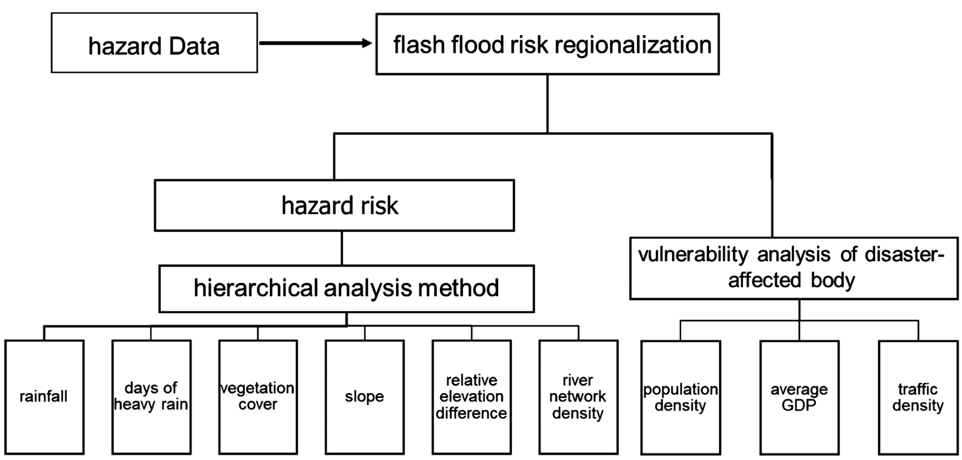


**Figure 1.** Evaluation index system for flash flood disaster in Tibet.

according to their impact on flash flood disasters (Table 1) in order to quantitatively measure the impact of these indicators on the hazard of flash flood disasters.

## 3. Result Analysis

### 3.1. Disaster Risk Assessment

Figure 2 shows the hazard distribution of flash flood, which uses ArcGIS natural

Table 1. Classification of evaluation index.

| factor | Level division | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| slope | <2 | 2 - 5 | 5 - 10 | 10 - 15 | 15 - 25 | 25 - 30 | 30 - 40 | >40 |
| | 0 | 0.1 | 0.2 | 0.35 | 0.55 | 0.7 | 0.85 | 1 |
| vegetation | residential land | desert | meadow | grasslands | thin trees and shrubs | alpine vegetation | coniferous forest broad-leaved forest theropencedrymion | |
| | 1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.4 | 0 | |
| GDP | <50 | 50 - 500 | 500 - 1000 | 1000 - 2000 | 2000 - 3000 | 3000 - 4000 | >4000 | |
| | 0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 1 | |
| population | <1 | 1 | 1 - 5 | 5 - 10 | 10 - 50 | 50 - 100 | >100 | |
| | 0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 1 | |

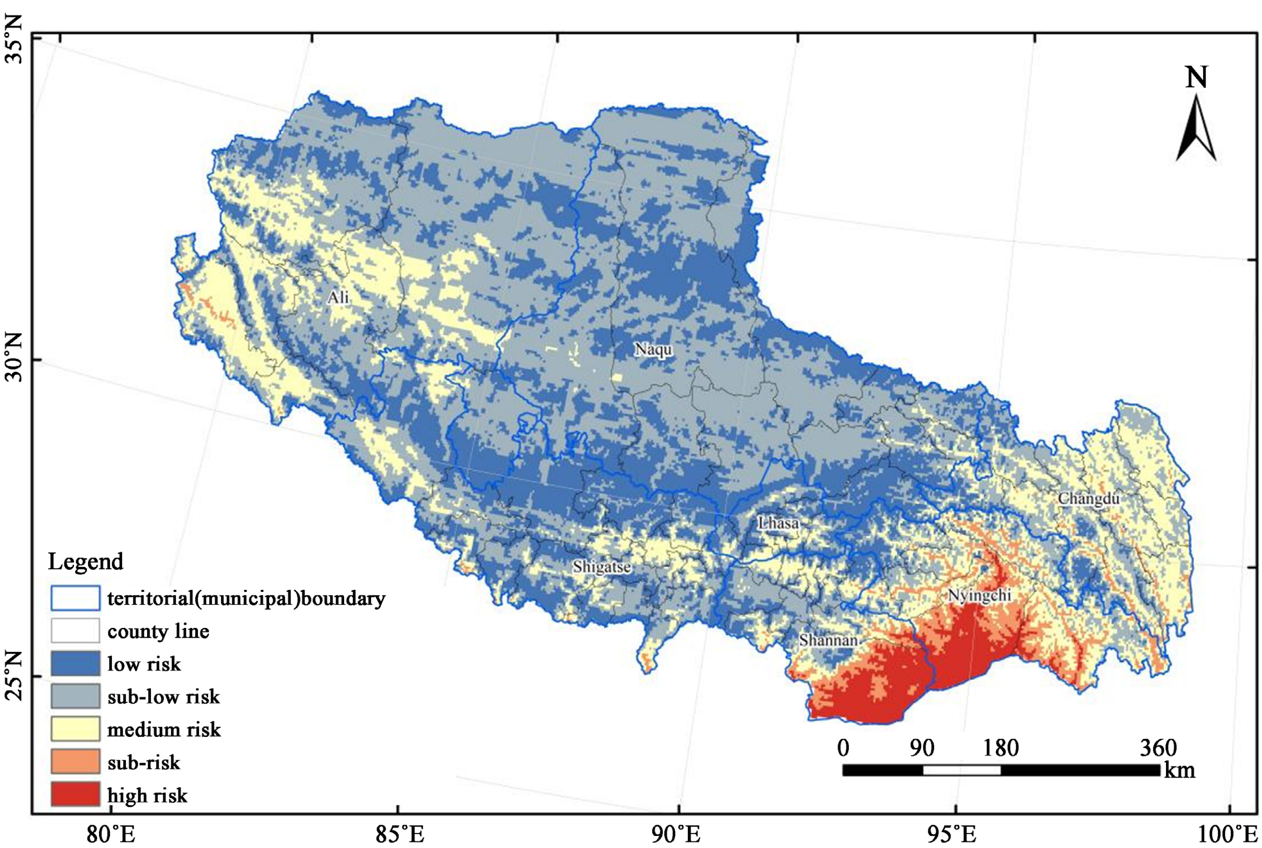


Figure 2. Hazard assessment of flash flood in Tibet.

classification method to divide the risk of flash flood disasters into 5 grades, with high risk area accounting for 9.7%, 18.3% for sub-high risk area, 23.6% for medium risk area, 24.9% for sub-low risk area, and 23.5% for low risk area accounting. The high-risk area is mainly distributed in the downstream of the Brahmaputra River, with large undulating terrain and large altitude differences. It is also located on the Brahmaputra River vapor channel (Lin et al., 2011; Lin et al., 2014), with abundant precipitation and many heavy rain days, although the ground vegetation conditions reduce the risk of flash flood to a certain extent, it is still the highest risk area for flash flood. The low-risk areas are the western and northern regions of TP, where the annual precipitation is less than 200 mm, the terrain is relatively flat, so the risk of mountain floods is relatively low.

### 3.2. Vulnerability Analysis of Disaster-Affected Body

Figure 3 shows the results of the analysis of the economic vulnerability of flash flood disasters, which reflect the unbalanced regional economic development in TP. High vulnerable area accounted for 1.7%, 6.1% for sub-vulnerable area, 16.1% for medium vulnerable area, 23.2% for sub-low vulnerable area and 52.9% for low vulnerable area. The "one river and two rivers" valley in the central and southeast of TP is the most vulnerable area to mountain flood disaster, where is the main agricultural and industrial area in TP. The climate in this area is warm and humid, and the population is relatively concentrated. The northern and

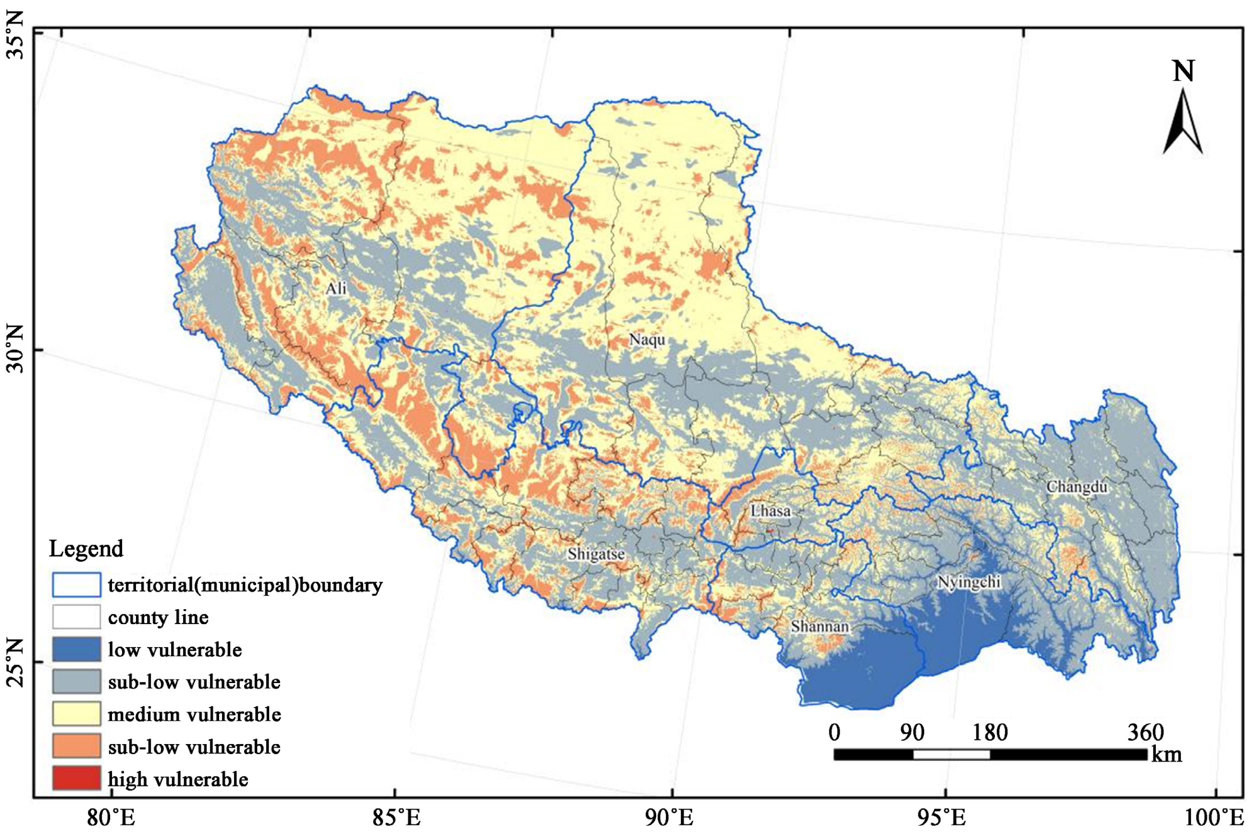


Figure 3. Vulnerability assessment of flash flood in Tibet.

western Qian-Tang Plateau in TP is the area with the lowest vulnerability to flash flood disasters, with an altitude above 4300 m, and a dry and cold climate. It is the main pastoral area in TP, with a population density of less than 1 person/km$^2$ in some areas and a large area of no-man's land. TP has a vast territory, and high mountain road risks. Complex and changeable terrain is a natural barrier for the transportation industry. Most of the roads in TP are of poor quality, low construction standards, and weak resistance to natural disasters. Highways, especially national highways, are mainly built along rivers. Densely populated areas, economically developed areas, and traffic trunk lines overlap in space with flash flood disaster risk areas. The distribution of areas with high vulnerability and high risk areas is relatively consistent. Once a disaster occurs, it is very easy to cause huge losses.

### 3.3. Risk Regionalization

Combined with the analysis results of flash flood risk and vulnerability, the flash flood risk distribution map in TP is obtained (Figure 4). From the perspective of area distribution, high-risk area accounted for 8.8%, sub-high-risk area accounted for 18.7%, medium-risk area accounted for 22.4%, sub-low-risk area accounted for 26.4%, and low-risk area accounted for 23.7%. The high-risk areas are mainly located in the middle and lower reaches of the Yarlung Zangbo River, the Nujiang River, the Jinsha River and the Lancang River. In addition, there is

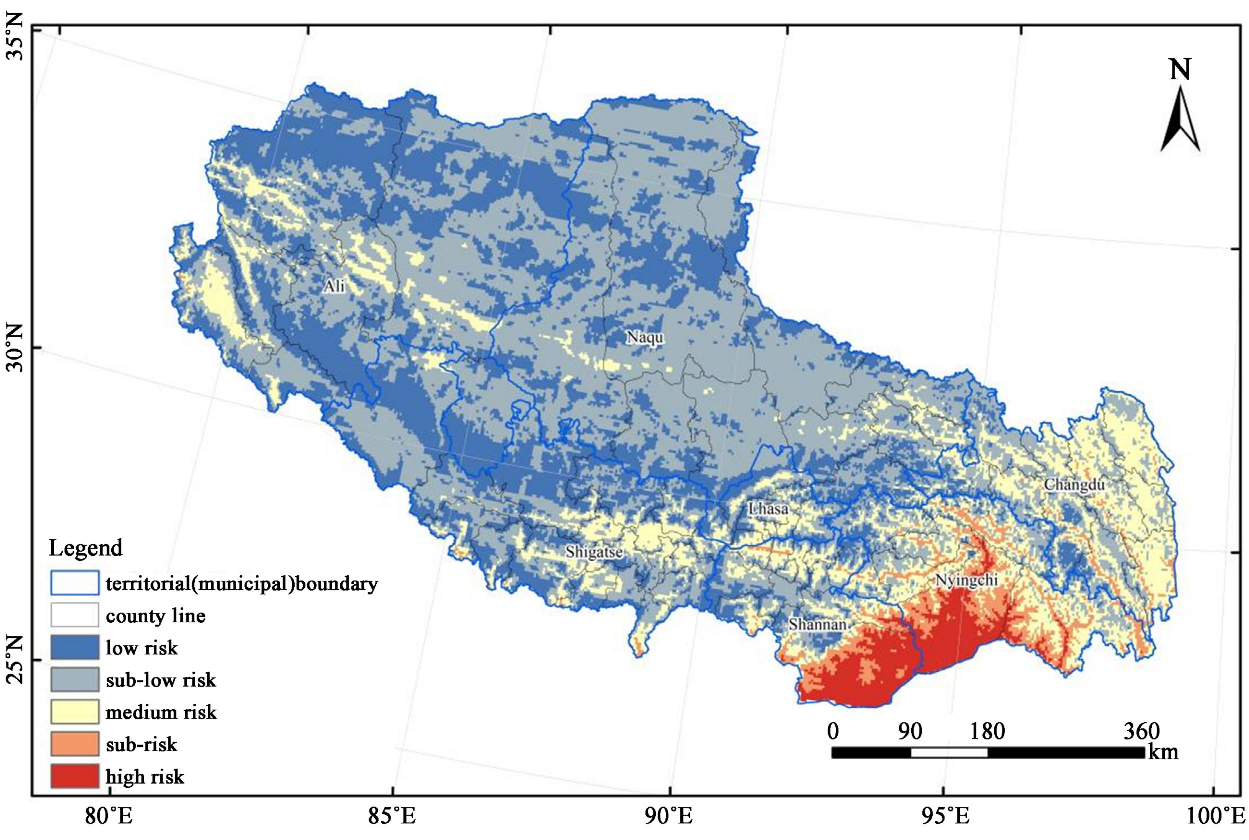


Figure 4. Risk assessment of flash flood in Tibet.

also a high risk of flash flood in the Langqin Zangbo and Senge Zangbo basins in the western Himalayas, the lower reaches of Pengqu-Aran River Basin in the Middle Himalayas and Yadong. The central and western regions of Naqu, eastern Ali and western Shigatse are low-risk areas of flash flood.

### 3.4. Risk Regionalization Test

In order to verify the results of flash flood disaster risk regionalization and test the rationality of regionalization, 126 flash flood disaster data collected by the Meteorological Department of the TP Autonomous Region in the first phase of the "Refined Survey of Rainstorm Flood Disaster Risk in TP" from 2014 to 2015 were used to verify the results of the flash flood disaster risk regionalization in this paper. **Figure 5** shows the risk levels of historical flash flood disaster sites, the actual location of flash flood is consistent with the high-risk area. The high-risk area and sub-high-risk area on the risk regionalization map include more than 73% of the historical flash flood disasters, of which 46.8% of the flash flood disasters occur in high-risk area, 26.2% occur in sub-high-risk area, only 20.6% occur in medium-risk area, and less than 6% occur in sub-low-risk area. Only one flash flood occurred in the low risk area (only 0.7 %). It is worth pointing out that the more serious flash flood disasters that cause casualties and economic losses of more than 100,000 CNY (Chinese Yuan) occur in high-risk area (63%) and sub-high-risk area (37%), which further explains the rationality

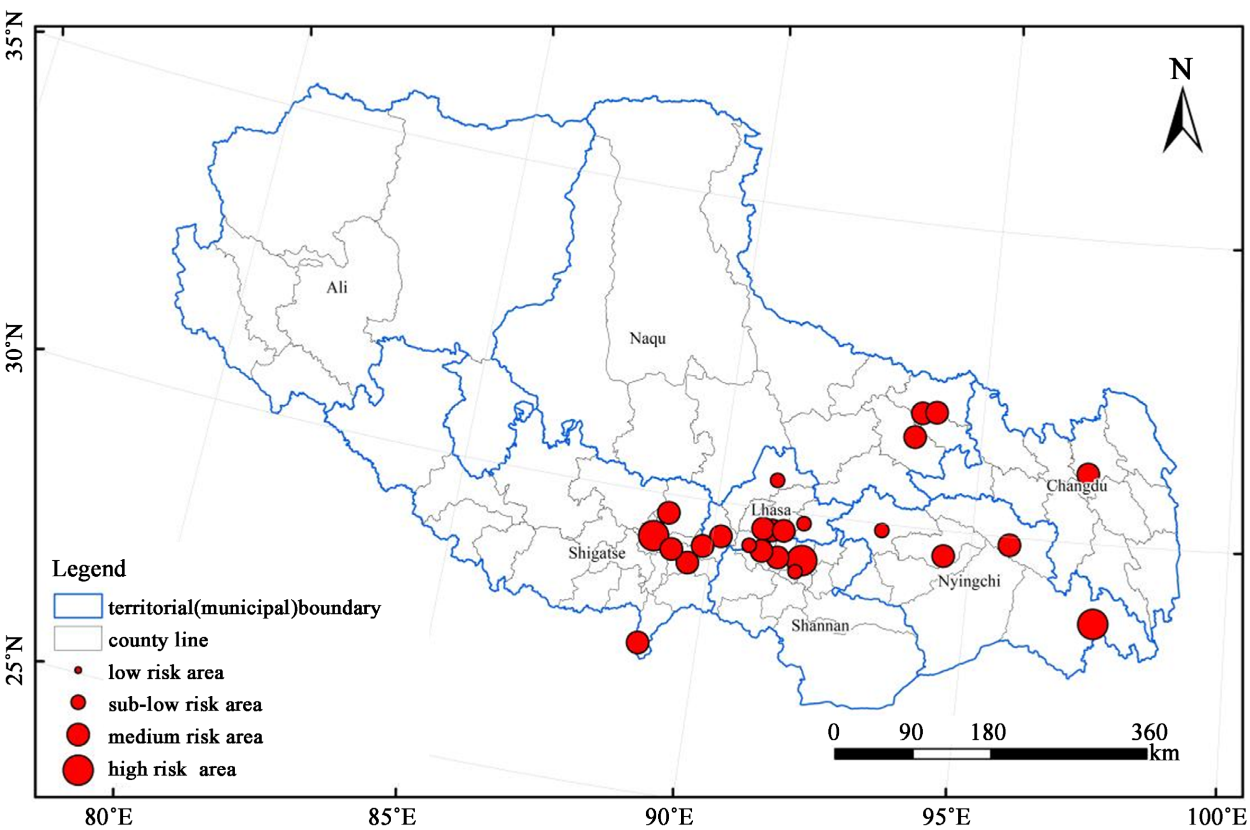


**Figure 5.** Historical flash flood disaster distribution and risk grade of occurrence place.

of the flash flood disaster risk regionalization in this paper, and can provide a scientific decision-making basis for government departments to defend against flash flood disasters.

## 4. Conclusion

Impact factors of the risk and the disaster bearer of flash flood including meteorology, topography, social economy and other influences are adopted to achieve the flash flood disaster risk regionalization map of TP. The impact weights of each factor are formulated based on expert scoring and hierarchical analysis method which has been widely used in different regions and different meteorological disaster risk regionalization with high operability. The results of the flash flood disaster risk regionalization of TP can be summarized as follows:

1) The high-risk area of flash flood in TP overlapped spatially with area with better economic development and developed transportation facilities.

2) Flash flood disasters could cause traffic interruptions, endanger social, economic development and the safety of people's lives and property, and are the main and secondary meteorological disasters in TP.

3) The results of flash flood disaster risk regionalization are verified by using historical flash flood disaster data, and the test results show that the results of flash flood risk regionalization is authentic.

## 5. Discussion

The flash flood disaster risk regionalization obtained in this paper is divided into high-resolution grid point data, which can be simply processed to form a regionalization map of flash flood risk in counties in the whole region, and can be used as a basic reference material for grass-roots meteorological bureaus and relevant departments. However, some deficiencies still exist in this study. 1) There is certain subjectivity in calculating the factor weight and the selection of evaluation indicators of flash flood risk. 2) The collection of historical flash flood is not complete, especially in the southwest and northeast regions, where there are many gaps in historical mountain flood data.

On the other hand, the occurrence mechanism of flash flood disasters in such a complex terrain area as TP is a severe challenge in science and technology. Flash flood disasters caused by heavy rainfall are mainly considered in this paper, and those caused by glacial lake outburst and ice and snow melting could be further considered. There is no doubt that the regionalization of flash flood disaster risk needs further improvement so as to provide more refined reference for flash flood prevention and mitigation.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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