Application of Mike11 and remote sensing in simulating flood – a case study in Tra Khuc River, Quang Ngai Province, Vietnam

L T Bui1,2 and A H Bui1
1Faculty of Environment and Natural resources, Hochiminh city University of Technology, 268 Ly Thuong Kiet St, Dist. 10, Hochiminh city, Vietnam
E-mail: longbt62@hcmut.edu.vn

Abstract. Flooding, inundation are two of five kinds of disaster (storming, erosion, drought, saline intrusion) which cause serious impacts on Vietnam. In addition, due to the effects of climate change, unstability and more serious disasters in term of frequency, locations, and intensity. In this problem, central of Vietnam, especially Quang Ngai, are famous examples. This study applys combined approach: remote sensing method for establishing flooding maps and MIKE11 for simulating flood in Tra Khuc river downstream. The research aims to provide scientific and practical basics for projects and sience missions. The data is provided from historical flooding event in Quang Ngai in 2013, the article presents results including (1) Map of flooding in Quang Ngai in 2013 with correlation coefficiency at 0.87; (2) Hydrological and hydrodynamic caribrated parameter for MIKE11 for downstream area; (3) Maps of inundation in 2013 for Tra Khuc downstream; (4) Potential flooding risk maps following climate change and sea level rise scenarios.

1. Introduction
Flooding is one of the most devastating natural disasters in the world, when the sudden flow of huge water comes out of the river in a short period of time due to tidal wave, heavy rain, broken lake [1,2]. In all of natural disasters related to climate occurred in the past two decades, flooding is a popular problem (accounts for 47%), impacts on 2,3 billion of people [3]. The majority of flooding events lead to negative effects [4]. These impacts are caused by the continuously events such as flooding, alluvium, groundwater, coastal areas inundation [5]. Flood impacts are mainly attributed to the extent and magnitude of a flood hazard which can be caused by one or a combination of fluvial, flash, pluvial, groundwater and coastal floods [6]. Multi-module, multidisciplinary approaching method is recommended for encouraging this researching field [7,8]. Flooding maps establishment are effective tools in order to improve shortterm and longterm relief in impacted areas [9]. Flooding risk assessment can be implemented in multiple scale, from local to global scale [9]. Geographic modern technologies, such as geographic informatics and its substitutions, for example Geographic Information System (GIS) and Remote Sensing (RS) play an important role in current efforts [9]. Sakamoto et al [10] developed a method to identify distribution of flooding by time in Cambodia and Vietnam by MODIS data. The main advantages of this method are: (1) time series data provided in flooding period; (2) Global data is available; (3) free downloading data from the Internet; (4) the accuracy of the inundation maps is acceptable. Combining modeling, GIS, and remote sensing simulates inundation is an approach which is attracted researchers in many years. In the report, Fortin et al [11] proposed HYDROTEL model
which integrates compatible dispersed basin hydrological model with RS and GIS. A model is applied in different applications is HEC-HMS. In research [12] there is an integration hydrologic, hydrodynamic, and habitat modeling simulates inundation in Sperchios River in Greece and the results are optimistic. A combination of RS and hydrological model was applied in the study of [13].

Vietnam is usually affected directly by storms formed from the Pacific Ocean, annually, there are 11-12 storms and tropical depressions in the East Sea, of which five to six storms directly impact on the mainland. Particularly, in 2017, the year with a record number of storms is 16 caused about 2.7 billion USD, accounting for 1 – 1.5 GDP [14,15]. Many researches in Vietnam mainly concentrates on application of hydrodynamic module such as MIKE 11 [16,17] to simulate the potential of inundation for different cases, however, do not pay attention in combination of hydrodynamic module and remote sensing to calibrate that can improve forecasting quality for future scenarios. The research applies remote sensing method to evaluate flood changes in the downstream area of Tra Khuc river by analyzing MODIS images, moreover, it is used as a scientific basis to assess the reliability of MIKE 11 in flood simulation. In order to simulate floods over time, the study used MIKE NAM and MIKE 11 models to simulate and build flood maps on the Tra Khuc and Quang Ngai river basins.

2. Materials and methods

2.1. Study area
The Tra Khuc river basin is located in Quang Ngai province with a total catchment area of 3,240 km², accounting for 55.3% of the province's natural area (figure 1). The downstream area of Tra Khuc river is often flooded every year, especially in Quang Ngai town with low terrain, therefore low-lying areas of urban areas with elevation from 3 m to 6m are often flooded.

![Figure 1. Study area location and boundary.](image)

2.2. Dataset

2.2.1. Remote sensing image. MODIS reflective surface image - MOD09A1 – combined eight days, the spatial resolution is 500 m and was taken from September 6th 2013 to December 27th 2013. This
data was collected freely from Earth observation satellites Terra of NASA for monitoring floods in Quang Ngai. The total number of satellite images MOD09A1 used for calculating the EVI index collected in 2013 are 18. However, the data has a significant number of points lost due to clouds, heavy aerosols, gaps between the transmission lines, failed extraction in certain conditions.

2.2.2. **Terrain.** The river cross-section system was collected, additional measurements were used for hydraulic calculation are as follows: Tra Khuc River: The cross-sectional data used includes 67 sections in the range of 57.44 km from the Co Luy station to upstream. The cross-sectional data used in calculation was measured by the General Department of Meteorology and Hydrology in 2013 [18,19].

2.2.3. **Meteorological.** Rainfall measurements were taken from four rain gauging stations: Gia Vuc, Son Tay, Son Giang, Tra Khuc and two meteorological stations: Quang Ngai and Ba To in 2013 [20,21] to build model parameters. Following that, calculating the average rainfall of the whole basin as well as the rain weight for the study basin.

2.2.4. **Boundary conditions.** Tidal water level at Co Luy gate is downstream boundary in MIKE11 HD was taken from DHI via Tide prediction tool of MIKE21 [20] in the period of time from January 1st 2013 to December 31st 2013. Fowrate data is upstream boundary in MIKE11 HD was calculated by MIKE NAM in 2013 after calibrating and validating.

2.2.5. **Climate change and sea level rises scenarios.** Climate change and sea level rises scenarios for Vietnam in 2016 was built according to RCP 2.6 (low scenario), RCP 4.5 (medium scenario), RCP 6.0 (medium scenario) and RCP 8.5 (high scenario). This research uses RCP 4.5 scenario for simulating floods impacted by climate change and sea level rises.

2.3. **Model**

2.3.1. **One – dimensional hydrodynamic model.** One – dimensional mathematical model is used to simulate the water quantity and quality. Theo Saint – Venant equations, which consisted of continuity and kinematic equations, were used in this model as follows [21].

Continuity equation:

\[ B \frac{\partial z}{\partial t} + \frac{\partial Q}{\partial x} = q \]

Kinematic equation

\[ \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{\partial Q^2}{A} \right) + gA \frac{\partial z}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0 \]

Where x and t denote spatial and temporal coordinates, respectively; Q and z denote the cross – section discharge and water level, respectively; A and R denote the cross – section area and hydraulic radius, respectively; B denotes the width of the river; q denotes the lateral inflow; C denotes the Chezy coefficient; and g denotes the gravitational acceleration.

2.3.2. **Hydrological model NAM.** The flood forecasting system in Mike11 includes the following modules: (1) Rain – Runoff (RR), (2) Hydrodynamic (HD), (3) FF process. NAM model (stands for Nedbør- Afstrømnings - Model) is part of the RR module in the Mike11 river simulation model system. The model called "Rain – runoff" is actually a centralized model consisting of many sub-modules, packaged to simulate the flow on the ground, the connecting with each other, and with the main flow.

2.4. **Flooding zoning using EVI water index**
Since Quang Ngai is completely within a MODIS image, it is recommended to skip the photo merge step. Use the Band Math tool to calculate the EVI index [10]:

$$EVI = 2.5 \times \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + 6 \times \rho_{RED} - 7.5 \times \rho_{BLUE} + 1}$$

In which: $\rho_{NIR}$ - Near infrared reflectance; $\rho_{RED}$ – Red reflectance; $\rho_{BLUE}$ – Blue reflectance.

This study uses algorithms to classify flooded objects named WFFI (The Wavelet-based Filter for detecting spatiotemporal changes in Flood Inundation) to assess the evolution of space and time of flood. Pixels are classified as flood when eligible: $EVI \leq 0.1$ [10]. The resulting map helps to identify the exact start date, end date and annual flooding time of the study area.

3. Results and discussions

3.1. Flooding maps

The results illustrate the flooded area from MODIS images and be validated based on observed data at monitoring stations. In flooding season, the water level of river increases resonant with heavy rains, the overflow phenomenon occurs and leads to flood. Therefore, the method that used the flooded area from the image interpretation results and find the correlation with average water level which is daily measured at Tra Khuc [18] station for verification is confirmed. Figure 2 expresses water level at Tra Khuc station exceeding the alarm level III from November 15, 2013 to November 16, 2013.

![Figure 2](image-url)

**Figure 2.** Measured water level results at Tra Khuc station from September to December in 2013.

Figure 3 shows that there is a correlation between daily observed average water level at Tra Khuc station and flooded area at the same time in downstream region of Tra Khuc river. The result of verification with high correlation coefficient $R=0.87$ illustrates that the flooded area results from interpreting RS images have scientific basic. Parallely, via this correlation, flooded area taken from interpretation of RS images and actual water level are proportional. That means the water level increases followed by the rise of flooded area and vice versa. Based on the multi-temporal EVI series, Quang Ngai is divided into four objects: no flooding; water and plants; rivers, lakes, sea, results are shown in figure 4. Additionally, the results express that flood in Quang Ngai appears in September, increases in October and November, then decreases in December. After the historical flood in 2013 from 15 to 16 November, the flooded area is quite large for the whole province of Quang Ngai (174,158 hectares), occurred on November 17, 2013.
3.2. Setup parameter system in NAM
The research conducted simulation of river flow, combining with calibrate and validate that were compared with observation data in 2013 at Son Giang monitoring station [18,19]. In this study, flow simulation, calibration and verification were carried out with actual flow data measured in 2013 at Son Giang station. Then having the set of specific parameters for hydraulic model to simulate the flow in Tra Khuc river upstream for 2013 and 2050 (according to climate change scenario). The results of calibrating the NAM model show that calculation flow process has a similar trend with the the measured flow process. The calculated and actual flood peaks are nearly match. Time of precipitation peaks and flood peaks match as well. From the results of calibration and validation of MIKE NAM model, it can be concluded that the model parameters ensure accuracy to be able to apply in upstream simulation for different period of time. Moreover, these set of parameters is applied in simulating middle sub basin as input data for MIKE 11 HD.

3.3. Calibrating and validating hydrodynamic model
The calibration of hydrodynamic model is mainly done by adjusting the Manning. Manning coefficient is found for each cross section and changed in calibrating process and combined with actual survey information. To evaluate the accuracy of calibrated parameter of MIKE11 model, that means the errors between observation and calculated value at Tra Khuc station, the research uses Nash – Sutcliffe for assessing the suitability of simulated water level process and evaluate via flood peak errors between calculation and actual measurement.

3.4. Flood modelling by MIKE11
After establishing network, cross section, boundary, parameters in MIKE11 HD, authors simulate hydrodynamic and inundation in 2013 and 2050 (according to climate change scenario) from September to December. Simulating time is from September 1st, 2013 to December 31st, 2013, when the historical flood occurred in Quang Ngai province. Furthermore, to assess the climate change factor, authors run MIKE11 HD from September 1st, 2050 to December 31st, 2050 in rainy season and combine with GIS to build the flooding maps. There is a result of flooding at 18h on November 9th, 2013 (figure 5). The result shows that calculated value of the model is quite consistent with the results of analyzing RS images in the downstream area of Tra Khuc River in section 3.1. Calculation results of flood simulation from September to December for 2050 are working as the basic for assessing the impacts of climate change on flooding corresponding to the average scenario RCP 4.5. The largest flood hazard map in 2050 for the sea level rises scenario of Tra Khuc river basin is displayed in figure 6.
4. Conclusion

The results of remote sensing interpretation in this research allow to analyze the evolution of the flood, the characteristics of the flood regime of the study area. The study used MIKE NAM model to calculate and simulate river flow. Calibrating and validating steps of MIKE NAM model and hydraulic model are conducted. The MIKE NAM results are used as input data for the hydraulic model and flow calculation at the points in the middle river. Based on the set of parameters that have been calibrated and validated to implement flood simulation according to climate change and sea level scenarios issued by the Ministry of Natural Resources and Environment in 2016 and built up the largest flood risk maps for Tra Khuc river basin in 2050 on the basis of flooding maps of the special flood in 2013. The study integrated the results of the hydraulic model MIKE 11 and the GIS tool to develop a flooding map of the Tra Khuc river basin. It can be seen that under the impact of climate change and sea level rise, the area at risk of flooding increases significantly. In order to mitigate the impacts of climate change and sea level rise, it is necessary to provide specific solutions for each area as well as adaptation activities with climate change.

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