DEVELOPMENT OF DYNAMIC FLASH FLOOD HAZARD INDEX (DFFHI) IN WANG RIVER BASIN, THAILAND

SATHIT CHANTIP
Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand, boyweboy@gmail.com

NAT MARJANG
Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand, fengnmj@ku.ac.th

KOBKIAT PONGPUT
Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand, kobkiat.p@ku.th

ABSTRACT

Flash flood is a natural disaster that damages lives, properties and economies in many parts of the world. World Meteorological Organization (WMO) reports that more than 5,000 people died per year caused by flash flood. Forecasting flash flood hazard areas accurately during heavy rainfall situation will increase the efficiency of decision making in disaster response and management. This study introduces the preliminary development of a Dynamic Flash Flood Hazard Index (DFFHI) using advanced geospatial analysis technique and index-based approach in Wang River Basin located in the northern part of Thailand. The DFFHI is formulated from three indices lead to the occurrence of a flash flood. The first index is Flash Flood Potential Index (FFPI) which is a static map for flash flood risk assessment using geo-topography data. The FFPI comprises of eight physical-geographical factors: land use, vegetation index, hydrologic soil group, slope, profile curvature, plan curvature, flow accumulation and distance from the stream. The second index is Soil Water Index (SWI), which is the daily spatial soil moisture data and the last index is Rainfall Index (RI), which is calculated from the near real-time high-resolution radar rainfall data. The validation result between the indices and historical flash flood event location shows that DFFHI can locate flash flood hazard area closely to historical data. It is found that DFFHI has a potential to be used for flash flood forecasting and can be further developed to be operational to closely monitor flash flood hazard area during a heavy rainfall event. In addition, Convective Rainfall Index (CRI) and rainfall forecast data will be included in the future work for development of a Flash Flood Warning Index (FFWI).

Keywords: Dynamic Flash Flood Hazard Index, Radar Rainfall, Soil Water Index, Rainfall Index, Flash Flood Potential Index

1. INTRODUCTION

Flash flood occur rapidly and difficult to forecast in insufficient warning time. The people affected globally from flash flood is a high-ranking compared to other natural disaster (Borga et al., 2011). Thailand also suffers from flash flood every year in mountain and steep terrain area (Chantip et al., 2018) (Figure 1a). According to the record or data, the critical effect leads to higher number of flash flood studies in past decade. Usually, there are three approaches for flash flood assessment including model-base, data-driven, and index-base. Each method has a different advantage and limitation. Model-base applies physically based distributed hydrologic models for flash flood simulation (Jonathan and Baxter, 2012; Zhai et al., 2018). The advantage of the method is providing high spatial and temporal resolution result, but high-quality data requirements, which are radar rainfall, good coverage of discharge stations, and long-term data record for calibration. The key limitation is a computation time that relate to model area and result resolution scale, such as large area affects to long duration of running time, that could not upgrade to forecast operation system. Data-driven approach for flash flood study has developed to solve the limitation (Piotrowski et al., 2006; Yang et al., 2015). Flash flood physical process knowledge is not required for this approach. This method uses small computation time because flash flood threshold is calculated from the correlation of rainfall and runoff data. Quality of long -term hydro-meteorology data and historical flash flood events affect the precision of result. Moreover, correlation and threshold depend on site specific and could not apply the threshold for ungauged catchment. Index-based approach has developed for area with lack of data. This method uses physiographic catchment properties and GIS techniques for flash flood assessments (e.g. flash flood potential index, flash flood susceptibility, flash flood risk, flash flood hazard). There are 2 levels of the assessment consists of basin scale and grid scale. The index is calculated from multivariable that related to flash flood. The highlight of this method uses historical flash flood data to adjust suitable weight of each variable. Usually, linear equation is applied for basin scale (Abdelkareem (2016)), and expert adjustment (Shehata and Mizunaga, 2018), statistical techniques (e.g., analytic hierarchy process, weight of evidence, frequency ratio) (Zeng et al., 2016; Costache, 2018) and machine learning (Popa et al., 2019) are used for grid scale. The recent study presents that rainfall data is added to be a key variable of index apart from physiographic variable. Rainfall variables are historical statistic data such as annual rainfall, maximum 6 hours rainfall, and maximum daily rainfall. However, the important flash flood factors such as dynamic soil moisture and rainfall data are not using in recent study works, thus the result is in static map and is not represent to current condition. This study aims to improve index-based approach by attempted using non-static variables such as soil moisture and hourly rainfall data for creating Dynamic Flash Flood Hazard Index (DFFHI), which is useful for monitoring the flash flood hazard area and be able to warning people in the hazard area with adequate evacuation time.

2. STUDY AREA

Wang river basin is located in the northern part of Thailand (Figure 1b). There occupy 10,793 sq.km. The basin has a long shape. The elevations in the range of 120 to 2,000 m.MSL. The northern part, western part and the eastern part are the high mountain range. The area is characterized by steep terrain starts from the upstream in the mountain range and runs to the lowland area in the middle. The average basin slope is 11°. The twenty percentage of the basin area has slope angle more than 20°, where locates in the upstream area. According to Figure 1b, the upper part of the basin has more flash flood events because it has more steep terrain area. The main river flows through the middle of the basin in the direction from north to south and has a length of approximately 300 kilometers. The tributaries have the total length about 3,500 kilometers. Average annual rainfall is 1,100 mm/year. The rainy season starts from May to October and maximum rainfall is in September. Average annual runoff is 1,800 MCM/year. The land use of the study area comprises forest area (67%), agriculture (24%), urban (5%), miscellaneous areas (2%), and water body (2%). Regarding the soil characteristic, the hydrological soil group C has 58% of the study area, the hydrological soil group B, group D and group A cover 36%, 5% and 1%, respectively.

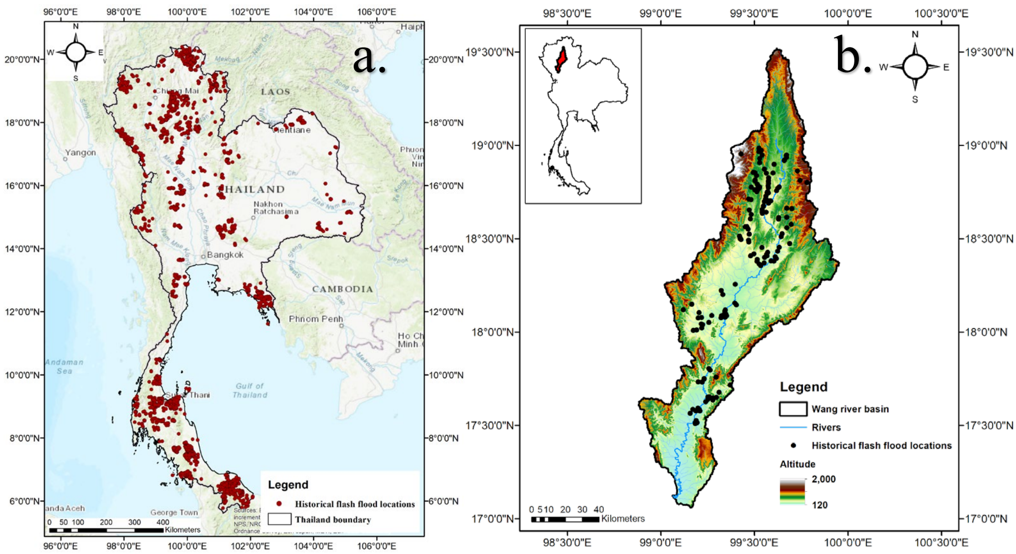

Figure 1. a. The historic flash flood locations in Thailand (2004-2014).; b. Study basin and their location in Thailand.

3. DATA AND MATERIAL

3.1 Flash flood conditioning factors

Base on a literature review, eight flash flood conditioning factors (Figure 2) are used to calculate the FFPI. Each factor has differently affected to surface runoff processing and flash flood occurring. The factors and impact are shown in Table 1. The physiographic catchment properties are used to process flood conditioning factors and their sources are shown in Table 2.

3.2 Radar rainfall

Flash flood is a rapid flooding that caused by heavy rain associated with poor soil absorption ability. The events are mostly occurred in local and small area. To capture local storm event, the high resolution for both space and time rainfall data is needed for flash flood study. This research uses historical radar rainfall data in 2016 from Omkoi weather radar station (Figure 3a). The radar is operated by the Department of Royal Rainmaking and Agriculture Aviation (DRRAA). The station is located in Omkoi district, Chiang Mai province (latitude 17.7976 N longitude 98.4331 E), where is 1,163 meters above sea level. This radar is S-band Doppler radar with a frequency of 2.80 GHz and the maximum range of the scanning rays is 240 km. The operating performs a volume scan every 6 min with 1 km x 1km spatial resolution.

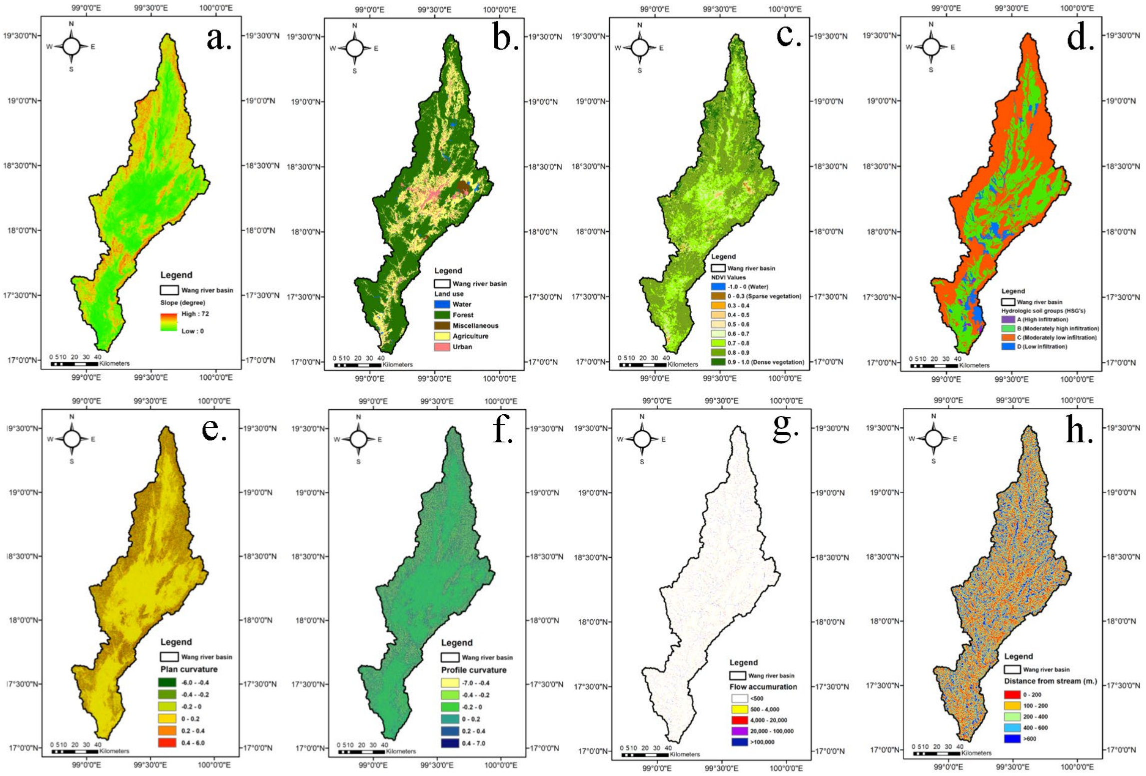

Figure 2. Flash flood conditioning factors (a. slope; b. land use; c. NDVI; d. hydrologic soil groups; e. plan curvature; f. profile curvature; g. flow accumulate; h. distance from stream).

Table 1. Flash flood conditioning factors.

Factor	Effect to flash flood
Slope	Steep terrain area has short time of concentration so this area should be flooding quicker than a flat area.
Land use	Land use influences runoff coefficient and infiltration rate. Particularly the urban area has low infiltration rate and high runoff coefficient which support the surface runoff.
Vegetation index	The high vegetation density area has a low runoff coefficient and more intercept precipitation, so it creates low runoff peak.
Hydrologic soil group	The HSG represents the soil infiltration capacity, which affects the proportion of base flow and direct runoff.
Plan curvature	The plan curvature is perpendicular to the direction of the slope. This factor represents the characteristic of surface runoff. A positive value indicates a divergence flow and a negative value indicates a convergence flow.
Profile curvature	The profile curvature is parallel to the slope. This factor affects an acceleration or a deceleration of flow. A positive value indicates low velocity flow and a negative value indicates high velocity flow.
Flow accumulation	The flow accumulation value is the number of cells that flows into the considered cell, therefore an increasing flow accumulation should be an effect to an increasing runoff.
Distance from streams	The low elevation areas near the drainage network are the flash flood risk area.

Table 2. The physiographic catchment properties.

Data	Year	Resolution	Flash flood conditioning factors	Source
Land use	2018	30 m.	Land use	Land Development Department
NDVI	2018	186.7 m.	Vegetation index	United States Geological Survey
Hydrologic soil group (HSG)	2004	30 m.	Hydrologic soil group	Land Development Department
Digital elevation model (DEM)	2005	30 m.	Slope Plan curvature Profile curvature Flow accumulation Distance from the stream	Royal Thai Survey Department

3.3 Soil moisture

Rainfall excess and saturated soil moisture are the main factors causing the flash flood. Accurate flash flood assessment requires the current state of soil moisture condition data. On the other hand, soil moisture station in Thailand is poorly coverage and hardly available on upstream area. So, soil water index (SWI) from Copernicus Global Land Service is applied to the study. SWI is a daily data with 0.1-degree resolution and processed from Surface Soil Moisture (SSM) at 1-5 cm of soil depth which is measured by MetOp-Ascat sensor. There is a percentage of soil moisture range from 0 to 100. SWI is reclassed from 0 - 100 to 1 - 10, and reclassified index is used for FFPI calculation (Figure 3b).

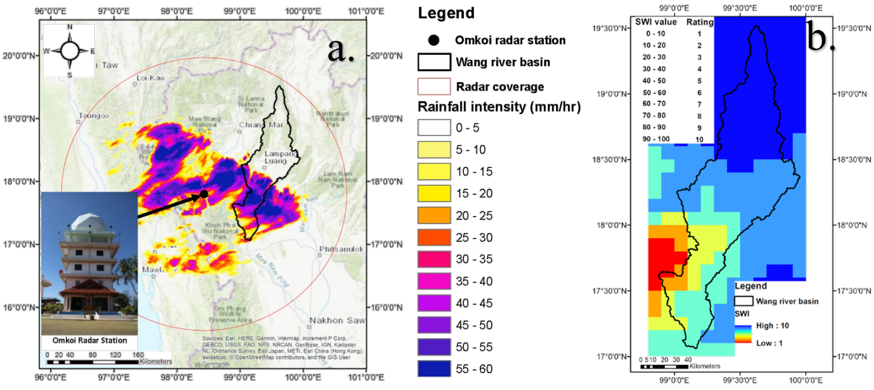

Figure 3. a. Omkoi radar station.; b. Soil Water Index (SWI) data.

3.4 Historical flash flood locations

The flash flood locations from Department of Disaster Prevention and Mitigation (DDPM) are defined in 2 groups. Group A is a flash flood events with 173 locations from 2004 to 2014 (Figure 1b), when is not an identical period of historical radar rainfall data. The weight of the FFPI is adjusted by the data. It should be noted that this data does not contain all detected flood events and the locations are not accurate at the village location level and not precise in longitude and latitude. Group B comprises only four flash flood events in 2016 (Table 3). The data is used to validate the DFFHI map.

Table 3. The group B historical flash flood events.

No.	Date	Time	Flash flood location			
			Province	**District**	**Subdistrict**	**Village Name**
1	20/07/2016	9:00 PM	Lam Pang	Thoen	Mae Thod	1,4,5,12
2	15/09/2016	4:00 AM	Lam Pang	Hang Chat	Wiang Tan	1,2,5,7,8,9
					Nong Lom	3,6
					Wo Kaeo	2,3,4,5
					Mae San	3
					Mueang Yao	3,4
3	6/10/2016	12:00 AM	Lam Pang	Soem Ngam	Soem Klang	1,2,3,4,5,6
4	26/10/2016	4:00 PM	Lam Pang	Mae Mo	Mae Mo	5,6

4. METHODOLOGY

The full methodology workflow in developing the DFFHI is presented schematically in Figure 4, which has 4 tasks for developing: I) data collection and processing; II) classification of variable and rating; III) weighting according to the importance of the flooding and IV) index map calculation.

4.1 Flash Flood Potential Index (FFPI)

FFPI is a static index for flash flood risk assessment using flash flood conditioning factors. Each factor is scored from 1 to 10 vary on the importance of flash flood and 10 being the worst condition or maximum flash flood potential (Table 4). This study uses expert adjustment approach and historical flash flood locations to estimate suitable weighting for each factor. The weighting is applied in Eq. (1).

$$FFPI = \frac{(F_1W_1 + F_iW_i + \ldots + F_8W_8)}{(W_1 + W_i + \ldots + W_8)} \quad (1)$$

where F_i is physical-geographical factors, W_i is weight for each factor and total sum of W_i=1

The FFPI output is reclassed to 1 – 10 by Eq. (2) before calculated in the DFFHI.

$$index = min\,index\,value + \left[\left[\frac{(cell\,value - min\,cell\,value)}{(max\,cell\,value - min\,cell\,value)}\right] x (max\,index\,value - min\,index\,value)\right] \quad (2)$$

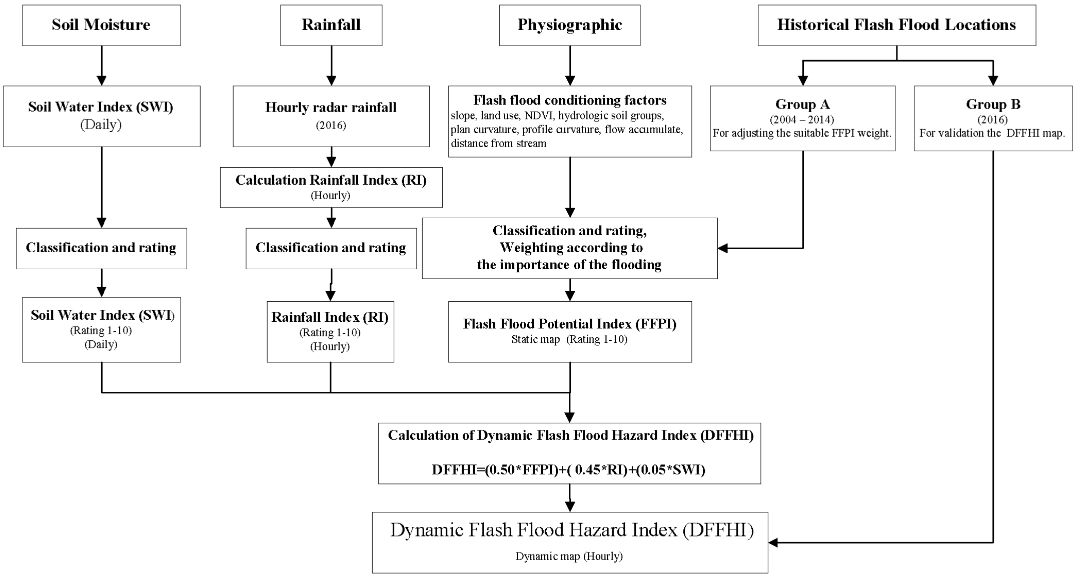

Figure 4. Schematic of the methodology

Table 4. Rating and weighting of each flash flood conditioning factors.

Factor	Class	Rating	Weight
Land use	Water	2	0.15
	Forest	4	
	Miscellaneous	5	
	Agricultural	6	
	Urban	9	
Hydrologic soil groups	A (High infiltration)	2	0.15
	B (Moderately high infiltration)	4	
	C (Moderately low infiltration)	6	
	D (Low infiltration)	8	
Vegetation index	-1.0 – 0.30	10	0.10
	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 – 1.0	4	
Slope (degrees)	Value = $10^{(slope/30)}$ for slope ≤ 30 and Value = 10 for slope > 30		0.25
Profile curvature	7.00 – 0.40	1	0.05
	0.40 – 0.20	2	
	0.20 – 0.00	4	
	0.00 – -2.00	6	
	-0.20 – -0.40	8	
	-0.60 – -7.00	10	
Plan curvature	6.00 – 0.40	10	0.05
	0.40 – 0.20	8	
	0.20 – 0.00	6	
	0.00 – -2.00	4	
	-0.20 – -0.40	2	
	-0.60 – -6.00	1	
Flow Accumulate (pixels)	<500	2	0.10
	500 – 4,000	4	
	4,000 – 20,000	6	
	20,000 – 100,000	8	
	>100,000	10	
Distance from stream (m.)	0 – 100	10	0.15
	100 – 200	8	
	200 – 400	6	
	400 – 600	4	
	>600	2	

4.2 Rainfall Index (RI)

Rainfall index (RI) is concepted from rainfall triggering index (RTI), which was developed by Chyan-Deng Jan in 2002 (Jan et al., 2007) and aimed to create the rainfall threshold for debris flow warning. According to Eq. (3), RI is analyzed from 3 days accumulated rainfall that is reduced the weighting by time and hourly rainfall intensity. Before DFFHI calculation, the RI output is reclassed to 0 – 10 by Table 5.

$$RI = \left[(R_{-3day} \times 0.2)+(R_{-2day} \times 0.3) + (R_{-1day} \times 0.5)\right] \times I \quad (3)$$

where, R_{-3day}, R_{-2day}, R_{-1day} = the daily rainfall in the past 3 day, 2day and 1day (mm);
I = the hourly rainfall intensity (mm/hr)

Table 5. Classification of Rainfall Index (RI) and rating.

Rainfall Index value	Rating
< 200	0
200 – 400	1
400 – 400	2
600 – 600	3
800 – 800	4
1,000 – 1,000	5
1,200 – 1,200	6
1,400 – 1,400	7
1,600 – 1,600	8
1,800 – 2,000	9
> 2,000	10

4.3 Dynamic Flash Flood Hazard Index (DFFHI)

Three indices (FFPI, SWI and RI) are used for the DFFHI calculation. Expert adjustment is used to define unequal weight for each index. According to Eq. (4), the high score represents the more significant for flash flood. The highest weight is FFPI (0.50), RI (0.45) and SWI (0.05), respectively.

$$DFFHI = (0.50 \times FFPI) + (0.45\text{x}RI) + (0.05\text{x}SWI) \quad (4)$$

The DFFHI output is the hourly high-resolution map (30m. x 30m.) with range between 1 to 10. This map is reclassified for 5 classes relevant to the hazard level (very low :1-2, low :2-4, medium :4-5, high :5-6, and very high :6-10).

4.4 Evaluation of Dynamic Flash Flood Hazard Index map performance

Validation criteria are the comparison between the subdistrict, which has a high and very high-risk area more than 5 km^2, and group B historical data on flash flood events. Due to the limitation of historical flash flood event data, only four historical flash flood events are available to use for index validation. The dichotomous (yes/no) forecast verification method (Table 6) is used for result validation at a subdistrict scale. In the present research, probability of detection (POD), false alarm ratio (FAR), critical success index (CSI) and accuracy are used as the indicators (Table 7).

Table 6. Contingency table for a dichotomous forecast.

		Observed	
		Yes	**No**
Forecast	**Yes**	Hit	False alarm
	No	Miss	Correct negative

Table 7. The indicators for results validation.

Indicators	Equations	Rang value	Best value
Probability of detection (POD)	Hits / (Hits + Misses)	0 - 1	1
False alarm ratio (FAR)	False alarms / (Hits + False alarms)	0 - 1	0
Critical success index (CSI)	Hits / (Hits + Misses + False alarms)	0 - 1	1
Accuracy	(Hits + Correct negatives) / Total	0 - 1	1

5. Results

5.1 Flash Flood Potential Index (FFPI) results

Figure 5. illustrates the middle part of the basin which is a lowland area. It shows FFPI range between 2-5. There is 76.5% of an entire area. The upstream shows the range between 6–8. The validation between FFPI map and historical flash flood points in group A was found 59.3% of 173 points agree with high FFPI values greater than 6. It can conclude that the FFPI map can define flash flood risk area.

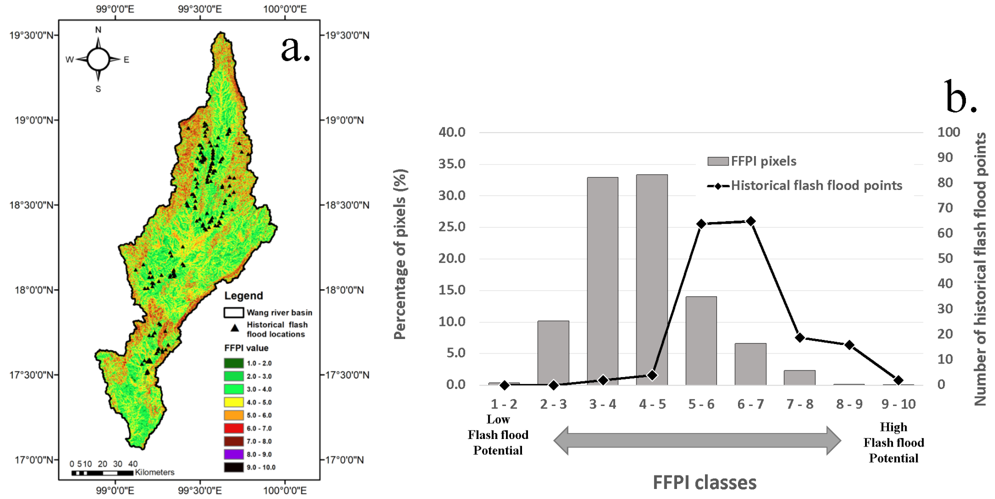

Figure 5. a. The Flash flood potential index map of the study area; b. Percentage of pixels and number of historical flash flood points for each FFPI classes.

5.2 Dynamic Flash Flood Hazard Index (DFFHI) results

DFFHI result is analyzed and validated by historical events on 20/07/2016, 15/09/2016, 6/10/2016 and 26/10/2016. The map (Figure 6) and the validation results (Table 8) represent the good performance of the index. The flash flood events occur in the high hazard level. The average value of POD, FAR, CSI and Accuracy is 0.90, 0.13, 0.78 and 0.99, respectively. In general, the hazardous area can be pointed by the index at a subdistrict scale, but it still cannot precisely define for a village scale. It should be noted that the number of historical flash flood event data affects the results improving. The limitation of this study for index validation is the lack of more historic flash flood event data.

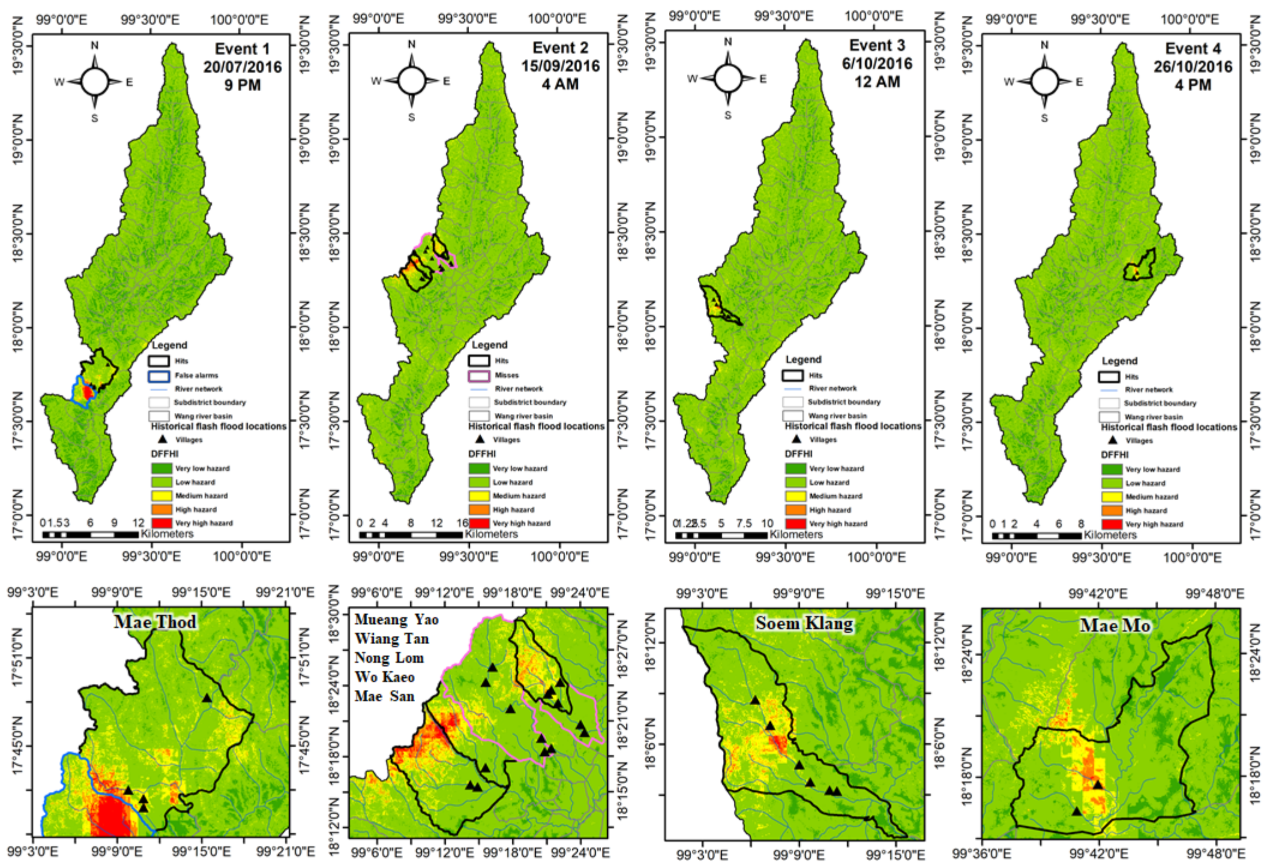

Figure 6. The Dynamic Flash Flood Hazard Index (DFFHI) results and historical flash flood locations maps.

Table 8. The validation of Dynamic Flash Flood Hazard Index map.

Events	Hits	False alarms	Misses	Correct negatives	Indicators			
					POD	FAR	CSI	Accuracy
1	1	1	0	92	1.00	0.50	0.50	0.99
2	3	0	2	89	0.60	0.00	0.60	0.98
3	1	0	0	93	1.00	0.00	1.00	1.00
4	1	0	0	93	1.00	0.00	1.00	1.00
Average					0.90	0.13	0.78	0.99

6. CONCLUSIONS AND FUTURE WORK

The purpose of this study attempts to use dynamic variables such as rainfall and soil moisture for the development of the DFFHI. Hourly radar rainfall and the observed daily soil moisture data from the satellite were used to create RI and SWI. The FFPI was the static map which was calculated from 8 flash flood conditioning factors (slope, land use, vegetation index, hydrologic soil groups, plan curvature, profile curvature, flow accumulate and distance from the stream). Expert adjustment method was used to find a suitable weight for each variable. From the FFPI, the result shows that the FFPI map can define the high risk area successfully. RI, SWI and FFPI were used for the DFFHI calculation by using unequally weight method. The high weight performs highly significant for flash flood occurrence. The highest weight is FFPI, RI and SWI, respectively. According to the results of validation indicators (POD, FAR, CSI and Accuracy), DFFHI map can indicates the hazardous area very well in subdistrict scale but the index still cannot precisely define for a village scale, because it does not consider the flood routing behavior. This map can be used to gain knowledge about imminent flash flood hazard areas and can be further developed to be operational to closely monitor flash flood hazard area during a heavy rainfall event. In future research, FFPI should be improved by advanced statistical technique or machine learning approach for suitable weight estimation. In addition, DFFHI should be added flood routing index in order to improve accuracy for village scale estimation and upgraded to flash flood warning index (FFWI) by using rainfall forecast data and convective rainfall index such as Convective Available Potential Energy (CAPE) and Convective Inhibition (CIN). FFWI is useful for disaster mitigation and management by warning and monitoring flash flood events.

ACKNOWLEDGMENTS

We wish to thank Department of Royal Rainmaking and Agricultural Aviation (DRRAA) and Department of Disaster Prevention and Mitigation (DDPM) for the radar data and historical flash flood data.

REFERENCES

Abdelkareem, M. (2016). Targeting flash flood potential areas using remotely sensed data and GIS techniques. Nat Hazards, 85, 19 – 37.

Borga, M., Anagnostou, E.N., Bloschl, G., Creutin, R. , and Zhan, J.-D. (2011). Flash flood forecasting, warning and risk management: the HYDRATE project. *ENVIRONMENTAL SCIENCE&POLICY*, 14:834-844.

Chantip, S., Mooktaree, A., and Sisomphon, P. (2018). Development of an operational flash flood forecasting system for Thailand. *The 13th International Conference on Hydroscience & Engineering Proceeding*, 250.

Costache, R. (2018). Flash-Flood Potential assessment in the upper and middle sector of Prahova river catchment (Romania). A comparative approach between four hybrid models. *Science of the Total Environment*, 659:1115-1134.

Jan, D.C., Kuo, F.H., and Lee, M.H. (2007). A Case Study on Debris-Flow Warning and Evacuation during Typhoon Haitang. *2nd International Conference on Urban Disaster Reduction Proceeding*.

Jonathan, L., and Baxter, V. (2012). An assessment of distributed flash flood forecasting accuracy using radar and rain gauge input for a physics-based distributed hydrologic model. *Journal of Hydrology*, 413:114-132.

Piotrowski, A., Napi´orkowski, J.J., and Rowi´nski, P.M. (2006). Flash-flood forecasting by means of neural networks and nearest neighbor approach - a comparative study. *Nonlinear Processes in Geophysics*, 13:443-448.

Popa, M.C., Peptenatu, D., Draghici, C.C., and Diaconu, D.C. (2019). Flood Hazard Mapping Using the Flood and Flash-Flood Potential Index in the Buzau River Catchment, Romania. *Water 2019*, 11, 2116.

Shehata, M., and Mizunaga, H. (2018). Flash Flood Risk Assessment for Kyushu Island, Japan. *Environmental Earth Sciences*, 77:76.

Yang, T.H., Yang, S.C., Ho, J.Y., Lin, G.F., Hwang, G.D., and Lee, C.S. (2015). Flash flood warnings using the ensemble precipitation forecasting technique: A case study on forecasting floods in Taiwan caused by typhoons. *Journal of Hydrology*, 520:367-378.

Zeng Z., Tang G., Long D., Zeng, C., Ma M., Hong Y., Xu H., and Xu J. (2016). A cascading flash flood guidance system: development and application in Yunnan Province, China. *Nat Hazards*, 84:2071-2093.

Zhai, X., Guo L., Liu R., and Zhang, Y. (2018). Rainfall threshold determination for flash flood warning in mountainous catchments with consideration of antecedent soil moisture and rainfall pattern. *Natural Hazards*, 94:605-625.