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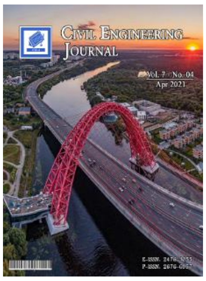

Primarily Results of a Real-Time Flash Flood Warning System in Vietnam

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Abstract

In recent years, losses and damages from flash floods have been steadily increasing worldwide as well as in Vietnam, due to physical factors, human activities, especially under a changing climate. This is a hotspot issue which requires immediate response from scientists and policy-makers to monitor and mitigate the negative impacts of flash floods. This study presents a way to reduce losses through increasing the accuracy of real-time flash flood warning systems in Vietnam, a case study developed for Ha Giang province where the topography is relatively complex with severe flash floods observed. The objective of this paper is to generate the real-time flash flood system based on bankfull discharge threshold. To do this, HEC-HMS model is applied to calibrate and validate observer inflow to the reservoir with nine automatic rain gauges installed. More importantly, on the basic of measured discharge at 35 locations from the fieldtrips, an empirical equation constructed is to identify the bankful discharge values. It bases on the relationship between basin characteristics of river length, basin area and bankfull discharge. The results indicate an effective approach to determine bankfull threshold with the established-empirical equation. On the scale of a small basin, it depicts the consistency of flood status and warning time with the reality.

Keywords: Flash Flood; FFG; Real-Time; Bankfull Discharge, Ha Giang Province.

1. Introduction

In recent years, flash flood events have caused particularly serious consequences in Ha Giang, a province in the northwest of Vietnam. It has become more complex and more extreme in frequency of occurrence and intensity. In the period of 2012 to 2016, more specifically, Ha Giang recorded 15 flash flood events killing 70 people, injuring 82 peoples, and damaging 19500 houses and many crop areas. The damage cost was estimated at 1500 billion VND [1]. The extreme flash flood events which can be listed are one killing 7 people in July 2014 in Hoang Xu Phi district, and one sweeping 3 others away in September 2015 [2]. Currently, mitigation measurements of this disaster are facing many challenges due to a complex interaction mechanism of natural conditions. They are meteorology, geology, topography, and climate change. In addition, flash floods often occur at the same time with other natural disasters, such as landslides, making research even more difficult. Consequently, the asset and human losses derived from the flash floods are severely recorded in Ha Giang province where its topography is fairly complex with steep slopes. Although there have been many studies on flash flood, knowledge about its mechanism is limited. Flash floods have different features from floods in river, notably short time lag and occur in small mountain catchments with few hundred square kilometers or less [3]. This shows that forecasting of flash floods is quite challenging compared to

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traditional flood forecasting approaches. According to Miao et al. [4], the monitoring system in areas where flash floods occur is often insufficient. This is exactly the case for a sparse station density like Ha Giang area. There are only 33 hourly rainfall stations on 7945.8 square kilometers of the province (http://kttvqg.gov.vn/).

Dealing with flash floods, there has been much attention from scientists for several decades [5-7]. Kumar et al. [8] implemented a comparison of Emotional Neural Network with Artificial Neural Network for modeling rainfall-runoff in the Sone Command, Bihar where flood events were frequently recorded under conditions of heavy rainfall. Using a high resolution model of distributed rainfall-runoff, Takahiro et al. [9] also investigated ensemble flash flood predictions in cases of heavy rain events in Japan. It showed the different results for each heavy rain events. In general, there are lots of approaches to study the flash flood. Water amount, an indicator, is importantly used to identify flash flood in the river that exceeds the transport capacity of the river. The river discharge at this moment is called bankfull discharge. Many authors identified bankfull discharge values in the range from 1 to 2.5 years returned interval [10, 11]. This approach faces the difficulty because calculated basins are often ungauged catchments. Moreover, the channel geometry strongly affects the value of bankfull discharge. The bankfull discharge can also be identified by field survey. Bankfull stage, which is water level corresponding with bankfull discharge, can be recognized in the field by several physical indicators and characteristics along the stream's banks. These indicators discussed in Carpenter et al. [6] and Mulvihill [12] and proposed the regression equation between the bankfull discharge and the basin characteristics, which can be easily identified using geography information system technique [6, 12].

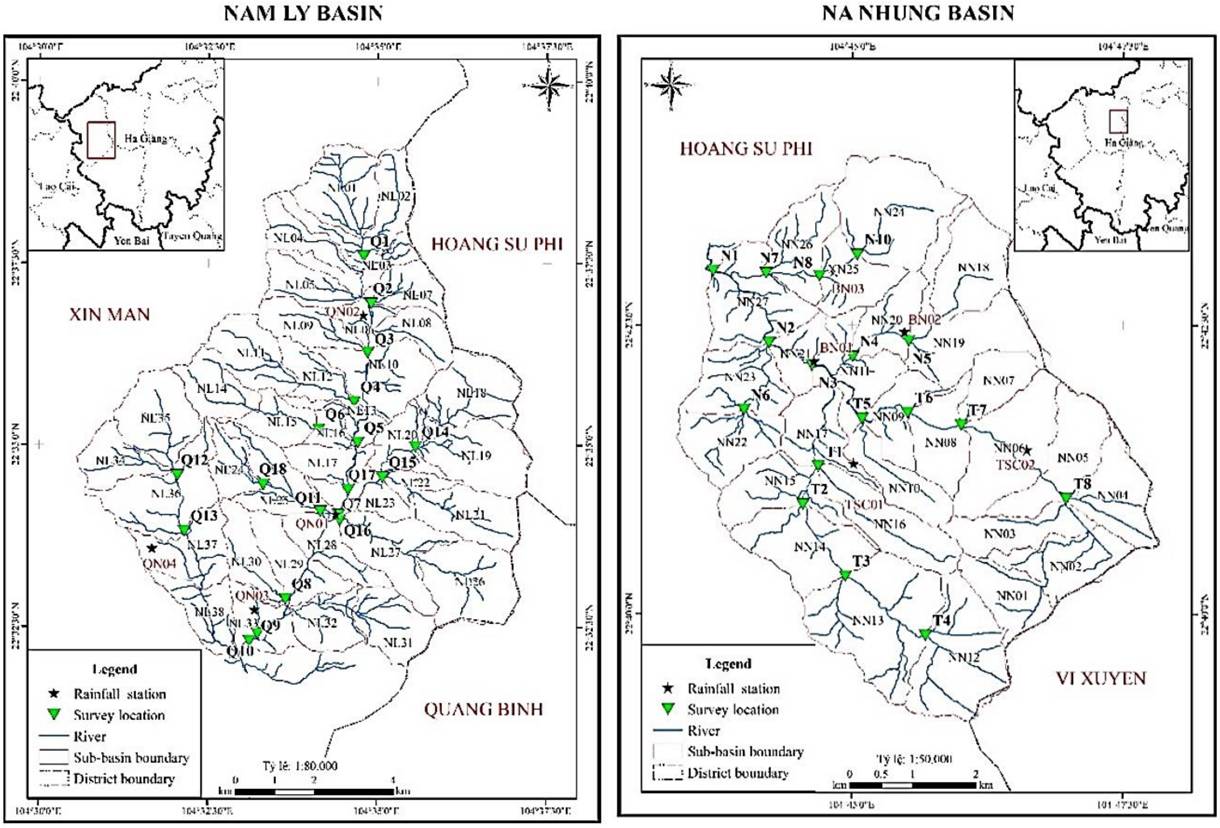
Bent et al. [13] developed this approach for streams in Massachusetts. This approach will enhance the accuracy of the important locations where channel geometry is surveyed. For location without conditional investigations, the regression equation will be used to reduce the amount of work. The next issue in flash flood warning process is to identify the rainfall threshold [4]. Flash Flood Guidance (FFG) method has been used in many studies [14-16]. FFG is the rainfall in a certain period (1-, 3- or 6-hour), causing water in the river to reach bankfull discharge value. The value of FFG is temporal variation and is closely related to soil moisture. According to Borga et al. [3], the impact of antecedent soil moisture on flow is nonlinear and important. Georgakakos [14] used Sacramento soil moisture accounting (SAC) model to describe the complex process of soil moisture. The SCS-Curve Number (SCS-CN) method [17, 18] is also a common method to define soil moisture condition which were discussed in researches [3, 19].

Flash flood forecast is specially a complex issue due to depending on many factors (e.g., meteorological conditions or river characteristics). As illustrated in lots of studies that meteorological contributions to flash flood are significantly important [20-22]. The reason for this is that extreme rainfall events potentially leading to pluvial flash floods closely associates to air moisture like dewpoint temperature, relative humidity or precipitable water. However, one of the most important factors is the river characteristics (e.g., river cross section, river slope) [23-24]. They identify the transport capacity river segments and decide the bankfull discharge threshold. Another important contributing factor of flash flood event is the current basin condition. Basin conditions can be expressed through soil moisture as well as current river water levels. This condition will determine the FFG value at each time. The accuracy of forecast and nowcasting rainfall also plays a decisive role for flash flood warning. In this study, the authors mentioned all these factors to improve the accuracy of the flash flood warning system via a real-time flash flood warning system. This research process combines (1) designing the field survey to investigate bankfull discharge values; (2) developing the rainfall-runoff model associated with observer real time rainfall data to assess the current status of the basin; and (3) determining the FFG value in real time, combined with the forecasting rainfall to appropriate flash flood warnings. The study is applied to the Nam Ly and Na Nhung basins in Ha Giang province, Vietnam**.**

2. Materials and Methodology

2.1. Research Area

This study was conducted for two catchments of Nam Ly and Na Nhung River in Ha Giang province, Vietnam. Areas of the two basins are 92.72 and 41.46 km^2, respectively. These basins have a steep slope of 44.17% for Nam Ly and 58.82% for Na Nhung. The study basins are located near the rainfall band eye Bac Quang with an annual rainfall of about 4000 mm. In these areas, flash floods often occur with serious consequences. Figure 1 shows the location of the study basins



(a) (b)

Figure 1. Nam Ly (a) and Na Nhung (b) basin

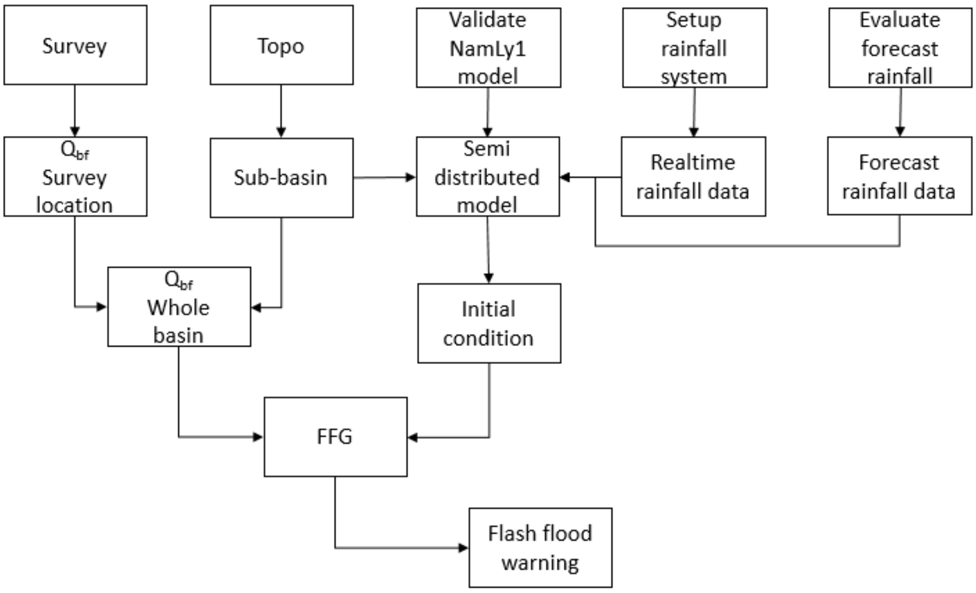


Figure 2. The methodology flow chart

2.2. Overview of Methods

The research method is presented in the Figure 2. Based on the field survey data, the values of the bankfull discharge at the survey locations are determined. A regression equation is developed between the basin characteristics and bankfull discharge value. This equation is used to calculate bankfull discharge values for all sub-basins. The semi-distribution models are conducted for the research basins. The research used real-time rainfall data from the station system in the basins as input to the mathematical model. The peak discharge at the outlet of the basin would be continuously updated and compared with bankfull discharge to define the FFG values. In this study, the forecasting rainfall product from the Global Environmental Multiscale Model (GEM) model is selected [25]. The forecast rainfall value is compared with the FFG value in each time to issue the appropriate warning message. The flowchart of computing processes is described in these sections below

2.3. Bankfull Discharge

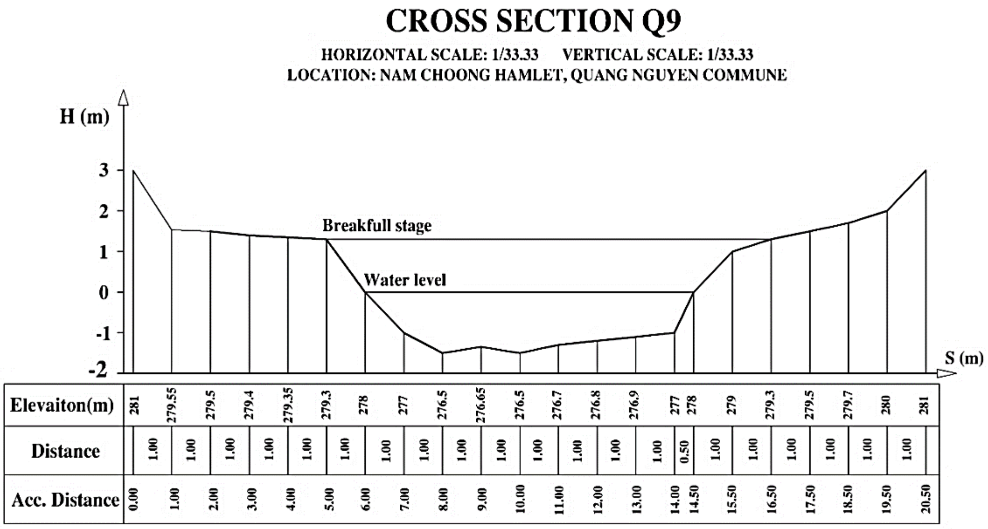
Research did a survey at 35 locations in two basins of Nam Ly and Na Nhung (Figure 1). The investigated locations are shown in Figure 1. The selected locations included main streams and tributaries to increase the representativeness of collected data. In each location, channel geometry is measured. In addition, the discharge value at 2 times in the flood and dry seasons are determined. Based on these data collected, the discharge – water level curve (Q = f(H)) for each location used the Manning's Equation 1:

$$Q = \frac{1}{n} A . R^{2/3} S^{1/2} \tag{1}$$

Where Q: Discharge (m^3/s); A: Flow Area (m^2); R: hydraulic radius (m); S: Slope of Energy Gradient (-); n: Manning's Roughness Coefficient

In the right-hand side of the equation, A and R are determined from cross section data corresponding with each water level. The n value of each cross section is preliminary selected following instruction of Barnes (1967) [26] depending on investigated locations. The value of S can be assumed to equal river slope at these locations. The Q = f (H) curve should be adjusted to fit observer discharge values.

At each cross-sectional measurement site, the bankfull indicators are identified. The Figure 3 presents an example of cross section at Nam Choong village, Quang Nguyen commune. In this location, changes in slope from vertical bank to a horizontal flood plain are the identifier bankfull indicators. The detail archived data is listed in the Table 1. Based on the Q~H curves which mentioned above, bankfull discharges at these locations are calculated.



Elevaiton(m)	281	279.55	279.5	279.4	279.35	279.3	278	277	276.5	276.65	276.5	276.7	276.8	276.9	277	278	279	279.3	279.5	279.7	280	281
Distance		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
Acc. Distance	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	14.50	15.50	16.50	17.50	18.50	19.50	20.50

Figure 3. An example of cross section Q9 in Nam Ly basin

Based on the topographic map at a scale of 1: 10000, the Nam Ly and Na Nhung basins were divided into 38 and 27 sub-basins, respectively (Figure 1). The area of each sub-basin varies from 0.7 to 4.5 km^2. The outlets of these sub-basins are the junction or where populations are close to the river. The watershed division considers the spatial distribution of rainfall which causes the difference in the flow on the tributaries. At each outlet of sub-basin, discharge should be carried out via mathematical model. Therefore, flash flood warning can be done with more detailed at these locations.

Due to data limitations, measurements could not be made at all sections, so an alternative method was used to estimate bankfull discharge for whole basins. The survey locations are presented in Figure 1 and corresponding sub-bassin characteristics is shown in table 1. In this table, F is basin area, L is mainstream length, Z is average elevation of sub-basin, Sriver and Sbasin is river slope and basin slope, respectively, CN is CN index which was estimate by land cover data. A regression equation between the bankfull discharge and the basin characteristics is established based on survey data. This equation was used to define bankfull discharge values for all sub-basins

Table 1. Bankfull stage and bankfull discharge value at investigated location

ID	Name	Bankfull stage (m)	Bankfull discharge (m^3/s)	F (km^2)	L (km)	S_{basin} (-)	Z (m)	S_{riverr}	CN
1	Q1	817.44	41.55	6.63	2.950	0.737	890.78	0.276	67.714
2	Q2	653.30	27.78	1.73	1.875	0.773	835.75	0.265	65.412
3	Q3	532.65	78.66	18.94	5.560	0.691	928.2	0.167	69.293
4	Q4	464.60	36.87	4.70	5.239	0.627	965.48	0.193	73.861
5	Q5	378.75	117.17	28.37	8.216	0.668	926.08	0.100	69.854
6	Q6	623.50	37.37	4.13	3.947	0.614	1230.6	0.225	72.843
7	Q7	367.73	130.02	50.45	10.213	0.648	1060.8	0.075	70.256
7	Q8	290.50	31.04	2.13	2.202	0.455	666.66	0.059	68.682
9	Q9	279.40	163.80	77.17	14.566	0.619	967.29	0.057	69.866
10	Q11	385.65	35.43	4.28	3.725	0.553	947.43	0.231	67.551
11	Q12	757.63	45.18	5.71	2.541	0.663	1371.8	0.284	72.576
12	Q13	603.80	57.78	10.24	4.052	0.619	1202.8	0.178	70.407
13	Q14	510.56	52.73	7.72	3.315	0.679	1115.7	0.233	70.821
14	Q15	470.75	71.01	13.63	4.916	0.663	1019.9	0.139	71.283
15	Q16	366.60	60.11	8.05	4.583	0.651	1001.2	0.138	73.325
16	Q17	410.80	122.45	34.99	9.543	0.652	1106.1	0.079	70.047
17	Q18	830.75	22.79	1.57	1.880	0.529	1098.4	0.222	68.867
18	T1	970.80	80.48	10.57	5.449	0.617	1415.9	0.142	71.272
19	T2	1044.80	65.93	7.60	4.779	0.640	1466.3	0.137	72.63
20	T3	938.00	48.87	5.69	3.432	0.675	1560.4	0.148	74.098
21	T4	1350.50	31.89	2.48	1.638	0.677	1665.7	0.233	75.932
22	T5	737.86	91.56	13.11	5.986	0.593	1327.9	0.127	67.979
23	T6	827.80	80.43	11.07	5.126	0.578	1381.6	0.122	68.017
24	T7	980.73	60.47	8.95	4.208	0.565	1427.8	0.116	67.784
25	T8	1128.75	31.77	5.05	2.098	0.537	1487.5	0.160	69.566
26	N1	571.20	140.79	41.46	10.134	0.601	1230.7	0.084	68.105
27	N2	651.13	132.98	34.55	8.218	0.601	1286.3	0.113	68.541
28	N3	651.19	128.28	30.96	7.420	0.601	1330.1	0.130	68.308
29	N4	717.45	43.49	4.71	3.055	0.592	1252.2	0.184	63.289
30	N5	837.70	35.42	3.75	1.987	0.602	1336.4	0.297	63.002
31	N6	780.80	24.86	1.42	1.434	0.601	953.56	0.268	71.386
32	N7	610.75	52.46	5.00	3.579	0.616	1053.3	0.157	64.293
33	N8	683.70	31.77	3.67	2.695	0.621	1131.1	0.223	62.644
34	N10	825.86	28.85	2.59	1.993	0.651	1243.5	0.273	61.345

Note: F and L is basin area and mainstream length up to basin outlet, they were defined from topography data.

2.4. Semi-Distribution Model

2.4.1. Realtime Rainfall System

To establish a flash flood warning system, the study required 9 automatic rain fall stations on 2 basins. 4 stations were setup in Nam Ly basin and 5 stations were in Na Nhung. Figure 1 and Table 2 present the location of rainfall station system. The observation rainfall data was updated continuously to the system with 5-minute interval. This data was input for rainfall runoff model to define real time condition of the basin.

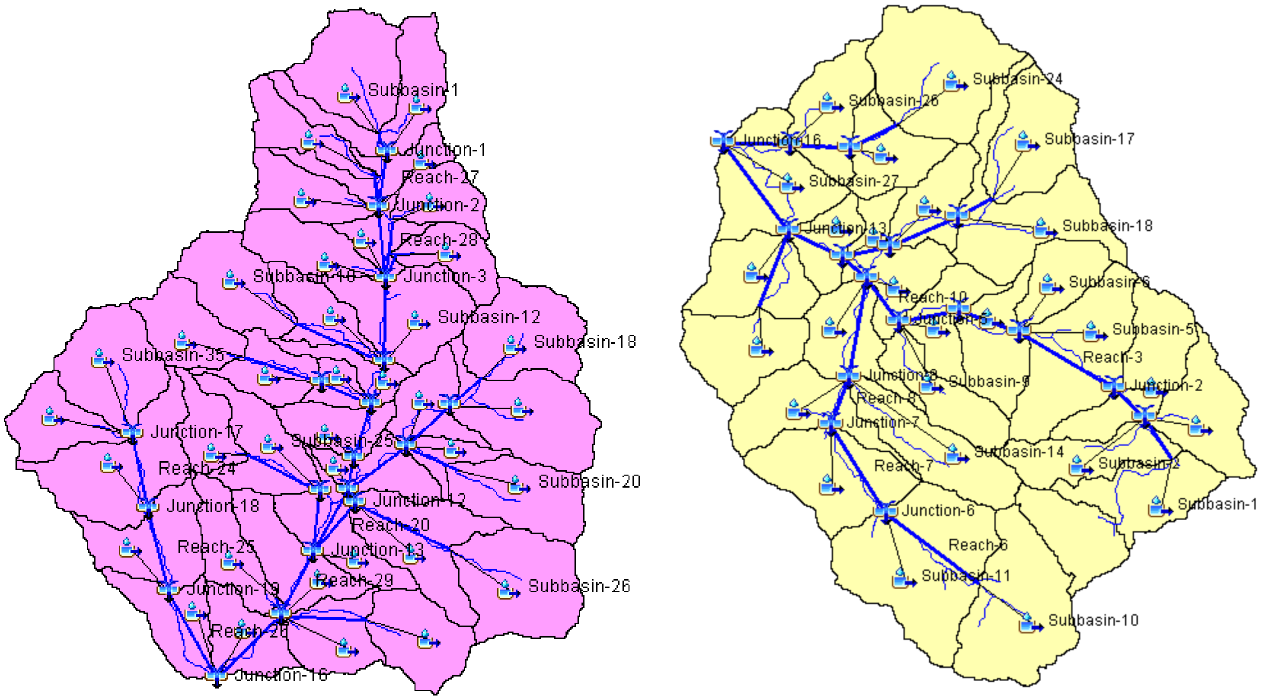
Table 2. Location of rainfall station system

ID	Station	Lat.	Long.	Commune
1	QN01	22°34'29"	104°33'18"	Quang Nguyen
2	QN02	22°33'41"	104°31'55"	Quang Nguyen
3	QN03	22°32'49"	104°33'22"	Quang Nguyen
4	QN04	22°36'52"	104°34'42"	Quang Nguyen
5	TSC01	22°40'49"	104°44'20"	Ta Su Choong
6	TSC02	22°41'44"	104°45'30"	Ta Su Choong
7	BN01	22°42'41"	104°45'31"	Ban Nhung
8	BN02	22°42'70"	104°44'43"	Ban Nhung
9	BN03	22°42'60"	104°44'33"	Ban Nhung

2.4.2. Semi-distribution Model

The processes of calibration and validation were conducted in Nam Ly basin 1. The area of this basin is 76.4 km2. Nam Ly basin 1 is a part of Nam Ly basin. The outlet of Nam Ly 1 basin has a hydropower construction, which measures inflow to the reservoir. This construction has just operated thus only data of 2 flood events at June 4, 2018 and June 24, 2018 were observed. The calibration process and process validation were carried out with data collected from these events.

Based on the results of the sub-basin division, the study established the HEC HMS semi-distribution models for Nam Ly and Na Nhung basins. The structure of semi distributed models can be found in Figure 4. The similar model framework was described in Zhai et al. [27]. In this model, each sub-basin was described by an independent component. The transformation process from rainfall to discharge was carried out through 3 components: loss, transform, and baseflow. Loss is carried out continuously in both dry and wet conditions. The model simulated in both dry and wet conditions, so the SMA model was used. Details of SMA were elaborated in Bennett et al. [28]. The transformation process from excess rainfall to direct runoff via Soil Conservation Service (SCS) dimensionless unit hydrograph [18]. According to Mishra et al. [17] publication, this method was simple and useful for ungauged watersheds. Baseflow was sustained runoff of prior precipitation that was stored temporarily in the watershed [17]. This flow plays an importance role in dry condition. The exponential recession model [29] has been used to present the recession of flow. This is made to ensure that an almost zero flow can occur in the sub basins after a long period without rain. In this model, sub basins were linked by river segments. Muskingum method had been selected to rout water in river segments. The structure of models is shown in the Figure 4.



(a) **(b)**

Figure 4. Hec-HMS model for Nam Ly (a) and Na Nhung (b)

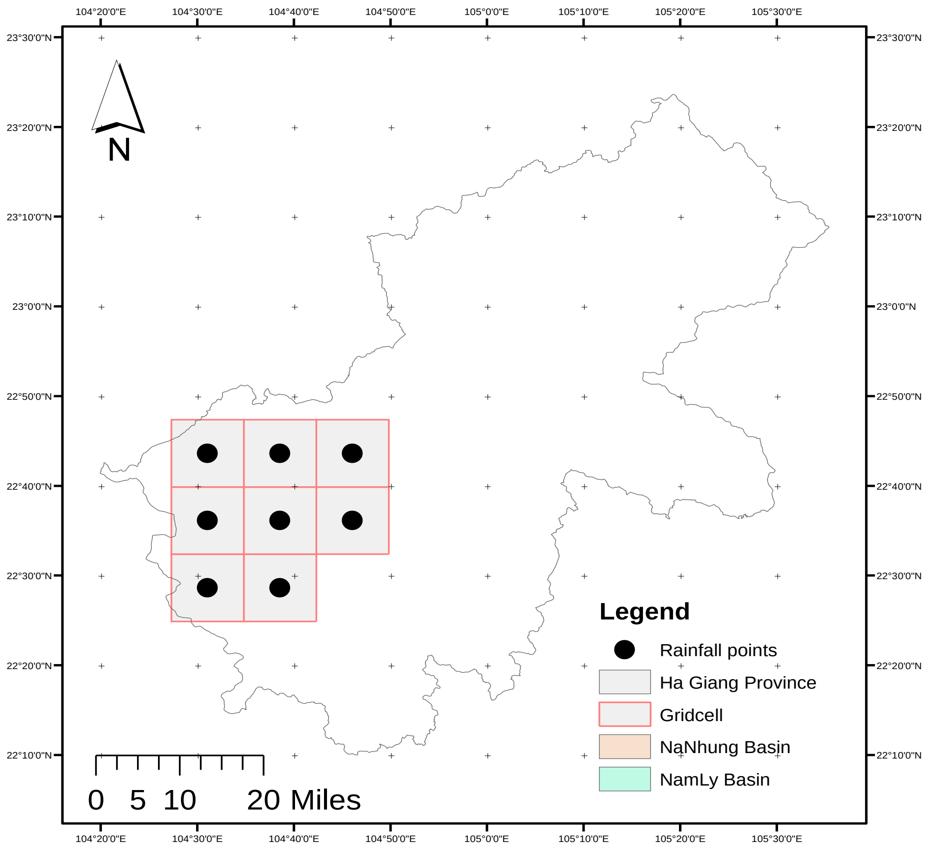


Figure 5. Grid cells of GEM model over the study

2.5. Forecasting Rainfall and Flash Flood Guidance

2.5.1. Forecasting Rainfall

Forecasting rainfall data is adopted from the Global Environmental Multiscale Model (GEM) [18]. This model, often known as the CMC model in North America, is an integrated forecasting and data assimilation system developed in the Recherche en Prévision Numérique (RPN), Meteorological Research Branch (MRB), and the Canadian Meteorological Centre (CMC). GEM is a non-hydrostatic atmospheric model and described briefly in Cote et al. (1998). The physical paramteristics mainly included (1) Planetary boundary layer based on turbulent kinetic energy; (2) fully-implicit vertical diffusion; (3) stratified surface layer, distinct roughness lengths for momentum and heat/moisture; (4) improved force-restore method for land surface processes (evapotranspiration, snowmelt, soil types); (5) solar/infrared radiation schemes with cloud-radiation interactions based on predicted cloud radiative properties; (6) shallow convection parametrization; (7) Fritsch-Chappell deep convection mesoscale scheme with diagnostic cloud properties; (8) explicit cloud water/ice prediction scheme (Sundqvist) with quasimonotone semi-Lagrangian 3D advection and (9) gravity wave drag parametrization. The model is run two times a day and produces forecasts for up to 240 hours with the interval of 3 hours. In this study, the lead-time up to 24 hours with a resolution of 15 kilometers is considered for testing flash flood warning system. Figure 5 shows values of rainfall at grid cells from the model.

2.3.2. Performance of GEM Weather Forecast Model

As first step, skills of the GEM run are compared against the rain gauge in time and space. The spatial comparison is done for 8 grid cells. It is emphasized that the gridded precipitation is created for the whole Ha Giang province. The data from automatic rain gauges during three episodes of June 1-14, 2020; July 04 - 07, 2020 and July 19 - 22, 2020 is used to confirm the performance of GEM run. The temporal comparison uses hourly accumulations for the stations located in the basin. The following metrics are used for the degree of agreement between model and observed rainfall (i) the bias (Equation 3), (ii) the root-mean-square error (RMSE; Equation 4) and (iii) the correlation coefficient r (Equation 5):

$$\mathrm{Bias} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}(\mathrm{M_i} - \mathrm{O_i}) \tag{3}$$

$$\mathrm{RMSE} = \sqrt{\frac{(\sum_{\mathrm{i}=1}^{\mathrm{N}}(\mathrm{M_i}-\mathrm{O_i})^2)}{\mathrm{N}}} \tag{4}$$

$$r = \frac{\mathrm{Cov}(O_i - M_i)}{S_{O_i} . S_{O_i}} \tag{5}$$

Where M_i is the i-th value estimated from the model, O_i is the value observed at the terrestrial station and N is the number of data analysed, r is the linear correlation coefficient between O_i and M_i; and SM_i and SO_i are the standard deviations of M_i and O_i, respectively.

Importantly, HSS index [30] is applied and calculated using the Equation 6.

$$HSS = \frac{(hits + correct\ negatives) - (expected\ correct)_{random}}{N - (expected\ correct)_{random}} \tag{6}$$

Where $(expected\ correct)_{random} = \frac{1}{N}[(hits + misses)(hits + false\ alarms) + (correct\ negatives + misses)(correct\ negatives + false\ alarms)]$.

The HSS values can range from -1 to 1, where the value of 1 indicates a perfect forecast; zero indicates no predictive ability or a forecast equivalent to a reference forecast

2.5.3. Flash Flood Guidance

The principle of FFG definition is illustrated by Figure 6. In this figure, the amount of rainfall up to current situation is shown as back columns. The flow at the outlet of the basin caused by this amount of precipitation is indicated by the black line. The maximum discharge is compared to the horizontal black thin line as bankfull discharge value. In many cases, the maximum discharge does not reach the threshold value. The precipitation in the (patten column) that causes the flow at the outlet is shown as a dash line. The accumulative flow at the outlet is plotted by a dot line. Through the trial and error process, an amount of rainfall will be determined so that maximum of dot line will reaches the threshold value which is shown in Figure 6. This rainfall value will be the FFG value 1h. This process is carried out continuously to determine the temporal basin condition as well as FFG value. For each time step, the value of FFG is compared with the forecasting rainfall value so that it can issue an appropriate warning.

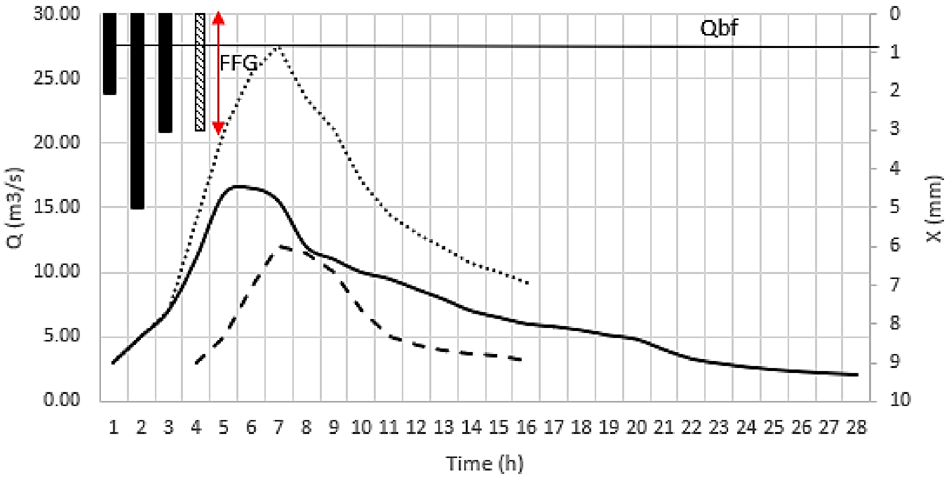


Figure 6. Methodology to define 1h FFG

3. Results and Discussions

3.1. Regression Equations for Estimating Bankfull Discharge

The most accurate way to determining the basin characteristics is survey. However, the survey could not be conducted in the entire basin due to many factors. For that reason, research has developed regression equation to identify bankfull discharge from basin characteristics. The development of this regression equation is often developed by the authors based on exponential form. This has been mentioned in the research of Carpenter et al. [6]. In this study, the same method was also used.

An issue of concern is the selection of characteristics for the regression equation. Lumia et al. [31] Selected 14 variables to determine flood peak flow with different frequencies. According to Bent and Waite [13], among factors, basin area plays an essential part. However, other factors such as main-channel slope and elevation also have certain effects [32]. Manmade structure such as dams, weir, and diversions can also affect bankfull discharge, but in the study basin, small hydroelectric reservoirs have no effective volume. Therefore, this effect might be neglected. In this study, the authors also tested with several variables that can be easily collected such as catchment area, main river length, catchment slope, and forest area ratio. For the study area the result in Table 3 shows that, the bankfull discharge is closely related to the catchment area and the length of the main river with correlation index are 0.97 and 0.94, respectively. As a result, these characteristics were finally chosen for developing multiple regression equations in these areas.

Table 3. Correlation index between river characteristic and bankfull discharge

	Q_{bf}	Sbasin	Zmean	Sriver	CN	F	L
Q_{bf}	1						
Sbasin	0.131	1					
Zmean	0.101	0.017	1				
Sriver	-0.733	0.326	0.153	1			
CN	0.150	0.137	0.139	-0.163	1		
F	0.973	0.148	0.068	-0.703	0.141	1	
L	0.942	0.087	-0.023	-0.741	0.179	0.946	1

The multiple regression equations for bankfull discharge with these two variables are presented in Equation 7:

$$Q_{bf} = 17.661F^{0.424}L^{0.197} \tag{7}$$

Where Q_{bf}: Bankfull discharge (m^3/s); F: Basin area (km^2); L: Main river length (km).

These selected variables offer many advantages. For example, the values of these two variables can be easily determined from the topographic data. Currently, remote sensing technology is developing rapidly, available topographic data sources are freely available and easy to collect (e.g., Global Digital Elevation Model, Shuttle Radar Topography Mission). Besides, with GIS tools, the catchment area as well as the main river length has been determined with very high accuracy. Nearly the whole process is automated and everyone will get the same result with same input. The sensitivity analysis was also performed with 10% variation of input variables. The result shows that the bankfull discharge only vary within 6%.

This equation was developed by using base-10 log-transformed bankfull discharge and basin characteristic data (Table 1) for all 34 study sites. The standard techniques of multiple regression analyses were evaluated by reviewing the Adjusted R Square (coefficient of determination). The Adjusted R Square for bankfull discharge (0.95) was good. The Significance F value in the ANOVA (analysis of variance) result is close to 0. It means that, this regression equation is reliable, and it can be extrapolated to other sub-basins. Similar to other study conclusions [31, 32], the basin area is a vital factor because its P value is the smallest.

As mentioned above, the survey will give appropriated value of bankfull discharge with each river segments. For this approach, the priority sites such as riparian areas will be selected in advance for the survey. Thereby, improving accuracy at these positions needs more attention. Using regression equations should minimize the survey work. The basin characteristics can also be easily determined from available data. However, in some cases, bankfull indicators may not easy to identify. In addition, the application of regression equations for basin out of survey data range might also bring some errors. To reduce error incidence, it should be considered when selecting measurement locations.

3.2. Selection of Forecasting Rainfall

Performance of the GEM model is examined using the continuous and dichotomous indices. These values are calculated from the basin-averaged rainfall values of GEM model as plotted from the Figure 5 and 04 and 05 automatic rainfall stations for basins of Nam Ly and Na Nhung, respectively. The results for 3 periods from June 1-14, 2020; July 04 - 07, 2020 and July 19 - 22, 2020 shows that the GEM model obtains the values for RMSE (12 mm/3 hours), Bias (0.7 mm/3 hours), r (0.12) and HSS (0. 51) for Nam Ly basin. For Na Nhung basin, the values of Bias (-3.5 mm/3 hours), RMSE (13.5 mm/3 hours), r (0.22) and HSS (0.43) are calculated. The comparison with recorded rainfall, the GEM performance is specially emphasized and presented for the periods of 5-8 July, 2020 and 19-22 July, 2020. The reason for this is that the recorded rainfall from automatic stations sharply alters during these periods.

Figure 7 shows a distribution of daily rainfall between GEM model and recorded rainfall over Nam Ly and Na Nhung basins. Generally, it can be seen from this figure that GEM model unsuccessfully captures rainfall events that sharply change from day to day for Nam Ly. Contrary to this, GEM model could relatively capture the mount of rainfall over Na Nhung:

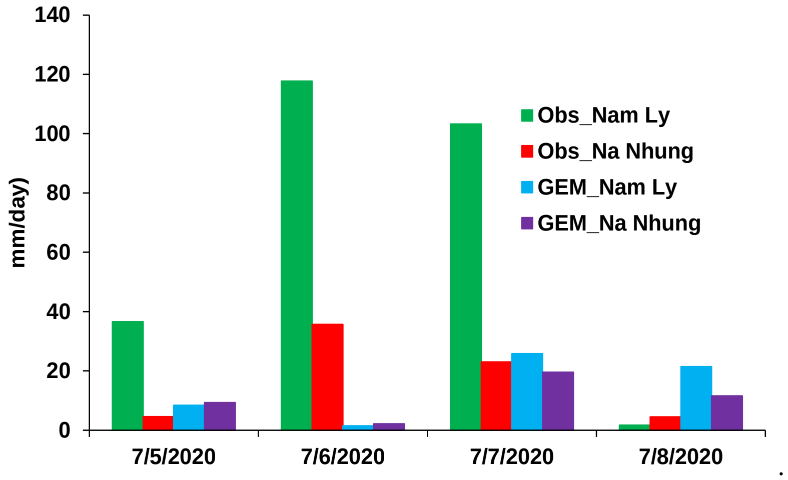


Figure 7. Distribution of daily rainfall during 5 - 8 July, 2020 over basins of Nam Ly and Na Nhung

During the period of 19-22 July, 2020, it is specially pay attention to the GEM model product that produces the rain events in all spans of rain events for Nam Ly basin. Basically, the cumulative distribution function of GEM model well matches the distribution of measured rainfall as shown in Figure 7. Thus, it is deemed to be reliable and highly potential for hydrological and environmental applications at a temporal scale of 3 hours. It is noted that the model could not catch up the events of very extreme heavy rainfall recorded in Na Nhung basin (Figure 8). Regarding to this is very likely from the local types of rainfall due to an ensemble of complex mountain shapes and convective clouds

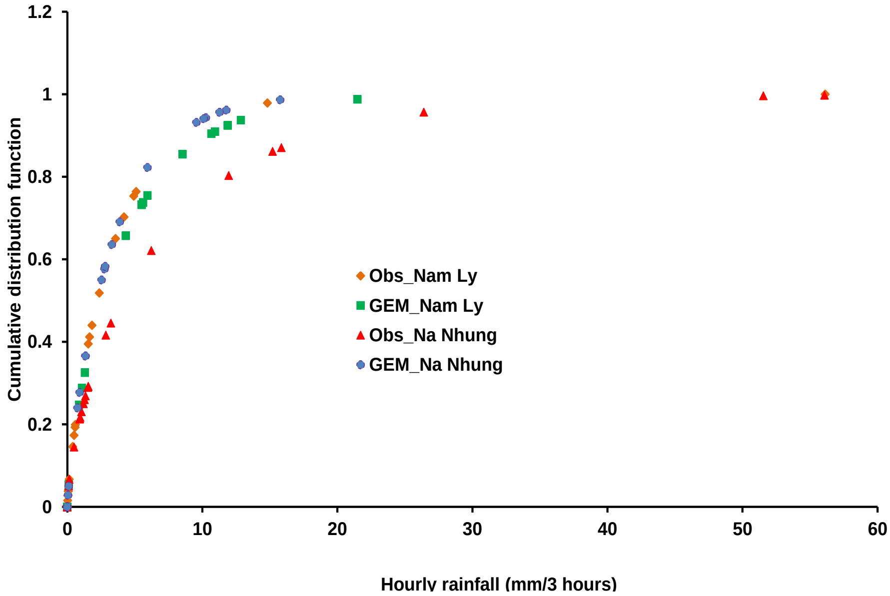


Figure 8. Cumulative distribution function of model and automatic rains over basins of Nam Ly and Na Nhung for the period of 19-22 July, 2020

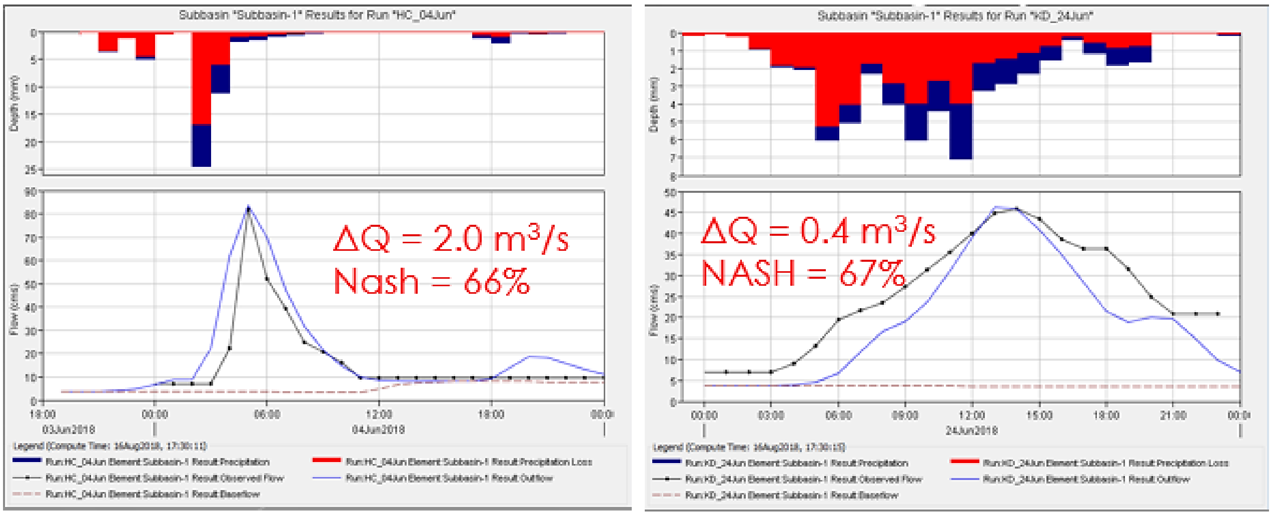
Above analysis of model performance confirm that GEM products potentially use for hydrologic applications and thus they are selected for testing a real-time flash flood warning system developed for Ha Giang Province located in the northern of Vietnam in this study.

3.3. Flash Flood Warning System

The study area locates in Ha Giang province, Vietnam. This is a mountainous area with a steep slope, and it has many waterfalls along rivers. In this region, some segment rivers only have water during flood season. It shows that, hydraulic models can be unstable when being simulated. Considering updated rainfall interval is only lats 1 up to 10 minutes. As a result, all the process in warning system must be completed during this time. This leads that, the semi-distributed HMS distribution model is appropriated selection. This selection ensures the detail level as well as the reasonable simulation time run.

The major issue when using a mathematical model is to ensure its accuracy. In this study, the authors enjoy an advantage when collecting data to validate the model. However, in many cases, the insufficient data is very common.

It is thus necessary to take measures to preliminarily define the model parameters. Chau [33] developed a method to estimate main parameters for HMS model based on basin characteristics (e.g., land use, river length, river slope). This method was successfully applied for Vu Gia - Thu Bon river system. Duc et al. [34] were also successfully adopted by the same approach for Kone - Ha Thanh river basins. Based on this approach, parameters of NamLy 1 were found in this study. The correlation equations are constructed between the basin characteristics and validated model parameters. Using these equations to find the appropriate parameters corresponding to the characteristics of the calculated basin (Nam Ly & Na Nhung). The result of comparison between calculated and observer inflow to the reservoir is shows in figure 6. The Nash indexes are 66% and 67% for calibration and validation, respectively. These values indicate that the performance rating of model is good [35]. As is indicated by this figure, the peak discharge was well simulated in terms of the values and the time occurrence. These are also the most important issues to identify the flash floods. It leads that the study uses this set of parameters to simulate the study basins



(a) **(b)**

Figure 9. Calibration (a) and validation (b) process of Nam Ly 1 basin

After determining the set of parameters, distribution models were used to forecast flash floods. The input of the model is a combination of observer rainfall data and forecast rainfall from GEM product. The output of the model will be the discharge at the outlet of the sub-basin. With semi-distributed model, the system will take advantage of the basin's spatial rainfall station system. The spatial distribution of precipitation in the basin is very large, this will be demonstrated in the experimental prediction process part. Therefore, the model is capable of simulating the changes in the current state for each small sub-domain. Updating the current condition of the basin is particularly important, cause it define the FFG value at certain time and particular location. Compared to other studies in this region [36-37], that only showed flash flood susceptibility map. Our results go beyond previous reports, showing that flash flood can spatial and temporal forecast in our system.

The flexibility is also one of the system's advantages. In the future, under socio-economic development, some new residential areas may be formed, or some new important locations need to be further forecasted. The redistribution of sub-basins, as well as recalculation of sub-basin characteristics, can also be easily done. Therefore, the system is fully capable of changing to adapt to each specific requirement

3.3. Experimental Forecast

The study carried out the experimental forecast in the research areas in 2020. In early flood season 2020, there were 3 extremely flood events happen in this region. The temporal rainfall distribution at all the station in the area is presented in Figure 10. The first event occurred on June 13-14th. This was an extremely rainfall in Nam Ly basin with rainfall amount up to nearly 215 mm (e.g., QN02). However, the total rainfall in Na Nhung ranged from 43 to 75 mm in this event. The rainfall caused severe flooding in Quang Nguyen town (Nam Ly basin) as Figure 11. Flooding did not occur in the Na Nhung basin. The second rain appeared on July 6th. The rainfall concentrated in the Nam Ly basin. Meanwhile, amount rainfall in Na Nhung was not too much. In this event, the massive rainfall intensity reached to 49 mm/h at QN01 station or 41 mm/h at QN03 station. It leaded to flooding in Quang Nguyen town (Nam Ly basin) as shown in Figure 12. The 3rd flood appeared in on July 20-21st. Heavy rains mainly occurred in Na Nhung basin. This was a flood causing the heavy damage to people and properties in the study area. Figure 12 shows some images at Coc Nam village, Ban Nhung commune (Na Nhung basin) after the flood.

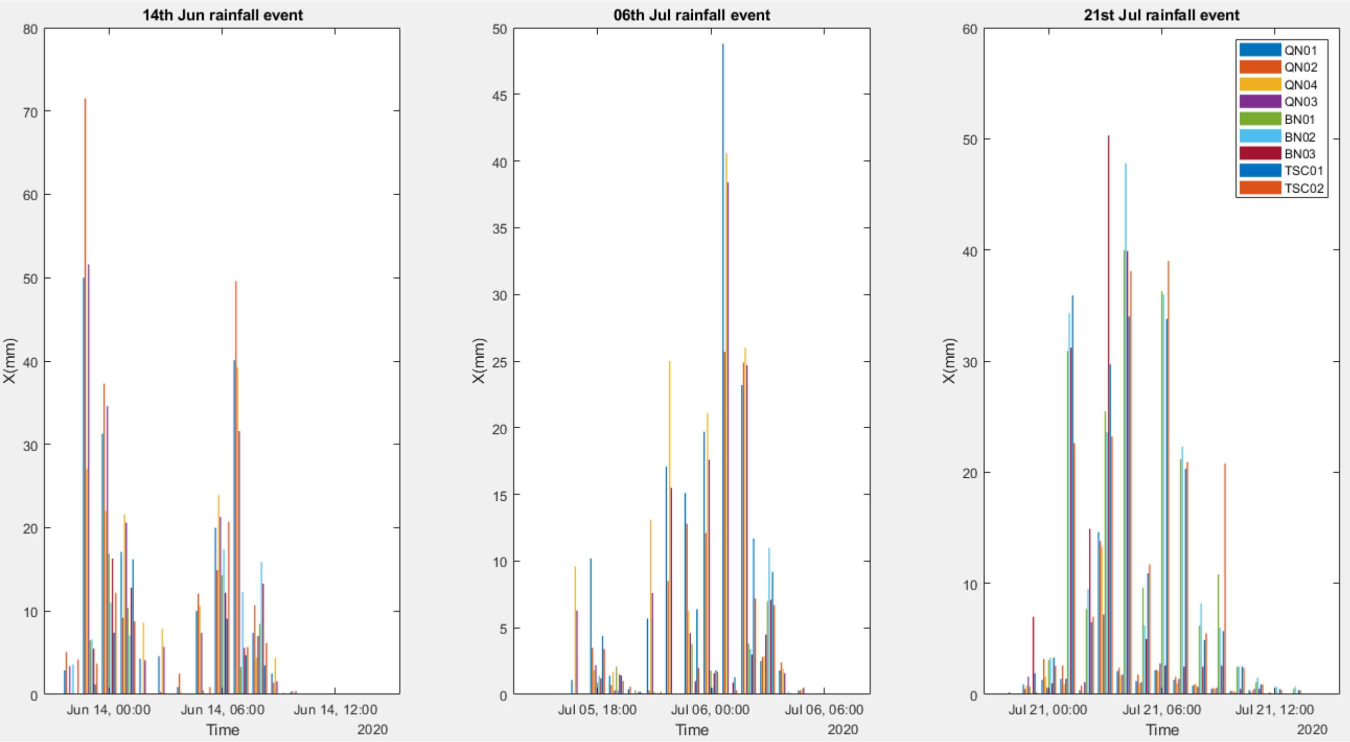


Figure 9. The temporal rainfall distribution in 3 events

Figure 10. The flooding in Quang Nguyen town (Nam Ly basin) during the flood on 13-14 June 2020

Figure 11. The flooding in Quang Nguyen town (Nam Ly basin) during the flood on 06 July 2020

Figure 12. The picture in Coc Nam village, Ban Nhung commune (Na Nhung basin) after the flood on 21 July 2020

Table 4 shows the experimental forecast results of system. Due to the limitation of hydrology station in research area so it is difficult to define exact moment when water level gets over the riverbanks. The data used to verify was collected immediately after the event from local staffs. Therefore, this comparison is only approximate. However, the positive results have shown the potential capability of the system.

Table 4. Rainfall data in extreme event on June 13-14th

Date	Nam Ly Basin		Na Nhung Basin	
	Actual Situation	**System Forecast**	**Actual Situation**	**System Forecast**
13-14 Jun	At 03:00 on 14th, the Quang Nguyen town (NL23) was inundated.	The warning message at sub basin NL23 (Quang Nguyen town) was released at 23h00 13rd.	Light rainfall in this area provided no indication of flooding.	No warning was announced by the system.
05-06 Jul	At 4h00, Quang Nguyen town (NL23) was inundated.	The warning message at sub basin NL23 (Quang Nguyen town) was released at 01h15 06th.	Light rainfall in the Light rainfall in this area provided no indication of flooding.	No warning was announced by the system.
20-21 Jul	Light rainfall in this area provided no indication of flooding.	No warning was announced by the system.	Because the local people live on the mountain flanks, there is no information about inundation. However, landslides killed 2 people in this flood.	The warnings were issued for 11/27 sub-basins from 1:00 on 21rd.

According to the measurement data, it is noticed that the complex spatial distribution precipitation across the research area. There was a big difference between amounts of rainfall on two basins during 3 calculated events, although the distance between these two basins was only 23 km. This shows that the essentials for installing rainfall system for each specific area. Based on these rainfall stations, the local rainfall was accurately measured. This contributes to improving the quality of the warning system in our study. Besides, through the survey process, the bankfull values (discharge and stage) in important locations are determined in a specific way, especially in residential areas when the river channel is strongly affected by artificial constructions. This value will help the system minimize errors compared to using the design flood value of P = 2% like other systems [4]. The results in table 4 confirm that this a good system for flash flood forecasting. The system has issued the correct warnings for all 3 heavy rain events in this region. From the results, it is clear that warning message was announced 3 to 4 hours before the moment when

Quang Yen town was recorded as inundation. Although, the starting point of inundation should be earlier. However, this area is small and flat. We speculate that the flooding process takes time cannot up to 3 hours. The results confirm that the system can provide early warnings. This will be very helpful for local residents as well as decision makers.

Although the system brings many key advantages, it also has limitations. After an operation period, the leaves might fall into the rain gauges, which affect the measurement results. To solve this problem, regular maintenance of rain gauges is required. This is also the reason why we set up these stations in residential areas for the study. Another limitation is the data transmission process performed through the cell signal. Because the systems are set up in the mountain areas, the interruption of cell signal may occur. It is very dangerous to lose the signal at the right time of heavy rain. This can only be overcome by improving the quality of the beacon. However, this is beyond the capabilities of our research

4. Conclusion

The study has setup a real-time flash flood warning system for the Nam Ly and Na Nhung basins in Ha Giang province, Vietnam. The system is a combination of a number of factors to improve the accuracy of flash flood warnings. Firstly, a real-time rainfall system has installed in the research basin to measure spatial and temporal rainfall distribution. For areas with complex rain distribution such as the study area, this observer system is a prerequisite. Based on the comparison of observer and calculated rainfall, the study's result shows that, the forecast rainfall GEM model has appropriate results with the BIAS indexes are 0.7 mm/3 hours and -3.5 mm/3 hours for Nam Ly and Na Nhung respectively. Another factor that contributes to improve the accuracy of our system is the approach to determine bankfull threshold. An empirical equation is established for the study area to determine bankfull discharge from basin characteristics. The empirical equation has a high relation coefficient ($R^2 = 0.95$). The system was experimental forecasted for the June three flood events in June and July 2020 for both basins Nam Ly and Na Nhung. The primarily results show that the status of the flood as well as the warning time of the system are consistent with the reality in the basins. However, it is necessary to carry out further performance for other flood events to confirm the reliability of the system**.**

5. Declarations

5.1. Author Contributions

Conceptualization, Tran Kim Chau and Nguyen Tien Thanh.; Methodology, Tran Kim Chau and Nguyen Tien Thanh.; Formal analysis, Investigation and data pre- and post-processing, Tran Kim Chau, Nguyen Tien Thanh, Nguyen The Toan.; Writing-original draft preparation, Tran Kim Chau.; Writing-review and editing, Tran Kim Chau, Nguyen Tien Thanh, Nguyen The Toan. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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