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Determination of Mountain Flood Warning Index Based on Distributed Hydrological Model

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Determination of Mountain Flood Warning Index Based on Distributed Hydrological Model

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Abstract: Mountain flood in small watershed comes unexpectedly, and the determination of water index is hard. Combined with the actual situation of Miaoxia Watershed, this paper proposes a design of flood calculation method based on HEC-HMS distributed model, and determines mountain flood warning index by using the method of water level backstepping discharge. The result calculated by this paper's method has little difference compared with those using rational formula or instantaneous unit hydrograph, and the determination of the warning index is basically reasonable. The applied results shows that the determination of mountain flood warning index based on distributed hydrological model is simple and feasible, which is consultative for mountain flood warning index selection.

1. Introduction

In recent years, with global warming and extreme weather occurring frequently, mountain flood happens from time to time, which poses great threats to the national economy and the safety of people's lives and property [1]. Because of the river short length and the rapid flow in small watershed, the flood has multiple characteristics, such as, heavy rain intensity, short duration, strong suddenness and great harm. Therefore, prevention of mountain flood has been the main part in flood control and disaster reduction in hilly areas, and mountain flood disaster warning has also become a popular research topic.

The foundation of mountain flood disaster warning is determination of rainfall warning index, which refers to the rainfall amount and intensity when mountain torrent happens. Traditional methods include statistical induction, rainfall frequency analysis, hydrologic-hydraulic calculation, empirical analysis and comprehensive analysis. For example, Zhao et al.(2011) uses rainfall frequency analysis to determine mountain flood warning index in Linq County, indicating this method requires high accuracy of data and it has certain limitations when applied in ungauged regions [2]; Combined with the empirical relationship of rainfall and runoff in Hubei Province, Wang et al.(2006) generates warning index by using empirical analysis [3]; Guo et al.(2018) puts forward composite warning index indicators through comprehensive analysis to study mountain flood warning index in Beizhangdian small watershed [4].

With the development of computer science and 3S technology, especially the widespread application of digital elevation model (DEM), hydrological model has changed from lumped model to distributed and digital model. Hydrological simulation brings in more underlying surface information to reflect the physical mechanism. Considering distributed hydrological model can better reflect the physical characteristics of the watershed, this paper presents a calculation method for the flood in small watershed and an approach to determine mountain flood warning index of rainfall in small watershed, which are based on the distributed hydrological model—HEC-HMS model. This paper applies above method and approach to Miaoxia Watershed in Zhejiang Province, which provides a new reference for



determination of mountain flood index in small watershed, and for prevention and control of mountain flood disasters.

2. Overview of study area

This paper's research subject is Miaoxia watershed, which locates in southwest of Longyou County, Zhejiang Province. Miaoxia watershed is originated from Maolianli and it belongs to the Qiantang River system. There is no reservoir in upstream of the basin to control flood, and the basin is formed by Xiyuan Stream and Nanyuan Stream. In addition, the basin is located in the subtropical monsoon climate area, where has uneven spatial and temporal distribution of precipitation and obvious seasonality and regionality. From July to September, affected by typhoons, high-intensity rainstorms often occur. Furthermore, due to the influence of the east wind and strong convective weather, the rainstorms often last for short time, and they have small range and large intensity. The rainstorm gathers quickly in short time, and it is likely to creat impulsive surface runoffs, which leads to flood outbreak and further causes disaster.



Figure 1. Diagram of Miaoxia Watershed

3. Methodology

3.1. Data processing

Hydrological data: There is a rainfall station called Helingjiao station in Miaoxia Watershed. Helingjiao Station was established in 1965 and it is located in the west of the watershed. Its rainfall information (since 1965 to 2013) have been compiled and approved by Zhejiang Hydrological Survey Bureau. The information accuracy can meet the calculation requirements.

Topographic data: Using ArcGIS software to process and analyze DEM data of Miaoxia Watershed, and extract the watershed characteristics of area, river length and gradient. Those data would be checked with 1:10000 scale map. Finally, it is determined that the drainage area of Miaoxia Watershed $F=69.6\text{km}^2$, the river length $L=18.1\text{km}$, and the average river gradient $J=13.9\%$.

3.2. Model building

In this paper, HEC-HMS distributed hydrological model is used to analyze and calculate runoff yield and flow concentration. HEC-HMS hydrological model is mainly composed of Basin Model,

Meteorological Model, Control Specifications and Time-series Data. Basin Model is a generalization of the rainfall-runoff process in the actual watershed, which involves the content of runoff yield and flow concentration in the watershed. Meteorological Model mainly provides and processes the meteorological data needed for model calculation, such as pre-processing rainfall, evapotranspiration and other meteorological data, and establishing the geographical relationship between meteorological data stations and sub-basins. Control Specifications is mainly used to set simulative time periods, time steps and simulate the rainfall process in the basin [5]. Time-series Data is mainly about inputting information, such as relevant rainfall station coordinates, rainfall, river discharge and evaporation, so as to prepare for the simulation of the whole basin [6].

Considering the difference of topography, landform and river network shape, Miaoxia Watershed is divided into Xiyuan and Nanyuan watersheds in this study, and then the model is constructed by units. Due to small area of Miaoxia Watershed, the rainstorm data of Helingjiao Station is used to design rainstorm calculation in each sub-watershed, and the rationality of the calculation results is analyzed based on Zhejiang Province Rainstorm Atlas. Stored-full runoff, SCS CN(Soil Conservation Service Curve Number) and exponential decay were employed for runoff yield, flow concentration and base flow in each sub-basin. In detail of runoff yield calculation, this study takes excess rain from full storage runoff analysis as the model input, and selects the simple loss method in software, in the meanwhile set the loss as zero. According to the soil types and channel conditions, the model parameters are as follows:

Table 1. Information of Relevant Parameters of Miaoxiaxi Small Watershed

Sub watershed	Watershed characteristics				Runoff generation		Flow confluence	
	area (km ²)	River length (km)	stream gradient	Maximum Watershed storage capacity (mm)	Watershed storage capacity (mm)	Squares curve of tension water storage capacity and area distribution	Lag time (min)	Roughness
Xiyuan	33.34	1.396	0.0349	120	100	0.2	144	0.03
Nanyuan	32.10	1.605	0.0162	120	100	0.2	120	0.03

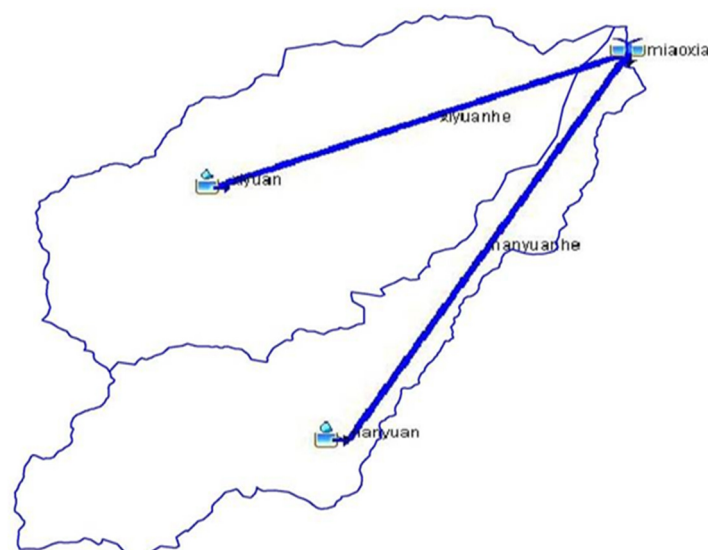


Figure 2. Diagram of Miaoxia Watershed sub-unit

3.3. Design flood calculation

Frequency analysis and ocular line-fitting method are used for rainstorm design. Rainstorm time distribution is calculated by storm formula. The rainstorm design process is determined according to the rainfall arrangement rule of "Zhejiang Short-duration Rainstorm".

Designed Flood is calculated by designed rainstorm through runoff generation and flow confluence. In the part of runoff generation, the net rainfall is calculated by full storage runoff generation model, considering mountain flood characteristics in small watersheds. The evaporation deduction is not considered in the calculation process. Unit hydrograph method is used for flow confluence calculation and kinematic wave method is used for flood routing in each reach.

3.4. Determination of Warning Index

(1) Warning period: Early warning period is determined by confluence time analysis. Confluence time of Miaoxia Watershed is 4 hours, so the longest warning period is 4 hours. Considering other typical periods, the warning periods are set as 1 hour, 3 hours and 4 hours.

(2) Soil water content: Considering that Zhejiang Province is in the southern wet region, this paper uses two typical values of $P_a=0.75 \times W_m$ and $P_a=0.9 \times W_m$ to represent the medium and abundant conditions of soil water storage in the basin. According to "Design Rainstorm Flood Atlas of Small and Medium Rivers in Zhejiang Province (Yield and Confluence Part)", the W_m value is estimated to be 100 mm.

(3) Water level backstepping discharge: based on field investigation and analysis, the disaster-causing water level of the river basin control section is determined, and critical disaster-causing flow by interpolation is calculated. The trial algorithm is used to calculate the critical precipitation [7,10]. The specific calculation process is: firstly assuming the initial precipitation value; Secondly calculating the flood process at control section by using the distributed hydrological model by inputting conditions of rainfall and rainfall pattern analysis result.; Thirdly, comparing calculated peak discharge with critical discharge at the control section. If the difference between the calculated peak discharge and the critical discharge at the control section is insignificant, the input rainfall is the critical rainfall in this period. If the difference is significant, the initial rainfall value should be reset and calculated repeatedly until the difference between the calculated peak discharge and the disaster critical discharge is less than the preset allowable value [8,12]. Finally, on the basis of the critical rainfall, the mountain flood warning index is synthetically determined, after considering river channel characteristics, warning response time and flood rising rate at the control section.

4. Results and rationality analysis

4.1. Design flood result and its rationality analysis

Considering lacking of observed flood data in Miaoxia Watershed, and in order to compare and analyze the rationality of design flood results by using distributed model, rational formula and instantaneous unit hydrograph method are used to calculate designed flood respectively. The comparative analysis of the results calculated by different methods are shown in Table 2.

Table 2. Comparison and analysis of design flood calculation results in miaoxi watershed

Design frequency (%)	Rational formula			Instantaneous unit hydrograph			Distributed model (HEC-HMS)		
	Calculation of flood peak (m ³ /s)	Confluence time (h)	Daily flood volume (m ³)	Calculation of flood peak (m ³ /s)	Confluence time (h)	Daily flood volume (m ³)	Calculation of flood peak (m ³ /s)	Confluence time (h)	Daily flood volume (m ³)
1	746	3.71	16263888	662	4	17314094	657	4	16362000

2	649	3.84	14188654	577	4	15248008	583	4	14324500
5	521	4.06	11432406	469	4	12601256	486	4	11590900
10	384	4.27	9497754	383	4	10523658	410	4	9509300
20	328	4.56	7181079	298	4	8389817	330	4	7356500

Through the comparative analysis of the above data, it can be seen that the result of distributed model (HEC-HMS) method is slightly larger than that of instantaneous unit hydrograph method, while the calculation result of flood peak discharge by using rational formula is quite different from those of the other two methods.

Rational formula method is mainly applicable to small watersheds less than 50 km². According to the habits of designed flood calculation in Zhejiang Province, and considering the catchment area of Miaoxia Watershed is larger than 50 km², its designed flood calculation usually adopts instantaneous unit hydrograph method, so the calculation result of distributed model (HEC-HMS) method are basically reasonable.

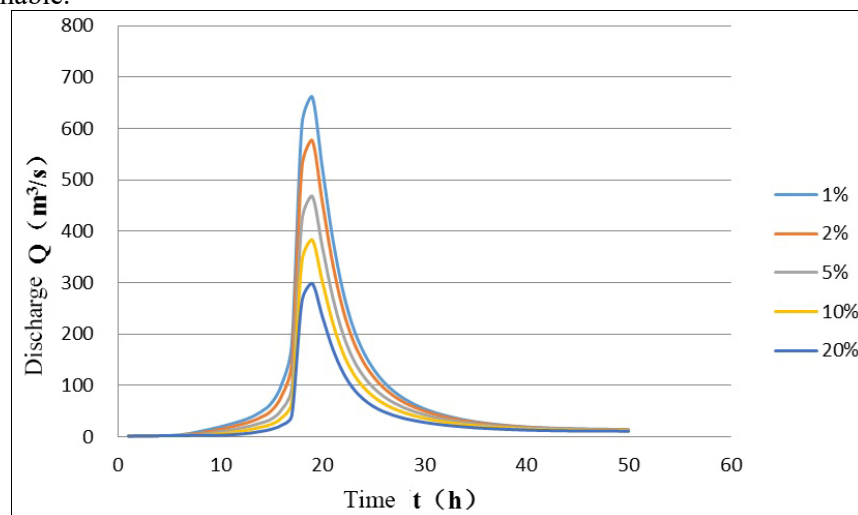


Figure 3. Flood process chart of each frequency at the control section of Miaoxia Watershed

4.2. Mountain flood warning index result and its rationality analysis

Based on the critical rainfall calculated by distributed hydrological model, considering two states of medium and abundant soil water storage, the critical rainfall corresponding to the disaster water level is taken as the immediate transfer index, and its preparation transfer index will decrease from critical rainfall basis corresponding to the disaster water level.

Table 3. Mountain flood warning index results

Period	Preparation transfer index under different soil water storage (mm)		Immediate transfer index under different soil water storage (mm)	
	Medium (0.75WM)	Abundan (0.9WM)	Medium (0.75WM)	Abundan (0.9WM)
1h	35	30	42	38
3h	46	39	54	45
4h	55	47	61	53

According to the records of “Longyou Water Conservancy Records” and field investigations, two typical mountain torrents occurred in Miaoxia Watershed in recent years. They were from 14:00 to 17:00 p.m. on June 26, 2007 and from 16:00 to 23:00 p.m. on September 5, 2008. The data of Heingjiao rainfall station during two typical mountain torrents are shown in Table 4.

Table 4 Helingjiao Rainfall Station Partial Rainfall Abstraction Data Table

Specific date	Starting time	Termination time	Rainfall (mm)	Specific date	Starting time	Termination time	Rainfall (mm)
2007-6-24	9:00	10:00	1.2	2008-9-4	1400	1500	0.2
2007-6-24	10:00	11:00	11.3	2008-9-4	1900	2000	1.1
2007-6-24	13:00	14:00	5.8	2008-9-4	2000	2100	1.8
2007-6-24	16:00	17:00	0.2	2008-9-4	2100	2200	3.6
2007-6-24	19:00	2:000	0.3	2008-9-4	2200	2300	0.3
2007-6-25	6:00	7:00	0.1	2008-9-4	2300	2400	0.2
2007-6-25	2:000	21:00	31.5	2008-9-5	200	400	0.4
2007-6-25	21:00	22:00	17	2008-9-5	500	600	0.1
2007-6-25	22:00	23:00	3	2008-9-5	1600	1700	7.8
2007-6-25	23:00	24:00	0.4	2008-9-5	1700	1800	9.8
2007-6-26	1:00	2:00	0.1	2008-9-5	1800	1900	0.1
2007-6-26	14:00	15:00	0.8	2008-9-5	1900	2000	17.2
2007-6-26	15:00	16:00	28.7	2008-9-5	2000	2100	29.4
2007-6-26	16:00	17:00	19.4	2008-9-5	2100	2200	54
2007-6-26	17:00	18:00	0.1	2008-9-5	2200	2300	6.9
2007-6-26	21:00	22:00	0.1	2008-9-5	2300	2400	0.1

From Table 3, it can be seen that before the occurrence of mountain torrents, there was rainfall in the watershed, and the soil water content was relatively rich. After analyzing the rainfall of "June 25, 2007", it is found that the cumulative rainfall reached 48.9 mm from 14 p.m. to 17 p.m. in 3 hours, which is 3.9 mm higher than the 3-hour flood mountain warning index of 45 mm under the condition of abundant soil moisture, and meeting the warning criteria. After analyzing the rainfall of "September 5, 2008", it is found that the cumulative rainfall of 21 p.m. to 22 p.m. in 1 hour reached 54 mm, which is 16 mm higher than the 1-hour flood mountain warning index of 38 mm under the condition of abundant soil moisture. It also meets warning criteria, which proves that rainfall warning index calculated by this analysis and evaluation is basically reasonable.

5. Conclusions

Taking Miaoxia Watershed as an example, this paper uses HEC-HMS software to construct a distributed hydrological model, and explores a new method for determining flood warning index in Zhejiang Province. The results show that the distributed hydrological model HEC-HMS can be applied to design flood calculation and flood warning index determination in hilly areas of Zhejiang Province. In the course of the study, it is also found that the lack of measured flood data in hilly watershed has brought some difficulties to the rational analysis of calculation results. At the same time, the determination of disaster-causing water level and the patterns of designed rainstorm as input conditions have great influence on mountain flood warning index. Therefore, in order to better prevent and control mountain flood disasters, accumulating data and paying attention to investigation are still the basic part of mountain flood early warning work in the future.

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