BUILDING A REAL-TIME INFORMATION AND FLASH FLOODS, LANDSLIDES EARLY WARNING SYSTEM IN MOUNTAINOUS AND MIDLAND AREAS OF VIET NAM

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Abstract: *Flash flood is a natural disaster occurring shortly on small scale albeit with great devastation. In fact, the current flash flood events, landslide investigations and surveys from research agencies and local authorities play an important role in creating diverse data sources for researching and exploring the signs as well as modeling adjustment for detecting the risks. This article presents the results of making a Web portal used for the reception and integration of early warnings from citizens, local authorities and governing bodies against flash floods and landslides. This system collects real time rainfall data from the CDH of Meteorology and Hydrology Administration, integrates the numerical weather prediction WRF (the Weather Research and Forescast) model with 6 h, 24 h, 48 h forecast lead time and SEAFFGS product results. Also, it would elaborate on the system providing tools for aiding, analysing, producing and disseminating warning bulletins against flash floods and landslides for mountainous and midland areas, sending warning message about high risk flash flood and landslide with the total observed rainfall or rainfall forecast over the threshold via email or Zalo automatically. This information which can be accessed everywhere via the internet, will effectively support the forecasters in mornitoring and publishing the flash flood and landslide warning bulletins; help the authorities and citizens become aware of natural disasters early and mitigate damage caused by flash floods and landslides.*

Keywords: *Flash flood, early warning system, Flash Flood Rainfall Threshold.*

1. Introduction

In recent years, the application of science and technology to natural disaster prevention and control has developed widely. The employment the social media by the government and the public during major disasters has attracted the attention of a number of authorities and organisations. The community is the centre of attention when it comes to the distribution of news concerning disasters, especially those happening on a small scale with great impacts on socio-economic stability like flash floods and landslides. Social media is not only for delivering information to the public, but is also for receiving information from high-risk individuals. For example, Community-Based Early Warning Systems has been implemented in many countries. Early warning systems based on data bring enormous benefits to the communities and help them decide upon their actions. Agencies are responsible for understanding how local people respond to disasters. Community members have decided by themselves when, where and how to evacuate. Organizations tailor the content of warning messages to meet the need of users [1] A complete and effective early warning information system consists of four interrelated elements: (1) Collecting geotechnical data, topographic and geomorphological data of the basin (including ground stations and satellites); (2) Monitoring and warning: Developing

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a disaster monitoring and early warning system; (3) Disseminating and transmitting early risks; (4) Responding: Building response capacity in the community and country. An effective early warning system is the one that has close cooperation and effective communication channels between all elements. Most flash flood warning methods are implemented with a forecast period of 1 - 6 hours, but some are up to 72 hours. However, the flash flood warning leadtime mainly depends on the precipitation forecast. Each method has its own merits and demerits. In fact, no research has been performed to compare the effectiveness of different flash flood warnings. Therefore, the choice of a method should be considered based on the availability of data resources, characteristic of the area (e.g., rainfall pattern and distribution, topography, landcover, or socioeconomic dynamics), spatial and temporal scales as well as scopes of warning [6].

The rapid development of the global Internet has created more and more early warning Web portals as well as open database resources which allow access from all over the globe. Traditional means of communication such as television, radio, speakers, signs, etc., combined with new solutions such as internet, satellite, handheld devices, etc., are directly connected to supported forecasting systems to optimize the community services.

Currently, in some countries, flash floods and landslides information as well as early warning systems have been established for monitoring and analyzising data (Table 1). Japan has established an early warning system against landslide disasters operated by the Japan Meteorological Agency (JMA) [9], [16]. The main method of the system is developing criteria for the occurrence of mudflow events, slope landslides based on rainfall threshold (60-minute cumulative rainfall and soil-water index). Spatial distributions is 5 km × 5 km model grid resolution covering the entirety of Japan. Landslide warning map is displayed in 5 colors for each 1 square kilometer (grid) area on the map which was previously displayed for every 5 square kilometers. The information is also updated every 10 minutes to give a detailed increasing risk map.

The Hydrologic Research Center, United States has developed a flash flood and landslide risk evaluation system which has been integrated in the flash flood warning system FFGS [2], [3], [4], [5]. The FFGS system has been implemented in 14 regions around the world. Real-time remote sensing data is used to estimate rainfall on a regional scale with high resolution (4 km x 4 km). FFGS systems combine rainfall data from several satellites, radars, and rain gauges, a high-resolution model accounting for soil moisture, landslide sensitivity and landslide risk assessment. In Taiwan, the Department of Land and Water Conservation has successfully built 17 automatic stations and 03 mobile stations to monitor mud for an early warning system including camera images which send data every 10 minutes [7]. Data collected in the field is transmitted to the Emergency Response Center by satellite connection, is used for establishing and investigating the landslide warning threshold. This system provided real-time data to aid the decision-making of the management.

Table 1. The summary of operational flash flood and landslide warning systems [6]

Forecast System	Country	Hydro-meteorological input data	Methods/Models	Operational resolution (temporal & spatial)	Forecast lead-time
ALERT	Australia	Real-time rainfall and water level data	Input data are fed into a hydrological model to assess the magnitude and timing of a flood event.	Flash Flood/ Event-based and catchment scale	Now-cast

Forecast System	Country	Hydro-meteorological input data	Methods/Models	Operational resolution (temporal & spatial)	Forecast lead-time
Gridded Flash flood Guidance (GFFG)	Northern America	Multi sensor precipitation estimates and forecasts, based on NEXRAD radar, rain gauges, and NWP model outputs	A distributed hydrologic model (HL-RMS model) to account for soil moisture changes, the Natural Resource Conservation Service's (NRCS) Curve Number Model and the NRCS Unit Hydrograph Model. The HL-RMS model is applied to 4 x 4 km^2 grid in a catchment.	Flash Flood and Landslide/ hourly and 100 - 300 km^2 catchment scale	3 - 24 h
Central American Flash Flood Guidance (CAFFG)	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama	Gauged rainfall, satellite-based rainfall derived by the Hydro-Estimator, and NWP model (WSETA) output	CAFFG uses a saturation-excess physically-based soil moisture accounting model to compute soil moisture deficit in real-time.	Flash Flood and Landslide/ hourly and 100 - 300 km^2 catchment scale	3 - 6 h
Sothest Asia Flash Flood Guidance System	Viet Nam, Lao, Cambodia, Thailand	Gauged rainfall, precipitation estimates from satellite, radars and WRF-NWP model outputs	Rafall Threshold, bankfull flow and SacraMento model compute soil moisture in sub basins	Flash Flood and Landslide/ catchment scale 20 - 50 km^2	1 h, 3 h, 6 h
Flash Flood Forecast system in Northern Austria	Northern Austria	Observed discharge, gauged rainfall, radar rainfall, and NWP model outputs	A grid-based distributed model is used for river flow forecasting with Ensemble Kalman Filtering	Flash flood/15 minutes and 1 km^2 grid	48 h
European Flood Forecast-ing System (EFFS)	Europe	Gauged rainfall, radar rainfall, GCM outputs downscaled by two NWP models	A distributed rainfall-runoff modelling suite, LISFLOOD-FF for generating river flow. Then a two-dimensional hydraulic module, LISFLOOD-FP is used to model the overbank flows and inundation areas.	Flash Flood/ LISFLOOD-FF: hourly and 1 km^2 grid LISFLOOD-FP: 10 - 100 m grid	72 - 120 h

Forecast System	Country	Hydro-meteorological input data	Methods/Models	Operational resolution (temporal & spatial)	Forecast lead-time
Decision support system for flash flood warning in Thailand	Thailand (Uttaradit, Sukhothai, and Phrae provinces)	Gauged rainfall and discharge, NWP model outputs and satellite images	An artificial neural network model is used to forecast river flow.	Flash Flood/ Event-based and catchment scale	24 h
GEOREX FLOOD	Malaysia (state of Kelantan)	Gauged rainfall and radar rainfall	The Stream-flow Synthesis and Reservoir Regulation (SSARR) model is used for river flow forecasting.	Flash Flood/6 h and catchment scale	Now-cast
Flash flood forecasting system of the Ayalon stream	Israel	Gauged rainfall and discharge	This system includes a module that auto-regresses discharges at stations	Flash Flood/ Event-based and catchment scale	30 min-3.5 h
Real time Risk Map	Japan	Gauged rainfall, precipitation estimates from satellite, radars	TANK model, Lanslide threshold	Landslide/ 1 km^2 grid	1 h

In Viet Nam, an early warning information system for flash floods and landslides has also been initially constructed. The first flood and flash flood warning system was built by Viet Nam Hydrology and Meteorology Administraton at Nam La in 1991 for Nam Pan river basin, Son La Province, including water levels automatic monitoring stations for warning against flash floods in Nam Pan - Nam La stream, Mai Son district, Son La Province. Do Minh Duc (University of Science, Viet Nam National University, Ha Noi) set up a website http://quangnam.truotlo.com in 2020 in Quang Nam Province. It is based on IoT and cloud platforms. This study applied statistical analysis methods and machine learning models. The subject has built an early warning matrix of landslide risk by combining landslide risk of road sections with landslide-causing rainfall threshold. The Institute of Geosciences and Minerals has built a WebGIS system to publish the mapping results and landslide risk zoning on the website http://www.canhbaotruotlo.vn on the scale of the project "Investigating, assessing and zoning for landslide hazard warning in mountainous areas of Viet Nam" [13]. In 2016, the Institute of Meteorology, Hydrology and Climate Change established the first FFGS system to warn against flash floods for Viet Nam (VNFFGS) in the framework of the project "Investigating, surveying, and mapping the distribution of flash flood risk areas in the Central, Central Highlands and building a pilot system for warning high-risk localities against flash floods, allowing planning, directing and operating disaster prevention to adapt to climate change" [11]. In 2022, the Southeast Asia Flash Flood Guidance System (SeAFFGS) funded by WMO was transferred to the Viet Nam Hydrology and Meteorology Administration for management [3], [14]. SEAFFGS is the first flash flood warning support system that uses extremely short forecasting data and integrates a large number of different data sources. In this system, Viet Nam provides data including: 10 radars, 1,500 automatic rain stations, administrative maps of districts, communes, now-casting products, rainfall estimated from radar and product of numerical rain forecasts from WRF model. The FFG approach for flash flood warnings is based on a comparison of the observed or forecasted rainfall over a certain time period in a watershed with the estimated Qbf (FFG) for Viet Nam.

Based on the inherited current research results and development methods, with more suitable and convenient flash floods and landslides warning, this paper presents the results of the research on setting up a flash flood and landslides warning information system having the following functions: (1) Receiving, updating flash flood, landslide alerts; (2) Integrating automatic rain gauge the data and traditional rainfall stations from The Viet Nam Hydrology and Meteorology Administration; (3) Monitoring fluctuations, occurrence of heavy rain areas, supporting analysis and implementation of flash floods and landslides warning messages; (4) Flash floods and landslides warning and communication.

2. Materials and Methods

2.1. Description of the study site

Many severe floods, flash floods and landslide events which are fairly common natural disasters occur frequently in the mountainous and midland areas due to high rainfall intensity and steep terrain. According to the statistics data, there are 10 - 15 flash floods and landslides every year. In 2020, from October 4 to October 31, the Northern and central regions were hit by 4 tropical cyclones in a short period. Heavy rains brought by these cyclones are considered to have been responsible for triggering many landslides and disastrous floods in the provinces of Quang Tri, Thua Thien Hue (Rao Trang 3 hydropower plant) and Quang Nam, causing 159 deaths, 71 missing people and serious economic repercussions. In 2023, during the first months of the rainy season, landslides occured and caused damage in the Central and Central Highlands regions such as Da Lat city (6/2023); Bao Loc Pass near Da Lat City, Lam Dong Province buried three police officers (July 2023). The number of extreme rainfall events is predicted to increase because of climate change. Therefore, landslides and flash floods risk also tend to increase strongly, resulting in direr consequences in the mountainous and midland areas.

2.2. Data used in the study

The data for building a Web portal receiving information and early warning against flash flood and landslide in mountainous and midland areas of Viet Nam includes:

Observed data: Hourly and daily rainfall from 1500 rain gauges, 350 hydro-meteorological stations from the Data Center Hub (CDH), Hydrological and Meteorological Administration.

Model data: The results of the Southeast Asia flash flood guidance system (SEAFFGS) supported by The World Meteorological Organization and Hydrologic Research Center include: MAP (Merged Mean Areal Precipitation); FMAP (Merged Mean Areal Precipitation Forecast in next 3 h, 6 h, 24 h); FFG (Flash flood guidance); IFFT (Imminent Flash Flood Threat); FFFR (Flash Flood Risk); LST (Landslide Threshold). The data are updated on an hourly basis.

Forecast rainfall: The output of numerical weather prediction WRF model (The Weather Research and Forecasting Model) with 3 km solution downscaled by the National Center for Hydro_Meterological Forecasting with forecast lead time of 3 h, 6 h, 24 h, 48 h; The data are updated 2 - 4 times per day.

Map: Digital Google Maps; communes, districts, provinces, and national boundaries, flash flood and landslide current map

2.3. Design data receiving and analysing system for flash floods and landslides warning

a) Design the overall system

The overall Web portals for early warning against Viet Nam flash floods and landslides is designed to meet the e-Government 2.0 framework of the Ministry of Natural Resources and Environment [11]. They show the position of the applications in the overall architecture in the field of early warning against landslides, mud and rock floods, pipe floods, flash floods, ensure adequate communication channels, applications and services based on an integrated, shared platform (Figure 1). The system is divided into layers with different roles:

- Users: (1) People: Sending messages and warnings when the areas/regions where they live are at risk of landslides, flash floods,... (2) Research agencies: Sending messages and warnings when the places are at risk of landslide, flash flood, etc. (3) Local authorities: Sending message and warnings when the areas/regions under local government control are at risk of landslides, flash floods,... Handling information from local people in the areas; (4) Professional officer, forecaster: Handling the information sent by the people, local authorities, research agencies; Exploiting collected data, making warning decisions; (5) Management agencies: Receiving information, announcing and warning about areas at risk of landslides and flash floods; sending feedback to the management unit....

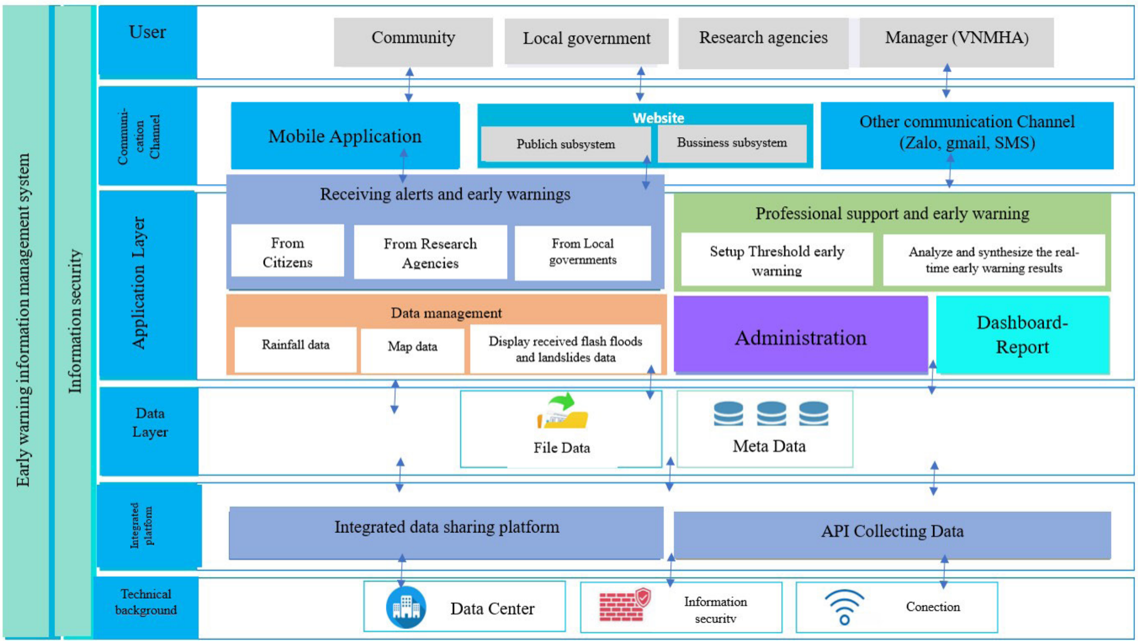


Figure 1. Diagram showing the compatibility of information system for landslides, mud and rock floods, pipe floods, flash floods early warning with the framework of e-Government architecture of Ministry of Natural Resources and Environment

- Communication channels: The flash flood warning message from the users layer, the high-risk areas with total rainfall over the threshold, rainfall observered or flash flood and landslide warning bulletins from Application layer will be shown on the website portal, mobile applications or sent by email or Zalo.

- Application layer:

+ The system collects data from different resources (user layer, data layer) for landslide and flash flood early warning: Information from people, local authorities, research agencies; data monitoring (observed rainfall, forecast rainfall data); model data (from SEAFFGS).

+ Setting thresholds; forecasting, warning, supporting decision-making; exploiting information collected; administering systems, managing users and configuring systems

+ Supporting the professional officer and forecaster to collect and synthesize data; extracting informations, issuing early warning, supporting decision-making.

- Data layer: File data and digital data format.

- Integrated platform:

+ Integrating information from people, local authorities, research agencies (user layer) from the Big data platforms via the integrated and data sharing platform of the Ministry of Natural Resources and Environment (LGSP).

+ Collecting observed data, model results (data layer) via API service.

b) Methods of setting up rain threshold for flash floods and landslides warning

Rainfall threshold is a key factor widely used worldwide in flash flood warning. However, it is difficult to determine the exact rainfall threshold in different areas due to several factors, including hydrometeorology, topography, land cover, human activities,etc. Rainfall thresholds are determined using a methodological approach defined in the SEAFFGS flash flood warning system [2] [10], providing users with essential information to assess the potential for flash flooding areas.

3. Introducing the features of the Web portals and flash flood, landslide early warning systems

The real-time information and flash floods, landslides early warning system is an website adressed http://101.96.116.68/ and mobile application (Android environment) Cảnh báo trượt lở & lũ quét including main elements (Figure 2):

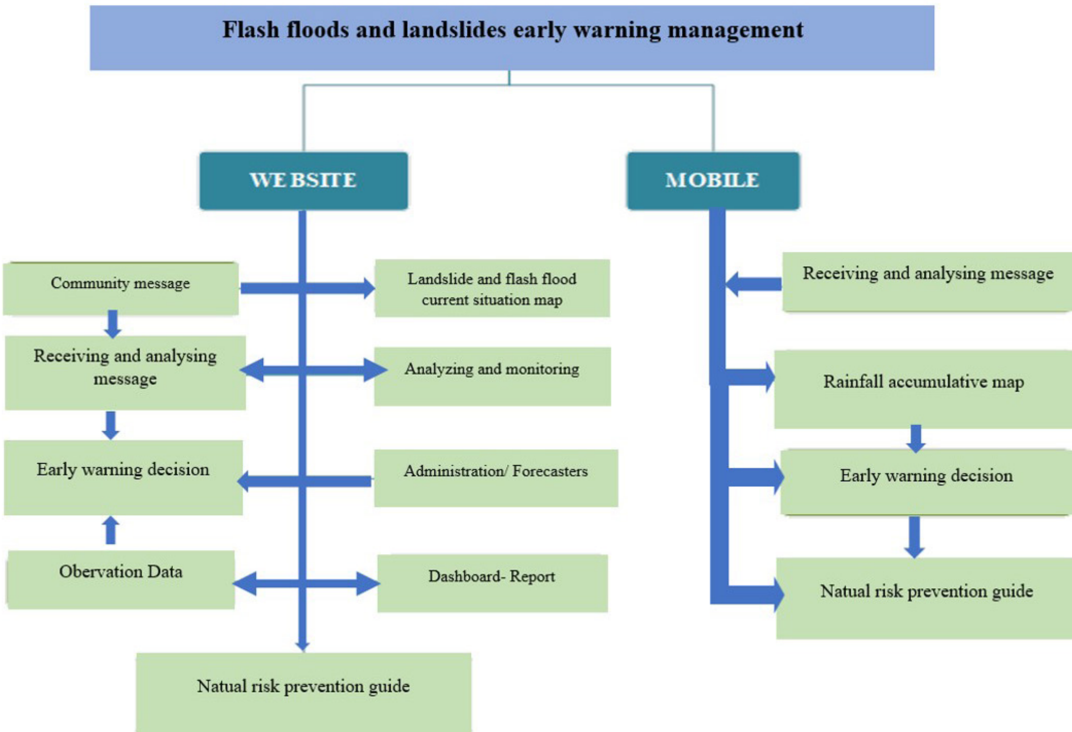


Figure 2. Block diagram processed in the Web portals of the information system and flash flood, landslide early warning systems

- Updating, processing and storing information from people, local authorities, management agencies, research agencies related to locations/ areas where flash floods and landslides have occurred or may occur;

- Receiving real-time rain monitoring data from the SEAFFGS data system for forecasting and warning;

- Analyzing and synthesizing the results of making decisions on flash floods and landslides warnings based on model data and rainfall thresholds;

- Disseminating alert decisions to management agencies and people through websites, emails and zalo.

3.1. The function of updating and news proccessing

Citizens, local authorities, research agencies can create user accounts on the system. The management units will review and delegate the function of updating news. When detecting locations/areas at risk of landslides, flash floods or locations/areas, people and management units can update and send alerts to the system.

The management unit considers, receives or cancels the message; the received messages can update the positions on the current map. In addition, based on flash flood and landslide information on the media and social networks, managers can also update risk points on the current map of flash floods and landslides. (Figure 3)

3.2. The reception of real-time rain collecting data and model data function of the SEAFFGS system

Rainfall data has been collected via LGSP and API service from the CDH of Meteorology and Hydrology Administration. There are 2 types of stations: The automatic stations are updated every 1 hour; The manual station are updated every 6 hours (1 h - 7 h - 13 h - 19 h). These data sources are used to calculate the amount of rainfall in 6 h, 12 h, 24 h in the past (Figure 4). Model data from the SEAFFGS system will be collected and used as an input data component for early warning analysis. The displayed map indicators including: MAP, FMAP, FFG, ASM, IFFT, FFR are updated every 1, 3 hours and LST is updated every 24 hour (Table 2, Figure 5).

Table 2. SEAFFGS Results

STT	Name	Forecast lead time	Data
1	MAP	1 h - 3 h - 6 h - 24 h	Merged Mean Areal Precipitation
2	FMAP	1 h - 3 h - 6 h - 24 h	Merged Mean Areal Precipitation Forecast
4	ASMU	1 h	Average Soil Moisture upper zone
5	ASMT	1 h	Average Soil Moisture lower zone
6	FFG	1 h - 3 h - 6 h	Flash Flood Guidance
7	IFFT	1 h - 3 h - 6 h	Imminent Flash Flood Threat
8	FFR	12 - 24 h - 36 h	Flash Flood Risk
9	LST	24 h	Landslide Threshold

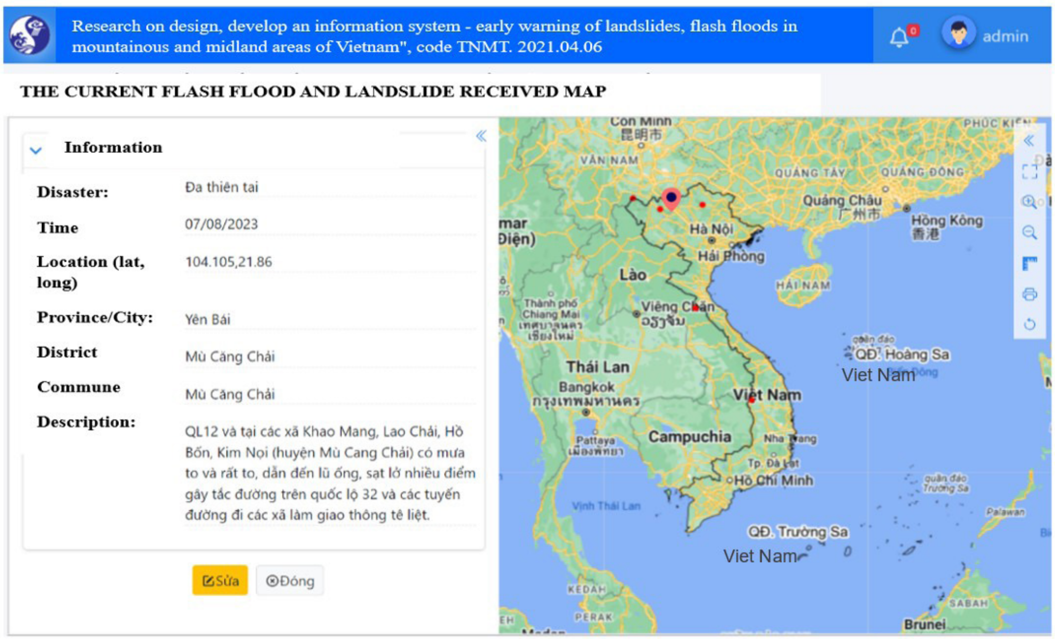


Figure 3. Alert collecting, analyzing and point risk map updating

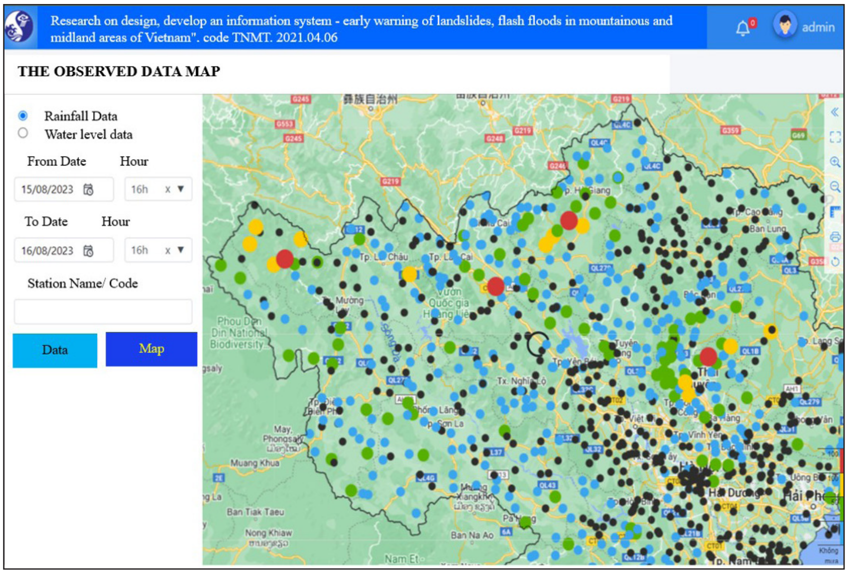


Figure 4. Rainfall observation data collecting interface

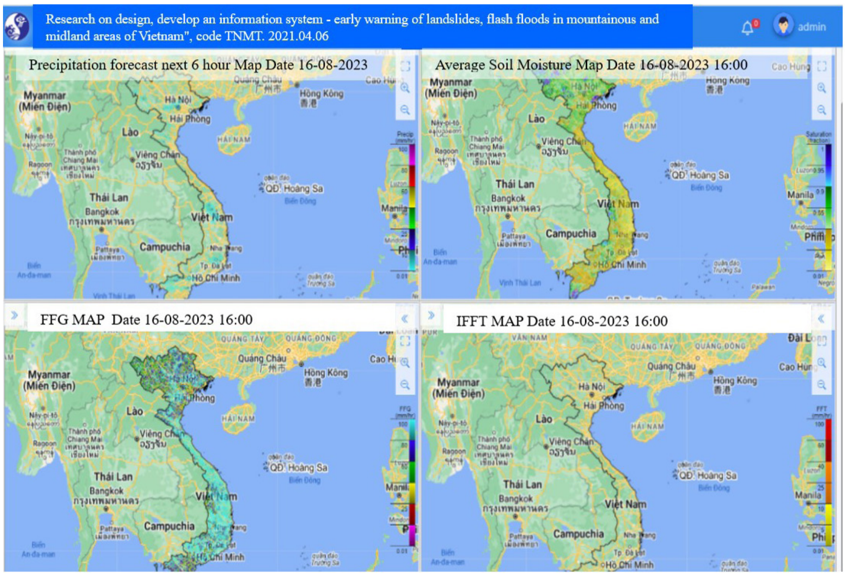


Figure 5. Data comparing and SEAFFGS result collecting interface

3.3. The function of analyzing and synthesizing the results of making decisions on flash floods and landslides warning

The real time rainfall observed is used for data analysing and making recommendations on flash floods and landslides risk areas based on the comparison with thresholds. If these data are equal to, or exceed the thresholds, the areas are at risk of natural disasters. The flash floods and landslides risks are divided into 3 levels from medium, high to very high. There are 04 analysis scenarios to make warning decisions, including:

- Synthesize analysis results from SEAFFGS result with threshold indexes of each product of MAP, FMAP, FFG and ASM;

- Synthesize analysis results of rainfall data measured during 6 hours, 12 hours, and 24 hours in comparison with the threshold index;

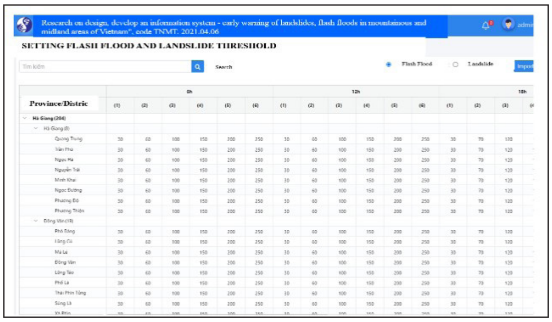
- Synthesize the results of analysed forecast rain data in the next 6, 12, 24, and 48 hours compared with the corresponding threshold indexes;

- Synthesize analysis results from forecasted rain data (next 6 hours, next 12 hours) combined with actual rainfall data measured in the past 12, 18, and 24 hours.

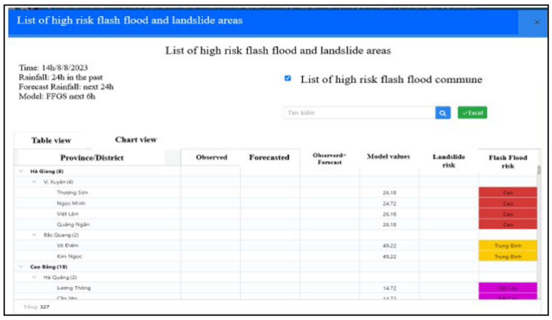
Rainfall thresold indexes that cause flash floods and landslides according to time frame are set from the smallest administrative unit to the commune level. The threshold indexes from the SEAFFS are performed for each sub-basin and referenced at the commune level (Figure 6).

3.4. Dissemination of warning to management agencies and people via website, email and Zalo

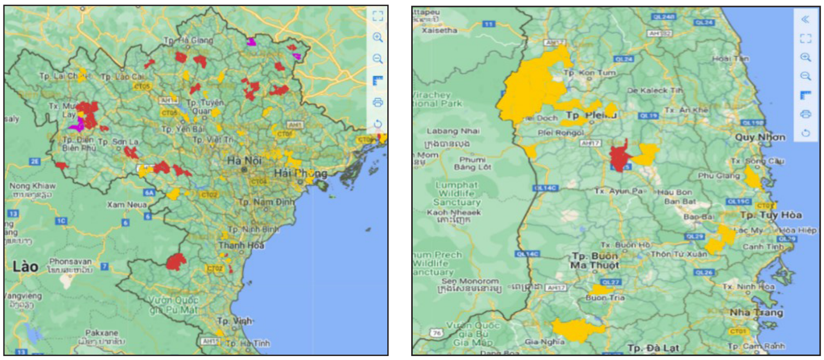
After issuing the warning message, the system can automatically send alert messages to the people, local authorities, as well as instructions to prevent natural disasters via a Zalo account, email and display information on the portal (Figure 7).



a) Threshold index setting



b) High risk areas analysing result



c) High risk map displaying on commune scale

Figure 6. Data analyzing and decision making of warning bulletins in Portal features

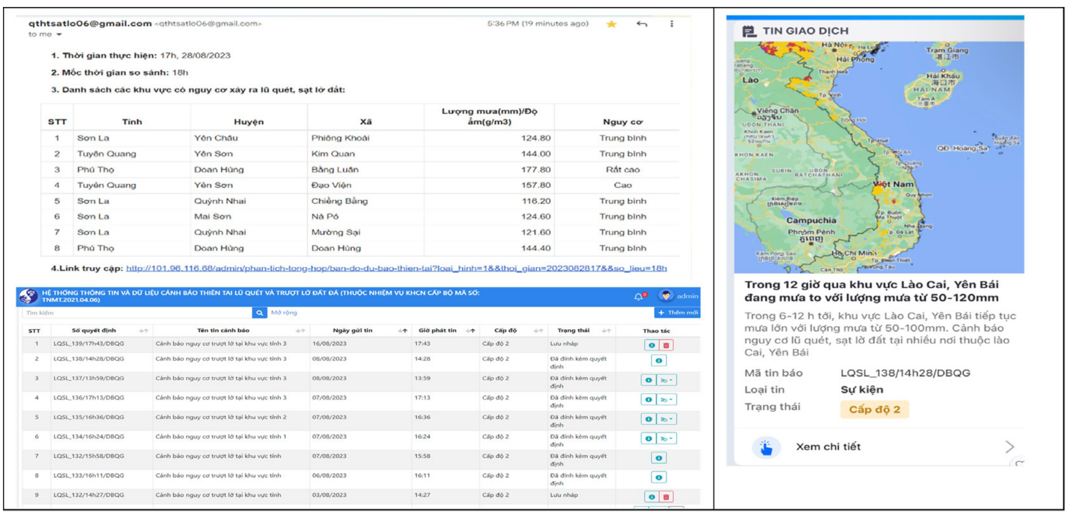


Figure 7. Function of sending warning message by email and Zalo

4. Conclusion

The main functions of this real-time information and flash floods, landslides early warning system include many features from aggregating and updating people's information about flash floods and landslides to integrating real-time rain monitoring data of 1,500 automatic rain gauges analyzing the real-time rainfall data; decision making of warning based on rainfall thresholds; integareting model input data of the SEAFFGS with warning lead times from 6 hours to 48 hours, spatial alert levels detailed to commune, district level. This system has been established to link agencies for the sharing, updating of the current information on flash floods and landslides. Moreover, this system also support management units and forecasters in charge of warning and forecasting natural disasters. The Alerts messages can be automatically emailed and transmitted via Zalo (social network). With the rapid development of the internet and social networks, the research results of this flash flood and landslide warning information system, when shared with people and authorities, will play a critical role in prevention and response, thus raising the awareness of citizens about the natural disasters risk related to flash floods and landslides.

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