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Research Article

Exploiting SEAFFGS to determine threshold runoff and bankfull discharge – pilot application for Quang Nam province

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Abstract: Flash flood is a natural disaster occurring in a short time due to heavy rainfall combined with topography, geomorphology, economic growth in the basin. Although it happens on a small scale but it leaves far–reaching destruction in its wake. Recent years have recorded, several consecutive flash flood events causing great damage in the mountainous area of Quang Nam province. For example, in 2020, the successive flash floods and landslides occurring in October and November has been a pressing disaster problem which causes great loss of life and property. Flash flood prediction poses a big challenge for not only Vietnamese but also international scientists. The general method of flash flood prediction is based on threshold runoff and bankfull discharge. Currently, the Viet Nam Meteorological and Hydrological Administration is selected as Regional Centre for supporting flash flood warning by the World Meteorological Organization, has received the "Southeast Asia Flash Flood Guidance System (SEAFFGS)" developed by the U.S Hydrological Research Center and initially applied in flash flood and landslide warning. This paper presents the results of a methodological application for determining the guidance threshold runoff and bankfull discharge for flash flood warning in the SEAFFGS, which will be applied for the mountainous area of Quang Nam province as a pilot study area. The research results will be the first step for studies to determine the threshold runoff formed for flash flood warnings and can be referred for other mountainous regions of Vietnam.

Keywords: Flash Flood; SEAFFGS; Bankfull discharge; Threshold runoff.

1. Introduction

Flash flood is considered as one of the disasters causing the most terrible loss of human lives and properties because of their occurrence on a small scale, rapid development when there is heavy rainfall combined with triggering factors related to topography, geology and land cover. The concept of flash flood is defined differently due to various studies approaches, but they overlap when describing a flood that forms quickly after heavy rainfall with high intensity. According to WMO [1], a flash flood is a flood occurring in a short period of time with a relatively high flood peak. The American Meteorological Society (AMS) [2] defines that flash flood as a flood event with very short duration of rising and falling and with little to no forewarning, it is a result of highly intense rainfall events across the small basin. The US National Weather Service (US NWS) [3] also defines a flash flood as a rapid and intense flow which is caused by high water mass reaching a frequently dry area or a very high–water level rise in streams, canals, rivers exceeding the predetermined flood level and usually occurring within 6 hours of the incident (heavy rain, dam breaking, ice melting). Flash flood thresholds may vary from regions to regions and basins to basins. Besides, [4] states that flash floods often occur in mountainous basins with catchment areas ranging from a few tens of square kilometers to several hundred square kilometers. Flash floods with a peak time of less than 3 hours in a 5–10 km^2 basin in the United Kingdom while in the US, a peak time of up to 6 hours for a 400 km^2 basin is considered a potential flash flood basin.

Vietnamese Scientists have also introduced many different concepts of flash floods in order to express the fast and intense characteristics of this type of disaster. [5] said that Flash flood is a type of big flood which occurs suddenly and lasts for a short time (fast up and down quickly) with great destructive power. [6] gave the definition: Flash flood is a type of flood with rapid speed (sweeping which occurs suddenly (usually appears at nights where it rains small–flood pipes) on a small or large scale, maintained for a short or long period of time (depending on the rainfall–flood event), carries a lot of mud and sand and has great destructive power. According to [7] flash flood is a flood formed by rainfall combined with unfavorable combinations of buffer surface conditions (topography, geomorphology, cover, etc.) to produce mud, rock flows on the steep slopes (basins, rivers and streams) and propagate very quickly downstream, causing sudden and terrible destruction in the mountainside areas and along the rivers and streams through which it overflows.

Currently, following the functions and tasks prescribed by the Government, flash flood warnings are carried out at the Viet Nam Meteorological and Hydrological Administration (VNMHA and implemented directly at the National Center for Hydro–Meteorological Forecasting (NCHMF), Regional Hydro–Meteorological Centers and Provincial Hydro–Meteorological Centers. The Early Warning Systems (EWS) are considered the key to reducing the impacts of flash floods.

For the purpose of enhancing the capacity of warning small–scale natural disasters such as flash floods, the World Meteorological Organization (WMO) cooperates with the United States Agency for International Development/Office of U.S. Foreign Disaster Assistance (USAID/OFDA), the National Oceanic and Atmospheric Administration/National Weather Service (NOAA/NWS) and the Hydrological Research Center (HRC) are collaborating to develop a supporting system. Flash Flood Guidance System with Global Coverage (GFFGS) for the benefit of the community with multi–stakeholder coordination. Flash flood guidance system (FFGS) is developed to provide a system of tools to support hydrometeorological forecasters around the world in operational work, analysis, monitoring and warning of flash flood disasters through observed data, real–time model data, and real–time information on guidance rainfall thresholds capable of generating flash floods in a certain area [8].

In 2019, the first FFGS system was established for Vietnam under the name of VNFFGS within the framework of the project "Investigation, survey, and mapping of flash flood risk zoning for the Central and Highland regions, and develop a pilot system of flash floods warning for high–risk localities in order to serve planning, directing and operating disaster prevention and climate change adaptation" implemented by the Viet Nam Institute of Meteorology, Hydrology and Climate Change [9].

In 2022, the Southeast Asia Flash Flood Guidance System (SeAFFGS) funded by WMO was transferred to the Viet Nam Meteorological and Hydrological Administration (VNMHA) for management as the representative role of SeAFFGS's Regional Center. SeAFFGS is the first flash flood warning supporting system using extremely short–term forecast data and integrating a large number of different data sources from Southeast Asian countries including: satellite and radar estimate rainfalls, telemetry rainfall, 04 quantitative precipitation forecast products, real–time and historical data received from member countries, products of Flash Flood Risk with warning time up to 36 hours. In this system, Vietnam provides and shares data including: 10 radars, 1500 automatic rain gauges, and administrative maps of districts, communes, and extremely short–term forecasting products (Nowcasting), quantitative precipitation forecast products from radar and from numerical weather forecast model WRF with coverage for 04 countries Laos, Cambodia, Thailand, Viet Nam. The sub–basins divided in SeAFFGS have an average area of about 20 km^2 with a total of over 71,000 sub–basins for 4 member countries in Southeast Asia, of which 18,345 sub–basin are in Vietnam. The FFG approach implements flash flood warnings based on the comparison of observed or forecast rainfall over a certain period of time in a watershed with the estimated Q_{bf} (FFG) rainfall generation for Vietnam only.

The SEAFFGS system has been tested, evaluated and applied in the flash flood warning service for mountainous areas of Vietnam. The purpose of the study will be: (1) Presenting the method of determining threshold runoff for FFGS oriented warning; (2) Applying this method to calculate threshold runoff and bankfull discharge in the SEAFFGS, pilot application in the mountainous area in Quang Nam province.

2. Materials and Methods

2.1. Description of study site

The Central region has been facing natural disasters such as flooding, flash flood that occur frequently with enormity. Most of the provinces of this region recorded flash floods which cause great loss of life and property. Quang Nam is one of the central coastal provinces that suffer from many types of disasters, including flooding and flash flood. The topography of Quang Nam province features many areas with a combination of several disadvantages such as: steep terrain, strong cleavage forming narrow V–shaped stream, slope of 30–45 degrees, two walls in both sides of the stream with the condition of breakable soil structure, bedrock lying leading to landslides situation [10]. The short and steep characteristics of the stream networks as well as narrow valleys in the upstream are the basic factors for high–risk of flash floods and landslides.

In October 2020, 4 communes in Quang Nam face landslides, flash floods, and tube floods which cause great destruction. Districts where flash floods often occur are Bac Tra My, Nam Tra My, Phuoc Son, and Tam Giang. The study selects Quang Nam province which has many high–risk points for flash floods in recent years, to pilot the application of the threshold runoff generating flash floods and the bankfull discharge in mountainous areas.

2.2. Data used in the study

Observed data: Hourly and daily rainfall from 150 rain gauges, flood peak records of 60 hydrological stations in the whole country.

Model data: The catchment data of the Southeast Asia flash flood guidance system (SEAFFGS); Survey data on flash floods (rainfall, causes) of the Viet Nam Institute of Meteorology, Hydrology and Climate Change, Viet Nam Institute of Geosciences and Minerals Resources, Provincial Hydro–Meteorological Center in Quang Nam province.

Map data: DEM (Digital Elevation Model) map (30m×30m) scale obtained from free website of United States Geological Survey–USGS at http://gdex.cr.usgs.gov/gdex/.

2.3. Calculation methods of flash flood formed rainfall threshold and bankfulldischarge threshold

Threshold Runoff is an important factor which is widely used worldwide in flash flood warning methods. However, determining the exact threshold runoff in different areas is a big challenge because flash floods are caused by many factors including hydro–meteorology, topography, land cover, and human activities. The approachable SEAFFGS flash flood warning system is based on several concepts of FFG, FFT and Q_{bf} [9], providing users the necessary information to assess the potential of flash floods in areas, including:

(1) Flash Flood Guidance (FFG) is the volume of rainfall over a given duration in a small catchment which is required for the occurrence of a Bankfull discharge at the river basin outlet. The FFG is an indicator of the volume rainfall needed to overcome the soil water storage and streambed, causing minor flooding in the basin. The FFG is continuously updated based on current soil saturation water deficits (as determined by previous soil moisture conditions), precipitation, evaporation, and infiltration losses.

(2) Flash Flood Threat (FFT) is the mean precipitation of a basin in a certain period exceeding the corresponding FFG value. The Flash Flood Threat index is determined according to the difference (or percentage) between the cumulative rainfall during the forecast period and the corresponding FFG.

(3) Bankfull discharge (Q_{bf}) is the discharge in a river/canal that is just enough to cause flooding to the entire riverbed at the same level as the bankfull channel [10].

2.3.1. Q_{bf} determination in the FFGS

Bankfull discharge is an important parameter that determines the volume of guidance rainfall capable of generating flash floods (FFG). The method of determining the bankfull discharge is based on the geometrical features of the basin or riverbed where the bankfull discharge occurs. The method of determining Q_{bf} based on cross–sectional geometry is only suitable for rivers and streams condition with clear banks and riverbeds. In mountainous areas, many river sections have a V–shaped cross–section with two steep banks, not separating the riverbed and the riverbank [9].

The determination of bankfull discharge based on topography requires a lot of surveys and measurement albeit with irregular sufficient data for calculation. Many researches have stated that Qbf is usually a peak flood discharge with a return period of about 1–2 years [10–12]. So, in the FFGS system, Q_{bf} is also defined according to $Q_{max50\%}$. Thus, each sub–basin has a Q_{bf} value, and the FFG of different periods will be different to the form the Q_{bf}. When establishing the FFGS, the bankfull discharge is determined by the HRC based on the relationship between the bankfull discharge at hydrological stations with a catchment area of less than 2000 km^2 and the basin characteristics in Table 1. This method has been implemented in many US states such as California, Iowa and Oklahoma,... The regression equation is built in the following 3 types [9]:

$$Q_{bf} = bA^{a} \quad (1)$$

$$Q_{bf} = bA^{a1}R^{a2} \quad (2)$$

$$Q_{bf} = bA^{a1}S^{a3} \quad (3)$$

where Q_{bf} is the bankfull discharge; A is the catchment area; R is the mean annual precipitation; S is the catchment slope; b, a, a_1, a_2, a_3 are calculated coefficients.

Table 1. Correlation of bankfull discharge with area A, basin slope S, and annual precipitation R in Iowa and Oklahoma (US) [14].

State	Correlation function
Iowa	$Q_{bf}= 20,4*A^{0,0607}S^{0,44}$
Oklahoma	$Q_{bf}= 0,03*A^{0,59}R^{1,84}$

Inheriting research results from the project "Investigation, survey, and mapping of flash flood risk zoning for the Central and Highland regions, and develop a pilot system of flash floods warning for high–risk localities in order to serve the purpose of planning, directing and operating disaster prevention and climate change adaptation" [9] conducted by the Viet Nam Institute of Meteorology, Hydrology and Climate Change in 2019, analyzed the relationship Q_{bf} according to formulas (1), (2) and (3). Vietnam is divided into 4 regions for analysis and identification based on rainfall and flood characteristics, including the Northern, Northeast and Middle North, the Northwest, the North Central and Highlands. The calculation results are in Table 2.

Table 2. Relationship Q_{bf} with basin features [9].

Region	No station	$Q_{bf}= bA^a$			$Q_{bf} = bA^{a1}S^{a2}$				$Q_{bf} = bA^{a1}R^{a3}$			
		a	b	R^2	a_1	a_2	b	R^2	a_1	a_3	b	R^2
Whole VN	60	0.844	2.44	0.616	0.0790	0.40	18	0.670	0.9	1.9	0.31	0.725
Northern	34	0.765	3.60	0.600	0.0760	0.33	15	0.602	0.9	2.0	0.26	0.737
NorthEast &Middle North	14	0.768	6.01	0.724	0.0778	0.45	20	0.796	0.9	1.4	0.44	0.810
NorthWest	20	0.721	2.27	0.536	0.0770	0.47	15	0.537	0.9	3.1	0.38	0.768
Central&Highland	27	0.871	4.90	0.729	0.0629	0.47	16	0.735	0.9	1.1	0.27	0.772

Through the analysis results, the addition of mean annual precipitation and catchment slope as independent variables to determine runoff showed an improvement albeit insignificant, while uncertainty increases in all sub–catchment.

2.3.2. Determination of rainfall threshold causing flash flood

The rainfall threshold causing flash floods or the threshold of bankfull precipitation can be determined by the following formula [14]:

$$R_{thr} = A*Q_{bf}/q_{dv} \quad (4)$$

where A is the catchment area (km^2); Q_{bf} is the bankfull discharge (m^3/s); q_{dv} is the unit hydrograph peak for a specific duration ($m^3/(s.km^2.mm)$).

The unit flood hydrograph peak can be determined by measured data. However, this method will not be feasible in the case of limited hydrological time series. The unit flood peak is calculated by using the Geomorphological Unit Hydrograph method. Accordingly, the peak flood discharge in the time period t_R is determined by the formula:

$$Q = 2.42iAt_R/\Pi^{0.4}(1- 0.218t_R/\Pi^{0.4}) \quad (5)$$

where $\Pi=L^{2.5}/(iAR_L\alpha^{1.5})$; $\alpha = S_c^{0.5}/nB^{2/3}$; t_R is the duration of effective rainfall (h); L is the main stream length (km) ; i is the effective rainfall intensity (cm/h); R_L is the Horton's length ratio. Assign n as the corresponding river level of the tributary in which the precipitation threshold for bankfull is to be calculated, n+1 is the river level of the tributary and the pour into river, the R_L ratio determined by the total length of the n–level rivers divided by the total length of (n+1) level rivers (in the same main river system); Sc is the local channel slope; n is the Manning roughness coefficient; B is the channel top width at bankfull (m).

The top width (B), hydraulic depth (D) at bankfull and local channel slope (Sc) can be determined according to the relationship between basin area characteristics. The relations between features B, D and Sc has been developed for some US states. In Iowa and Oklahoma in the US, sets of channel cross–sectional data were available and utilized to develop these regional relationships:

Table 3. The relation between B, D Sc and A corresponding Qbf in some states of US.

California	Iowa	Oklahoma
$B = 3.29A^{0.3714}$	$B = 2.8A^{0.363}$	$B = 2.33A^{0.542}$
$D = 0.3A^{0.261}$	$D = 0.82A^{0.160}$	$D = 1.03A^{0.198}$
$Sc = 0.006A^{-0.385}$	$Sc = 0.045A^{-0.203}S^{0.564}$	$Sc = 0.006A^{-0.385}$

Threshold runoff R_{thr} equal to the rainfall intensity times its duration tR(i×tR). We have:

$$Q = 2.42RA/\Pi^{0.4}(1 - 0.218tR/\Pi^{0.4}) \quad (6)$$

Thus, the threshold runoff with different time can be calculated based on the basin characteristics such as: catchment area, local chanel slope, the top width, Manning roughness coefficient, Horton's length ratio and bankfull discharge. The parameters of the relations of B, D, Sc with the basin characteristics is taken according to the relation of the state of California, where the climate and rainfall conditions are similar to Vietnam. The formulas to calculate B, D, Sc are as follows:

$$B= 3.29A^{0.3714} \quad (7)$$

$$D= 0.3A^{0.261} \quad (8)$$

$$Sc= 0.006A^{-0.385} \quad (9)$$

where B is the top width at bankfull; D is the hydraulic depth at bankfull; Sc is the local channel slope.

According to [14] gave the formula for calculating Manning's roughness coefficient (for cases with roughness coefficient higher than 0.035) as follows:

$$n = 0.43\ Sc^{0.37}/D^{0.15} \quad (10)$$

where n is the Manning's roughness coefficient; Sc is the local channel slope; D is the hydraulic depth.

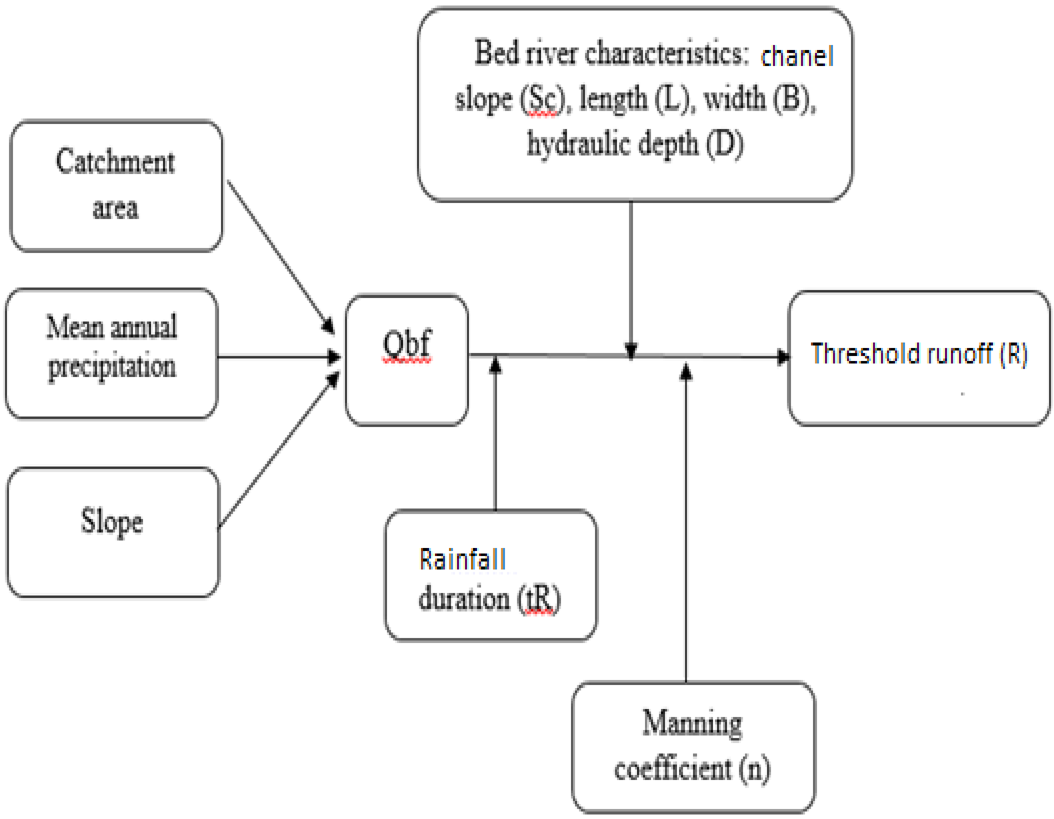


Figure 1. Diagram of bankfull discharge and threshold runoff for flash flood warning.

3. Results and Discussion

3.1. Division of sub–basins of Quang Nam province

Mapping data for dividing sub–basins in Quang Nam province is extracted from the sub–basin division map layer for the entire Southeast Asia region in the SEAFFGS system (source: https://222.255.11.76/SEAFFGS_MAPSERVER/). Using QGIS software, Clip tool to separate sub–basins in Quang Nam province with 643 sub–basins in total (Figure 1).

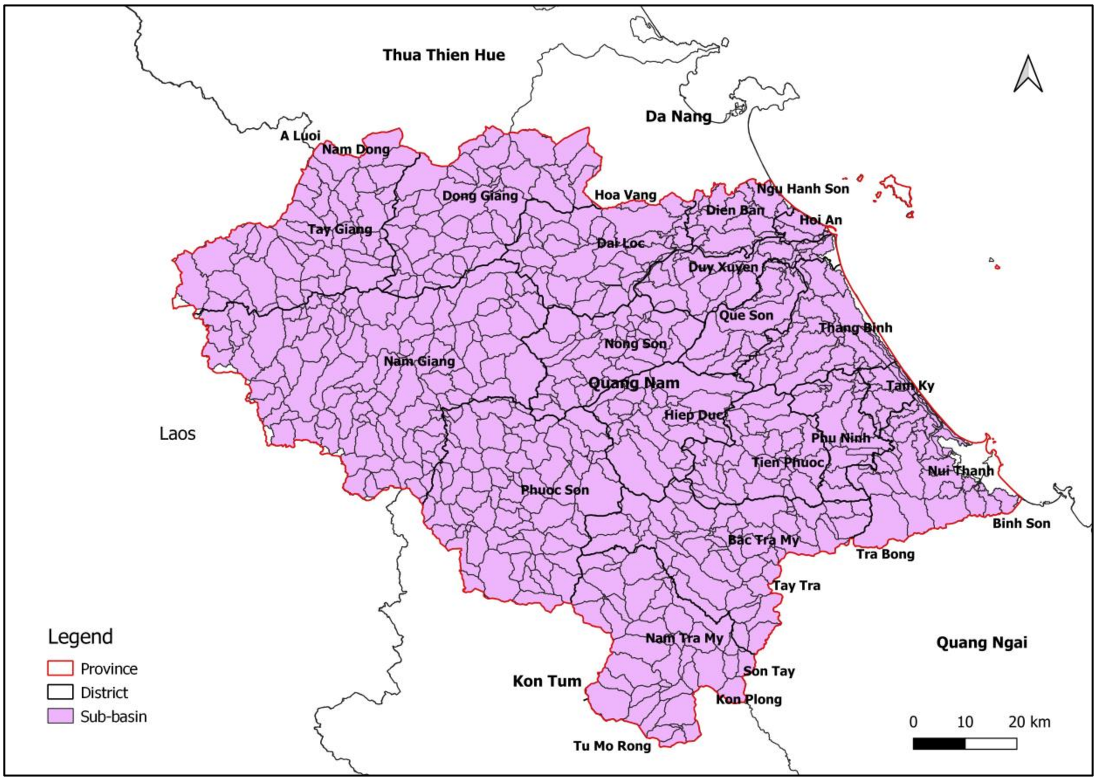
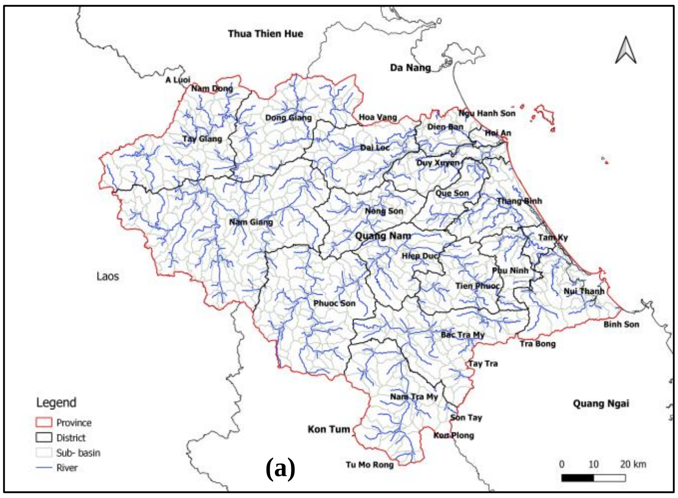
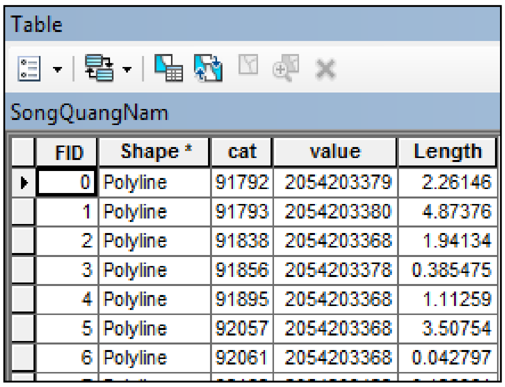


Figure 1. Sub–basins devided in Quang Nam Province.

3.2. Calculating the length of rivers and streams in Quang Nam province

Using ArcGIS software, Flow Accumulation and Flow Direction tools create a network of rivers and streams in Quang Nam province. Using the Calculate Geometry tool in ArcGIS calculate the river length (Figures 2a–2b).





FID	Shape *	cat	value	Length
0	Polyline	91792	2054203379	2.26146
1	Polyline	91793	2054203380	4.87376
2	Polyline	91838	2054203368	1.94134
3	Polyline	91856	2054203378	0.385475
4	Polyline	91895	2054203368	1.11259
5	Polyline	92057	2054203368	3.50754
6	Polyline	92061	2054203368	0.042797

(b)

Figure 2. (a) River network used in calculations in Quang Nam province; (b) Example of calculating river length in sub–basins of Quang Nam province.

3.3. Calculation results of bankfull discharge in Quang Nam

Applying the method of calculating the bankfull discharge (Q_{bf}) following the method of the SEAFFGS system, the bankfull discharge will be calculated for the sub–basins with an area less than 2000 km^2. The study will not calculate Q_{bf} for areas which cover rivers, lakes, ponds, etc. Using the calculating Q_{bf} formula in Table 2 for the Central and Highlands's regions [9] apply for sub–basins in Quang Nam province:

$$Q_{bf} = 4.9\ A^{0.871} \quad (11)$$

Calculation results show that: The Q_{bf} discharge value of sub–basins range from 10–130 m^3/s: with sub–basins less than 20 km^2, the Q_{bf} value is below 60 m^3/s; with sub–basin with area of 20–50 km^2, the Q_{bf} value ranges from 60–130 m^3/s (Figure 3).

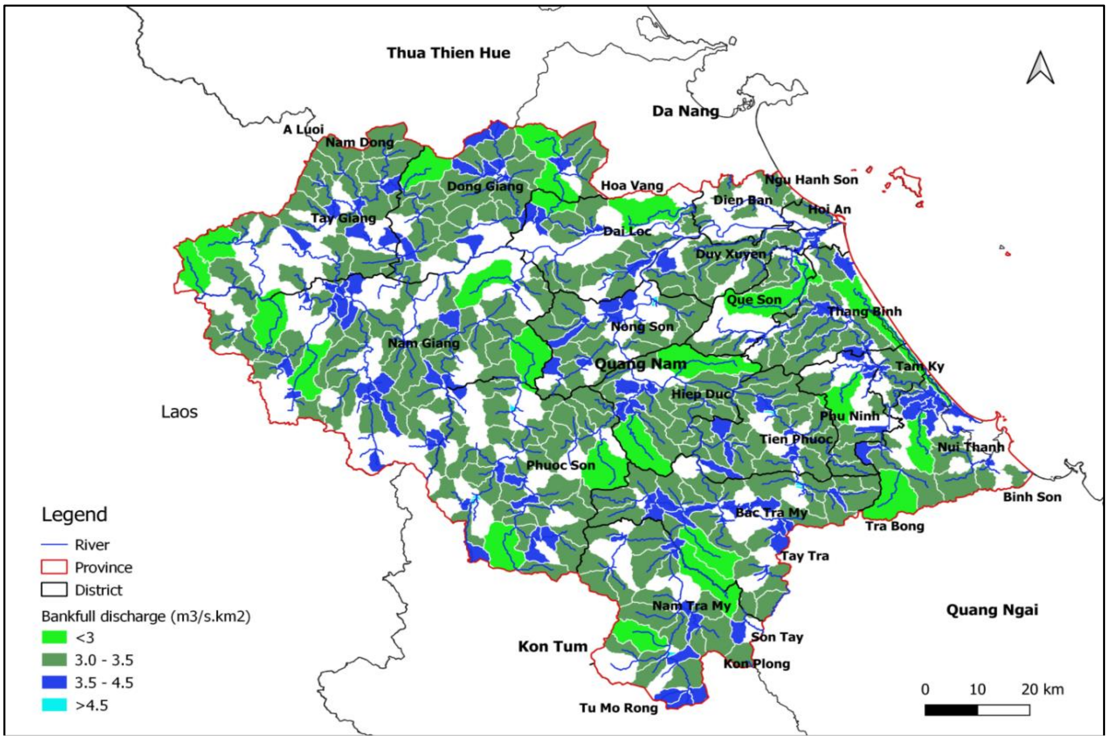


Figure 3. Module of bankfull discharge in the sub–basins of Quang Nam province.

3.4. Calculation results of the threshold of rainfall causing flash floods in Quang Nam

The rainfall threshold causing flash flood or the threshold runoff generating Q_{bf} in the duration of 3 hours and 6 hours is calculated by formulas (5) and (6). Calculation results of Q_{bf} will be the basis for calculating the threshold runoff. According to formulas (5) and (6), intermediate features B, D, Sc, Manning roughness coefficient will be intermediately calculated according to formulas (7), (8), (9), (10). The R_L index, which is the ratio of the Horton length taken as a reference from the calculated value following the river basin characteristics of the state of California with a climate similar to that of Vietnam, is 1.9 [14].

The results show that the threshold runoff with duration of 3 and 6 hours in upstream areas such as Phuoc Son, Nam Tra My, Bac Tra My, Nam Giang and Tay Giang tends to be higher than in the downstream districts such as Nui Thanh, Nong Son, Hiep Duc, Dong Giang. Threshold runoff values for basins less than 20 km^2 in 3 hours or 6 hours are equal or less than 20 mm; for basins of 20–50 km^2, the common threshold runoff is from 20–35 mm in 3–6 hours; for basins with an area larger than 50–80 km^2, the threshold runoff varies widely from 35–80 mm; for basin larger than 80 km^2, the threshold runoff for flash flood generation is greater than 80 mm in 3–6 hours (Figures 4–5).

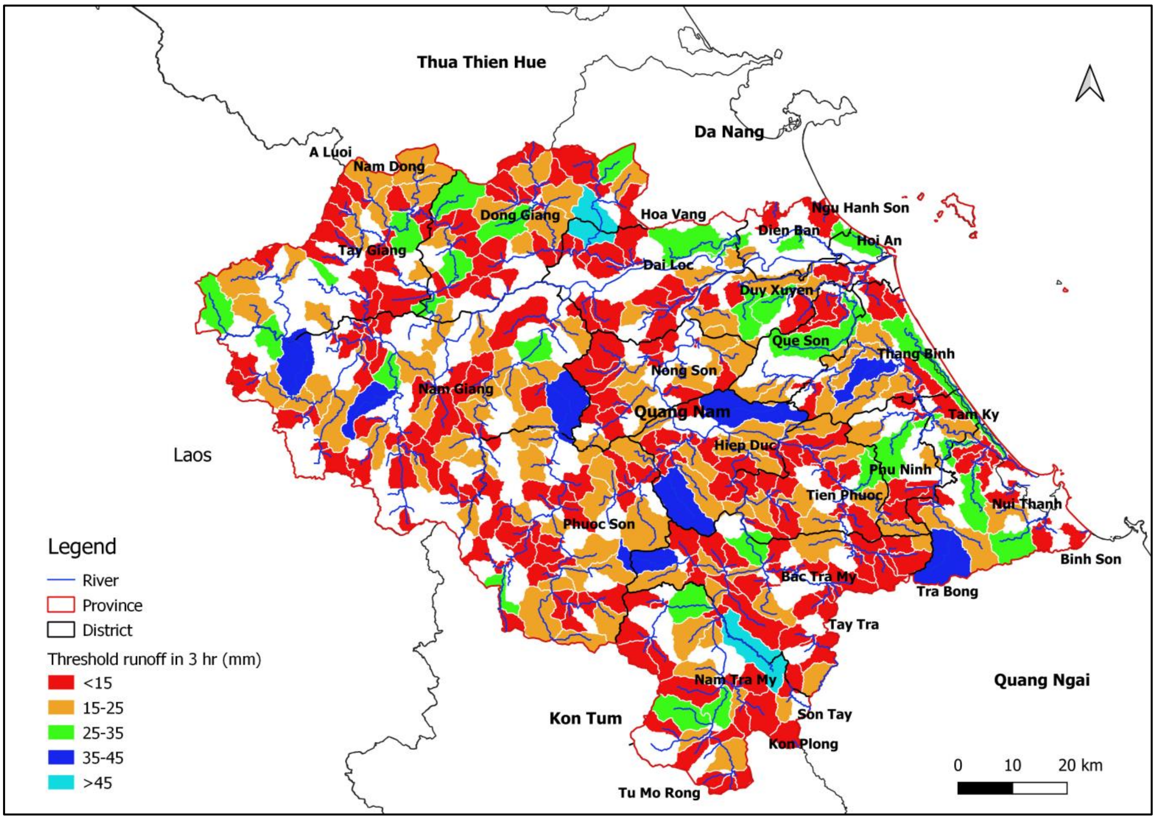


Figure 4. Threshold runoff in the 3–hour period in sub–basins of Quang Nam province.

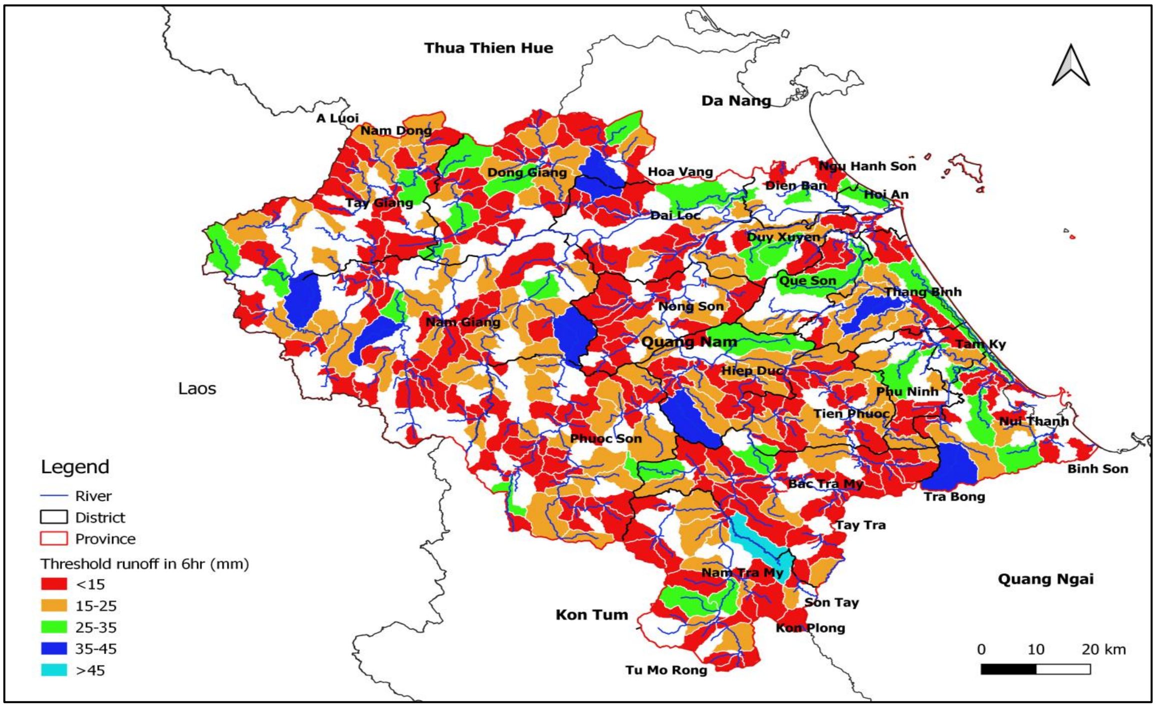


Figure 5. Flash flood generating rainfall threshold in the 6–hour period in sub–basins of Quang Nam province.

3.5. Experimental application ofthreshold runoff for some flash flood events in Quang Nam

Currently, monitoring data on flash floods in disaster–prone areas is limited. Statistical data and detailed monitoring data on flash floods such as time of occurrence, hourly rainfall accumulation, current status of the basin...have not been systematically collected and stored in uniformed database. The information is mainly collected scatteredly from many sources such as: the Central Steering Committee on Natural Disaster Prevention and Control, the Provincial Committees for Natural Disaster Prevention and and Rescue, the Regional and Provincial Hydro–Meteorological Centers, other sources from media or broadcast. The calculation and experimental application of the flash flood generation rainfall thresholds require a lot of detailed information for testing and evaluating.

In Quang Nam, the stored data on the flash flood situation in the past is limited with a lack of detailed information except in recent. According to statistics from the Quang Nam province Hydro–Meteorological Center, there have been 4 flash floods in Nam Tra My and Bac Tra My districts (Table 3) in the year 2020–2021. As a result of the influence of storm No. 9, heavy rainfall occurred in Quang Nam province especially on October 28th when the rainfall was extremely high with the total precipitation recorded at 320 mm. During the occurrence time of historical flood in October and November, 2020, recorded rainfall for 3 and 6 hours before flash flood apparency is relatively large, from 146–259 mm in 3–6 hours; for flash flood event in the November 2021, recorded rainfall of 34 mm/3 hours and 80 mm/6 hours. During the flash flood events in October and November 2020, rainfall occurred a few days earlier. When compared, the calculation results in section 3.4 show that the threshold value of flash flood generating rainfall for the basin over 50 km^2 is quite consistent with 3 flash flood events on 28/10/2020, 6/11/2020 and 18/11/2021. Particularly for flash flood No. 4 in Tra Bui commune, the rainfall threshold for generating flash floods is high.

In general, the reliability of flash flood warning depends on rainfall forecast. The main basis for determining rainfall threshold is based on statistical data on rainfall, basin–specific data. The exact determination of the flash flood generation rainfall thresholds depends on the length and wholeness of time series of survey and investigation data, flash flood events in order to analyze and experimentally adjust. During the warning implementation, the forecasters have to refer to the actual rainfall information measured in the previous period, analyze the future precipitation trend and catchment information, etc. to identify the possibility of flash floods.

Table 3. Statistical data of sseveral flash floods in Quang Nam in 2020–2021.

Position	Area (km^2)	Occurrence time	Precipitation before flash floods (mm)	
			3h	6h
Commune Tra Leng, Nam Tra My, Quang Nam	116.53	15h 28/10/2020	146	195
Commune Tra Leng, Nam Tra My, Quang Nam	116.53	16h 6/11/2020	216	259
CommuneTra Đoc, Bac Tra My, Quang Nam	54.37	06h18/11/2021	34	80
Commune Tra Bui, Bac Trà My, Quang Nam	137.2	09h/29/11/2021	10	34

4. Conclusion

The problem of flash flood warning is associated with determining the thresholds for rainfall and flow that cause this disaster. Currently, according to different research approaches, many scientists have come up with different methods to calculate these thresholds. In Vietnam, the FFG system in the Southeast Asia Flash Flood Guidance System Project (SEAFFGS) has been transferred by the World Meteorological Organization to be used in flash flood, landslide warning that integrates multiple local data sources [15]. Approaching this warning system, the research presents a method to calculate the flash flood generating guidance rainfall threshold and bankfull discharge in the FFGS system of flash flood generation, pilot application for mountainous areas in Quang Nam province.

The characteristics of the basin such as local channel slope, river length, basin area is calculated by ArcGIS software, which are necessary parameters to calculate the threshold runoff. The relationship between basin characteristics for excess rainfall formed flood in small basins tends to be closer than that in large basins [16]. In many watersheds, the cross–section of rivers and streams have a lot of variations over short distances and over time according to the flood situation. Therefore, it is difficult to determine the bankfull discharge in areas with unstable channel cross–section. On the other hand, the method of applying the bankfull discharge occurs in a period of 1–2, the frequency of 50% may be underestimated in many basins. Hence, the threshold runoff calculated from the formula with the bankfull discharge parameters may alsobe underestimated. Determining the frequency of bankfull discharge depends a lot on the length of the river, and the historical time series of flow monitoring at the outlet of the basins. Understanding the methods and knowledge of these limitations is crucial in selecting a method for calculating flow threshold, in interpreting and applying flow threshold estimates.

In the current situation, there is almost no monitoring data at the outlet of small sub–basins (around 20 km^2), and very little monitoring data on the mainstream and tributary with a much larger area. In addition, it is necessary to have a lot of detailed data on rainfall, time of flash flood events, flow...in order to test the threshold runoff and bankfull discharge with highest reliability. Currently, this data source is limited and not fully stored. Therefore, the calculation and experimental application of flash flood thresholds still have gaps that cannot fully reflect the level and threshold of flash flood risk of the basin.

In the condition of limited monitoring data, simple and straight forward methods are still the priority in selecting practical applications. The calculation results of this study combined with the warning products from the SEAFFGS system will lay a foundation assessing the possibility of flash flood risk in Quang Nam area, creating a reference premise for other studies to determine the threshold runoff in other mountainous areas of Vietnam. In the near future, when the automatic rain gauge network is expanded and the observation time series is much longer extended, the flash flood data stored in detail will be a valuable data source for updating and developing more the flash flood generating thresholds runoff and bankfull discharge. Moreover, proactive preventative measures in addition to early warning system should be implemented in order to alleviate the loss caused by flash flood.

Author's contribution: Developing research ideas: T.T.P., T.T.M; L.H.D.; Data processing: T.T.M., N.T.N.Q., N.T.K.; Draft of the article: T.T.P.; T.T.M.; Editing: T.T.P.

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