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Forecast, Monitoring and Local Warning Constitute a Complementary Early Warning System in Flash Flood Risk Management: A Case Study in Lianxi River of Zhejiang Province

Zhengjie ZHOU [a,1], Lihong ZHANG [a] and Hanze LI [a]
[a] *Zhejiang Institute of Hydraulics & Estuary(Zhejiang Institute of Marine Planning and Design), Hangzhou, Zhejiang 310020, China*

Abstract. In the southeast coast of China, flash flood risk management is usually based on natural villages. In recent years, extreme rainfall increased, with the impact of man-made activities, flash floods occur frequently. This paper introduces an Early Warning System, which is composed of forecast warning, monitoring warning and local warning complementing each other. In order to explore the key role of early warning system in flash flood risk management, we study a flash flood disaster prevention case in Lianxi River Basin of Zhejiang Province during Severe Typhoon In-Fa in 2021. In addition, we analyze and discuss the main problems encountered in the case and put forward some suggestions to provide references for the prevention and control of flash flood disaster.

Keywords. Flash flood, early warning system, forecast warning, monitoring warning, local warning

1. Introduction

1.1. Flash Flood Disaster

Flash flood refers to a sudden and rapid rising flood in the mountain stream. Its most intuitive feature is the water current is usually very concentrated, occurred suddenly and moved fast, carried with sediments and stones, could bring a strong scour destructive power. The disaster factors caused by flash flood have the dual attributes of nature and society, its formation, development and harm are the result of natural conditions such as Heavy rainfall, topography and geology, and social factors such as human economic activities, in which, the main inducement is Heavy rainfall. Due to the direct effect and excitation of Heavy rainfall, surface runoff in mountainous areas gathering quickly into flash flood, while mudslides, landslides or any other geological disaster is accompanied or followed. In addition, human activities disturb the

[1] Zhengjie Zhou, Corresponding author, Zhejiang Institute of Hydraulics & Estuary (Zhejiang Institute of Marine Planning and Design), Zhejiang, 310020 China; E-mail: 419844810@qq.com.

disturbance on the surface environment, and the site selection of rural houses and the layout of villages along the river are unreasonable, which exacerbates the severity of flash flood disaster. It has become one of the main types of natural disaster in the world, causing a large number of casualties and economic losse [1, 2]. In recent years, with the global climate change, the number of extreme weather events has increased, and the trend of Heavy rainfall, especially scattered local Heavy rainfall is obvious, the record of strong rainfall has been constantly refreshed, together with man-made and any other unpredictable factors, flash flood disaster show a frequent trend.

In the southeast coast of China, flash flood disaster prevention and control is usually based on natural villages, where people produce and live together in a certain natural environment for a long time, is usually highly adaptable to the local small watershed ecological environment (water resources, water security, etc.). As the result of natural selection, in theory, the risk of flash flood is relatively controllable. However, with the increase of the village population, the forest vegetation is destroyed, the land use is expanded to dangerous areas, and even the river are occupied, lead to poor waterways and the surge of flash flood risks, and it is difficult to resist the risks by effective engineering measures. The characteristics of flash flood determine that townships and villages are the frontier and the main battlefield, and the non-engineering measures are the most effective means to reduce the risk of flash flood disaster.

1.2. Flash Flood Early Warning System

Disaster early warning is the most important non-engineering measure. According to the United Nations International Strategy for Disaster Reduction (ISDR) authoritative definition, early warning means that "specialized agencies provide timely and effective information to individuals or organizations in danger, so that they can take prompt actions to avoid or reduce risks and formulate effective response measures" [3]. Flash flood disaster early warning refers to the behavior of issuing or warning disaster information in advance to the area where flash flood disaster may occur, its purpose is to prevent natural hazard changed into natural disaster, it can save lives, reduce the public's fear of sudden disaster, maintain orderly order, and encourage people to actively seek solutions and get out of difficulties as soon as possible [4]. Years of experience in flash flood disaster prevention shows that: The early warning of flash flood is generally divided into forecast early warning, monitoring early warning and local early warning, it is the key to successfully preventing flash flood disaster to establish and give full play to the complementary role of early warning system of forecasting, monitoring and local early warning.

The forecast early warning refers to the early warning issued based on the rainfall forecast results in the next 1, 3, 6 and 24 hours provided by the meteorological department. Among them, the next 24-hour forecast early warning based on the 5km*5km rainfall grid numerical forecast results in the next 24 hours has the advantage that the disaster forecast period is more than 24 hours, and the disadvantage is that the warning granularity and accuracy are not enough. It is usually issued by counties or townships as early warning units as early warning prompts for flash flood disaster risks. The forecast early warning for the next 1, 3, or 6 hours is based on the numerical forecast results of the 1 km*1 km rainfall grid numerical forecast results in the next 1, 3, or 6 hours. It is still limited by weather uncertainty and the technical level of weather forecasting.

Monitoring early warning is based on the early warning issued by the rainfall monitoring station of the water conservancy and meteorological departments in real-time monitoring of rainfall, regards natural villages as the early warning unit. Usually, one or more rainfall stations in the upstream of the village are selected as early warning related monitoring stations according to geographical location, watershed area, watershed shape, etc., to monitor and analyze the real-time rainfall in the upstream. Its advantages are that the granularity and accuracy of early warning have been significantly improved, while its disadvantages are that the disaster prediction period is generally less than 3 hours.

Local early warning is the spontaneous early warning or alarm at the place where the disaster occurs, including local observer warning and local acoustic-photoelectric equipment early warning. Local observer warning refers to the early warning given by the rural monitoring and early warning personnel to the people in their responsible areas through holding horns, gongs, radio, etc. when monitoring the water level that may cause flash flood disaster or finding signs of flash flood disaster. Local acoustic-photoelectric early warning refers to the early warning automatically issued when the acoustic-photoelectric equipment installed in the flash flood disaster risk area detects the disaster causing water level. The advantage of local early warning is that its granularity and accuracy are quiet high, which can make up for the gap of forecast early warning and monitoring early warning, while the disadvantage is that the disaster prediction period is short, generally less than half an hour.

To sum up, whether it is forecast warning, monitoring warning or local warning, a single early warning method has its inherent deficiencies and cannot deal with the uncertainty of when and where risks will occur. But when they are combined into a system, can help us make best use of advantages and bypass the disadvantages, and play a huge role in flash flood risk management.

1.3. Flash Flood Disaster Prevention Case in Lianxi River Basin of Zhejiang Province

Lianxi River is located in Xialv Town, Keqiao District, Zhejiang Province. It originates from Yejia mountain with an altitude of more than 470 meters and flows out through Qiaoxiling Mountain Pond, it runs through Shuangqiao, Jianmin, Jianxing, Lianhua and other natural villages from south to north. Based on ArcGis hydrological analysis, the river is 6.5km long, with a water supply and drainage systems area of 8.2km^2. The slope is steep and the flow is rapid, and the flood rises and falls quickly. It is a typical small watershed in mountainous areas. Due to the shortage of land resources in the mountain area, most of the houses along the Lianxi River are built near the water, while the standard of is not enough high. In addition, there are many buildings occupying the river, and the residents along the line are greatly threatened by flash flood disaster.

During the period of Severe Typhoon In-Fa in 2021, a rare rainstorm occurred in the Lianxi River Basin, causing flash flood. Prior to the formation of flash flood, the early warning system of forecast warning, monitoring warning, and local warning complemented each other played an effective role. After a series of progressive early warning messages were sent, the threatened residents were moved to disaster shelters in advance, and 153 people in 65 households in the danger zone were successfully prevented from being injured or killed by flash flood disaster. The case is as shown in figure 1.

Figure 1. Flash flood disaster prevention case in Lianxi River Basin.

2. Disaster Cause Analysis in Flash Flood Case of Lianxi River

2.1. Rainfall Factor

Severe Typhoon In-Fa landed in Zhejiang Province twice, the impact of wind and rain started on the July 20th and basically ended on July 28th in 2021. Among them, the rainfall in Keqiao District was mainly concentrated on July 24th, and the largest rainfall occurred in the Lianxi River Basin of Xialv Town.

According to the survey, there are no rainfall stations in the upper reaches of the Lianxi River Basin, but there are 3 rainfall stations around it. By analyzing the rainfall center and the location of the monitoring stations, the Xuezhai Reservoir station near the upper reaches of the basin and with the largest rainfall per station was selected as the representative station. According to the measured rainfall data at the Xuezhai Reservoir Station, the Heavy rainfall in the Lianxi River Basin was mainly concentrated on July 24th. It can be seen that the rainfall peaked at 9:00, and flash floods occurred 1.5 hours later. The Heavy rainfall of typical duration at Xuezhai Reservoir Station is shown in table 1.

Table 1. Heavy rainfall of typical duration at Xuezhai Reservoir Station.

Rainfall Station Name	Duration (h)	Rainfall (mm)	Time on July24
Xuezhai Reservoir Station	1h	45.5	08:00-09:00
	2h	66.0	08:00-10:00
	3h	105.0	08:00-11:00
	6h	160.5	05:00-11:00
	12h	239.0	03:00-15:00
	24h	304.5	00:00-24:00

In order to analyze the recurrence period of the rainstorm in the Lianxi River Basin, the rainstorm atlas method was selected to calculate the design rainstorm using Xuezhai Reservoir Station.

By looking the average point rainfall and the variation coefficient Cv of each duration at Xuezhai Reservoir Station according to the mean point rainfall contour map and the point rainfall variation coefficient contour map of Zhejiang Province's short-duration rainstorm atlas, we calculated the design rainstorm for each duration. The calculation results are shown in table 2.

Query the Short-duration Rainstorm Atlas of Zhejiang Province, according to the point rainfall average contour chart and the point rainfall variation coefficient contour chart, get the mean rainfall average and variation coefficient Cv of each duration of Xuezhai Reservoir Station, and calculate the designed rainstorm of each duration. The calculation results are shown in table 2.

Table 2. Design Rainstorm Results of Xuezhai Reservoir Station.

Station name	Duration	recurrence interval of rainfall (Hp)				
		100 year ($H_{1\%}$)	50 year ($H_{2\%}$)	20 year ($H_{5\%}$)	10 year ($H_{10\%}$)	5 year ($H_{20\%}$)
Xuezhai Reservoir Station	1/6h	42	37	32	28	23
	1h	102	92	77	66	54
	1.5h	117	105	88	75	61
	2h	129	115	96	81	66
	3h	148	131	109	92	74
	6h	186	164	135	113	90
	12h	237	208	170	141	111
	24h	302	264	214	175	137

According to the calculated design rainstorm results, the recurrence period of the heavy rain at Xuezhai Reservoir Station during the current rainfall period is analyzed, and the results are shown in table 3.

Table 3. Analysis results of the return period of heavy rain Xuezhai Reservoir Station.

Station name	duration	Rainfall (mm)	Return period
Xuezhai Reservoir Station	1h	45.5	Once in about 5 years
	2h	66	Once in about 5 years
	3h	105	Once in about 20 years
	6h	160.5	Once in about 50 years
	12h	239	Once in about 100 years
	24h	304.5	Once in about 100 years

From the analysis of the return period of the heavy rain at Xuezhai Reservoir Station, the 24-hour rainfall of this heavy rainfall was slightly larger than the design rainstorm of once in 100 years.

2.2. Topographic Factor

The center of the rainstorm was concentrated in the upper reaches of the Lianxi River Basin. The source of stream is more than 400m above sea level, and The mountains are steep and dense, while the river slope is steep and straight, this makes the runoff formed by the rainstorm have high potential and kinetic energy, it has more impact force compared with the flood peak of the same magnitude. As a result, the ability of water current to carry sand and rocks is enhanced, and it is very easy to form destructive flash flood disaster.

2.3. Human Activity Factor

The width of the Lianxi River is about 4 meters to 8 meters, and the flood control standard along Lianxi River is not enough high. Disorderly development of Lianxi River Basin has increased the destructive power of rainstorm floods to varying degrees. The survey found that in order to facilitate production and living needs, most of the local villagers chose to build houses near the river, have built 6 simple low bridges across the front and rear of the river, and set up 8 weirs and 1 simple sluice that could only be half-opened. What's more, there is a section of river road and culvert with a length of 900 meters. So many water-blocking structures have different degrees of encroachment on the river course. In the event of a major flash flood, the flood current is blocked, causing the flood to overflow to the top of the embankment or even divert the route, aggravating the formation of flash flood disaster.

3. The Effect of Early-warning System in Flash Flood Case of Lianxi River

It is not difficult to find that the early warning system of forecast warning, monitoring warning and local warning complements each other has played a key role in flash flood case of Lianxi River.

3.1. The Forecast Early Warning

At 17:15 on July 23, the Zhejiang Provincial Department of Water Resources, based on the meteorological results of the grid numerical forecast for the next 24 hours, combined with the previous rainfall, typhoon path, and the trend of changes in water and rain conditions, studied and judged the possible occurrence of mountain torrents in Keqiao District. The Water Resources Bureau sent a blue warning message for the next 24 hours to remind the region to strengthen the prevention of flash flood disaster.

At 9:35 on July 24, the Zhejiang Provincial Department of Water Resources, based on the meteorological results of the grid numerical forecast for the next 3 hours, sent a message to the key mountain torrent villages such as Jianmin, Jianxing, and Lianhua along the Lianxi River Basin in Xialv Town for the next 3 hours. Short-term early warning information, reminding to do a good job in flash flood disaster monitoring and early warning, dangerous situation inspection, and organize personnel to transfer and avoid danger in time.

3.2. Monitoring Early Warning

From 6:00 on July 24th, the Agriculture and Rural Affairs Bureau of Keqiao District will send monitoring and early warning information to key mountain torrent villages such as Jianmin, Jianxing, and Lianhua along the Lianxi River Basin, remind people to make preparations for impending flash flood, or order them to immediately organize personnel to transfer and avoid danger. According to statistics, the flash flood disaster monitoring and early warning system in Keqiao District automatically sent early warning text messages to the responsible persons for mountain torrent defense in Xialv Town and Lianxi villages more than 20 times.

3.3. Local Early Warning

After receiving all kinds of early warning information, the responsible persons at the town and village levels quickly took measures to strengthen the encryption inspection and risk elimination. After finding that the water level of Lianxi River was abnormally rising, they issued an alarm to the people in their responsible areas through hand-held horns, gongs, and radio. And the transfer signal, and immediately arranged for village cadres to enter the village and households to organize the transfer of personnel. At 9:00 on July 24, the transfer and resettlement of all 65 households and 153 people in the dangerous area was completed.

At 10:30 on July 24, flash flood broke out in the Lianxi River Basin. The flood submerged all villages along the line, and the submerged water depth was more than 1 meter. Fortunately, the transfer was carried out in advance, and no casualties were caused.

4. Conclusions and Suggestions

Heavy rainfall is the most important factor causing flash flood disaster in the small watershed of Lianxi River. The steep terrain has created the turbulent rainstorm and floods. The successful defense experience of flash floods in Lianxi shows that establishing and giving full play to the role of an early warning system that complements each other in forecasting warning, monitoring warning, and local warning is the key to successfully defending against flash flood disaster. It has played a huge role in helping 65 households and 153 people in the flash flood risk areas along the line to transfer and avoid danger.

Although there were no casualties due to the effectiveness of the early warning system, some problems were still found in the prevention of flash flood risks in small watersheds that are worth summarizing. To this end, the following specific suggestions are put forward to provide reference for the management of small watersheds and the prevention of flash flood disaster.

(1) Houses built near the river are vulnerable to the threat of flash flood disaster. When building a house along the small watershed, it is necessary to stay away from or avoid the areas impacted by flash flood.

(2) Unfavorable human activities have weakened the flood-carrying capacity of the river to varying degrees, increased the destructive power of rainstorms and floods, and brought great hidden dangers to flood control safety [5].

(3) Promote diversified monitoring, forecasting and early warning [6], adhere to the combination of forecast, monitoring and local early warning, and form a gradual early warning pattern in which the combination of points and areas and the combination of long and short are complementary to each other, so as to increase the timeliness and reliability of mountain flood early warning, play an important role in decision-making support for grass-roots governments in flash flood disaster prevention, emergency response and disaster avoidance, and effectively ensure the safety of people's lives and property.

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