FLASH FLOOD PREDICTION USING HIGH RESOLUTION SATELLITE RAINFALL DATA IN THE SOUTHERN PART OF THAILAND

THEERAPOL CHAROENSUK
Hydro - Informatics Institute 4, Bangkok, Thailand, theerapol.c@hii.or.th

APIMOOK MOOKTAREE
Hydro - Informatics Institute 1, Bangkok, Thailand, apimook@hii.or.th

SATHIT CHANTIP
Hydro - Informatics Institute 2, Bangkok, Thailand, sathit@hii.or.th

TICHA LOLUPIMAN
Hydro - Informatics Institute 3, Bangkok, Thailand, ticha@hii.or.th

WATIN THANATHANPHON
Hydro - Informatics Institute 5, Bangkok, Thailand, watin@hii.or.th

NARONGRIT LUANGDILOK
Hydro - Informatics Institute 6, Bangkok, Thailand, narongrit@hii.or.th

PIYAMARN SISOMPHON
Hydro - Informatics Institute 7, Bangkok, Thailand, piyamarn@hii.or.th

ABSTRACT

Southern part of Thailand is vulnerable for flash flood. The long ridge of western mountains lying from North to South is receiving high intensity of rainfall especially during northeast monsoon. Due to its high slope area and highly saturated soil during the monsoon season the flood can occur in a short period of time so called "flash flood". Excessive rainfall with high intensity and saturated soil moisture are the main factors causing this flash flood. But it is difficult to get direct measurement of soil moisture or even to estimate the soil moisture content from rainfall amount because the rain gauge station is poorly distributed or rarely available on the upstream mountain area. Therefore, in this study an attempt has been made to incorporate a real time global high-resolution satellite precipitation data from PERSIANN-CCS (4km x 4km) in the estimation of soil moisture. The bias correction has been studied and applied to the satellite rainfall PERSIANN-CCS to reduce the spatial and temporal uncertainties of the satellite rainfall product. The state of soil moisture condition has been identified using Antecedent Moisture Content (AMC) based on 5 days accumulated rainfall. The Flash Flood Potential Index or FFPI has been developed to provide information of flash flood risk area. In combination with hourly rainfall forecast computed from WRF-ROMS the flash flood risk area can be predicted. The approach has been tested and evaluated its performance. The results are confirmed with more accurate flash flood warning area during heavy rainfall event.

Keywords: Flash Flood Potential Index (FFPI), PERSIANN-CCS, WRF-ROMS, Antecedent Moisture Content (AMC), Southern Part of Thailand.

1. INTRODUCTION

In the past decade, flash flood in Thailand is continuous occurrence until the present, and the magnitude of events is still higher. The main cause of flash flood is a heavy rainfall, which exceeds the limit of soil capacity. The water becomes runoff and flush the soil and vegetation cover. Moreover, the soil capacity to absorb water is decreasing because of land-cover changes, especially in slope area, mountain plain, and alluvial plain. The exceeding water flows into the low area or downstream and becomes flash flood (Montz and Gruntfest, 2002). The flash flood runs downstream towards the agricultural area and urban area. Events affect the loss of life and property. Thus, to mitigate all loss, flash flood early warning technology should be developed.

At the present, flash flood early warning system was set up in the risk area of flash flood and landslide, where is located in steep terrain and mountain plain area. Warning threshold is developed from comparison between Antecedent Precipitation Index (API), soil moisture measurement, and accumulated catchment rainfall. The accumulated catchment rainfall is estimated from the hydrology model. The rainfall is a critical accumulated rainfall, which impacts downstream flood in 4-6 hrs.

This study aims to develop flash flood prediction using overlay technique from Flash Flood Potential Index (FFPI), Antecedent Moisture Condition (AMC), and predicted rainfall.

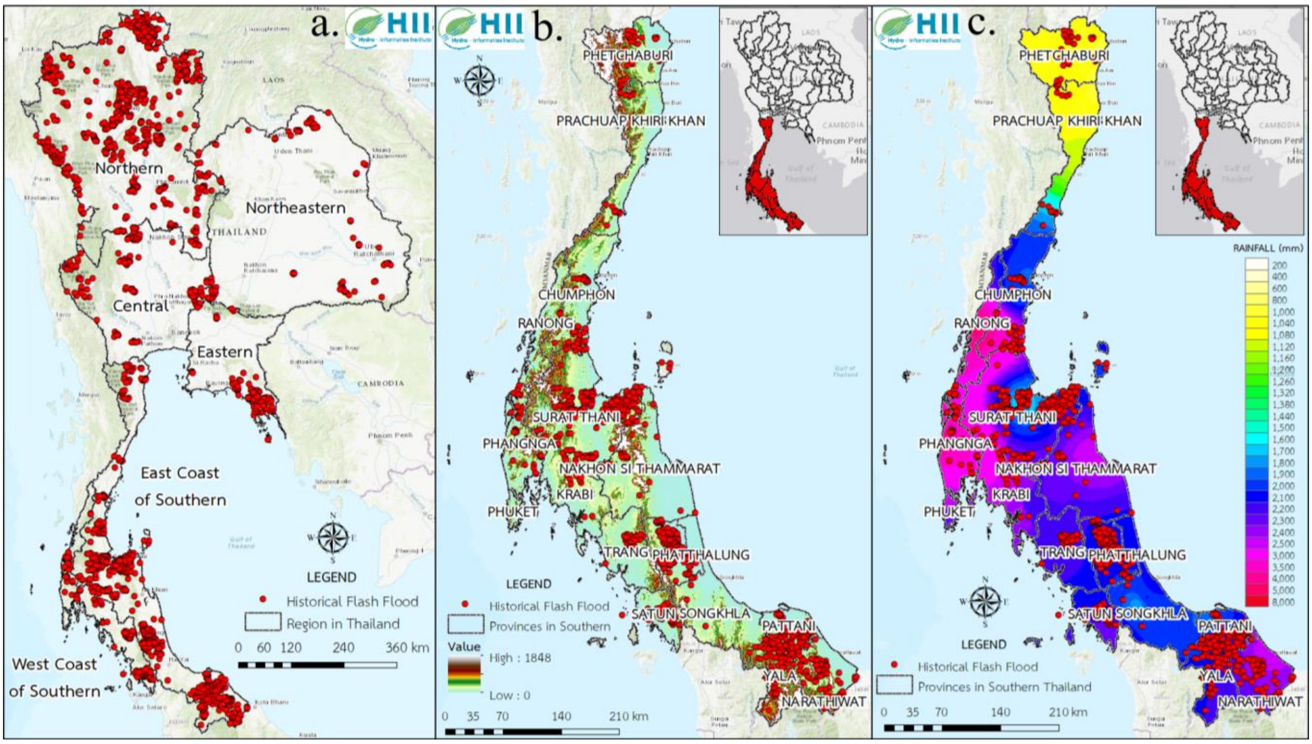


Figure 1. a. The historical flash flood locations in Thailand (2004-2014).; b. Topography and catchment of the study area.; c. Average rainfall in the Southern Part of Thailand.

2. STUDY AREA

The southern part of Thailand is categorized by meteorology characteristics from the meteorological patterns (Figure 1a.). The pattern covers from Petchburi to Narathiwat province. There are two main basins which are divided by mountain line, including Peninsula-East coast and Peninsula-West coast. The total area is 84,556 km^2 with a long shaped, narrow width, and flanked by the sea. The elevation is between 0 to 1,848 m.sl and mountain high between 600 – 1,848 m.sl. The mountains are located in the middle of the region and lay from north to south. The average slope of this region is 10 degrees, approximately 9% of the area has a slope more than 30 degrees, where located in the eastern more than western is around 76% and 24% respectively. According to Figure 1b, historical flash flood events occur in the steep areas or on the top of the mountain. The Catchments in the southern part is a small catchment because the catchment contains small and short stream.

Annual rainfall is 2,108 mm (Figure 1c.). Rainfall in the southern part is higher than the other regions because the region is affected by two monsoons, including southwest monsoon (May-Oct) and northeast monsoon (Oct – Feb). Moreover, another cause of high rainfall in southern is humidity from both seas beside the land. Land use consists of agricultural area (58%), forest area (31%), miscellaneous area (5%), urban area (3%), and water body (3%). Mostly, soil texture is contained in Hydrological soil group C, which covers 54% of the area. The hydrological soil group B, group A and group D cover 40%, 3%, and 3% respectively.

3. DATA AND MATERIAL

3.1 Physiographic catchment index.

The Flash Flood Potential Index (FFPI) indicates the potential of flash flood derived from physical properties. This study selected 4 indices from physiographic catchment properties (Figure2) to calculate FFPI. It consists of the Slope index, Land use index, Vegetation cover index and Hydrologic soil group index. Each index has different effects on the characteristic of the flash flood occurring, shown in Table 1. The details of Physiographic catchment Properties are shown in Table2.

Table 1. Physiographic catchment index

Index	Derive from	Effect to flash flood
Slope Index	Digital elevation model (DEM)	Flash floods are highly dependent on the slope of the catchments as an increasing slope causes an increasingly rapid response in the catchment runoff and in local streams.
Land use index	Land use	Land use influences the runoff characteristics of a drainage basin to a large extent, which in turn, affects the surface and groundwater availability of the area.
Vegetation cover index	NDVI	Involved the intercept precipitation, the high vegetation density area has a low runoff.
Hydrologic soil group index	Soil series	The HSG represents the runoff potential and infiltration rates.

Table 2. The Physiographic catchment Properties.

Data	Year	Resolution	Source
Digital elevation model (DEM)	2005	30 m.	Royal Thai Survey Department
Land use	2009	30 m.	Land Development Department
NDVI	2017	186.7 m.	United States Geological Survey
Soil series	2004	30 m.	Land Development Department

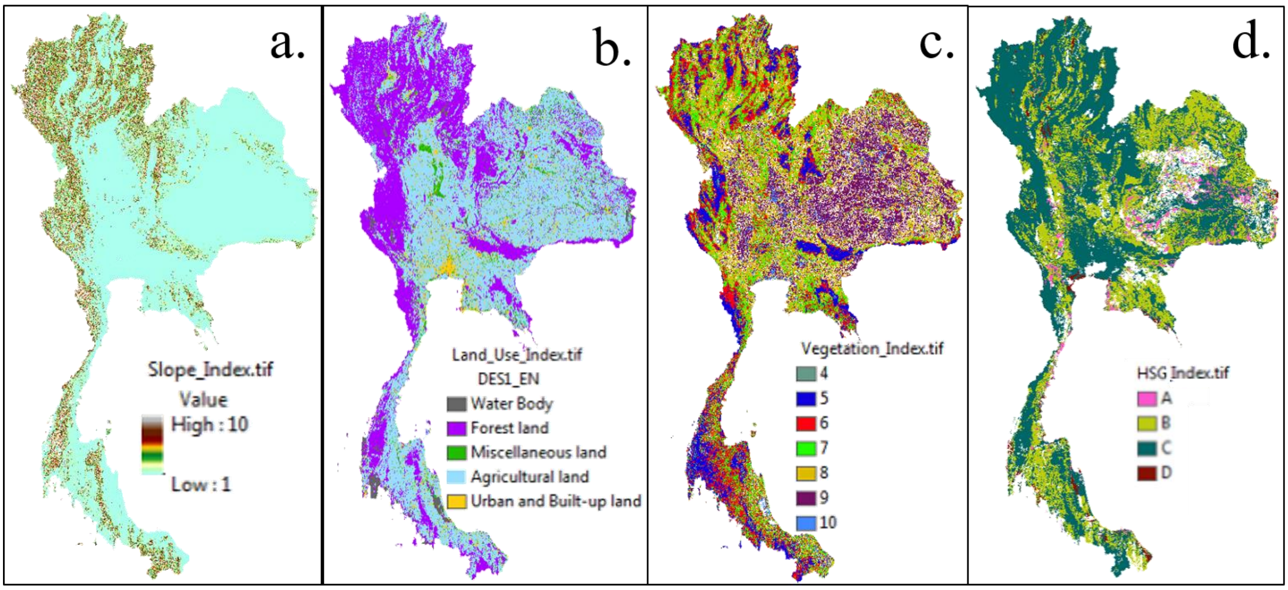


Figure 2. Physiographic catchment properties index.

3.2 Satellite rainfall (PERSIANN-CCS)

The soil moisture is poorly estimated due to the limitation of observation data particularly over the mountainous areas where the flash floods frequently occur. Therefore, an attempt has been made in this analysis to integrate real-time, high-resolution global satellite precipitation data from PERSIANN-CCS (4 km x 4 km) in soil moisture calculation.

3.2.1 The bias correction for satellite rainfall

The uncertainty of data needs to be corrected. The bias in satellite-based rainfall data is corrected with HII ground station by quantile mapping and spatial bias correction method (Lolupiman, et al., 2017). The first method is quartile mapping method which is commonly used to correct systematic distributional biases. The quantile mapping was created with the Cumulative Distribution Function (CDF) calculated from rainfall data. The second approach is spatial bias correction method (Cheema and Bastiaanssen, 2012). This method uses the difference between the satellite pixel and each rain gage adjusted from the quantile mapping method with the use of an inverse distance weighted (IDW) interpolation technique to spatially interpolate the difference between the satellite and the rain gage. Figure 3 shows the bias PERSIANN-CCS rainfall compare with the raw and the gauge in the tropical storm “PABUK” on 4 Jan 2019.

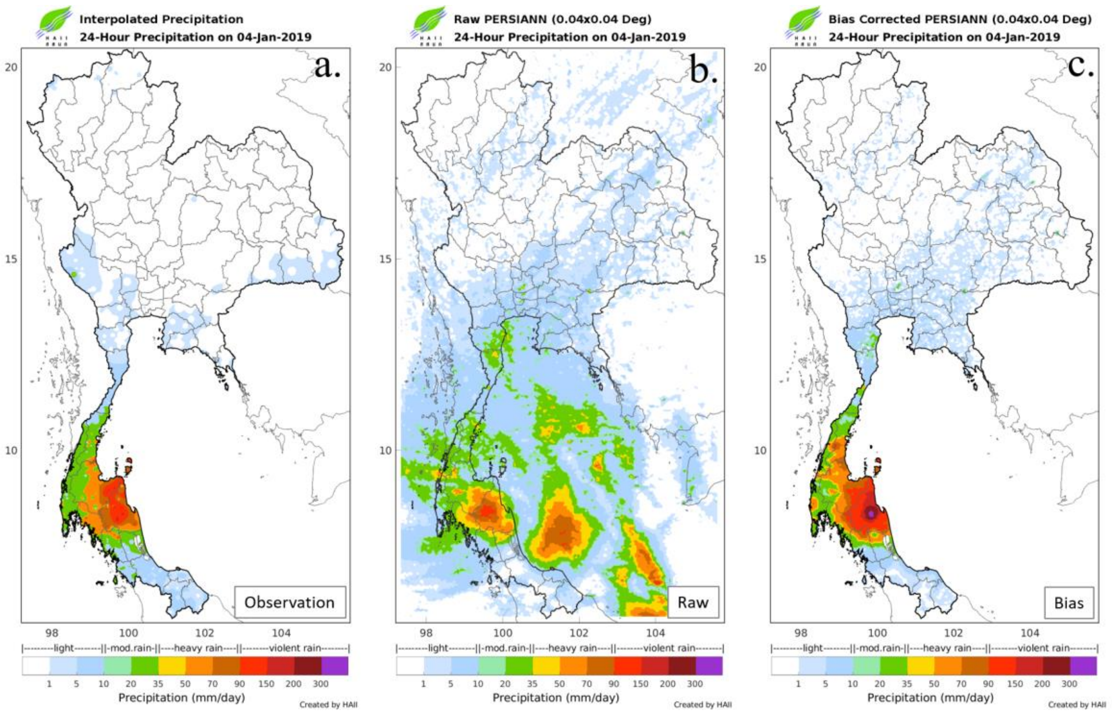


Figure 3. a. Rainfall from gauge station.; b. PERSIANN-CCS (raw).; c. PERSIANN-CCS (bias)

3.2.2 The evaluation of PERSIANN-CCS (Bias)

This study uses rainfall-runoff model (NAM), which is developed from HII to compare the runoff from corrected dataset and raw dataset of PERSIANN-CCS in 2017. The output shows that the correlation between runoff from corrected rainfall and measured runoff increase from 0.18 to 0.61 at Ratchaprapa dam in southernpart of Thailand as shown in Table 3. Figure 4 is an inflow of reservoir, PERSIANN-CCS, and corrected PERSIANN-CCS.

Table 3 Correlation (R) of runoff/inflow at discharge stations/reservoirs using bias corrected PERSIANN-CCS.

Basin/Region	Station/Dam	Correlation (R)	
		PERSIANN (Raw)	PERSIANN (Bias)
Chao Phraya	P.1 (discharge station)	0.54	0.78
	Bhumibol dam	0.67	0.90
Chi-Mun	Ubonrat dam	0.50	0.83
	Lam Takhong dam	0.62	0.82
Eastern part	Si Yat dam	0.49	0.57
	Prasae dam	0.60	0.64
Southern part	Ratchaprapa dam	0.18	0.61

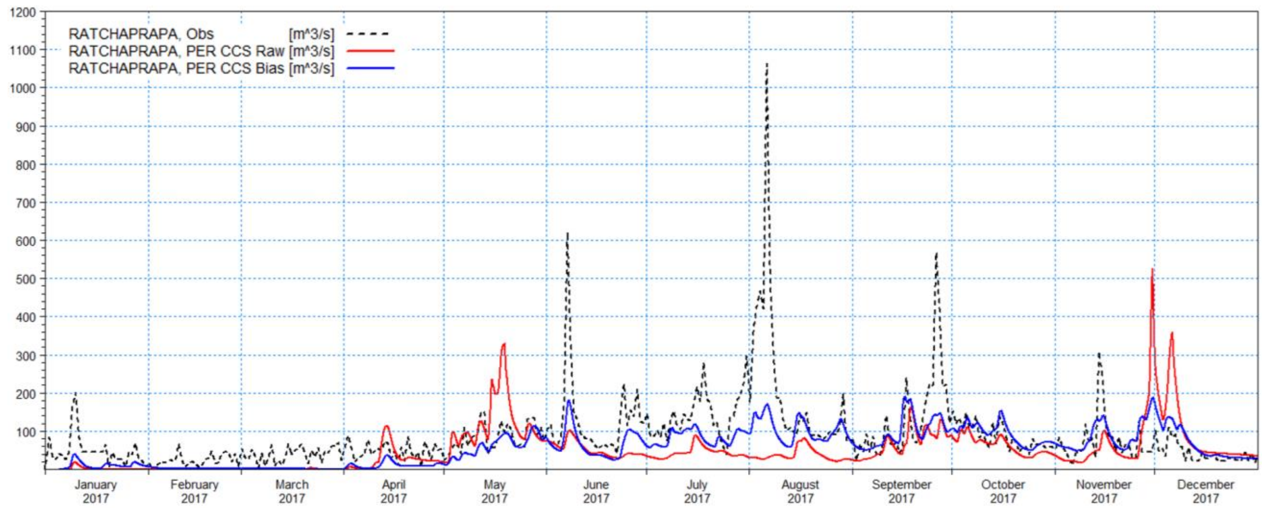


Figure 4 Comparison between observed inflow, PERSIANN-CCS (raw), and PERSIANN-CCS (bias)

3.3 Predicted rainfall (WRF-ROMS)

The 168-hr predicted rainfall is given by a couple WRF-ROMS modeling system. The WRF-ROMS was developed and routinely operated at the Hydro-Informatic Institute (HII), a governmental organization under Ministry of Higher Education Science Research and Innovation (MHESRI), Thailand since 2014 (Torsri *et al.*, 2014). The model has 3-nested domains with horizontal resolution of 27km, 9km, and 3km by which the first and second domain covers most of Asia, and Southeast Asia, while the highest resolution domain is dedicated for Thailand.

This study uses 24-hr predicted rainfall from the highest resolution domain that has the accuracy around 69% (Thodsan *et al.*, 2014). Figure 5 shows 24-hr predicted rainfall from WRF-ROMS compares the gauge stations in the tropical storm “PABUK” on 3-5 Jan 2019.

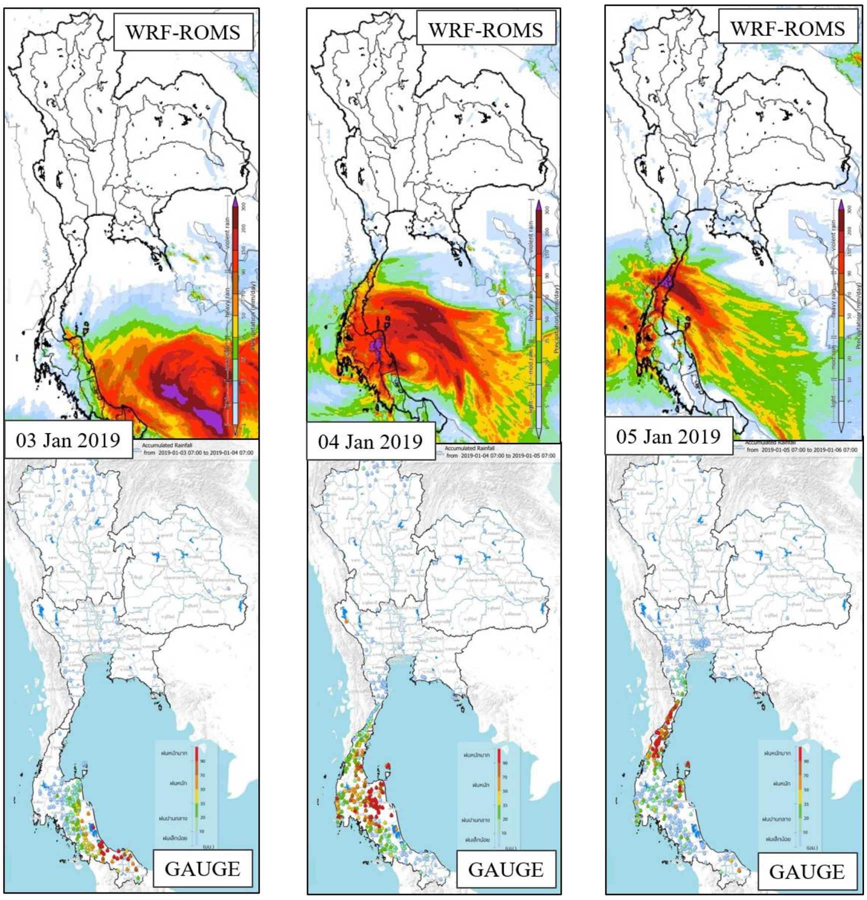


Figure 5. The 24-hr predicted rainfall from WRF-ROMS in the tropical storm “PABUK” on 3-5 Jan 2019

4. METHODOLOGY

This study develops the flash flood prediction by 3 concepts (Figure 6): I) Select the high potential areas using the Flash Flood Potential Index (FFPI), which depends on physical properties. II) Update soil moisture state using AMC class, which calculated from the last 5 days accumulated PERSIANN-CCS rainfall. III) Forecast flash flood-risk areas 24 in advance, which using predicted rainfall from WRF-ROMS.

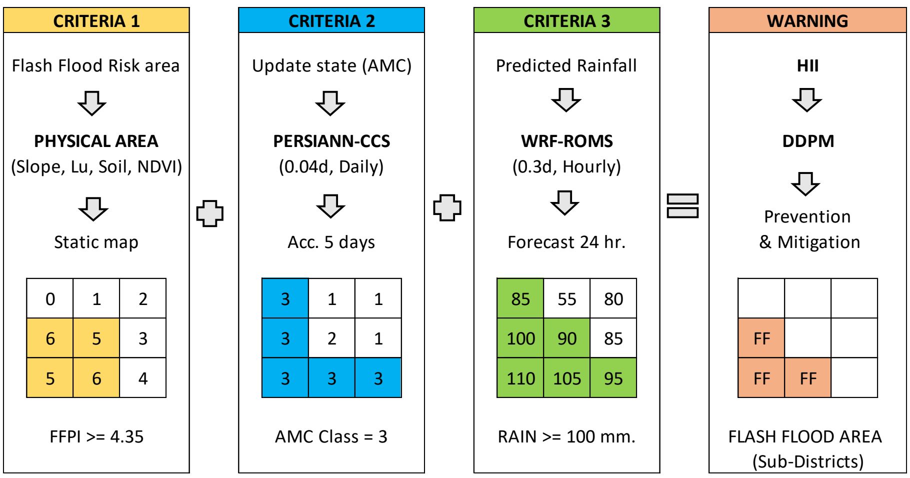


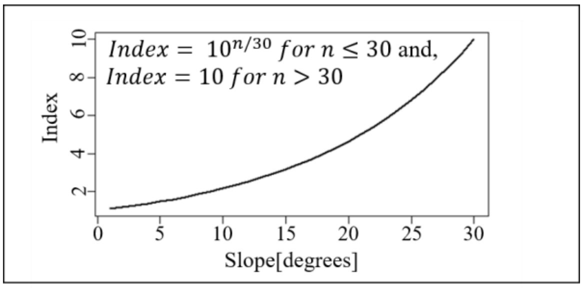
Figure 6. The Concept of development for flash flood predictions.

4.1 Flash Flood Potential Index (FFPI)

The FFPI is an analysis of physical catchment data that are responsible for flash flood occurring, which consists of two methods, the first is the weighting of each index, and the second is the rating score of data layers in each index (Smith, 2003). The range of rating score is 1 to 10, reflecting its individual effect on flash flooding (10 being the worst condition or maximum potential). FFPI equation is shown in Eq. (1), where a, b, c, and d, that is a weighting score of each index. Total value of the weighting score is 1. Weighting and rating scores are defined in Table 4.

$$FFPI = \frac{(a * slope\ index) + (b * \text{land use index}) + (c * \text{vegetation cover index}) + (d * HSG\ index)}{(a + b + c + d)} \tag{1}$$

Table 4. Rating and weighting of each physiographic catchment index.

Index	Class	Rating	Weighting
Slope			0.40
Land use	Urban and Built-up land	9	0.15
	Agricultural land	6	
	Miscellaneous land	5	
	Forest land	4	
	Water Body	2	
Vegetation cover (NDVI)	-1 – 0.30	10	0.15
	0.30 – 0.40	9	
	0.40 – 0.60	8	
	0.60 – 0.70	7	
	0.70 – 0.80	6	
	0.80 – 0.90	5	
	0.90 – 1.00	4	
HSG	A (High infiltration)	2	0.3
	B (Moderately high infiltration)	4	
	C (Moderately low infiltration)	6	
	D (Low infiltration)	8	

Weighting score is defined by impacted to flash flood occurrences. Slope is a major factor, which causes of flash flood, and increasing slope highly affect to runoff, thus the slope score is declared as 0.4, which highest score because of highest impact to flash flood. Slope index is calculated from percentage of slope, where is higher than 30% is defined the index as 10 (Zogg, 2013).

HSGs is analysed from soil group and soil texture. Soil group and texture relate to infiltration of rainfall into the ground or called soil saturated. Soil saturated is another main cause of flash flood. Therefore, this study defines HSGs as 0.3, which is a second level of weighting score that impacts to flash flood. HSGs index is analysed by declare the index for each soil group. The highest score relates to low infiltration and leads to rapidly run off. The rating score is set as default according to table 3, which is rely on soil characteristic in Thailand.

According to previous research, there are other causes of flash flood including land use and vegetation cover. Difference type of land use and vegetation cover impacts on flash flood, for example, rubber tree impacts on flooding than paddy field. However, land use and vegetation cover is lower affect to flash flood when compared with the other factors. Therefore, weighting score of these factors are defined by 0.15. The Rating score of land use and vegetation cover are defined as Table 3. Land use index is applied from previous (Brewster, 2010) and modified the index for Thailand. Vegetation cover is derived from MODIS NDVI dataset. Vegetation index depends on the density cover of agriculture. Low vegetation density leads to higher impact of flash flood occur, thus the score is defined as high value, while high vegetation density affects to low risk of flash flood, and is defined as low value of the score.

This study uses FFPI more than 4.35 for flash flood warning. According to historical flash flood events, FFPI ≥ 4.35 match with the real situation as show in figure 7. Moreover, FFPI should be improved with the historical events and adjusted the weighting factors in up to date.

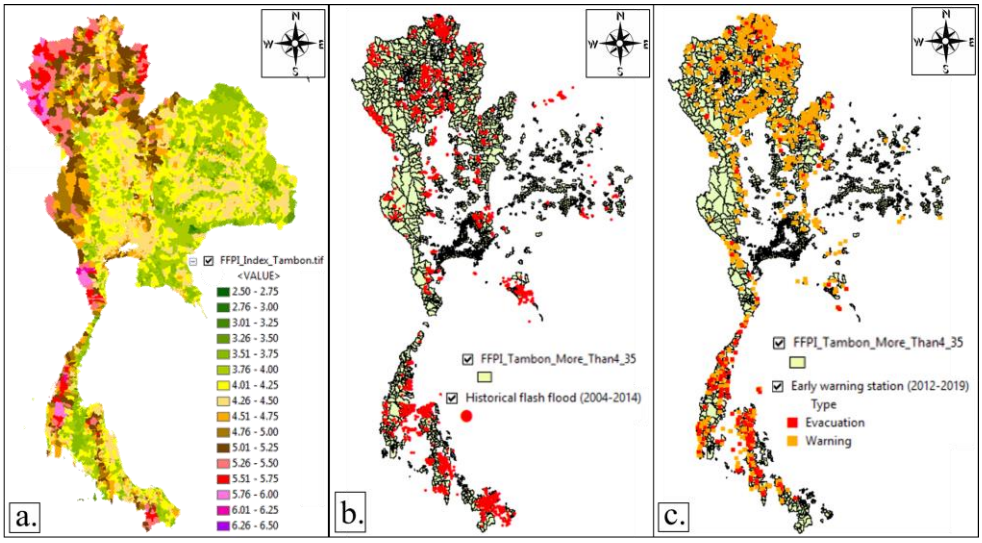


Figure 7. a. The FFPI Index.; b. FFPI areas ≥ 4.35 overlay with historical flash flood (2001-2014).; c. FFPI areas ≥ 4.35 overlay with early warning stations (2012-2019).

4.2 Antecedent Moisture Content (AMC)

AMC is reclassed to 3 classes and each class represents soil moisture from low to high. AMCIII provides the highest runoff, which considers the same value of rainfall and time. The AMC class is calculated from the last 5 days accumulated PERSIANN-CCS rainfall and presents in Eq. (3) (Paola., 2013).

$$\begin{array}{c} < 35.56mm : AMC\ I \\ 35.56\text{mm} < \text{P} < 53.34 : \text{AMC II} \\ > 53.34\text{mm} : \text{A MCIII} \end{array} \quad (3)$$

Moreover, this study compares soil moisture between AMC, which is calculated from PERSIANN-CCS, and observed soil moisture from soil water index (SWI), which derives from METOP satellite with ASCAT sensor. The comparison shows that most area of southern part has a consistency in term of spatial during Pabuk storm event. (Figure 8)

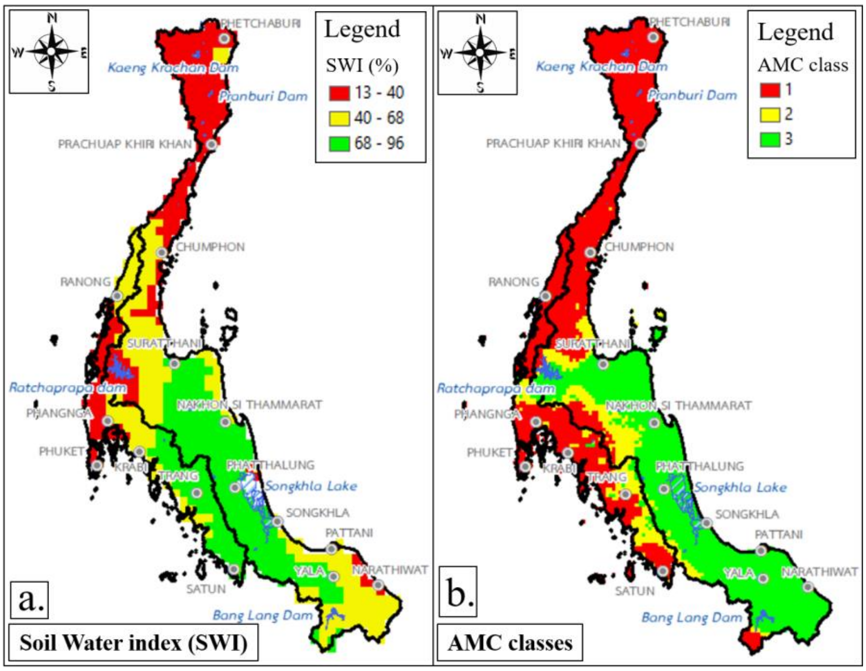


Figure 8. a. The soil moisture from satellite data (SWI).; b. The AMC class from PERSIANN-CCS (bias).

4.3 Predicted rainfall

Forecasted rainfall criteria for flash flood prediction is considered by rainfall data records in time of events (Figure 9a.), 12 hrs.-accumulated rainfall (Figure 9b.), and 24 hrs.-accumulated rainfall (Figure 9c.), which are from 1,558 early warning stations of DWR. The statistical records report rainfall during events is more than 12 hrs. and 24 hrs. accumulated rainfall. Thus, this study decides to use 24 hrs.-accumulated rainfall or 100 mm, which this value has a consistency in term of temporal scale when compared with predicted rainfall from WRF-ROMs.

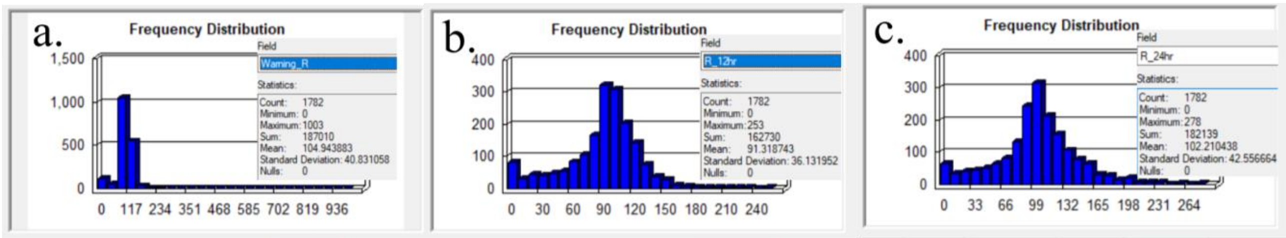


Figure 9. The statistic of accumulated rainfall while warning.; b. The statistic of 12 hrs. accumulated rainfall.; c. The statistic of 24 hrs. accumulated rainfall.

5. RESULTS

The result of predicted flash flood area during the Pabuk storm on 4th January 2019 (Figure 10a) is similar to the news report of the flash flood case in Kanchanadit district of the Surat Thani province, Nobpitam district at Nakon Sritammarat province (Figure 10b.) (MCOT HD 30 news.,2019)., and Khao Luang mountain in Muang district at Nakon Sritammarat province (Figure 9c.) (PPTV HD 36 news.,2019).

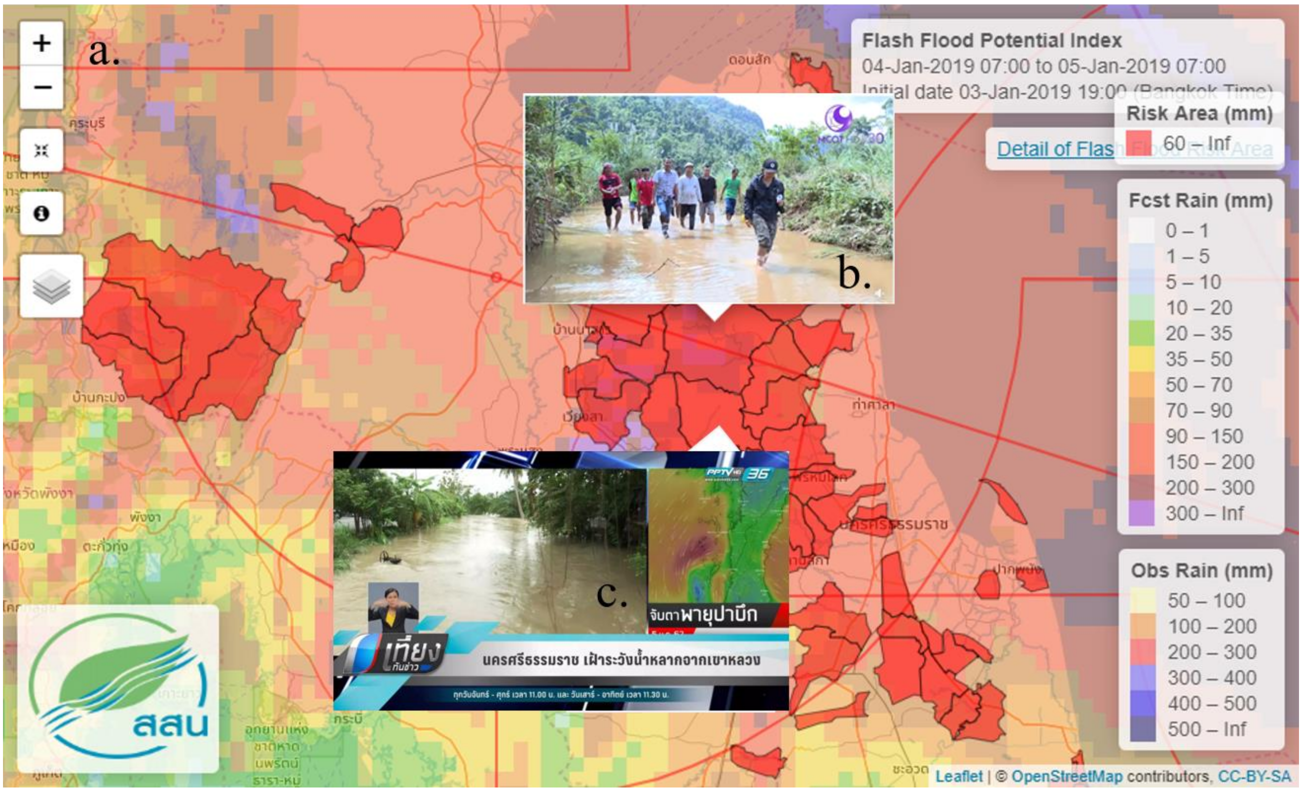


Figure 10. a. Predicted flash flood area.; b. Flash flood occurs at Nobpitam district, Nakhon Si Thammarat province.; c. Flash flood occurs from Khao Luang National Park toward Mueang District, Nakhon Si Thammarat province.

6. CONCLUSIONS AND RECOMMENDATIONS

This study indicates that soil moisture calculated from PERSIAN-CC rainfall can provide accurate estimates of flash floods in the event of a Pabuk storm, and coverage is both spatial and temporal. Moreover, the project should be developed into operation system for warning and supporting decision planers.

However, this study considers only a few records of flash flood events. To increase the accuracy, it is recommended to use FFPI in pixel values instead of in area values, satellite SWI instead of rainfall, and use spatially forecast rainfall instead of just one constant reference. It is also suggested that flash floods should be predicted every one and 12 hours in advance.

ACKNOWLEDGMENTS

We wish to thank Department of Water Resources (DWR) and Department of Disaster Prevention and Mitigation (DDPM) for the early warning data and historical flash flood data.

REFERENCES

Montz, B. E. and Gruntfest, E. (2002). Flash flood mitigation: recommendations for research and applications. Global Environmental Change Part B: Environmental Hazards 4 (1): 15–22.

Lolupiman, T., Thanathanphon, W., Sisomphon P., Ram-Indra, T. and Ruangrassamee, P. (2017). Improvement of Satellite-Based Rainfall for Flood Forecasting System in Chao Phraya River Basin, Thailand. The 14th Annual Meeting Asia Oceania Geosciences Society.

Cheema, M. J. M. and Bastiaanssen, W. G. M. (2012). Local calibration of remotely sensed rainfall from the TRMM satellite for different periods and spatial scales in the Indus Basin.International Journal of Remote Sensing, vol. 33, issue 8, pp. 2603-2627

Torsri, K., Wannawong, W., Sarinnapakorn K., Boonya-Aroonnet, S., Chitradon, R. (2014). An Application of Air-Sea Model Components in the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWAST) Modeling System Over an Indochina Peninsular Sub-region: Impact of high spatiotemporal SST on WRF model in precipitation prediction. *The 11th Annual Meeting Asia Oceania Geosciences Society*.

Thodsan, T., Chankarn, A., Sarinnapakorn K. and Boonya-aroonnet S. (2014). Analysis and accuracy of the Weather Research and Forecasting Model (WRF) for Climate Change Prediction in Thailand. The 19th National Convention on Civil Engineering.

Smith, G. (2003). Flash Flood Potential: Determining the Hydrologic Response of Ffmp Basins To Heavy Rain By Analyzing Their Physiographic Characteristics. A white paper available from the NWS Colorado Basin River Forecast Center at http://www.cbrfc.noaa.gov/papers/ffp_wpap.pdf, 11 pp

Zogg, J. and Deitsch, K. (2013). The flash flood Potential Index at WFO Des Moines, Iowa

Brewster, J. (2010). Development of the flash flood potential index (FFPI) for central NY&Northeast PA. in Eastern Region Flash Flood Conference, NOAA's National Weather Service.

Paola, F. D., Ranucci, A. And Feo, A. (2013). Antecedent Moisture Condition (Scs) Frequency Assessment: A Case Study in Southern Italy. Irrigation and Drainage, 62, pp. 61-71

MCOT HD 30. (2019). News report on 4 January 2019. Online, https://www.facebook.com/watch/?v=233825944177423

PPTV HD 36. (2019). News report on 4 January 2019. Online, https://www.pptvhd36.com/news/%E0%B8%9B%E0%B8%A3%E0%B8%B0%E0%B9%80%E0%B8%94%E0%B9%87%E0%B8%99%E0%B8%A3%E0%B9%89%E0%B8%AD%E0%B8%99/96095