# BUILDING AN EARLY WARNING SYSTEM FOR MOUNTAINS AREA, CASE STUDY IN THUAN CHAU DISTRICT - SON LA PROVINCE

Ngoc Thach Nguyen[1], Thi Hong Nguyen[1], Xuan Canh Pham[1], Quoc Huy Nguyen[1],
[1]*University of Science, Viet Nam National University, Hanoi*

## Abstract

*Thuan Chau is a district of Son La province in the north mountainous region of Viet Nam. In the rainy season, it is one of the places where is mostly occurred flash flood hazard, causing significant damage to the localities. The early flash flood warning system includes 3 components online conection: automatic weather stations, WebGIS software and Web site . The system is based on hydrological and hydrological access to the catchment basin, which is based on the principle that hazards will only occur where there is a high potential risk and when heavy rainfall exceeds threshold. In the model build map risk of flash floods, eight parameters of the main basin and sub basins had been analyzed and evaluated the weight is determined by the pair-wise comparison methos of the Thomas Saaty-Analytics Hierarchy Process (AHP). Early flash flood warning software is built based on open source programming tools. With the spatial module and online processing in the internet, predicted precipitation of 1- 6 days early from the IMETOS automatic weather station will be interpolated and online integrated with the potential risk maps.The results will exactly determine the locations of flash flood at the risk level corresponding to the predicted rainfall values at the meteorological stations. The system was constructed and applied for early warning flash floods disaster in Thuan Chau district,Son La province by multimedia methods such as e-bulletin boards, SMS messages, Web pages or via traditional warning signals such as speakers or gag. Base on this informations, the manager and the end-users can make appropriate decisions in implementing the prevention before the catastrophe occurs.This technology is being mở rộng expand applied in Viet Nam to avoid, minimize damage caused by the flash flood damage.*

***Key words:*** *flash flood; model; early warning; rainfall threshold, opensource software*.

## 1. Introduction

Thuan Chau is a mountainous district in the north-west of Son La province with a natural area of 154,126 ha (Fig.1.). Locating along Highway No.6 (Hanoi - Hoa Binh - Son La - Dien Bien route and then can connect to the LAO PDR ), Thuan Chau is the residence of diversity ethnic minorities (including: Thai 74.05%, H'Mong 11.16%, Kinh 9.32%, Resistance 2.57% and other ethnic minorities other (2.94%).The typical topography of Thuan Chau is high, steep and strongly divided. The highest and lowest point in Thuan Chau is Copia peak and Da River with an altitude of 1,817 m and 200 m, respectively. In the rainy season, Thuan Chau is one of the places where is mostly occurred land slide and flash flood in Son La province.

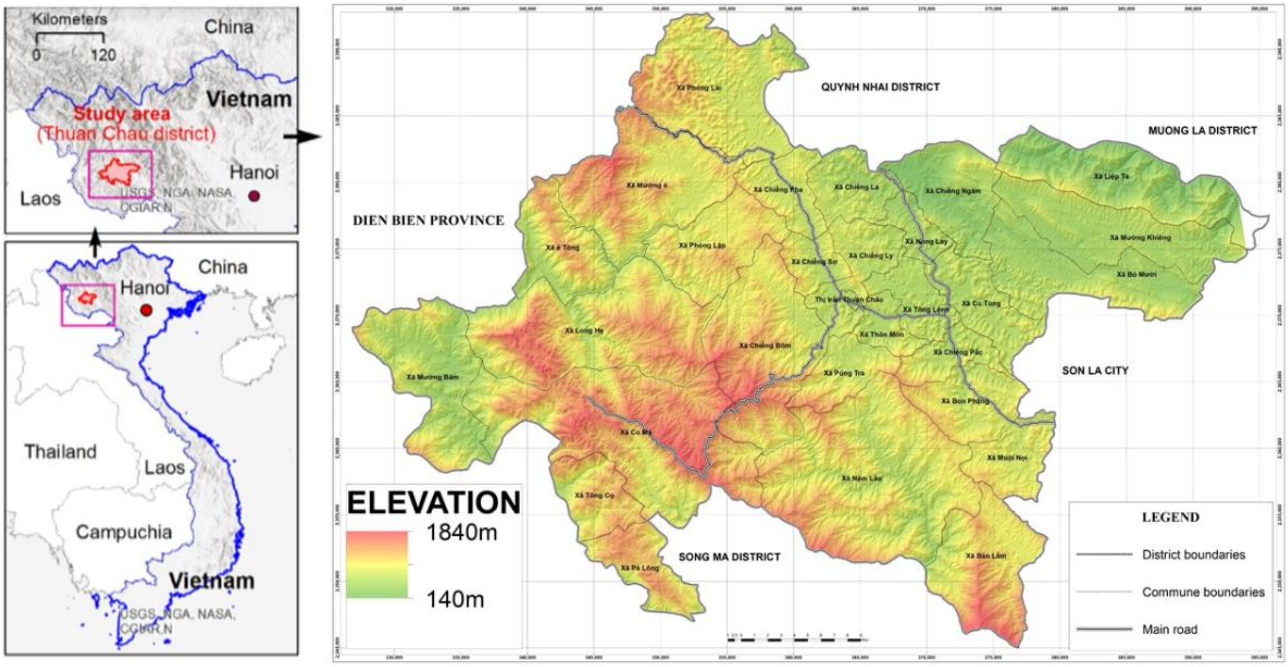


Fig.1. (a) Position in Son La province and (b) map of Thuan Chau district

In recent years, flash flood phenomenon tends to increase in both intensity and frequency, causing significant damage to the localities. Therefore, it is imperative, urgent and practical to build a 1-6 days early warning system on flood risk at district level. The system can transmit alert information to the public via multimedia methods such as e-bulletin boards, SMS messages, Web pages; or via traditional warning signals such as speakers or gag. The manager can then make appropriate decisions in implementing the prevention before the catastrophe occurs.

## 2. Object of study and research methodology

### *2.1. Flash flood definition and objects of the study*

#### *2.1.1. Basin approaching in flash flood research area*

In definition, flash floods are the type of large flood which is suddenly occur in very short time in small basins with steep terrain and high velocity. Thus, flash floods have the significant destruction as compared with normal floods. The formation of flash flood is closely related to the rainfall intensity, climatic condition, terrain properties, human activities and flood drainage condition. Flash flood usually occur a few hours after the heavy rain [1]. However, in fact, the data about flash flood is always lacking and non-systematic. Thus, it is very difficult to use the conventional methods for hydrological forecast calculation in early warning of flash floods [2].

In this study, the approach to integrated watershed management is used as a theoretical basis. The basin is considered as a relative closed system, and all parameters will determine the transportation and accumulation mode of the buffer when the rain occur. There are several buffer parameters including heavy rainfall in specific terrains where have the basin' slope of $25^o$, vegetation cover is less than 40 % due to the forest devastation, the stability of surface land layer is low, and the morphological properties create the good condition for rapid accumulation of water. In those conditions, the flood peaks usually appear after 3 or 4 hours after the starting point of rain, when with the normal floods this time is double or triple[2].

#### *2.1.2. Early-warning model for flash flood*

The general principle of the model is that flash floods will only occur where there is a high potential risk and when rainfall exceeds the level of flood [2,3,10]. The concept is illustrated in the following diagram (Fig.2).

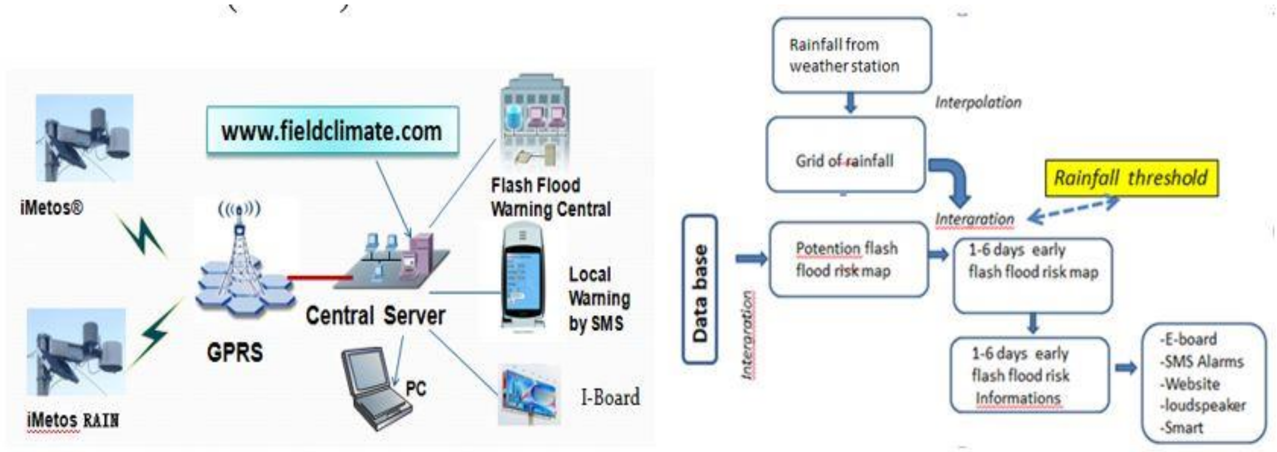


Fig.2. Schema of the system for early warning flash flood in Thuan Chau district

For early warning of flash flood risk, the tasks to be carried out are: (1) developing a potential flood risk map; (2) setting up an automatic climate system that can be connected in two directions with the Global meteorological network; and (3) building WebGIS software online in the Internet to quickly process rainfall forecasts. The precipitation can be quickly identified when it exceeds the threshold, and the information about the flood including time and position will be timely provided in different levels.

In the system, the automatically weather station used is the iMetos instrument of the pessil instrument company of Austria, which work by solar batteries, electric energy supply stability for the equipment even in conditions of lack of sunlight and autoconect to an global meterological network named *fielclimate.com* of Swiss. System can two-way for recording, storage of 120 parameters on weather, climate, environment of each station through the sensors and online receive by the Internet **.** In particular, the system can early weather forecast from 1-6 days with an accuracy of 70-80%. With the 24-hour early forecasts, accuracy can reach to 90-100%. The system also predicts rainfall from the beginning to the end, warning of over threshol-precipitation, extremes of temperature such as hot, cold in the service area. The active radius is 5 - 15 km, depending on the location of the station. In the other,all data are stored monthly in servers, convenient for processing, analyzing and exploiting data for production, scientific research.

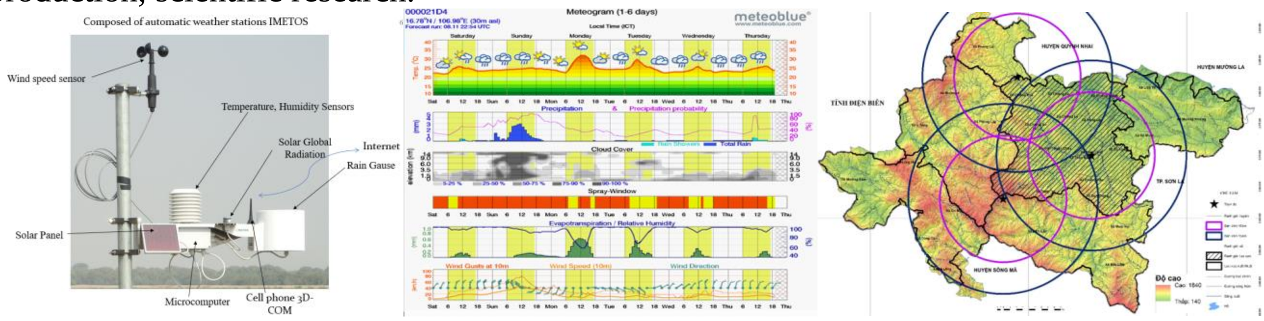


Fig.3. Weather automatic Imetos stations and its location in Thuan Chau

*2.1.3. Models for for flash flood risk mapping*

A flood hazard map shows the potential of flash flood generation for a maximum hydrological period of 33 years. Therefore, depending on the rainfall distribution, flash floods may not simultaneously appear in several areas at the same time, but it may be repeated after a hydrological period. Until now, the establishing a flood risk mapping is still a big challenge with many hydrological - hydraulic models are applying such as NAM, HEC - RAS, SWAT… [3,4,7]. Almost the flash flood maps were developed based on slope flash flood [2], thus they are constructed with very large slope with lack of detail, so the application capacity is limited. With the basin approach and the support of GIS technology, basin parameters are analyzed and processed in the multi-criteria analysis (MCA)[3], the entire basin's space is measured in each pixel with very detailed mapping, thus satisfy the requirements of every aspect.

*2.1.4. Evaluation the role of basin parameters in the formation of flash flood*

In the river basin, the following factors are considered as input data in the analytical model in develop flood risk maps[1,2,3,8]:

(a) Landslide hazard: this factor shows the combination of many other factors affecting the flash flood such as slope, annual average rainfall, geology - lithology, breaking density, deep cleavage density, cross sectional density, status of land use; risk map of river basin landslide.

(b) Maximum daily rainfall: the statistical results show that when a flash flood occurs, the area is often subjected to heavy rainfall with high intensity. Therefore, for flash flood hazards, maximum daily rainfall is included in the calculation and assessment as a necessary condition for flash flood generation. However, for multi-year statistics, this value can be replaced by the average rainfall index for many years.

(c) The flow accumulation value of topographic surface (or Topographic Wetness Index): This value is calculated per pixel unit (30m x 30m) compared to surrounding pixels, showing the ability to focus the face flow on each pixel. At each pixel, the higher this value, the greater the concentration of water in flash floods.

(d) Properties of cover of cushion surface: In the basin, each type of mulch will play a different role in retaining or decreasing the flow rate and flow of water on the terrain. For hydrological models, the role of the mulch - or forest is determined by the manning roughness coefficient or the Curnumber - CN coefficient.

(e) Properties of soil- weathering crust of cushion surface: the weathering crust or soil is capable in infiltrating or saving the rain water. The composition of the material, the thickness of the weathering crust (or soil) will have different effects on the water balance of the basin.

(f) The average slope of the tributaries: With a basin approach to integrated management, each basin is divided into several tributaries. The flow distribution (both flow and velocity) will depend on the characteristics of the tributaries, one of which is the average slope and shape index of the basin. It can be automatically calculated using GIS technology.

***2.2. Research methodology***

*2.2.1. The MCA Multi-Criteria Analysis Model for establishing the flash flood risk map*

MCA is a model that integrates the hydrological and geomorphological model in a basin with the help of GIS technology [2,3,6]. The study focused on identifying the baseline flooding factors, including: soil properties, vegetation cover, basin slope, river density, cumulative flow; and comparing with statistical data to classify the possibility of flash floods of each mapping unit. The flash floods will form when precipitation exceeds the threshold and the risk of flash floods will be determined throughout the basin. GIS application will determine the weight, and then make the integration between the factors with their respective weight, and graphing of flow charts in individual grid cells. This method is qualitative and mainly depend on each researcher, but it is suitable for the small and medium river basins where there is a lack of measurement stations [8,9].

The system diagram of the multi-indicator process is shown in the following diagram (Fig.4).

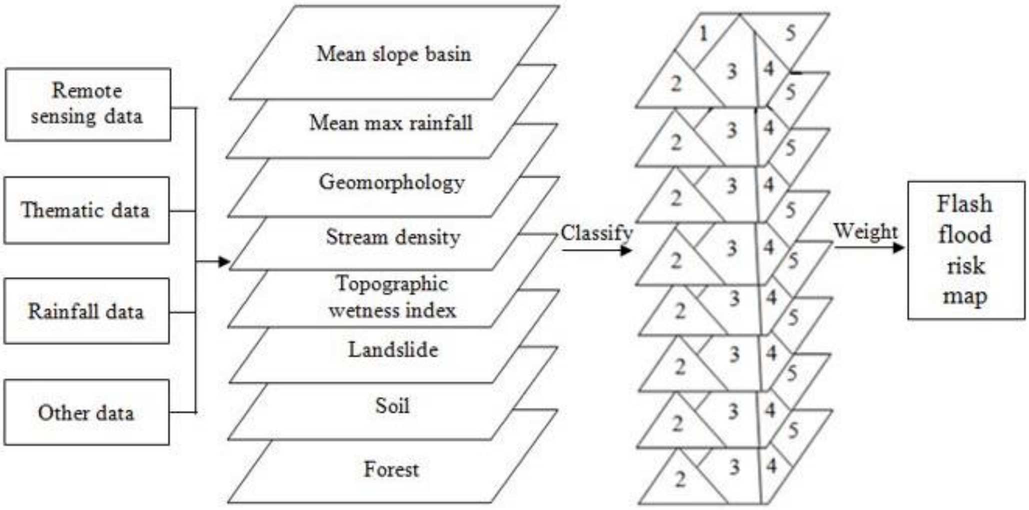

Fig.4. Process diagram of establishing flood risk map

*2.2.2. Spatial modeling in early flash flood warning*

- Determining the threshold of flash flood forming for warning

Flash floods occur only when rainfall exceeds the threshold, which is an important parameter, but it is difficult to determine accurately [2,5,9]. The rain levels which cause flash floods widely change, ranging from 100 mm/h to 220 mm/day, and it is depending on the surface of the basin. Most of the flash flood basins have the average slopes higher than 30% and forest cover lower than 10% [2]. The Vietnamese researchers who study on flash floods classified the probability of flash floods into 4 levels as follows:

✓ Level I (extremely high risk of flash floods): when all four factors occur at the same time in the basin: relatively frequent occurrence of maximum daily rainfall of 100 mm, average slope of more than 30%,less than 10% coverage,medium and low permeability

✓ Level II (high risk of flash floods): when three factors occur at the same time in the basin: relatively frequent occurrence of maximum rainfall of 100 mm,2 of the 3 remaining factors mentioned above

✓ Level III (average risk of flash floods): when two factors occur at the same time in the basin: relatively frequent occurrence of maximum rainfall of 100 mm,1 of the 3 remaining factors mentioned above

- Level IV (low risk of flash floods): not classified at the above levels

In Thuan Chau, as the statistical data from 2000-2017, the threshold of flash flood is defined as follows: Level 5: Xmax ≥ 300 mm, Level 4: 250 <Xmax <300 mm, Level 3: 200 <Xmax <250 mm, Level 2: 150 <Xmax <200 mm and Level 1: Xmax <150 mm.

It should be mentioned here that the flash floods often appear very fast and occur only in short time, thus the expected time of flood forecast warning is also very short, even impossible to forecast. This method allows rapid identification of risk areas based on the rainfall level.

Function for flash flood warning model

$$\boldsymbol{Fr} = \sqrt{\mathbf{f.p}} \qquad (1)$$

Where :Fr is flood risk forecast map,
f is maximum rainfall forecast and
p is potential flood risk map.

*2.2.3. The used data in the research đánh giá*

Depending on the scale of the study map, the number of information layer will be asessed differently. For the scale of 1: 10,000 of the district level, the information layers which is considered include: average rainfall of maximum years (RM), Topographic Wetness Index

(TWI), average slope of subbasin (SB), land slide density (LS), geomorphology (GM), soil (S), forest (FR) - or replaced with cover, river density (SD) ( fig 5).

The original materials for the construction of such layers were analyzed from remote sensing data or collected from various sources. (table 1)

Table 1. The used data in the research

| No. | Type of data | Description | Source |
|---|---|---|---|
| 1 | Topographic map | 1: 10.000 scale | Department of Cartography Ministry of Resources and Environment (belong to MONRE) |
| 2 | Forest map | 1: 10.000 scale | The Forestry Institute for planning and investigation-FIPI (interpreted from SPOT data and field checking |
| 3 | Land use/landcover map | 1: 10.000 scale | Analyzed from Landsat 8.OLI |
| 3 | Soil map | 1: 10.000 scale | Ministry of Agriculture and Rural Development |
| 5 | Geomorphology map | 1: 10.000 scale | Established by Project scientist, field checking |
| 6 | Land slide risk map | 1: 10.000 scale | Establish by GIS |
| 7 | Historical rainfall data | For 33 years | General Department of Hydrometeorology (belong to MONRE) |
| 8 | Forecasted rainfall | Online data | Data from IMETOS forecast station of project |
| 9 | Location flash floods from year 2000 to 2016 | Position, level | Data from statistic and interview |

The ratings are determined by the expert coefficient and the AHP method. Rating is classified into 5 levels: level 1 - very low, level 2 - low, level 3- medium, level 4 - high and level 5 - very high.

## 3. Results and discussions

### *3.1. Establishing the flood risk map*

Evaluate the information layers of the catchment area related to the risk of flash floods in Table 2

Table 2. Flood risk assessment for information layers of the catchment basin

The results of the evaluation of the information layers are shown in Figure 4.

| Level | GM (Unit) | TWI | SD | FR (type of forest) | LS (points /km$^2$) | SB ($^0$) | S (type) | R (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | HM,SP | 0.0 - 0.9 | 0.0 - 0.5 | D, G | 0.01 -0.02 | > 40 | A | <150 |
| 2 | 1FA | 0.9 - 1.3 | 0.5 - 1.5 | J, F | 0.02 - 0.04 | 30 to 40 | B | 150 to 250 |
| 3 | Fpp | 1.3 - 3.2 | 1.5 - 2.5 | A, C, E, I, L | 0.04 - 0.06 | 20 to 30 | C | 250 to 350 |
| 4 | 5TR | 3.2 - 5.4 | 2.5 - 3.5 | HH | 0.06 - 0.08 | 10 to 20 | E | 350 to 450 |
| 5 | VL | 5.4 - 15.4 | 3.5 - 4.5 | B, K | 0.08 - 0.1 | <10 | D | >450 |

### *3.2. Calculating the weight for each information layer*

Using the AHP method to calculate the weight for each information layer by the Thomas Saaty-Analytics Hierarchy Process (AHP) method (Saaty, 1980, 1983, 1990, and 1994) [11]. The results are shown in Table 3.

Table 3. The calculation matrix for determination of weight of each information layer

| IC | TWI | FR | LS | SB | RM | GM | S | RD | Total | Weight | Consistency index |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **TWI** | 0.33 | 0.26 | 0.23 | 0.25 | 0.45 | 0.34 | 0.18 | 0.22 | 2.27 | 0.28 | 8.72 |
| **FR** | 0.11 | 0.09 | 0.14 | 0.17 | 0.06 | 0.06 | 0.16 | 0.13 | 0.91 | 0.11 | 8.59 |
| **LS** | 0.07 | 0.03 | 0.05 | 0.03 | 0.04 | 0.04 | 0.11 | 0.09 | 0.44 | 0.05 | 8.29 |
| **SB** | 0.11 | 0.04 | 0.14 | 0.08 | 0.08 | 0.06 | 0.13 | 0.13 | 0.77 | 0.11 | 8.48 |
| **RM** | 0.16 | 0.35 | 0.28 | 0.25 | 0.23 | 0.34 | 0.18 | 0.22 | 2.02 | 0.25 | 8.93 |
| **GM** | 0.11 | 0.18 | 0.14 | 0.17 | 0.08 | 0.11 | 0.11 | 0.13 | 1.02 | 0.13 | 8.85 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **S** | 0.05 | 0.01 | 0.01 | 0.02 | 0.03 | 0.03 | 0.03 | 0.01 | 0.19 | 0.02 | 8.34 |
| **RD** | 0.07 | 0.03 | 0.02 | 0.03 | 0.05 | 0.04 | 0.11 | 0.04 | 0.38 | 0.05 | 8.20 |
| Random consistency index | | | | | | | | CL =**0.08** | | | |
| Random consistency index by n (number of factors) | | | | | | | | RI=**1.41** | | | |
| Total consistency index | | | | | | | | CR=**0.056** | | | |

The CR reliability of the matrix is determined by the CR consistency index. If the value of the CR index is less than or equal to 0.1, then the consistency between the factors in the comparison matrix is guaranteed. For the eight factors included in this study, the CR = CI / RI = 0.08 / 1.41 = 0.056 (this index is lower than 0.1, which is indicate that the reliability is warranted).

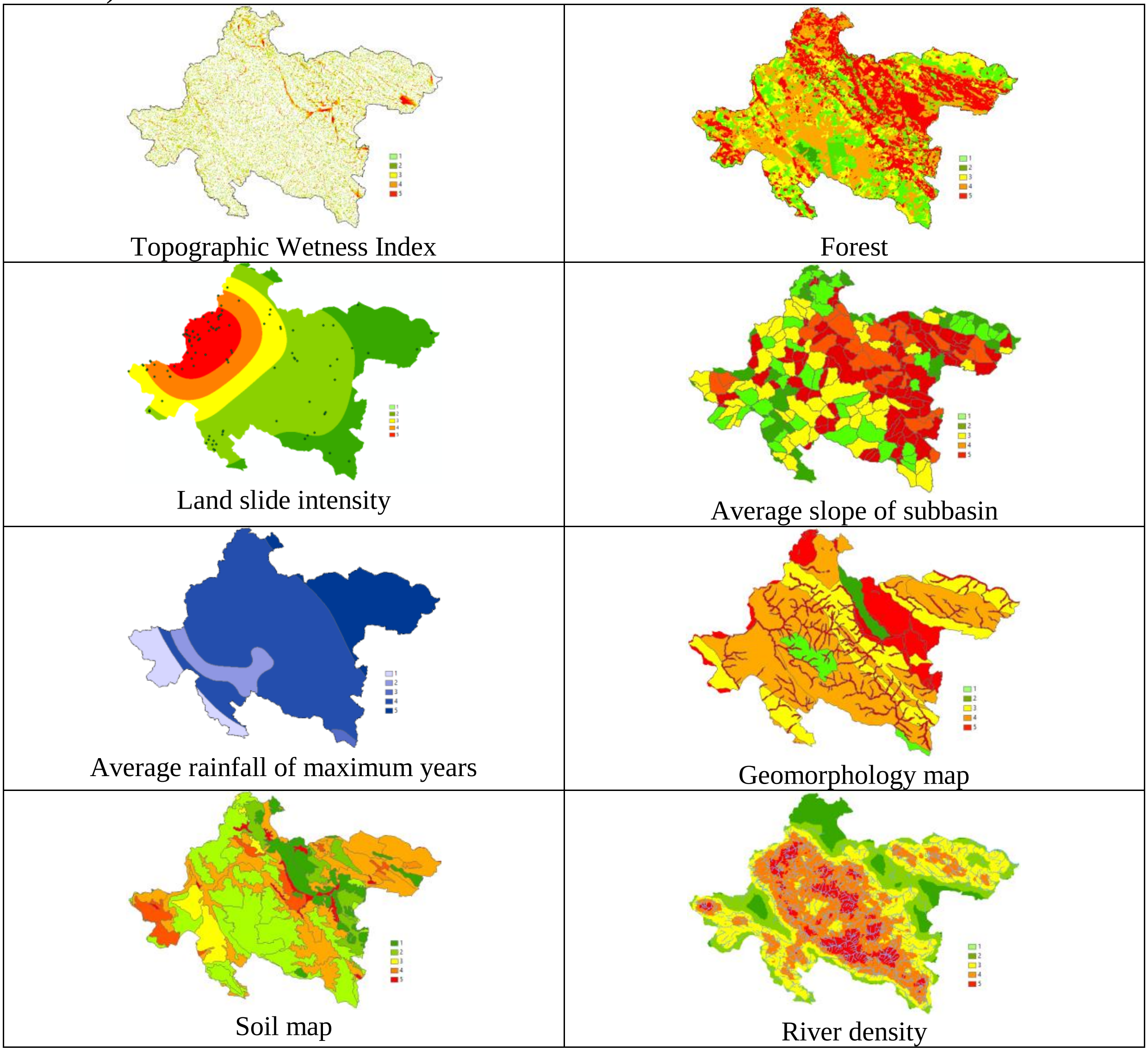


Fig. 5. The information layers to evaluate the flash flood risk

### 3.3. *Establishing the flood risk map with MCA model*

The calculation function for the flood risk mapping model is detailed as follows [12,13]:

$$\boldsymbol{FFR = \sum_{i=1}^{n} w_i x_i} \qquad (2)$$

Where : FFR is potential flood risk map,

Wi is weight of factor (i) ( *total weighs =1*),

Xi is the element (i) and n is number of elements (from 1 to n).

From the weight which is calculated from table 3, the function is detailed as follows:

***FFR*** *= 0.28 * WNI + 0.11 * F + 0.05 * LS + 0.1 * SB + 0.25 *R + 0.13 * GM + 0.02 *S + 0.05 * SD* (3)

The results of the flash flood hazard mapping with different numerical values (Fig 6). In its original form, it can be considered as the long term flood hazard warning map with probability 1%.

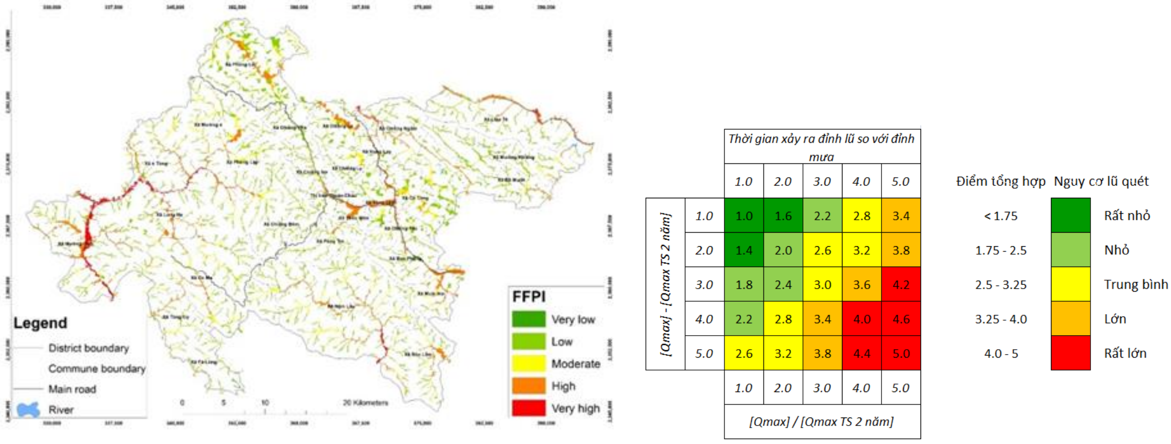

Fig.6. Flood hazard map and flash flood risk profile (FFPI) for each pixel

Compared with the data and location of flash flood events in the past since 2000, there is a good correlation between reality and forecast. At the same stream, there are also many places where there is a risk of flash flooding, which can be explained by the influence of various parameters of the cachment  basin surface.

### *3.4. Confirm the accuracy of the flood risk map*

Fig. 6 shows the similarities between places with high risk of flash flood (FFPI) on risk maps compared to places where local flash floods occurred in the past. To test the accuracy of the study results, the ROC method was applied. In the Signal Detection Theory [14,15], the number of received or unused signals will be used to evaluate the accuracy of the system. From the received signal, the SPSS software will analyze and draw a Characteristic Receiver Operating Characteristic (ROC) curve to distinguish right or wrong signals in several areas (Fig.7). Each point on the AUC curve is the coordinates correspond to the actual signal frequency on the vertical axis and the frequency assumed on the horizontal axis.

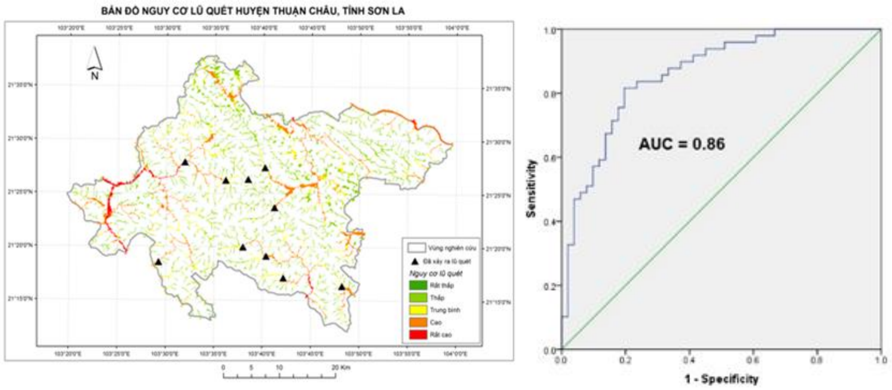

Fig.7. Comparison between the forecasts with historical floods and the ROC curve was constructed from the historical flash flood screening system compared with the Thuan Chau flash flood hazard map

The higher the value under the curve, the better the distinction between the two states of accuracy (value=1) and inaccuracy (value=0). Determine the accuracy level based on the following scoring system: 0.80 - 0.90 = very good (A), 0.60 - 0.70 = good (B), 0.50 - 0.60 = wrong (C).

Comparing past flash flood data and flood risk maps (Figure 7), the ROC curve constructed in Figure 6 for AUC = 0.86 indicates good accuracy.

### *3.5. Structure the system for early warning flash floods*

Apply calculation (3), with rain forecasting 1 day (or 2-6 days), early warning map is established. Where rainfall exceeds threshold, floods will appear (Fig.8).

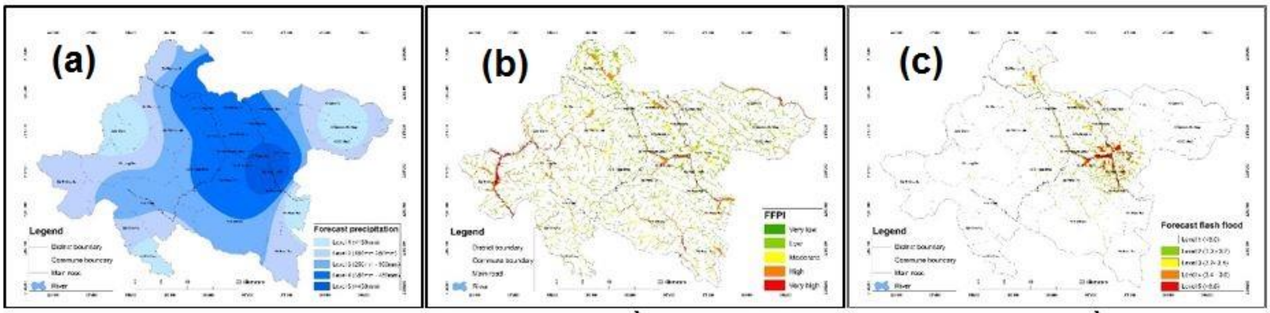


Fig.8. (a) Rainfall as the forecast, (b) flood risk map and (c) flood risk map follow the rainfall forecast

The process of processing and transmitting information quickly is done by the WebGIS system, the system includes databases, information analysis and processing software, website management and information to the user. The general model and main features of the system are shown in Fig.9.

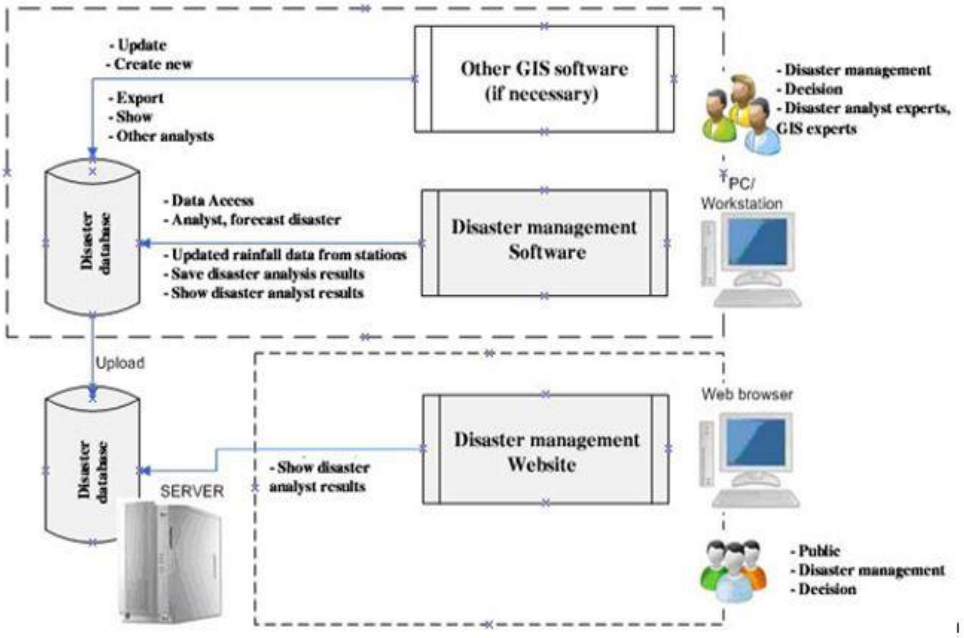


Fig.9. The general model and main features of the system

The software is based on open-source programming language Python, PHP and PostgreSQL database/PostGIS [16,17,18,19]. he software is organized simply with the following main functions: ESRI standard database management, spatial interpolation of rainfall, integration of information layers to build flash flood forecast map and export to map and metrics data. From the software, information is transferred to the Web site to provide information online and extract the SMS message to the end- users in the district.

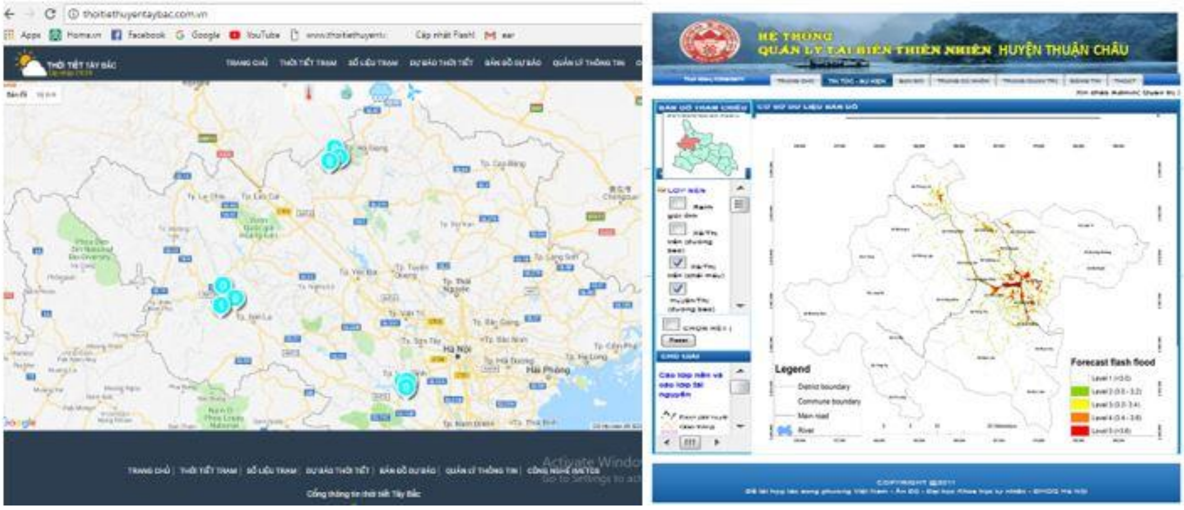

Fig.10. The main interface of the software (left) and hazard warning website (right)

## 4. Conclusions

In disaster management, a flash flood warning system can be a single integrated software, but it can also include many parts such as : WebGIS and Web operating in different phases (Fig 10). However, they must satisfy two basic functions: rapid processing of information according to the rainfall information from stations, rapid processing and transferring information about level and location of the flash flood to those who are interested[17,18]. The development of an early warning system need to follow both the technology and application directions. The close and complementary relationship between those two directions is an objective requirement to consolidate and perfect to provide powerful systems with high accuracy. That is the cooperation of multi-sector and multi-field, which is an indispensable trend in the development process. The system has successfully used to develop a disaster risk map for flash floods in Thuan Chau- Son La district and the results compared with past events were accurate.

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