

Comparative Study on Rainfall Early Warning and Flood Early Warning in the Prevention of Flash Flood Disasters

-- Take Nanping City, Fujian Province as an Example

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Abstract. With the acceleration of climate change and urbanization, the threat of flash floods to life and property is increasingly significant. Research on early warning methods for flash flood disasters is crucial for enabling timely responses and mitigating disaster losses. This study primarily explores two warning technologies: rainfall early warnings and flood forecast early warnings. Taking a heavy rainfall event in Nanping City, Fujian Province, from 0:00 on June 21, 2023, to 0:00 on June 22, 2023, as an example, it compares and analyzes these two flash flood early warning methods. The results indicate that compared to rainfall warnings, flood forecast warnings can predict flash flood disasters more accurately.

Keywords: Flash Flood Disasters; Early Warning Technologies; Rainfall Early Warnings; Flood Forecast Warnings.

1. Introduction

Flash floods are one of the natural disasters with the highest mortality rate in China [1]. Flash floods are characterized by strong sudden onset, and the onslaught, fast disaster, very destructive, the water flow is often accompanied by sediment, gravel, etc., and soon form localized floods [2, 3]. 1991 to 2020, China's average annual deaths due to floods or missing population of 2020, a total of more than 60,000 people died, the average annual direct economic losses caused by 160.4 billion yuan, a total of about 4.81 trillion yuan. The average annual direct economic loss is 160.4 billion yuan, totaling about 4.81 trillion yuan. In the face of flooding, the research and application of flash flood early warning technology can avoid a large number of social and people's life and property losses.

The common flash flood warning methods are divided into two kinds, the first is based on critical rainfall warning, including the static critical rainfall warning and dynamic critical rainfall warning; the second is based on hydrological modeling flood warning, including flood forecasting and warning based on distributed hydrological models [4-7], the existing hydrological models are SWAT model, WEP model, Xin'anjiang model, etc. The first is based on flood forecasting and warning based on distributed hydrological models [8]. Western developed countries started earlier, in the 1970s, the U.S. developed the Flash Flood Warning Guidance System (FFGS) [8], and in 2004, the U.S. developed the Flash Flood Warning Indicator (FFG) [9-12]; the World Meteorological Organization (WMO) successfully carried out a demonstration area project in South Asia [13, 14]; and the Japan International Cooperative (JICA) developed a community-based flood forecasting and warning system in the Caribbean [15]. Japan International Cooperative (JICA) developed a community-based early warning system for flash floods in the Caribbean [15, 16]. China's flash flood disaster monitoring and early warning research started late, and began to establish a flash flood disaster defense system in 2010 [17], which was initially built in 2016 [18]; Li Changzhi et al. studied several commonly used early warning methods based on empirical and theoretical methods in the review of methods for determining the critical rainfall for flash floods [19]; Zhang Hongping et al. combined the mechanism and characteristics of flooding of mountain streams and streams, and, in the

perspective of critical rainfall, analyzed and calculated the critical rainfall using the homoscedastic backpropagation method. analyzed and calculated by using the same-frequency backpropagation method [20]; Bao Hongjun et al. took the Dagou watershed, a tributary of the Qiaozhuang River of the Jialing River, as the study area, and researched the method of forecasting flash floods in small watersheds without information based on the distributed mixed-production hydrological model of the Xin'an River hydrological model (GMKHM), and the simulation effect yielded good results [21]; Liu Zewen et al. took into account the effect of soil saturation, and used the dynamic based on the API rainfall runoff hydrological model critical rainfall method, through the establishment of the relationship curve between the total rainfall that has fallen in the watershed, the previous rainfall and the critical rainfall, and the dynamic early warning study in the Puri River watershed of the Dabashan Mountains in Chongqing Municipality as the study area, the application of the results are good, and the flood early warning accuracy of the study area has been improved [22].

In order to be able to obtain more timely and accurate early warning information, this paper is based on the platform of flash flood disaster monitoring and forecasting early warning system in Fujian Province, taking Nanping City in Fujian Province as the study area, and comparing and analyzing the rainfall early warning and flood early warning methods, and striving to find a more timely and accurate early warning method for early warning real-time information of flash floods through the precision, empty report rate, hit rate and other early warning indexes, so as to provide technical support for safeguarding the safety of people's lives and properties in the mountainous areas.

2. Overview of the Study Area and Sources of Data Information

2.1 Overview of The Study Area

(1) Natural Geography

Nanping City in Fujian Province has a subtropical monsoon climate and is located in the northwest of Fujian, with a city area of about 26,300 square kilometers. The average temperature is 19.5°C and the average annual precipitation is 1780.8mm. The city has a wide distribution of low hills and mountains with a northeast-southwest orientation [10, 11], and the soil type is dominated by red loam.

(2) Overview of the river system

There are more than 700 rivers of various sizes in Nanping City, of which 174 rivers have a watershed area of more than 50 square kilometers. The main rivers are Minjiang, Futunxi, Jianxi, etc., with a river network density of 0.18 km/km². The river water comes from precipitation, and is influenced by topography, climate, and vegetation, and is characterized by short and rapid flow, rapid rise and fall, and large seasonal changes. The overview map of the study area is shown in 1.

(3) Characteristics of flash flood disaster

Special geomorphology, climate and other geographic environmental conditions lead to frequent flash flood disasters in Nanping City, with many points and serious disaster losses. Since the founding of the People's Republic of China, more than 200 flash floods have occurred in Nanping City, causing huge economic losses and a large number of casualties [12, 13].

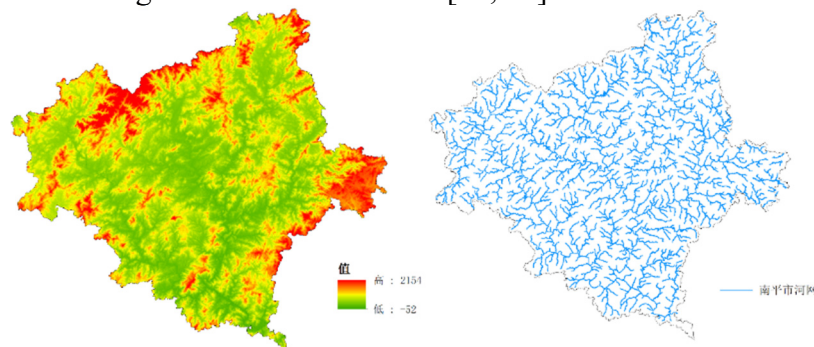


Fig 1. Topography and river network distribution in the study area of Nanping City

2.2 Data Sources

The main data used was the Fujian Province flash flood disaster monitoring, forecasting and warning platform [14, 15]. It includes:

(1) Basic data. The base data of flash flood disaster aims to identify the population and housing of the threatened residential areas within the key prevention and control area. It mainly includes specific information such as hydrometeorology, topography and river system.

(2) Real-time data. The real-time data of flash flood disaster determines the key of whether the early warning system is activated, which is one of the important basis for judgment. Is able to reflect the warning level of the most direct data, is a flash flood disaster, decision-making and command of the scene dependent on the data, these real-time data mainly include real-time rainfall, real-time flood or water level, soil moisture, rainfall forecasts and other information.

3. Early Warning Technology for Flash Floods

3.1 Rainfall Warning

In this study, rainfall early warning is delineated as a forecasting mechanism predicated on real-time rainfall data, with the primary aim to evaluate and issue warnings for flood risks in villages situated along rivers. In Fujian Province, a provincial-level flash flood disaster monitoring, forecasting, and early warning platform has been established, facilitating a close association between rainfall stations and riverside villages as the foundation for effective early warning. The subjects of these warnings are all administrative villages in the province, with their warning levels generated based on associated grid cells. This platform employs a 5 km grid as the basic unit and establishes four tiers of warning levels: high likelihood (Level 1), considerable likelihood (Level 2), moderate likelihood (Level 3), and potential occurrence (Level 4).

The final grid warning level is derived by juxtaposing grid warning indicators with 24-hour forecasted rainfall data. The warning level for each administrative village is contingent upon the warning level of its respective grid cell. The real-time rainfall early warning process encompasses inputting actual rainfall data from stations, accumulating rainfall over diverse intervals (10 minutes, 30 minutes, 1 hour, 3 hours, and 6 hours) and frequencies, and then amalgamating these with the station-village relational data to compute rainfall statistics for each village. Subsequently, warnings are issued based on the designed storm frequency (recurrence intervals of 2 years, 5 years, and 20 years) of the village's respective grid cell, accompanied by the output of codes for the associated rainfall observation stations. The warning levels are categorized into Attention (exceeding a 2-year recurrence interval storm), Caution (exceeding a 5-year interval storm), and Danger (exceeding a 20-year interval storm).

3.2 Flood Warning

In the field of hydrology, flood warning is defined as a predictive system based on hydrological and meteorological data analysis, aimed at providing advance notification of potential flooding in specific areas. This warning system utilizes distributed hydrological models to simulate changes in river water levels, incorporating a comprehensive analysis of various factors such as rainfall, evaporation, runoff generation, confluence, river channel development, and reservoir regulation. By calculating river channel peak flow rates and comparing them with designed flood data, the system is able to determine different levels of warnings, such as Attention, Caution, and Danger. Furthermore, flood warning also encompasses the analysis of the relationship between river channels and surrounding villages, ensuring the provision of timely and effective warnings to relevant areas, thereby mitigating the impacts and losses potentially caused by floods.

4. Case Study

Taking Nanping City in Fujian Province as an example, this study analyzes the rainfall early warning situation for a heavy rainfall event occurring from 0:00 on June 21, 2023, to 0:00 on June 22, 2023. There were 436 villages under rainfall early warnings, of which 70 were under flood warnings. Additionally, 25 villages were under rainfall warnings of orange level or higher, while 5 villages were under flood warnings.

4.1 Research on Early Warning Villages

The primary affected area of the rainfall event on June 21, 2023, was Guangze County in Nanping City. Field investigations revealed that out of the 11 villages that were issued warnings, 9 experienced damage, while 2 villages were unaffected. The distribution of the surveyed villages and the details of village damages along with the river warning situations are depicted in Figure 2.

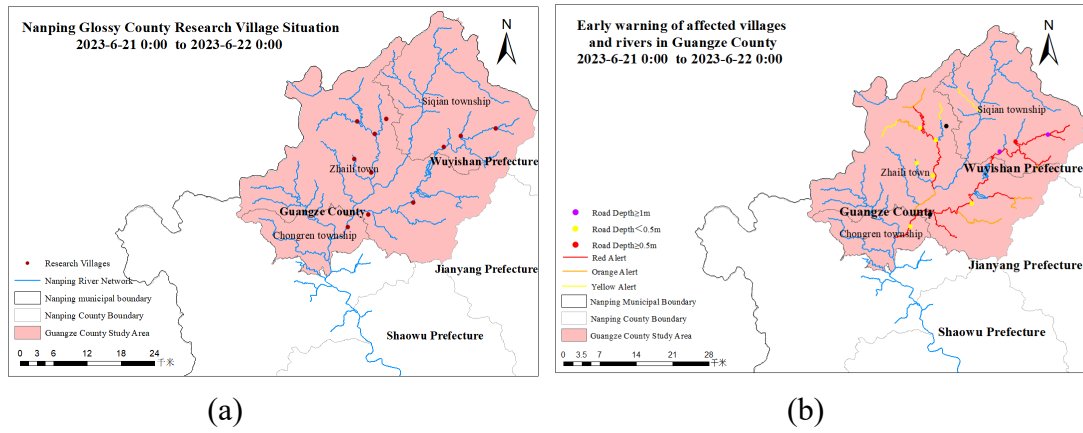


Fig 2. (a) Research villages in Guangze County, Nanping City
(b) The warning situation of affected villages and rivers in Guangze County

Among them, the number of rainfall warning villages is 10, the actual rainfall warning affected villages are 8, and there are 2 villages with empty report; 1 village with omission report is Rutang Village in Chongren Township; the number of flood warning villages is 7, the actual flood warning affected villages are 7, and there are 2 villages with omission report, and the omission report villages are Xikou Village in Sizian Township, and Qiaotting Village in Zhaili Township, and the specific warning evaluation indexes are as shown in Table 1.

The recurrence interval levels for rainfall are categorized as follows: 2-5 years for attention level, 5-20 years for caution level, 20-50 years for danger level, and over 50 years as extremely dangerous.

Table 1. Evaluation indicators for rainfall warning and flood warning

Type of warning	Hit Rate	Dropout Rate	Underreporting Rate
rainfall warning	88.9%	20%	11.1%
Flood warning	88.9%	0	11.1%

4.2 Analysis of Rainfall Warning Omissions

Rutang Village is situated in Chongren Township, Guangze County, Nanping City, with an upstream catchment area of 960.08 km². The village was under a flood danger warning, but there was no rainfall warning issued. Nearby river channels in the village overflowed onto roads, with the maximum water depth reaching 0.3 meters. The general situation of the upstream catchment area of Rutang Village and the conditions of the rainfall early warning associated stations in Rutang Village are shown in Figure 3.

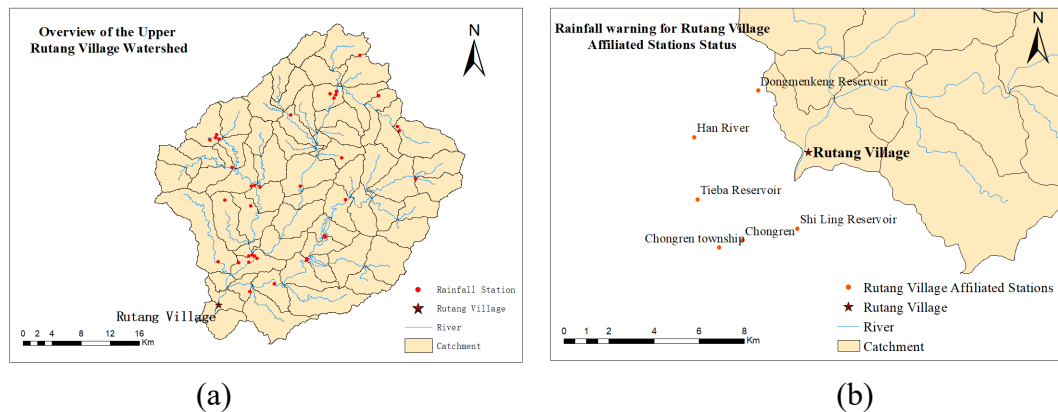


Fig 3. (a) Overview of the Upstream Catchment Area of Rutang Village
(b) Situation of Rainfall Early Warning Associated Stations in Rutang Village

4.2.1 Rainfall

Through the rainfall warning situation generated in Rutang village, the statistics of the maximum 1H, 3H, 6H rainfall and the time and return period of the station in Rutang village based on the rainfall warning are shown in Table 2.

Table 2. Rainfall at associated stations and time and return period

survey station	Maximum 1H		Maximum 3H		Maximum 6H	
	precipitation time	recurrence period	precipitation time	recurrence period	precipitation time	recurrence period
Teba Dam Reservoir	27	11-12	<5	35	9-12	<5
					37	6-12
					<5	

4.2.2 Analysis of Causes of Underreporting

Of the Rutang Village associated stations, the maximum rainfall at Tieba Reservoir 3H was 35 mm. however, the downstream rainfall stations associated with the Rutang Village watershed received relatively low rainfall, and the upstream area received higher rainfall. In the section of the river where Rutang Village is located, the flow is relatively high, making the flood warning level higher. Despite the high flow in the river section where the village is located, the rainfall associated with the downstream rainfall station in the village is low, and the rainfall warning is not associated with the rainfall station upstream of the watershed resulting in underreporting of the rainfall warning. The rainfall warning associated sites in Rutang Village are shown in Figure 3(b).

4.3 Analysis of Rainfall Early Warning Air Reports

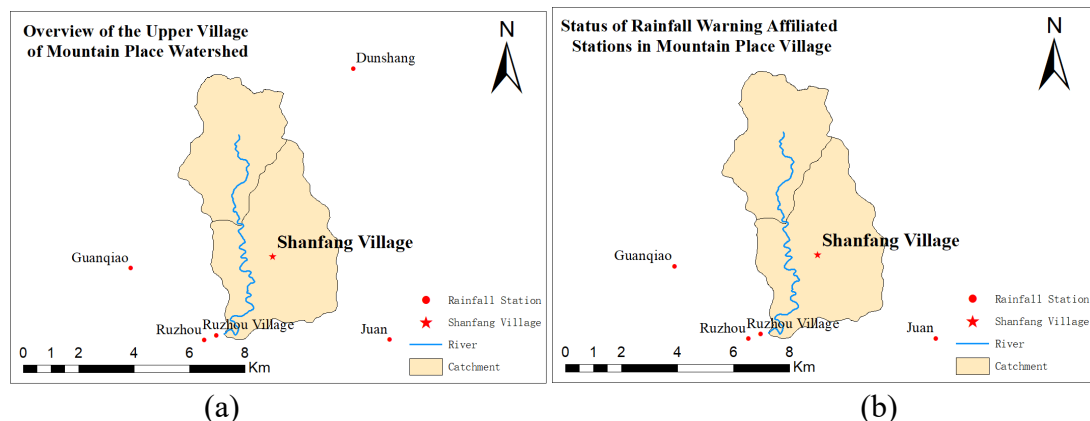


Fig 4. (a) Overview of the Upstream Catchment Area of Shanfang Village
(b) Situation of Rainfall Early Warning Associated Stations in Shanfang Village

Shanfang Village, located in Zhaili Town, Guangze County, Nanping City, has an upstream catchment area of 30.53 km². While it was under a rainfall danger warning, there was no flood warning issued for the village, and it did not actually experience any disaster. The overview of the upstream catchment area of Shanfang Village and the situation of rainfall early warning associated stations in Shanfang Village are depicted in Figure 4.

4.3.1 Rainfall

Through the rainfall warning situation generated in Shanfang Village, the rainfall amount, time and return period of 1H, 3H and 6H at the station (Ruzhouw) where the rainfall warning is based in Shanfang Village are counted as follows in Table 3.

Table 3. Rainfall at associated stations and time and return period

survey station	Maximum 1H			Maximum 3H			Maximum 6H		
	precipitation	timing	recurrence period	precipitation	timing	recurrence period	precipitation	timing	recurrence period
Ruzhouw	56.5	10-11	20-50	124	9-12	20-50	165.5	6-12	20-50

4.3.2 Analysis of the Causes of False Alarms

According to the distribution of the associated stations in Shanfang Village, the maximum 3H rainfall of 51mm at Dun Shang Station, a nearby station upstream of Shanfang Village (as shown in Fig. 6), does not exceed the one in five years; while Shanfang Village is based on the maximum 3H rainfall of 124mm at Ruzhouw Station, which exceeds the alert warning, and the rainfall warning associated with the rainfall warning of Shanfang Village are all in the downstream location, as shown in Fig. 4(b).

The reason for the empty rainfall warning in this case is that the actual rainfall in the upstream watershed of Shanfang Village is on the small side, and the downstream stations associated with the correlation rule have a larger rainfall, leading to a high warning level in the village, and the rainfall warning produces an empty report.

4.4 Analysis of Flood Warning Under-Reporting

Xikou Village is located in the township of Sizian, Guangze County, Nanping City, with an upstream watershed area of 17.56km². rainfall hazard warning, no flood warning, floodwaters diffuse out of the river channel, roads, roads with a maximum water depth of 0.5m. The overview of the upstream catchment area of Xikou Village and the Thiessen polygon calculation rules for the Xikou Village basin are illustrated in Figure 5.

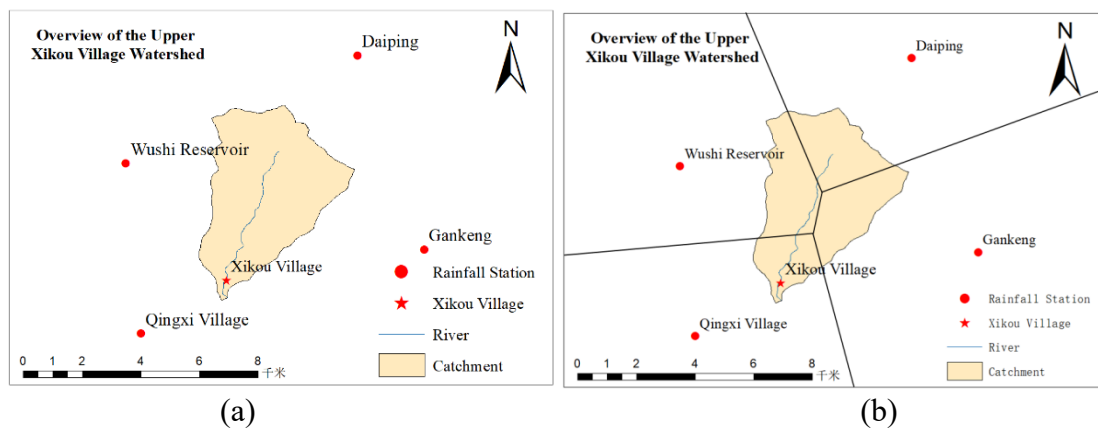


Fig 5. (a) Overview of the Upstream Catchment Area of Xikou Village
(b) Thiessen Polygon Calculation Rules for the Xikou Village Basin

4.4.1 Rainfall

Through the rainfall warning situation generated in Nishikou Village, the maximum 1H, 3H, and 6H rainfall and the time and return period of the measuring station (Qingxi Village q) based on the rainfall warning in Nishikou Village are counted as shown in Table 4 below.

Table 4. Associated site rainfall and time and return period

survey station	Maximum 1H			Maximum 3H			Maximum 6H		
	precipitation	time	recurrence period	precipitation	time	recurrence period	precipitation	time	recurrence period
Qingxi Village	70.6	10-11	10-20	132.1	10-13	20-50	152.5	6-12	10-20

4.4.2 Analysis of Causes of Underreporting

Based on the areal rainfall over time for the stations associated with Xikou Village, it is observed that the maximum 3-hour rainfall recorded at Qingxi Village and Gankan rain gauge stations was 132.2mm and 110mm, respectively, both exceeding the warning thresholds. However, the calculated areal rainfall for the basin where Xikou Village is situated did not reach the attention level for the 1-hour, 3-hour, and 6-hour return periods, as shown in Table 5(b).

Table 5. Surface rainfall in time section at the associated site in Saikou village

survey station	Maximum 1H			Maximum 3H			Maximum 6H		
	precipitation	time	recurrence period	precipitation	time	recurrence period	precipitation	time	recurrence period
Qingxi Village	70.6	10-11	10-20	132.1	10-13	20-50	152.5	6-12	10-20
Gankeng	56.5	10-11	5-10	110	10-13	10-20	148.5	7-13	10-20
Surface Rainfall	22	10-11	<5	43.48	10-13	<5	56.7	7-13	<5

The flood process, based on the Thiessen polygon algorithm, calculates the areal rainfall of the basin through rain gauges at Wushi Reservoir, Daiping, Qingxi Village q, and Gankan Station. The Thiessen polygon algorithm for the basin where Xikou Village is located is illustrated in Figure 5(b). However, the lack of rainfall data from Wushi Reservoir and Daiping Station resulted in an underestimation of areal rainfall calculated by the Thiessen polygon, leading to a smaller simulated flood scale.

4.5 Analysis of Results

Analyzing the Advantages and Disadvantages of Flood Forecast Warnings and Rainfall Early Warnings:

The advantage of rainfall early warnings lies in their ability to monitor precipitation in real-time, providing timely alerts for areas affected by heavy rainfall. These warnings are applicable across various regions, not limited to mountainous areas, and can be extensively used in urban and plain areas, offering a broad application scope.

However, the disadvantage of rainfall early warnings is the potential for a high false alarm rate due to the uncertainty in real-time precipitation prediction. Since rainfall forecasts focus solely on the amount of precipitation without considering factors like terrain, soil, and vegetation, the accuracy of these predictions may be lower.

On the other hand, the strength of flood forecast warnings lies in their consideration of terrain, soil, and vegetation, leading to more comprehensive and accurate predictions. Utilizing hydrological models, these warnings can more accurately simulate water flow and the likelihood of floods, enhancing the precision and foresight of predictions, and offering more comprehensive alerts.

The downside of flood forecast warnings is their high demand for data. They require a substantial amount of real-time monitoring data to support the operation of hydrological models, with data quality and accuracy significantly impacting the warning outcomes.

By integrating rainfall early warnings with flood forecast warnings based on distributed hydrological models, it's possible to compensate for the limitations of each, thereby enhancing the accuracy and reliability of the warnings.

5. Conclusion and Recommendations

Combined with the operation of the monitoring and early warning platform system that has been built in Nanping City, the conclusions are as follows:

Fujian Province flash flood disaster monitoring and forecasting early warning platform through a variety of flash flood early warning technology for flash flood disaster prevention and control, real-time flood early warning can be more accurate warning, reduce the rate of warning false alarms, improve the accuracy, hit rate. At the same time, attention is paid to optimizing the rainfall warning system to reduce the rate of false alarms, which can more effectively respond to flood risks in different areas and meteorological conditions.

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