การประเมินพื้นที่เสี่ยงน้ำท่วมโดยใช้เทคนิคการสำรวจระยะไกล (Remote Sensing) และแบบจำลองทางชลศาสตร์ (Hydraulic Modelling) ในพื้นที่ลุ่มน้ำคลองบางสะพานใหญ่ จังหวัดประจวบคีรีขันธ์

Flood Risk Assessment using Remote Sensing Techniques and Hydraulic Modelling in Khlong Bang Saphan Yai River Basin, Prachuap Khiri Khan Province

ศิริวาท สีชะนะ[1,2], ภัทราพร สร้อยทอง[1], Xiaoling Chen[2], Jianzhong Lu[2], กฤษนัยน์ เจริญจิตร[1] และ ปัทมา พอดี[1*]

Siriwat Seechana[1,2], Phattraporn Soytong[1], Xiaoling Chen[2], Jianzhong Lu[2],

Kitsanai Charoenjit[1] and Pattama Phodee[1*]

[1]คณะภูมิสารสนเทศศาสตร์ มหาวิทยาลัยบูรพา

[1] Faculty of Geoinformatics, Burapha University

[2] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, China

Received : 15 August 2022

Revised : 26 September 2022

Accepted : 17 October 2022

บทคัดย่อ

ลุ่มน้ำคลองบางสะพานใหญ่มีความสำคัญต่อพื้นที่เกษตรของจังหวัดประจวบคีรีขันธ์ เมื่อปี พ.ศ.2561ได้เกิดเหตุการณ์น้ำท่วมก่อให้เกิดความเสียหายในหลายพื้นที่ โดยสาเหตุเกิดจากฝนที่ตกหนักติดต่อกันหลายวัน ทำให้ระดับน้ำในคลองสูงและเกิดการล้นตลิ่ง และมีสาเหตุเกิดจากระดับน้ำทะเลสูง จึงส่งผลทำให้น้ำไม่สามารถระบายออกสู่ทะเลได้จนกลายเป็นน้ำท่วมในหลายพื้นที่ การศึกษาในครั้งนี้มีวัตถุประสงค์ เพื่อประเมินพื้นที่เสี่ยงน้ำท่วมที่เกิดจากการไหลล้นตลิ่งคลองบางสะพานใหญ่โดยใช้แบบจำลองทางชลศาสตร์ (HEC-RAS) ร่วมกับเทคนิคการสำรวจระยะไกล (Remote sensing) จากการศึกษาได้ใช้ค่าสัมประสิทธิ์ความขรุขระของแมนนิ่ง (n) ที่ตลิ่งของทั้งสองข้างเท่ากับ 0.045 และท้องน้ำเท่ากับ 0.050 โดยทำการปรับเทียบและสอบเทียบแบบจำลองกับข้อมูลปริมาณน้ำท่ารายวันในปี พ.ศ.2561 และ 2562 ได้ผลการปรับเทียบ มีค่า R^2 เท่ากับ 0.914 และค่า NSE เท่ากับ 0.861 และผลการสอบเทียบ มีค่า R2 เท่ากับ 0.822 และค่า NSE เท่ากับ 0.634 ผลการศึกษาพบว่า การจำลองสภาพน้ำท่วมด้วยแบบจำลอง HEC-RAS ได้ค่าอัตราการไหลสูงสุดที่สถานีท้ายน้ำ เท่ากับ 127.17 ลบ.ม./วินาที และค่าระดับน้ำสูงสุด 9.08 ม.รทก. สำหรับการวิเคราะห์หาพื้นที่เสี่ยงน้ำท่วมและประเมินความถูกต้องเปรียบเทียบกับขอบเขตพื้นที่น้ำท่วมจากเทคนิคการสำรวจระยะไกล พบว่า พื้นที่เสี่ยงน้ำท่วมที่ซ้อนทับกัน เท่ากับ 0.22 ตร.กม. คิดเป็นร้อยละ 17.5 มีพื้นที่เสี่ยงน้ำท่วม 4 ตำบล ได้แก่ ตำบลร่อนทอง, ตำบลทองมงคล, ตำบลกำเนิดนพคุณ และตำบลพงศ์ประศาสตร์ ตั้งอยู่ในอำเภอบางสะพานใหญ่ จังหวัดประจวบคีรีขันธ์

คำสำคัญ : สำรวจระยะไกล ; แบบจำลองทางชลศาสตร์ ; แบบจำลอง HEC-RAS ; พื้นที่น้ำท่วม ; ขอบเขตพื้นที่น้ำท่วม

Abstract

The Khlong Bang Saphan Yai River Basin is important in agriculture in Prachuap Khiri Khan Province. In 2018, there was a flood that affected several areas throughout the basin due to many days of heavy rainfall, resulting in high water levels in the Khlong Bang Saphan Yai River and overflows. Another factor is the high sea level which water could not drain into the sea and caused surface runoffs and floodplains in many areas. This study aims to determine the application of hydraulic modelling (HEC-RAS) integrated with remote sensing techniques to assess flood risk area in the Khlong Bang Saphan Yai River Basin. This study used Manning's roughness coefficient (n) of 0.045 for both riverbanks and 0.050 for the channel. The HEC-RAS calibration and validation indicated a good agreement with observed daily discharge data during the periods of 2018 and 2019. Calibration results showed the Coefficient of determination (R^2) value of 0.914 and the Nash-Sutcliffe coefficient of efficiency (NSE) value of 0.861. Validation results showed the R^2 value was 0.822 and the NSE value was 0.634. The result of HEC-RAS simulation found that the maximum flow rate value of 127.17 m^3/s and the maximum water level value of 9.08 m. MSL at the downstream gauging. In addition, the study of the validation assessment of the flood inundation from the model simulation was performed in comparison to the flooded extent derived from remote sensing techniques, the result showed overlapping of the flooded area of 0.22 km^2 (17.5%). It covered four sub-districts, namely Ron Thong, Thong Mongkhon, Kamnoet Nopphakhun, and Phong Prasat in Bang Saphan Yai District, Prachuap Khiri Khan Province.

Keywords : remote sensing ; hydraulic modelling ; HEC-RAS ; flood Inundation ; flood extent

***Corresponding author. E-mail** : pattamap@go.buu.ac.th

Introduction

In recent years, flooding has been one of the most frequent natural disasters, with several detrimental environmental and socioeconomic effects on human lives, infrastructures, and properties, as well as indirect effects on the economy of the country (Vanthan *et al.*, 2020). According to the United Nations Office for Disaster Risk Reduction (UNISD) and the Center for Research on the Epidemiology of Disaster (CRED), most flooding occurred between 1950 and 2017, with about 2% occurring during the 1950s, and more than 60% of total economic and human losses concentrated in Asia and Saudi Arabia between 1950 and 2017 (Abdelkarim *et al.*, 2020). Floods can be considered a hazard if they pose a threat to people, animals, or their welfare in a watershed area. Therefore, the flood inundation map has become critical for flood risk management, as well as providing vital information to residents in order for them to be aware of vulnerabilities (Chit Myo, 2020).

Thailand has been experienced flooding almost every year between October and March due to the influences of monsoon season and tropical cyclones. The worst floods occurred in 2011, 13.6 million people in 65 of 76 provinces were affected, loss of life 813 people, loss of jobs 400,000 people, and economic damage 46.50 billion US dollars (Haraguchi & Lall, 2015). These floods have resulted in the worst natural disaster in Thailand in terms of population growth and disruption of socioeconomic activities.

Because of the serious effects of floods on humans and the economy, many studies have been conducted to investigate flood hazard and its impact on urban areas, as well as to present experiences and illustrative examples of various types of flood maps. Increasing attention has been paid in recent decades to the effects of floods and initiatives that could be implemented to mitigate the effects of a flood (Elkhrachy *et al.*, 2021).

There are many different flood modelling methods to determine flood inundation, such as hydrological and hydraulic (Elkhrachy *et al.*, 2021). The hydraulic modelling is useful implements flood monitoring, management, and planning. Combining these models with remote sensing-based water extent extractions is possible to improve model accuracy (Nguyen *et al.*, 2020). The Hydrologic Engineering Center River Analysis System (HEC-RAS) has been used by several researchers for flood modelling (Abdelkarim *et al.*, 2020; Balogun *et al.*, 2020; Thoummalangsy *et al.*, 2019). HEC-RAS is one of the best software for developing and testing flood models. With HEC-RAS, one-dimensional modelling (HEC-RAS 1D) is used to identify the movement and timing of runoff in research regions, which helps in the determination of water depth, water velocity, and flood extent (Abdelkarim *et al.*, 2020; Balogun *et al.*, 2020). The HEC-RAS simulated results should be calibrated with observation data before being used to generate flood risk maps and assess flood vulnerability (Elkhrachy *et al.*, 2021).

Remote sensing data from Synthetic Aperture Radar (SAR) are used to detect water surface and give vital information for flood monitoring. SAR data can penetrate clouds and atmospheric interference, which are common during floods, and they can even use it at night (Nguyen *et al.*, 2020). Many researchers presented the application of SAR images to detect flood extent areas using remote sensing imagery data (Elkhrachy *et al.*, 2021; Huţanu *et al.*, 2020; Mihu-Pintilie *et al.*, 2019; Nguyen *et al.*, 2020; Psomiadis *et al.*, 2020; Psomiadis *et al.*, 2019). SAR images data are often used to calibrate and validate hydraulic models in flood research that combine SAR imagery data and hydraulic models. Few studies have inverted this process and used remote sensing-based flood extent extracts. Hydraulic modelling often requires extensive data inputs, such as topographic, soil, and land cover data (Nguyen *et al.*, 2020).

Based on the two separate approach to determine the application of hydraulic modelling (HEC-RAS) integrated with remote sensing techniques to provide flood risk maps in the Khlong Bang Saphan Yai River Basin. The objectives of this study were: i) To simulate the flood inundated depths and extents by using HEC-RAS modelling ii) To detect and extract surface flood extent from Sentinel-1 SAR remote sensing data iii) To validate and compare flood risk maps from HEC-RAS models with flood extent maps from remote sensing techniques. The HEC-RAS modelling was used to simulate flood inundation and Sentinel-1 SAR images from the European Space Agency were used to detect water extent during flood events of 2019 year. SAR images were processed and used to validate the flood inundation from the HEC-RAS modelling. The water depth and extent data were used to produce flood risk maps after the validation process was completed. The results as a valuable reference to support policy and decision-making for future planning and development in the current study area.

Methods

1. Study area

The Khlong Bangsaphan Yai River Basin is one of the basins in Thailand lies between latitude 11^{o} 6’ 00” N to 11^{o} 24’ 00” N and longitude 99^{o} 16’ 0” E to 99^{o} 32’ 0” E, covering an area of approximately 474 km^2. The Khlong Bang Saphan Yai River originates from the Tanao Sri Mountain in the western, flowing 16 km through the Bang Saphan district and outflows into the Gulf of Thailand in the eastern, having a mean annual discharge of 258.6 m^3/s.

This study aims to determine the hydraulic processing in the KBSYRB because this area suffered floods every year and caused damage to many villages in this area as illustrated. The key aim is to generate flood risk maps using remote sensing and hydraulic modelling in this study are, which starts from the upstream GT.7 station to the downstream GT.20 station (Figure 1).

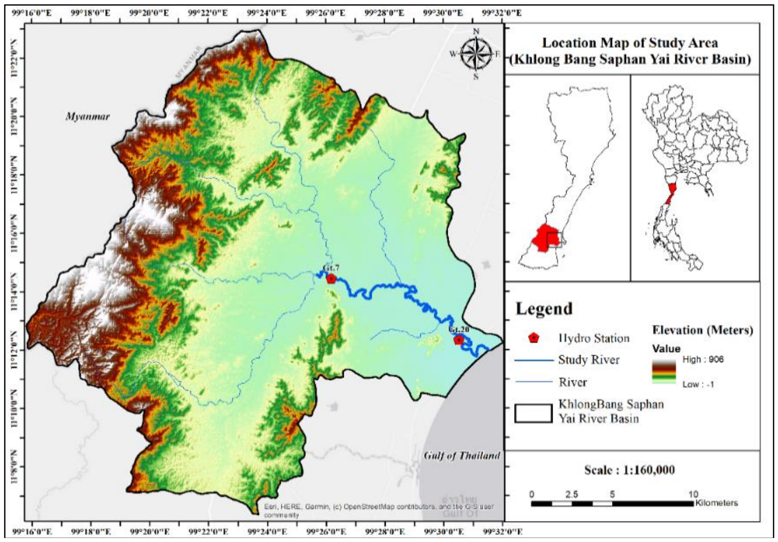

Figure 1 The Study Area of Khlong Bang Saphan Yai River Basin, Thailand

<u>*2. Data collection*</u>

In this study, the datasets used contains satellite-borne images, topographic data, land use data and statistical data. Sentinel-1 SAR images were acquired for multi-temporal monitoring of the flood occurrence. For flood extent mapping, two Sentinel-1 Level-1 Ground Range Detected (GRD) SAR images were obtained. The images were obtained via the Sentinels Open Access Hub and processed using the Sentinel's Application Platform (SNAP), an open source provided by the European Space Agency (ESA) (Psomiadis *et al.*, 2020). Each image has a 250 km coverage area and a spatial resolution of 10 x 10 m. The data were selected using the Interferometric Wide (IW) swath mode, which enables dual polarization products (VV+VH) (Psomiadis *et al.*, 2020).

For HEC-RAS modelling, (Nguyen *et al.*, 2020; Psomiadis *et al.*, 2020; Thoummalangsy *et al.*, 2019) it requires the digital surface model (DSM) with 30 x 30 m resolution was collected from the JAXA which is a sufficient resolution. This model contains topographic data (geometric data and elevation), land use data details to establish roughness coefficients (Manning's n value), and hydrological data (water discharge data and water level time series).

3. Methodology

In this study, the overall workflow of flood risk assessment is shown in Figure 2.

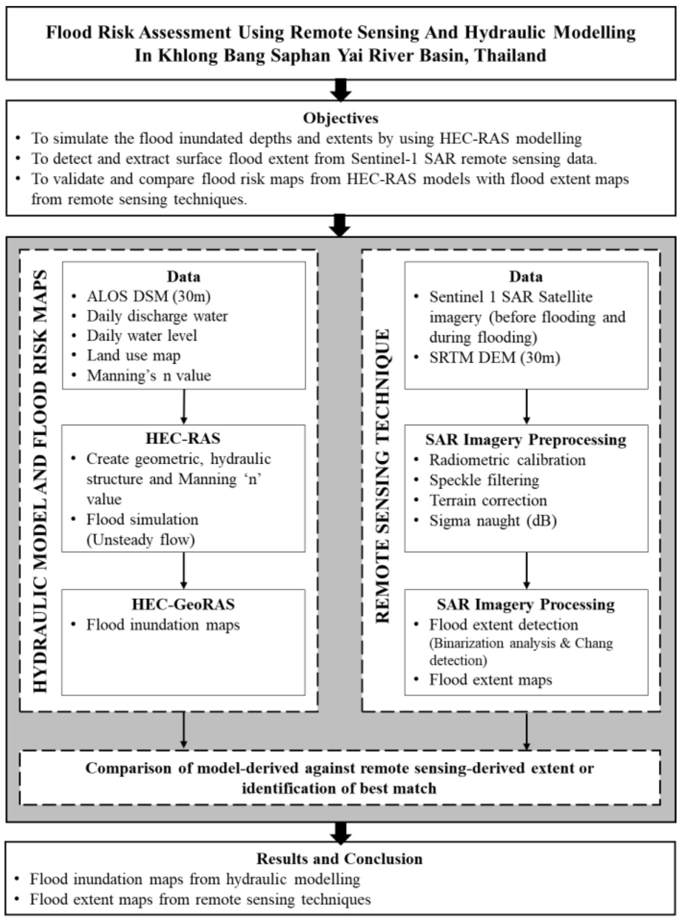

Figure 2 Flow-chart of Methodology for Flood Risk Map at the Khlong Bang Saphan Yai River Basin, Thailand

3.1 Hydraulic model analysis (HEC-RAS)

3.1.1 Pre-processing geometric data

Geometric data is the spatial data that must be provided in the hydrodynamic model. It includes (1) river networks, (2) river cross-sections, (3) reach length, and (4) hydraulic structure data. In addition, hydraulic loss coefficients are required for determining cross-section data (Chit Myo, 2020). In this study, the RAS geometric menu in the HEC-RAS software was created from DSM 30 x 30 m resolution and was utilized to pre-process geometric data for this study area (RAS GIS import file). After that, the RAS layers menu were used to create geometric data (stream centerlines, riverbanks, the flow path centerlines, cross-section, and storage area), which were then laid on top of each other.

3.1.2 HEC-RAS modelling

HEC-RAS is a popular software application that conducts one-dimensional (1D) and two-dimensional (2D) hydraulic computations for a complete network of natural and constructed channels, floodplain zones, and other features. The HEC-RAS system consists of four elements for one-dimensional river analysis: steady flow water surface profile simulation, unsteady flow simulation, sediment transport calculation, and water quality analysis (Thoummalangsy *et al*., 2019). The unsteady flow data was used as a boundary condition in HEC-RAS to replicate the historical event (Chit Myo, 2020; Vanthan *et al*., 2020)

In this study, the upstream of boundary condition for the river model would have recorded upstream flow data at GT.7 station during the flood events of 2018 and 2019, while the downstream boundary condition was set to the normal depth. HEC-RAS 1D modelling classified the flow as unsteady data, with the flow going downstream and the cross-section as the whole characterization of the river environment during the calculation (Equations 1 and 2) (USACE, 2018).

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + g\,A\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad (1)$$

Where V is the velocity of the flow, g is the acceleration because of gravity, A is an area of the flow, $\partial z/\partial x$ is the water surface slope, and S_f is friction slope.

$$Q = V_1A_1 = V_2A_2 \qquad (2)$$

Where A_1 is the cross-sectional area normal to the direction of flow at the downstream cross-section, A_2 is the cross-sectional area normal to the direction of flow at the upstream cross-section, Q is the flow rate/discharge, V_1 is the average velocity at the downstream cross-section, and V_2 is the average velocity at the upstream cross-section.

3.1.3 Calibration and validation of HEC-RAS model

In general, roughness reduces with increasing water level and flow in a free-flowing river. Calibration was accomplished by adjusting the model's parameters, mostly for roughness (Manning’s n values). For validation, the hydrograph of observed water flow data and water level data from the GT.20 downstream station was used for validation in 2018 and 2019. Statistics were used to assess the model performance, including Nash-Sutcliffe Efficiency (NSE) and Coefficient of determination (R2) were calculated using water discharge data and water level data *(Vanthan et al., 2020),* as standard shown in (Table 1) (USACE, 2018).

$$NSE = 1 - \frac{\sum_{i=1}^{n}[(o_i - s_i)^2]}{\sum_{i=1}^{n}[(o_i - \bar{O})]} \quad (3)$$

Where, O_i and s_i are observed simulated discharge dataset and $\bar{O}$ is average of the observed dataset, respectively.

$$R^2 = CC = \frac{\sum_{i=1}^{n}[(x_i - \bar{x})(y_i - \bar{x})]^2}{\sum_{i=1}^{n}[(x_i - \bar{x})^2]\sum_{i=1}^{n}[(y_i - y)^2]} \quad (4)$$

Where $x_i, y_i, \bar{x}$ and $\bar{y}$ are observed and simulated data and average data of these two datasets.

Table 1 Performance rating for summary statistics (USACE, 2018).

Performance Rating	R^2	NSE
Very Good	$0.65 < R^2 \leqslant 1.00$	$0.65 < NSE \leqslant 1.00$
Good	$0.55 < R^2 \leqslant 0.65$	$0.55 < NSE \leqslant 0.65$
Satisfactory	$0.40 < R^2 \leqslant 0.55$	$0.40 < NSE \leqslant 0.55$
Unsatisfactory	$R^2 \leqslant 0.40$	$NSE \leqslant 0.40$

3.2 Remote sensing techniques

3.2.1 Sentinel-1 SAR data processing

The SNAP software is an application platform of typical instruments for all Sentinel satellite toolboxes (Filipponi, 2019; V. Vanama *et al.*, 2021). The Sentinel-1 SAR data were calibration using the SNAP software to convent pixel intensity into radar backscatter coefficient (V. S. K. Vanama & Rao, 2019).

In this study, it used a random forest algorithm for the supervised classification in the study area. The Sentinel-1 SAR data were pre-processed by using SNAP software, Sentinel-1 Toolbox (S1TBX) developed by the ESA. In the pre-processing steps, All Sentinel-1 SAR images must be pre-processed with orbit file, thermal noise removal, radiometric calibration, single speckle filtering (Lee 5x5), Rang Dropper terrain correction, linear-tobackscattering coefficient decibel scaling (dB) transformation, using the SNAP software (Dadhich *et al.*, 2019; Megha *et al*., 2019).

3.2.2 Flood extent detection

SAR satellite imagery data were employed in the detection and inundation mapping approach. There are numerous approaches for detecting water bodies from SAR image backscatter, including histogram thresholding methods, interferometric coherence computation, regions expanding algorithm, active contour mode, and object-oriented categorization (Elkhrachy *et al*., 2021). Histogram threshold values were used to extract water bodies (Elkhrachy *et al.*, 2021; Psomiadis *et al.*, 2020). Moreover, the backscatter coefficient histogram was created, and it was used to determine a value that accurately indicates the boundary with water and non-water features (Dadhich *et al.*, 2019). In this study, the flood extent area for the date of the after-flood period was calculated by subtracting (change detection) during the flood occurrence, particularly for the flood peak phase. Finally, the individual flood area could be edited on a GIS platform.

3.3 Accuracy assessment of simulated and SAR flooded extent

In this study, for the accuracy assessment steps, used to compute the accuracy assessment between flood inundation from the HEC-RAS 1D model and flood extent from SAR images data, they were used to identify the raster layers fit between 2 data of flooded areas. F-statistic equation were used, shown in Equations (5) (Elkhrachy *et al*., 2021).

$$F_s = \left[\frac{X_{op}}{X_0 + X_p - X_{op}}\right] \times 100 \quad (5)$$

Where F_s is the F-statistics value, X_{op} is the flood area overlaid between Sentinel-1 SAR imagery and the HEC-RAS 1D model, X_o is the flood extent area for the Sentinel SAR imagery data, and X_p is the flood inundation area from the HEC-RAS 1D modelling.

Results

<u>1. Hydraulic model analysis (HEC-RAS)</u>

1.1 HEC-RAS simulation

After simulating the flow in HEC-RAS model by unsteady flow analysis, the model performs the relationship between water level (stage) and flow of Khlong Bangsaphan Yai River Basin simulated data. The result from model the stage maximum value as 9.08 meters (including mean sea elevation), the average mean sea level was 7.59 MASL, flow value as 127.17 m3/s, the period at max on January 6, 2019 as shown in Figure 3.

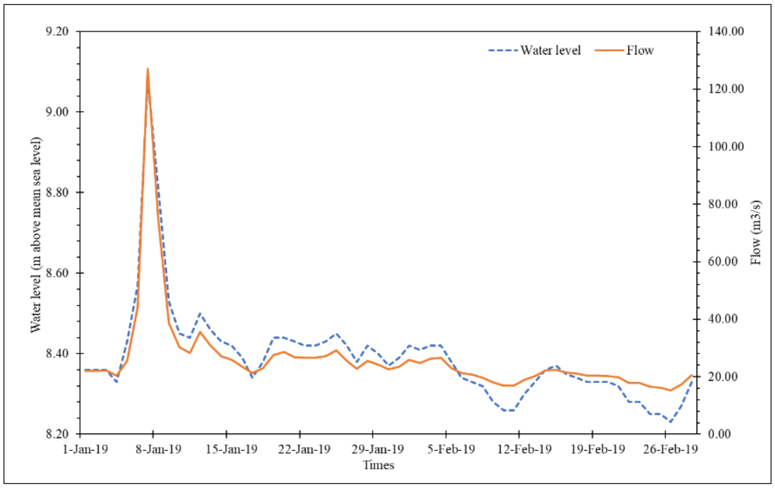

Figure 3 Relationship of water level (stage) and flow at Khlong Bangsaphan Yai River Basin

1.2 Calibration and validation results

For this study, the flood extent and flood depth maps were created using the HEC-RAS model. The flood depth of the 2019 flood events was checked with the observed data from Royal Irrigation Department (RID), while the flood extent was compared with the flood extent map calculated derived from remote sensing techniques.

The Roughness Coefficient Manning's n value was chosen for model calibration of all cross-sections along the Bang Saphan Yai River value at 0.045 for both riverbanks and 0.050 for the channel. The calibration result is presented in Figure 4. While the validation was carried out utilizing observed water discharge data from 1/1/2019 to 28/2/2019. Figure 5 showed the validation results that compare the simulated daily water outflow to the observed data.

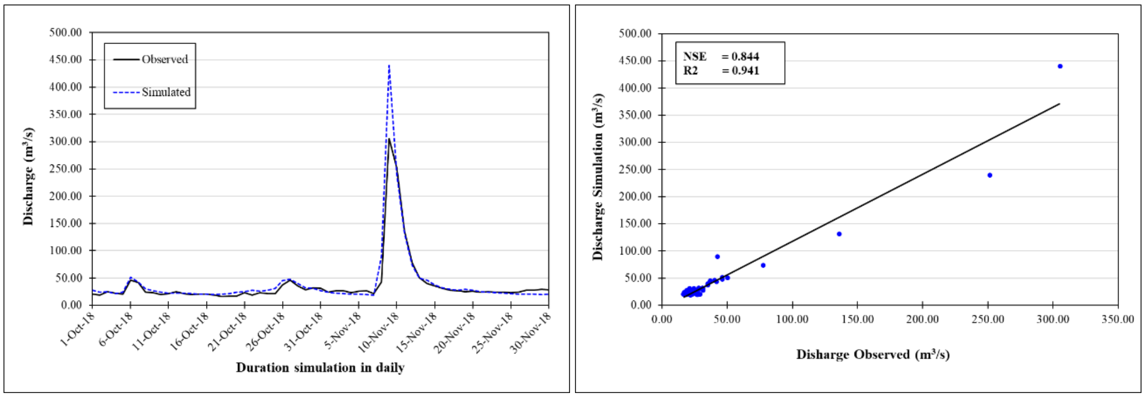

Figure 4 Calibration result of HEC-RAS model for 2018 flood events

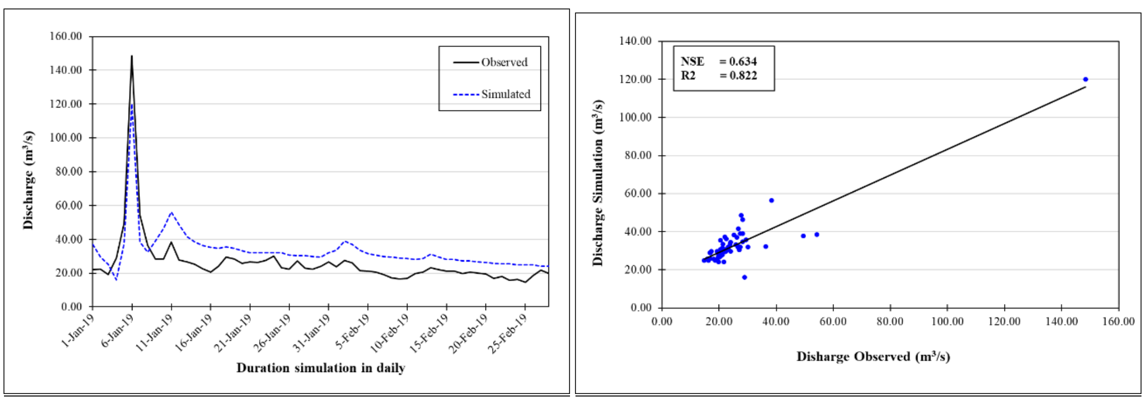

Figure 5 Validation result of HEC-RAS model for 2019 flood events

Hydraulic model performance was evaluated using NSE and R2 indicators with values of the year 2018 (0.844 and 0.941) and year 2019 (0.634 and 0.822), respectively. The calibration with simulated flood depths from the HEC-RAS model gives a good agreement with observed data.

Table 2 Model performance of the water discharge at the stations during calibration.

Year	Simulation period	Roughness coefficient Manning's n	Boundary condition Normal depth	R^2	NSE
2018	October – November, 2018	0.045 – 0.050	0.008	0.941	0.844
2019	January – February, 2019	0.045 – 0.050	0.008	0.822	0.634

1.3 Flood risk mapping

Flood risk mapping was used to investigate flood event in 2019 (January 4, 2019). The floodwater surface profile data and cross-section data were simulated from the HEC-RAS model and exported to a GIS platform. The flood depth of flood event was reclassified into three classes of flood inundation depth, namely as < 3 meters, 3 to 6 meters, 6 to 9 meters, 9 to 12 meters, and > 12 meters, to identify little or no flood, medium flood, and high flood events. The results are presented in Figure 6.

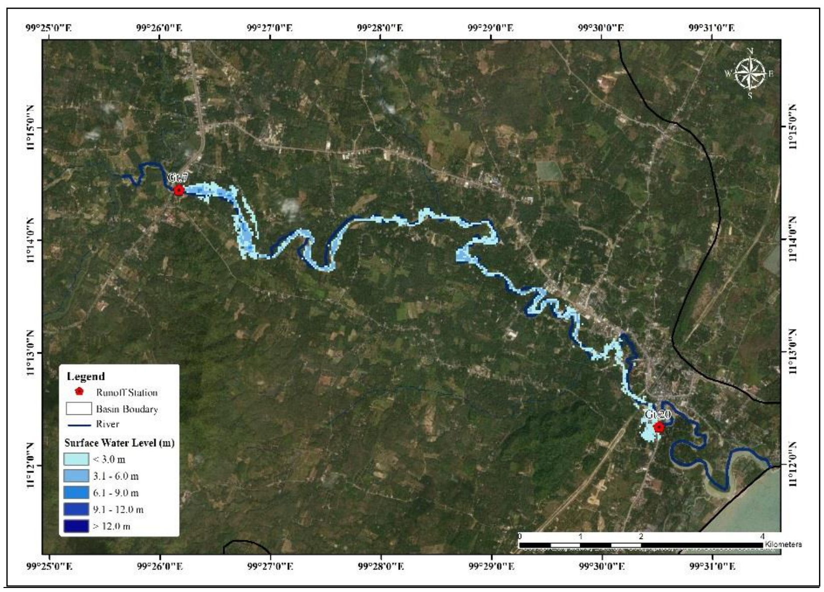

Figure 6 Flood inundation map for 2019 (January 4, 2019) simulated by HEC-RAS model

2. Validation assessment for the flooded area

Remote sensing techniques were also used in this study to extract the flooded area of various flood events from Sentinel-1 SAR satellite data. The use of remote sensing data in this study aims to validate the flooded area for the relevant flood events.

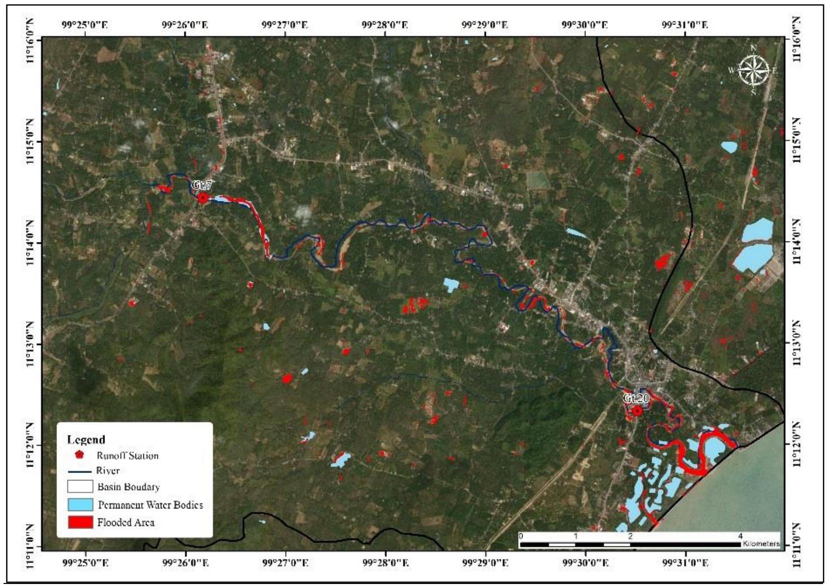

Figure 7 Flood area computed from the Sentinel-1 SAR satellite data in remote sensing techniques for 2019 flood area (January 4, 2019)

In this study, SAR flood extent was used to validate the flood inundation from the HEC-RAS model. Because of the overlap between the flood inundation and flood extent from the Sentinel-1 SAR satellite technique, approximately 0.22 km^2. According to the overlapped result, as presented in Table 3, 17.5% of the 2019 flood events are generally considered it is not good validated checked for simulated maps. The comparison map between the simulated map and the flooded extent map computed from remote sensing data is presented in Figure 8.

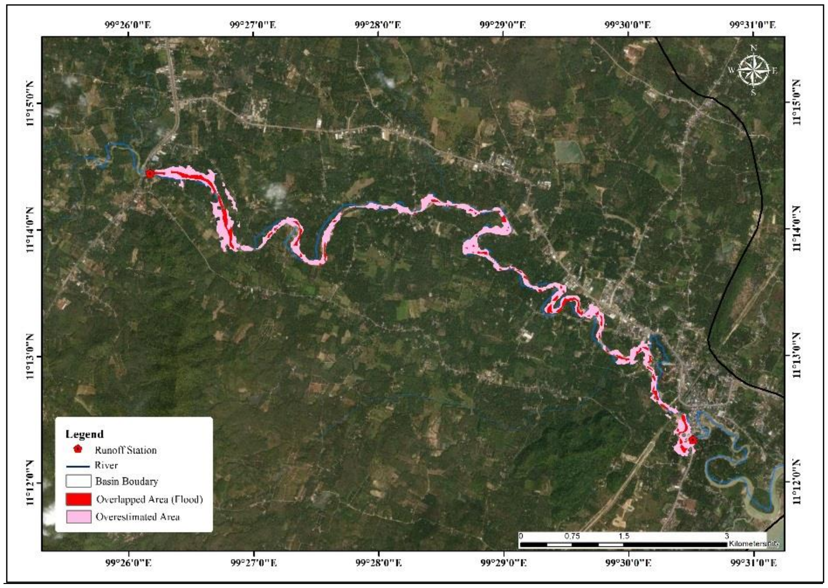

Figure 8 Flood comparison between flood inundation map by HEC-RAS model and flood extent map by remote sensing technique for overlapped area of 2019 flood

Table 3 Comparison of flood inundation area of simulated result and flood area from remote sensing.

Year	Unit	Remote Sensing	HEC-RAS Model			
		Flood mapping	Simulation	Overlapping	Over Estimation	Under Estimation
2019	Area (KM^2)	1.31	1.26	0.22	1.04	0.00
	Area (%)	-	-	17.50	82.50	0.00

Discussion

In the hydraulic modelling (Figures 3-5), a simulation of the 2019 flood events is presented and focuses on the upstream and downstream of Khlong Bangsaphan Yai River. This simulation was performed using the one-dimensional of the HEC-RAS software. The results of calibration and validation show the R^2 (0.941) and NSE (0.824) and a good correlation between the simulated and observed discharge data from the Royal Irrigation Department (RID). The findings result is consistent with Vanthan *et al.* (2020), Thoummalangsy *et al.* (2019) and Chit Myo (2020) study, which finding that the results of calibrated and validated of the HEC-RAS model using NSE and R2 statistics were a good agreement compared the model simulation with the observed data.

In flood extent mapping (Figure 6), the Sentinel-1 SAR satellite imagery was used to detect and extract flooded areas with the histogram analysis (threshold value) in the SNAP software. The thresholding value selected to extract the flood extent area is 11.00–12.00 dB (VV Polarization). The flood extent areas from the Sentinel-1 SAR satellite technique will be compared to the water permanent area of the Sentinel-1 image technique based on after flooding of the 2019 year. The results is consistent with Elkhrachy *et al.* (2021) and Nguyen *et al.* (2020) in previous studies that were performed using the Sentinel-1 SAR remote sensing techniques for flooded area detection.

Figure 8 and Table 3 show the comparison between the flood inundation maps computed by the HEC-RAS model and the flood extent map derived from the remote sensing technique. Moreover, the study area is too small for simulation, the overlap flooded area of the Khlong Bang Saphan Yai river basin is about 17.5 % (0.22 km^2) for the 2019 flood event and it covered four sub-districts, including Ron Thong, Thong Mongkhon, Kamnoet Nopphakhun, and Phong Prasat districts in Bang Saphan Yai District, Prachuap Khiri Khan Province. The results indicate that are not acceptable and reasonable between simulation and observed flood extent from remote sensing technique for validation assessment. This was probably because some uncertainties in the Sentinel-1 remote sensing technique, which affected the outputs. The SAR method to detect shall wet areas generally fails to detect flood areas in some land uses, such as mountain or shadow areas and detecting flooded areas in urban areas can be difficult due to the lack of detail in low-resolution SAR images. Therefore, the results are not consistent with Chit Myo (2020) and Elkhrachy *et al.* (2021) study, which found that the results of validation between simulation and observed flood extent areas from remote sensing technique are fairly good agreement and acceptable.

Conclusions

This study determined the application of the HEC-RAS model and Sentinel-1 SAR with remote sensing technique to a simulation of the flood event. This simulation was performed using an unsteady flow analysis of the HEC-RAS model. The simulation shows good results when compare with the observed discharge data collected by the Royal Irrigation Department. In addition, flood inundation simulation is also validated and compared with the flooded extent derived by Sentinel-1 SAR image techniques that show the overlap flooded area of 17.5%, calculating the areas of flooded affected about 0.22 km2 which impacted on four sub-districts (Ron Thong, Thong Mongkhon, Kamnoet Nopphakhun, and Phong Prasat), locating in Bang Saphan Yai district, Prachuap Khiri Khan province.

This simulation provides helpful information for decision-makers such as flood extent, flood depth, velocity, and flow time. These results can be a tool for flood risk mapping used for planning and flood risk manangement. This study is an important addition to the field of flood risk analysis. However, if a socio-economic study of flood risk, the application of deterministic modeling, the use of remote sensing and GIS tools, and the use of flood reconstruction and forecasting techniques were used, the results would be improved.

Acknowledgements

I would like to express my sincere gratitude to the professors at the Faculty of Geoinformatics, Burapha University and the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS), Wuhan University as the supervisors, this study offers suggestions, insightful comments, and assists in resolving the shortcomings. My sincere thanks go to the Royal Irrigation Department, and Land Development Department which contributed data to this research during this study is complete.

References

Abdelkarim, A., Elkarim, A., Awawdeh, M., Alogayell, H., & Al-Alola, S. (2020). INTERGRATION REMOTE SENSING AND HYDROLOGIC, HYDROULIC MODELLING ON ASSESSMENT FLOOD RISK AND MITIGATION: AL-LITH CITY, KSA. *International Journal of GEOMATE, 18*, 33.

Balogun, D., O McKelvin, A., Mohammed, A., Ogunbiyi, U., Okewu, A., Ikegwuonu, E., & Nkut, B. (2020). Flood Risk and Vulnerability Analysis of the Lower Usuma River in Gwagwalada Town Abuja, using GIS and HEC-RAS Model. *9*, 187-197.

Chit Myo, L. (2020). *Flood Hazard Mapping and Risk Assessment for Chindwin River Basing, Myanmar.* (M.Sc Dissertation of Wuhan University). Wuhan University, (10486).

Dadhich, G., Miyazaki, H., & Babel, M. (2019). APPLICATIONS OF SENTINEL-1 SYNTHETIC APERTURE RADAR IMAGERY FOR FLOODS DAMAGE ASSESSMENT: A CASE STUDY OF NAKHON SI THAMMARAT, THAILAND. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*.

Elkhrachy, I., Pham, Q. B., Costache, R., Mohajane, M., Rahman, K. U., Shahabi, H., Linh, N. T. T., & Anh, D. T. (2021). Sentinel-1 remote sensing data and Hydrologic Engineering Centres River Analysis System two-dimensional integration for flash flood detection and modelling in New Cairo City, Egypt. *Journal of Flood Risk Management, 14*(2), e12692. doi:https://doi.org/10.1111/jfr3.12692.

Filipponi, F. (2019). *Sentinel-1 GRD preprocessing workflow.* Paper presented at the Multidisciplinary digital publishing institute proceedings.

Haraguchi, M., & Lall, U. (2015). Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction, 14*, 256-272. doi:https://doi.org/10.1016/j.ijdrr.2014.09.005.

Huţanu, E., Mihu-Pintilie, A., Urzica, A., Paveluc, L. E., Stoleriu, C. C., & Grozavu, A. (2020). Using 1D HEC-RAS Modeling and LiDAR Data to Improve Flood Hazard Maps Accuracy: A Case Study from Jijia Floodplain (NE Romania). *Water, 12*(6). doi:10.3390/w12061624.

Megha, V., Joshi, V., Kakde, N., Jaybhaye, A., & Dhoble, D. (2019). Flood Mapping and Analysis using Sentinel Application Platform (SNAP)–A Case Study of Kerala. *Int. J. Res. Eng. Sci. Manage, 2*, 486-488.

Mihu-Pintilie, A., Cătălin, I. C., Cristian Constantin, S., Martín Núñez, P., & Paveluc, L. E. (2019). Using High-Density LiDAR Data and 2D Streamflow Hydraulic Modeling to Improve Urban Flood Hazard Maps: A HEC-RAS Multi-Scenario Approach. *Water, 11*(9), 1832. doi:http://dx.doi.org/10.3390/w11091832.

Nguyen, H. Q., Vu, A. T., Le Thi Thu, H., Nguyen Manh, H., Doan Thi, T., Dinh Thi, D., Ngo, D. A., & Hackney, C. R. (2020). Hydrological/Hydraulic Modeling-Based Thresholding of Multi SAR Remote Sensing Data for Flood Monitoring in Regions of the Vietnamese Lower Mekong River Basin. *Water, 12*(1), 71. doi:http://dx.doi.org/10.3390/w12010071.

Psomiadis, E., Diakakis, M., & Soulis, K. X. (2020). Combining SAR and Optical Earth Observation with Hydraulic Simulation for Flood Mapping and Impact Assessment. *Remote Sensing, 12*(23). doi:10.3390/rs12233980.

Psomiadis, E., Soulis, K. X., Zoka, M., & Dercas, N. (2019). Synergistic Approach of Remote Sensing and GIS Techniques for Flash-Flood Monitoring and Damage Assessment in Thessaly Plain Area, Greece. *Water, 11*(3). doi:10.3390/w11030448.

Thoummalangsy, S., Tuankrua, V., Pukngam, S., Pothitan, R., & Ongkeo, O. (2019). Flood Risk Mapping Using HEC-RAS and GIS Technique: Case of the Xe Bangfai Floodplain, Khammoune Province, Lao PDR. *The Environmental Engineering Journal, 33*(3), 27-38.

USACE. (2018). *Analyzing Flood Risk for Forecast Informed Reservoir Operatrtions in the Fussian River Watershed Using HEC-WAT*: Institute for Water Resources Hydrologic Engineering Center.

Vanama, V., Musthafa, M., Khati, U., Gowtham, R., Singh, G., & Rao, Y. (2021). Inundation mapping of Kerala flood event in 2018 using ALOS-2 and temporal Sentinel-1 SAR images. *Current Science, 120*(5), 915.

Vanama, V. S. K., & Rao, Y. S. (2019, 28 July-2 Aug. 2019). *Change Detection Based Flood Mapping of 2015 Flood Event of Chennai City Using Sentinel-1 SAR Images.* Paper presented at the IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium.

Vanthan, K., Sarintip, T., & Wayan, S. (2020). GIS-BASED FLOOD HAZARD MAPPING USING HEC-RAS MODEL: A CASE STUDY OF LOWER MEKONG RIVER, CAMBODIA. *Geographia Technica, 15*(1), 11. doi:10.21163/GT_2020.151.02.