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Flash flood disasters analysis and evaluation: a case study of Yiyang County in China

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Abstract. Global climate change leads to the more extreme precipitation and more flash flood disasters, which is a serious threat to the mountain inhabitants. To prevent flash flood disasters, China started flash flood disaster control planning and other projects from 2006. Among those measures, non-engineering measures are effective and economical. This paper introduced the framework of flash flood disaster analysis and evaluation in China, followed by a case study of Yiyang County.

1. Introduction

The flash flood disasters are considered as huge threats to those residents living in mountain areas [1]. As with the aggravation of global climate changes, the heavy precipitation events have frequently led to a series of flash flood disasters [2, 3]. So far, the flash flood disaster has become one of the major disasters causing casualties both in China and the rest of the world [4, 5].

The Flash Flood Disaster Control Planning (FFDCP) has come into force since 2006. The project is proposed to set up non-engineering facilities, such as establishment of sound monitoring and early warning system for flash flood and group testing system to achieve an effective reduction of casualties caused by flash flood disaster.

Followed in 2009, a series of pilot construction of non-engineering facilities including Monitoring and early warning facilities, monitoring and forecast platform, transfer plan, organization system, publicity and training and emergency drilling were established in 103 Counties. The facts proved that those establishments of non-engineering facilities could bring favorable effect to prevent the huge disasters but only with little investment.

Through implementations of flash flood disaster planning and pilot construction of non-engineering facilities, China has explored a set of experience and methods in accordance with China's real conditions. On that basis, China started to carry out the analysis and evaluation of flash flood disasters [6] covering a total of 2058 Counties nationwide in 2013.

The context gives an introduction of basic content and process of flash flood disaster analysis and evaluation, of which, Yi yang County is used as a sample to show the calculation process and results, and to provide reference for other countries and regions facing threats of flash flood disasters.

2. The framework of flash flood disaster analysis and evaluation

Flash flood disaster analysis and evaluation aims to assess the flash flood control capacity of village, determine hazard zoning, and analyze the early warning index. There are lots of data should be collected before flash flood disaster analysis and evaluation, such as small watershed characteristics, residence information, hydrological data, and meteorological data, and so on. The key contents is shown in figure 1. On the basis of adequate data, design storm should be calculated first. Then design flood could be obtained vie hydrological analysis. Also, the relation between water level and flow for specific section should be worked out at that time. After that, flood control capacity of village, early warning index, and hazard map could be obtained.

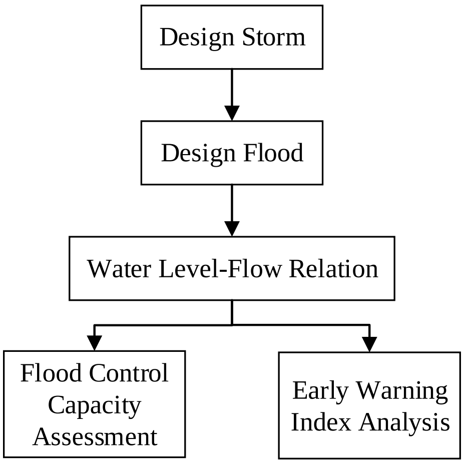

Figure 1. The flowchart of flash flood disasters analysis and evaluation

2.1. Design storm
The rainstorm calculation is designed to figure out the corresponding design flood precipitation and its time schedule of rainfall distribution in the process of analysis and evaluation of flash flood disaster including 3 parts of calculation items of rainfall in the small watershed, rainstorm frequency and time schedule of rainstorm distribution.

2.2. Design flood
An equivalent frequency for rainstorm and flood is regarded as the fundamental assumption to process the design flood analysis. The design flood contributes to acquire specific element information of flood on specific sites, such as the flood peak at specific frequency, flood volume, rise time and flood duration. The calculation is divided into 2 steps: Step 1: working out the design net rain through the analysis of rainstorm flood; Step 2, figuring out the design flood through the analysis of concentration of flow of design net rain.

2.3. Water level-flow relation
The water level-flow relation curve presents the interrelation between flash flood and disasters. The water level on submerged in specific reaches under design floods at different frequency can be obtained through the analysis of water level-flow relation curve. Generally, through Manning's formula, we can calculate and analyze on longitudinal slope and data of channel roughness.

2.4. Flash flood control capacity
Flood control status evaluation analyses the current flood control capacity of disaster prevention object through superimposing the distribution data showing the residential buildings on elevation on account of the acquisition of water level-flow relation curve on control section of disaster prevention object. Flood control status evaluation includes 3 parts: determination of the flood frequency corresponding to the disaster water-level, statistics of population in different dangerous level and drawing Current flash flood control capability map.

2.5. Early warning index

The early warning index, as the most common type index, is used in flash flood disaster. The early warning index refers to the minimum magnitude and intensity of rainfall and over on occurrence of a reaches or region suffered from flash flood disaster with its water-level corresponding to peek discharge near the disaster prevention channels which meets the requirement of disaster water-level. The basic calculation idea presented as follows: first, based upon the combination of disaster water-level, we work out the flood flow corresponding to the disaster water-level and water level-flow relation curve; second, we figure out in reverse the precipitation in different early warning periods when the flood peek is equivalent to the disaster flood flow, and use it as early warning index. The calculation can be divided into 4 steps: the determination of early warning period, figuring out the soil moisture content in the reaches, working out the disaster rainfall and making a comprehensive early warning index.

3. Case study of Yiyang County

3.1. Overview of research area

Yiyang County, as a study area and with an area of 1,616.8 km², is located in the west of Luoyang, Henan Province, China. With 1300 gullies over 205 m and 450 mountains with the height of 30 m and above, Yiyang County is vulnerable to the flash flood disaster due to its geography featured mountains, hills, river valleys and the geographical information is presented in figure 2 and figure 3.

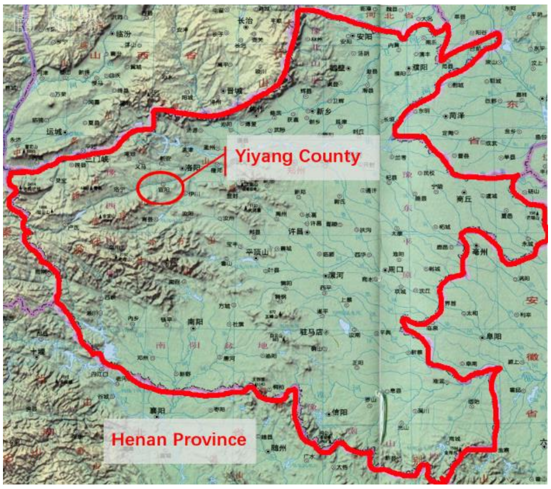

Figure 2. Location and topography of Yiyang County in Henan Province

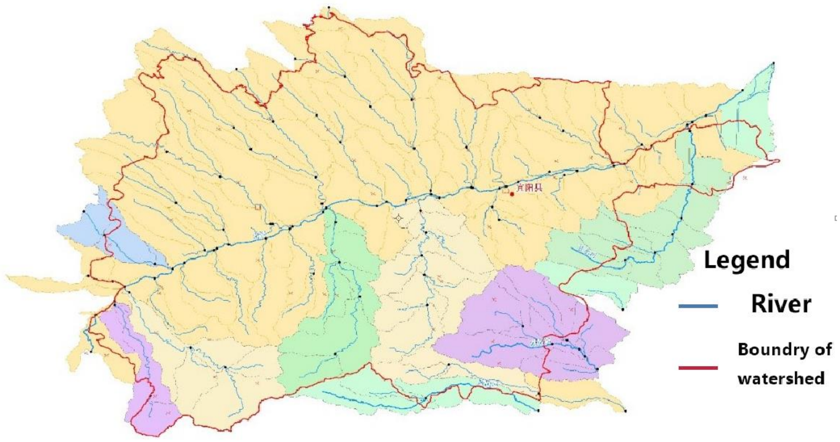

Figure 3. The river and watershed in Yiyang County

According to written records, Since from Yuan Dynasty, Yiyang County has been attacked by totally 70 times heavy flash flood disasters with casualties of 1100 and direct economic losses over 200 million yuan. 1 set of media-sized reservoir and, 18 sets of small-sized reservoirs and river height of 68 km are constructed by Yiyang County to control the flash flood disasters; in addition, Yiyang County set up large-scale construction work for conservation of water and soil and riverway treatment, which play significant roles in controlling the flash flood disasters.

The analysis and evaluation of flash flood disaster will greatly make up with the insufficiency and shortage in non-engineering facilities in Yiyang County. There are 193 objects in Yiyang County at which the analysis and evaluation of flash flood disaster are carried out depending on actual demands and accessible data for the flash flood defence, please see at figure 4. Xizhao village of Yiyang County is studied as an example to present how to do the analysis and evaluation for flash and flood disaster, Meanwhile, we have a discussion about the analysis and evaluation of flash flood disasters occurred throughout Yiyang County.

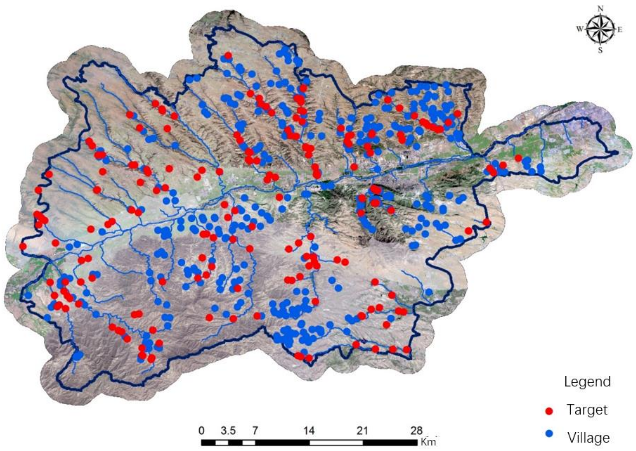

Figure 4. The target and villages of Yiyang County

3.2. Calculation of design storm

The coefficient of variation Cv and skewness coefficient Cs at different periods and frequency of rainstorm in Xizhao Village can be obtained from Henan Rainstorm Parameter Atlas. With assumption that the rainstorm distribution conforms to Pearson III, we can figure out different frequency values of design flood corresponding to the coefficient of modular ratio Kp through the calculation by Cv and Cs. First, the design point rainfalls at different design rainstorm frequencies can be worked out by multiplying an average value of rainstorm at this spot and Kp, and then times the conversion coefficient of point and areal rainfall to implement the conversion from point precipitation into areal rainfall; Finally, the distribution of design areal rainfall at typical rain sequence during local 24 hours can be charted out, as shown in figure 5.

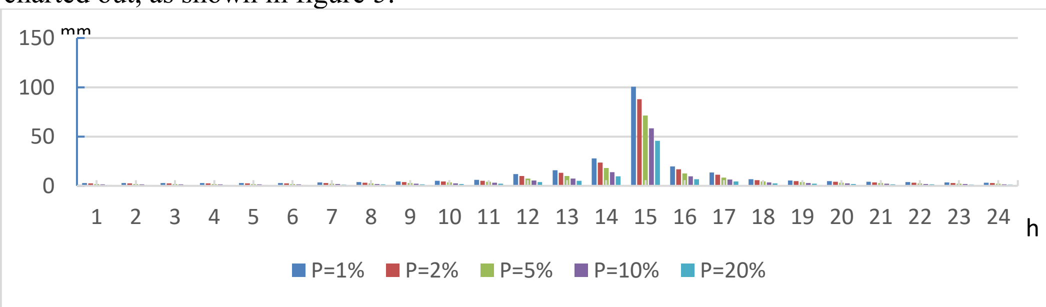

Figure 5. Temporal distribution of design storm

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3.3. *Calculation of design flood*

Before calculation on design flood, we should figure out the design net rain through runoff yield analysis. The runoff yield can be analyzed in various ways, we adopt the method of deduction of the steady water seepage to calculate the design net rain. With comprehensive consideration on local runoff yield mechanisms, vegetation cover and soil texture, we define the steady water seepage parameter of 5-8 mm. Please see figure 6 for design net rain. Afterwards works out the concentration of flow. The concentration of flow can be calculated by several methods as well, the method adopted here is called Standard Unit hydrograph, please see figure 7. With this method, we can calculate the design net rain, furthermore, we can get the design flood of Zhaoxi Village, Please see figure 8.

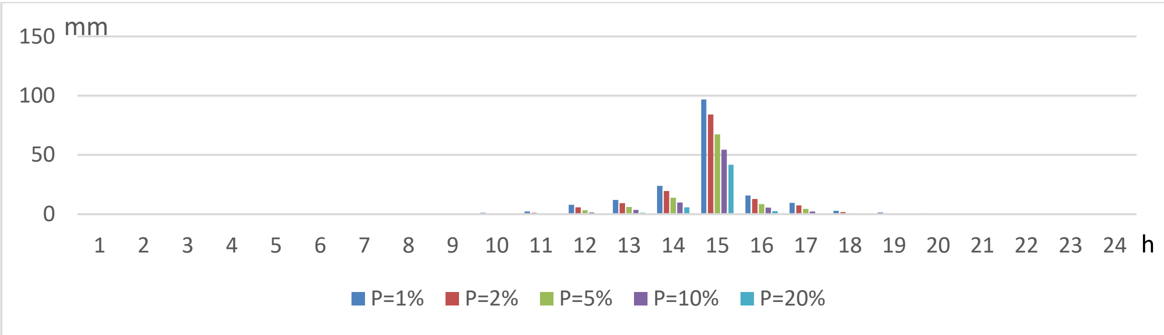

Figure 6. Temporal distribution of design net rainfall

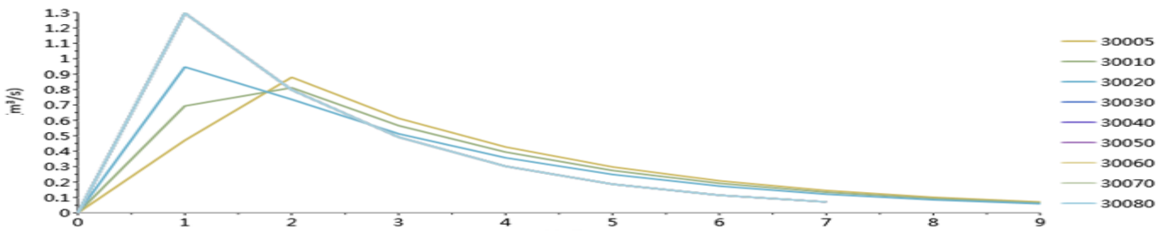

Figure 7. Standard unit hydrograph of Xizhao

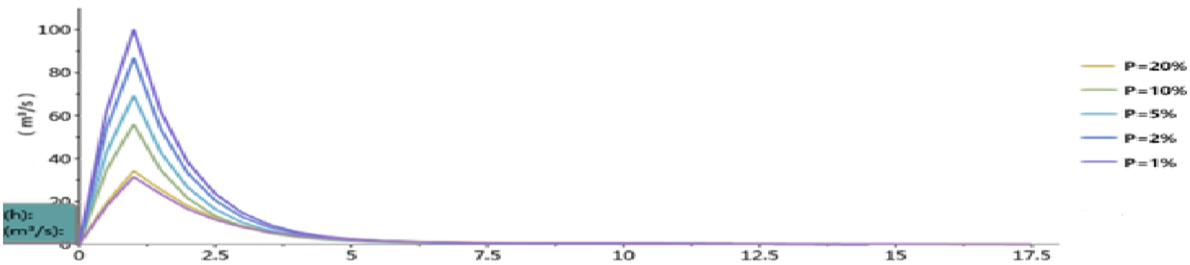

Figure 8. Design flood of Xizhao

3.4. *Calculation of water level-flow relation*

The critical parameters of slope and roughness shall be confirmed when performing calculation of water level-flow relation by Manning's formula. The channels longitudinal slope of approximate 0.0121 near Xizhao Village can be estimated based on the longitudinal data measured on the spot, as shown in figure 9. Apart from that, with soil bed the channels not always be filled with water and has trees with diameters of 10-15 cm sparsely spread inside. Thus, we confirm that the main channel roughness is 0.03 and the marginal roughness is 0.45; and we can figure out the water level-flow relation of channels near Xizhao Village by v Manning's formula, please see figure 10.

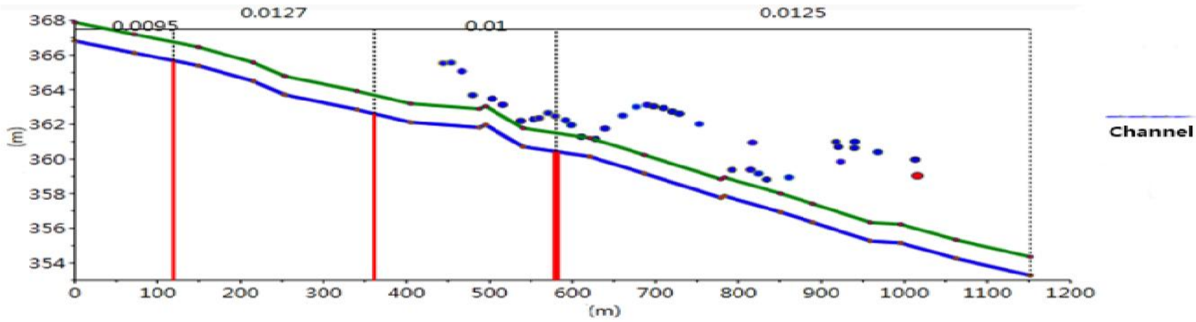

Figure 9. Channel profile diagram of Xizhao

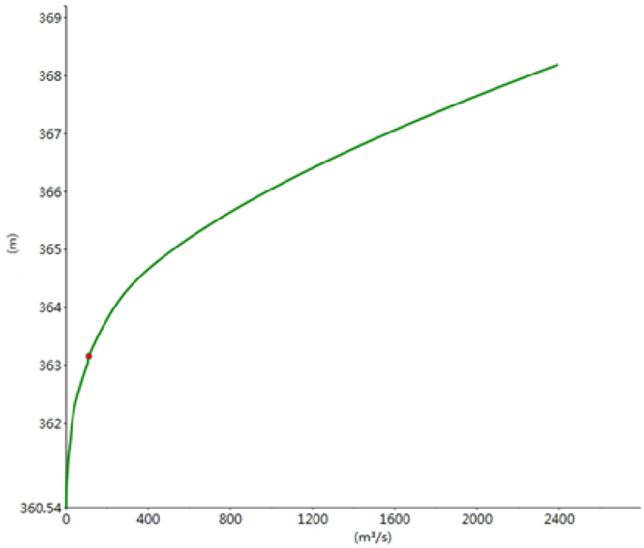

Figure 10. Water level-flow relation of Xizhao

3.5. Calculation of flash flood control capacity

The disaster water level value of 361.50 m is acquired from filed survey. According to the water level-flow relation calculated from previous section, the corresponding disaster flood flow is considered as 32 m^3/s. We can also figure out the flood frequency corresponding to the disaster water-level with a value of 25% by interpolation method. We can divide and define the extremely high hazard area, high hazard area and hazard area on the basis of the flood water-level once occurred within 5 years, 20 years and 100 years, please see table 1. Then, the Current flash flood control capability map of Xizhao Village can be drawn out, please see figure 11.

Table 1. Population information of areas in each danger level

Danger level	Frequency	Elevation	Population	Households	Houses
Extreme danger	<5	< 361.53	8	1	1
High danger	5-20	361.53-362.03	12	2	2
Danger	20-100	362.03-362.32	57	11	11
Others	>100	> 362.32	116	23	23

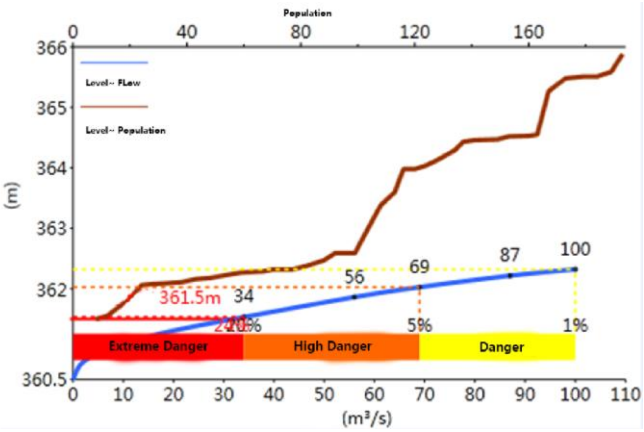

Figure 11. Current flash flood control capability map of Xizhao

3.6. Calculation of early warning index

The trial method is adopted to calculate the early warning index. The calculation flow is figured out by repeated calculation of design flood and trial of continuous adjustment of value of design rainstorm. In case of the calculation flow is equivalent to the disaster flood flow, the corresponding design rainstorm will be the disaster rainstorm. The disaster flux in Xizhao Village is 32 m^3/s according to the previous calculation; with consideration of soil water content in dry, medium dry and wet situations in the reaches. The early warning index can be figured out as showed in table 2.

Table 2. Early warning index of Xizhao

Soil moisture content	Period /h	Disaster caused rainfall /mm	Soil moisture content	Period /h	Disaster caused rainfall /mm	Soil moisture content	Period /h	Disaster caused rainfall /mm
0.20Wm	1	55	0.50Wm	1	51	0.80Wm	1	47
	2	63		2	59		2	55
	3	75		3	71		3	67
	4	82		4	78		4	74
	5	92		5	88		5	84
	6	99		6	95		6	91

3.7. Flash flood disasters analysis and evaluation result of Yiyang County

As same with Xizhao Village, we carried out the calculation and analysis for 193 villages in Yiyang Counties to acknowledge the data of current flood control ability, the distribution of dangerous zones at different levels and early warning index. As shown in table 3 and figure 12; there are 143 villages with disaster prevention ability which are capable of overcoming the disaster occurred only once within 100 years; 13 villages with disaster occurred more than once within 5 years; 1 village with disaster occurred more than once within 1year; 12 villages with disaster occurred once over 5 years but within 20 years; 24 villages with disaster occurred once over 20 years but within 100 years.

Table 3. The flash flood control capacity result of Yiyang County

Frequency	Number of village	Extreme danger		High danger		Danger	
		Population	Houses	Population	Houses	Population	Houses
P>=100%	1	8	2	0	0	4	1
100%>P>=20%	13	150	33	79	16	116	24
20%>P>=10%	8	23	3	150	30	126	22

10%>P>=5%	4	99	21	21	4	19	5
5%>P>=1%	24	20	4	30	6	298	64
1%>P	143	0	0	0	0	0	0
Totle	193	300	63	280	56	563	116

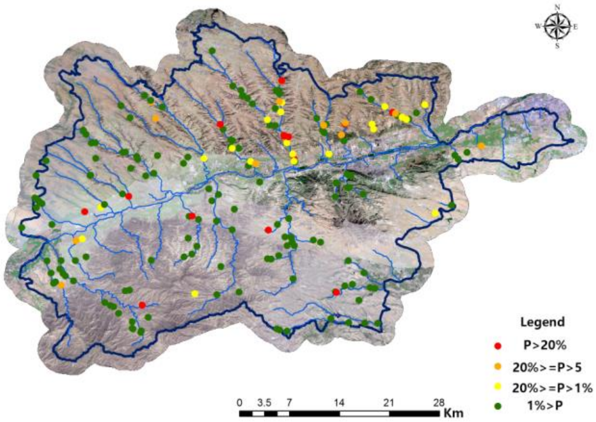

Figure 12. The flash flood control capacity distribution of Yiyang County

Similarly, the early warning index of flash flood disasters in 193 villages along the river are figured out. With marks of early warning rainfall value of key target villages which is vulnerable to disasters, we can get distribution map of early warning index under different soil water content as figure 13, figure 14 and figure 15.

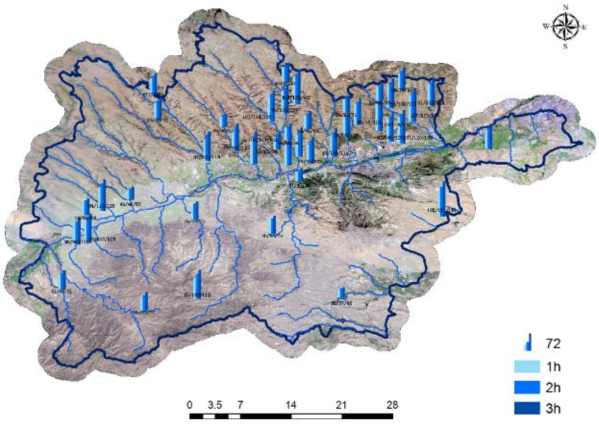

Figure 13. The early warning index distribution of Yiyang County (Pa=0.2Wm)

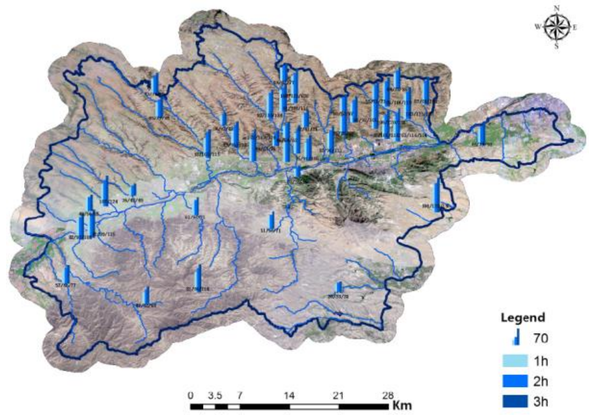

Figure 14. The early warning index distribution of Yiyang County (Pa=0.5Wm)

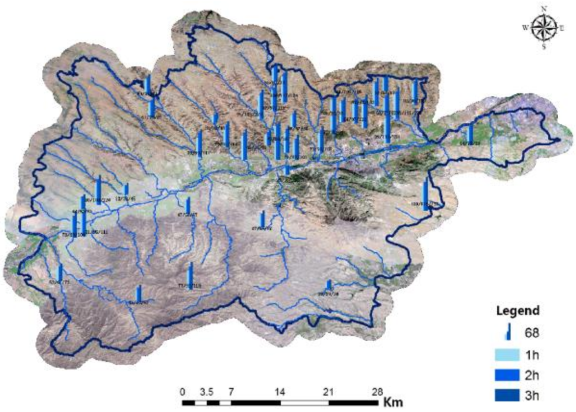

Figure 15. The early warning index distribution of Yiyang County (Pa=0.8Wm)

4. Conclusion

Flash flood analysis and evaluation is an important and efficient non-engineering measure for flash flood disaster prevention. It contains calculation of design storm, calculation of design flood, calculation of water level-flow relation, calculation of flash flood control capacity, and calculation of early warning index. Besides this paper's study, China had started other 2057 counties flash flood analysis and evaluation project. Until 2016, that project had already accomplished and made great sense in 2017. Although this project had already done and worked well, there still a lots of thing need to be done, such as disaster monitoring construction, flash flood early warning system building, more precisely warning index research, flash flood disaster insurance construction, and so on.

Acknowledgements

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