APPLICATION OF MIKE FLOOD MODEL FOR INUNDATION SIMULATION IN YEN BAI CITY

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Abstract: *Flood is a natural disaster that can cause loss of life and damage to property. The objective of this study is to create a flood map of Yen Bai city, where flood occurs regularly during heavy rain and Thao River's water level rises. The study used Mike Flood model based on the connection of 1D and 2D hydrodynamic models. The model parameters were calibrated and validated againts observed water level data of two major flood events in August 2008 and July 2009 which were measured by Bao Ha and Yen Bai hydrological stations, in addition with historical flood survey data in 2008. Flood map was developed corresponding to the alarm levels. The results show that the most affected areas by flood are 4 communes of Au Lau, Hop Minh, Tuy Loc, and Hong Ha wards.*

Keywords: *Yen Bai City, Inundation maps, Mike Flood, Thao River.*

1. Introduction

Urban flooding causing significant damage to the country's socio-economic development [1]. Flooding is possible to occur in most cities situated along the river banks. Yen Bai city, which is located on both sides of the Red River (Figure 1), faces frequently floods during heavy rains. Flooding can lead to loss of human life, damage to property and affect to socio-economic activities. Therefore, it is necessary to generate a flood inundation simulation in Yen Bai city, especially in the context of climate change.

Several methods can be used for flood inundation mapping, among which numerical modeling is widely applied because of its advantages such as: Saving time, low cost, high practical results. Some popular models of this type in creating flood inundation maps include Mike Flood [2, 3, 4, 5, 11], Hec-Ras 2D [6, 7, 8, 9, 10] and so on. This paper introduces the results of applying Mike Flood model to simulate flood in Yen Bai City on the basis of connecting the 1D from Mike 11 with the 2D from Mike 21 model.

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2. Study area description

Yen Bai city is often affected by flooding when it rains heavily. In recent years, large floods occurred causing serious damage to Yen Bai city with increasing intensity. In addition, in the upper of Thao River basin, a number of hydroelectric reservoirs were built. These reservoirs have significantly changed the flood flow in the basin. In recent years, when heavy rain occurs upstream at the end of the flood season, hydroelectric power plants release flood water, causing quite large floods at the end of the flood season resulting in inundation in many areas along the Thao River.

3. Data and methodology

3.1. Data

Data collecting and processing is the first step in running a model. Based on the models used in this study, the following data were colected and precessed:

a) Terrain data

Topographic data including cross-sections,

digital maps, topographic maps were collected to establish MIKE 11 and MIKE 21 hydraulic models. They are:

- Digital elevation map (DEM) of resolection 12.5 m x 12.5 m (https://vertex.daac.asf.alaska.edu/) as shown in Figure 2.

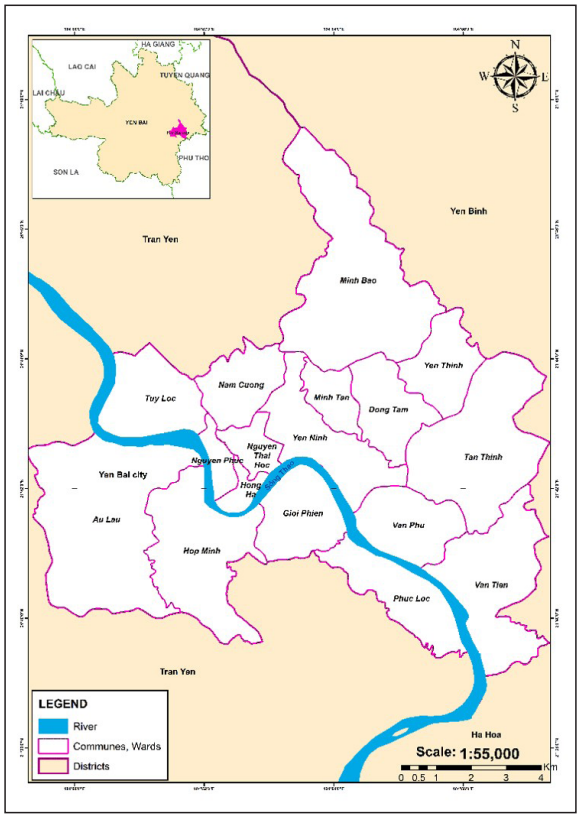

Figure 1. The location of study area

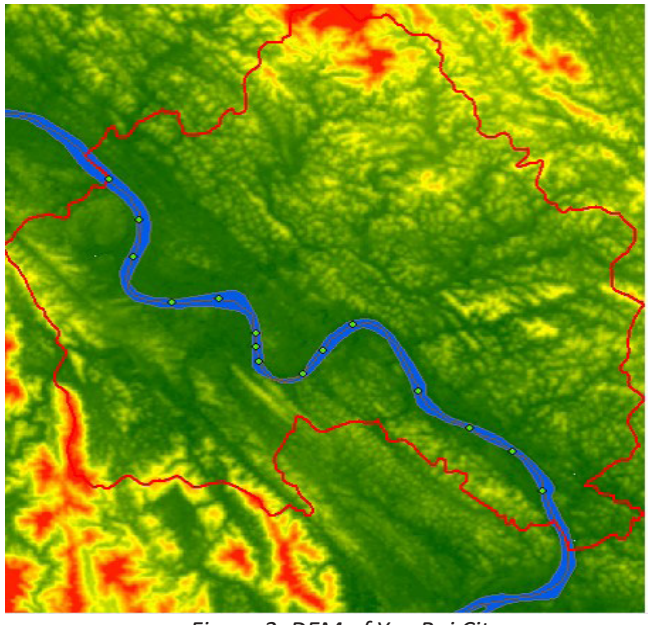

Figure 2. DEM of Yen Bai City

- Topographic maps of Yen Bai city with the scales of 1:10,000 and 1:5000 provided by the Geodesy and Mapping Data Center of the Viet Nam Department of Mapping and Geographic Information in 2019.

- 130 and 7 cross-sections of 2 tributaries of Thao and Bua rivers were used for 1-dimensional hydraulic simulations by the MIKE model. The Thao and the Bua rivers were simulated from the Lao Cai hydrological station to the Phu Tho hydrological station with a length of 234,287 km and from the Thanh Son hydrological station to the Thao river confluence with a length of 12,842 km, respectively.

b) Hydrological data

The simulation of hydraulic model incorporates with the flow discharge into the rivers which was extracted from realistic data at Lao Cai and Thanh Son hydrological stations. The flows entering the middle course were computed from the observed flow data of Ngoi Nhu, Ngoi Hut and Ngoi Thia stations. The water level data at Phu Tho hydrological station was selected for the lower boundary condition of the 1-dimensional MIKE 11 hydraulic model. On the other hand, the roughness coefficient of the results was calibrated and validated with the values from Bao Ha stations (H) and Yen Bai station (H, Q).

The study selected realistic hydrological data for the calculation, which was relative to the three alarm levels. The selected floods are following:

▪ The flood event occurred from August 5, 2008 to August 17, 2008 (especially large flood);

▪ The flood event occurred from July 2, 2009 to July 12, 2009 (corresponding flood alarm 1);

▪ The flood event occurred from July 29, 2015 to August 8, 2015 (corresponding flood alarm 2);

▪ The flood event occurred from July 19, 2018 to July 25, 2018 (corresponding flood alarm 3).

c) Historical flood survey data

This research used the historical flood survey data at 21 sites along the Thao River in Yen Bai city area surveyed by Viet Bac Regional Hydrometeorological Station in 2019, the locations of the floods are shown in Figure 3.

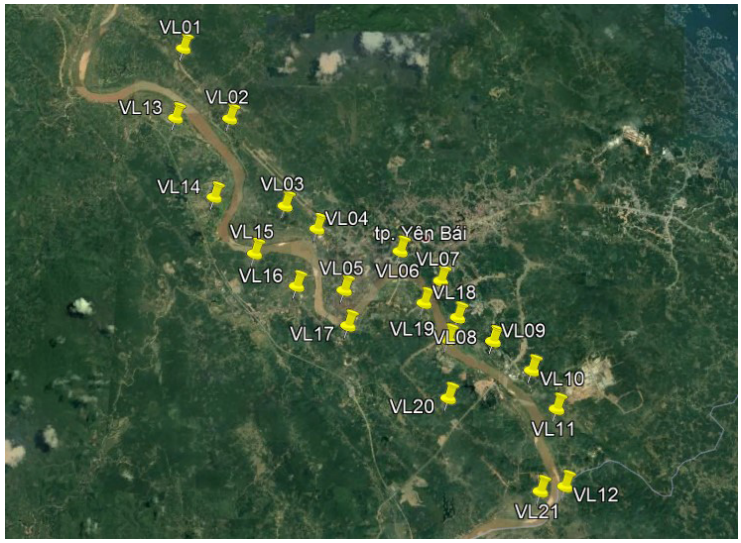

Figure 3. Location of the historical floods carried out by survey data in Yen Bai city

3.2. Methodology

MIKE FLOOD dynamically links two independent software packages: MIKE 11 (1D) and MIKE 21 (2D). In order to archieve the research objectives, the authors processed the research according to the diagram in Figure 4.

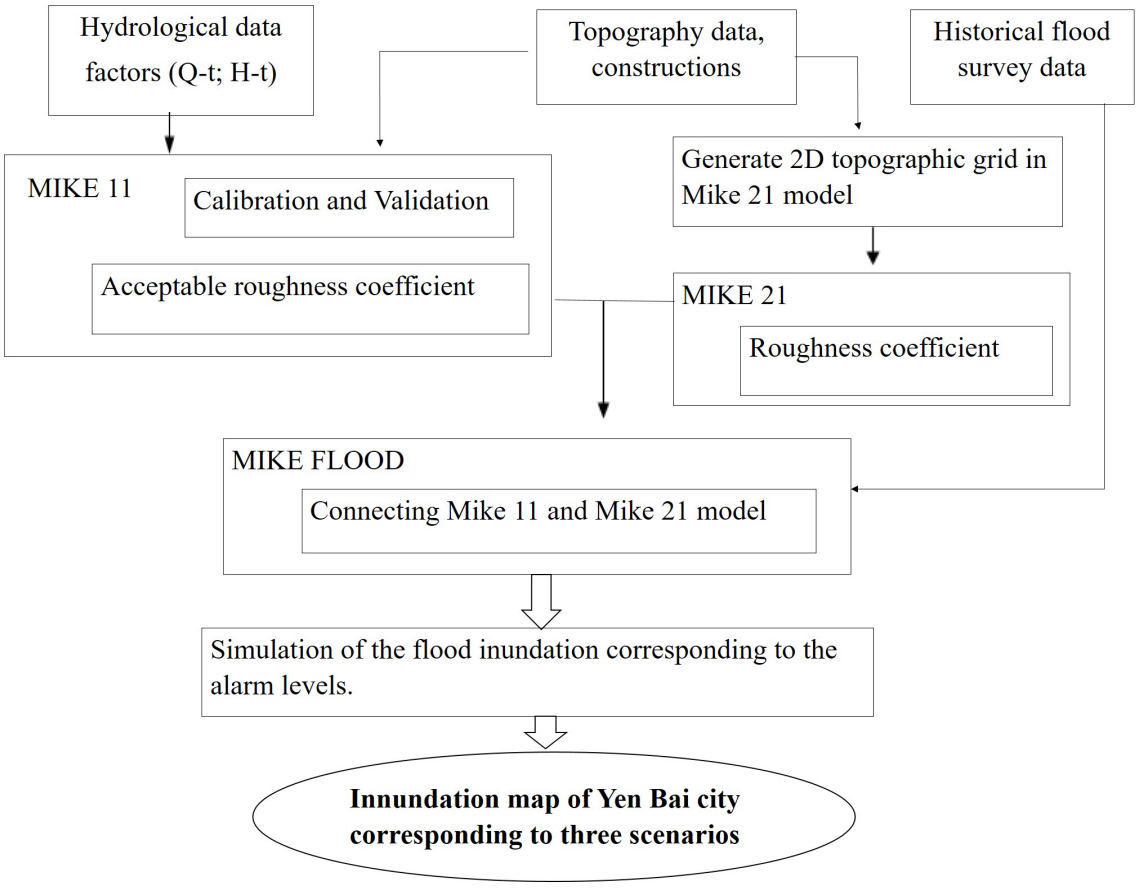

Figure 4. Scheme of conducting the inundation map in Yen Bai city

4. The model set up

4.1. Setting up of the Mike 11 model

- The river network in study area that was simulated in the one-way hydraulic calculation consists of two rivers: The Thao River and the Bua River.

- The length of Thao River is approximate 234,287 km, including 130 sections from the Lao Cai hydrological station to the Phu Tho hydrological station. Therein, the river's length in the 2D hydrologic simulated study area is around 20.12 km, in association with 15 cross-sections.

- The Bua River consists of seven cross-sections from Thanh Son hydrological station to its confluence with Thao River.

- The upper boundary of the hydraulic model is the flow-time process $Q=f_{(t)}$ at the following locations:

▪ On the Thao river: (Q ~ t) Lao Cai hydrological station;

▪ On the Bua river: (Q ~ t) Thanh Son hydrological station.

- The lower boundary of the model is the process of water level over time $H = f_{(t)}$, at the location of Phu Tho hydrological station

- Calibaration boundary: On Thao River, the simulated area has two hydrological stations, including Bao Ha (water level H) and Yen Bai (Flow Q, water level H). One-way hydraulic was used for the calibaration boundary.

Influence boundary: Besides the tributary of Bua River which flows into the Thao river, some main tributaries such as Ngoi Nhu, Ngoi Hut, Ngoi Thia and small tributaries are situated in the simulation area. Therefore, when simulating one-dimension hydraulics, the outflow from these tributaries is assumed to be at the point on the Thao tributary.

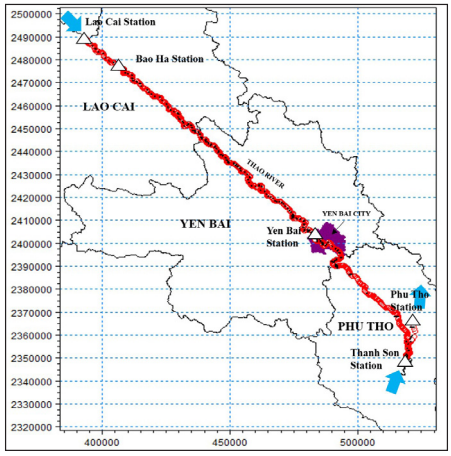

Figure 5. MIKE 11 HD hydraulic simulation scope diagram

	Boundary Description	Boundary Type	Branch Name	Chainage	Chainage	Gate ID	Boundary ID
1	Open	Inflow	Song Thao	0	0		Lao Cai
2	Open	Inflow	Song Bua	0	0		Thanh Son
3	Open	Water Level	Song Thao	233153.5273769	0		Phu Tho
4	Point Source	Inflow	Song Thao	128774.57	0		Ngoi Thia
5	Point Source	Inflow	Song Thao	104396.9990608	0		Ngoi Hut
6	Point Source	Inflow	Song Thao	42122.67217951	0		Ngoi Nhu

Figure 6. Boundaries of MIKE 11 HD hydraulic

4.2. Model calibration and validation

Two flood events of 2008 and 2009 were used to calibrate and validate the roughness coefficient. Various calculations with different roughness parameters were run, the river system's set of hydraulic parameters was determined with the roughness coefficient values range from 0.018÷0.031.

The results of calibration and verification at two hydrological stations Bao Ha and Yen Bai are shown in Figures 7 - 8 and the error is evaluated as follows:

Table 1. Table of table of flood simulation results evaluation after calibration and validation

Time	Station name	Evaluation criteria		Note
		Nash	ΔH(m)	
05-16/XIII/2008	Bao Ha	0.98	-0.77	Calibration
	Yen Bai	0.92	0.19	
11/02/2009	Bao Ha	0.76	-0.05	Validation
	Yen Bai	0.89	0.4	

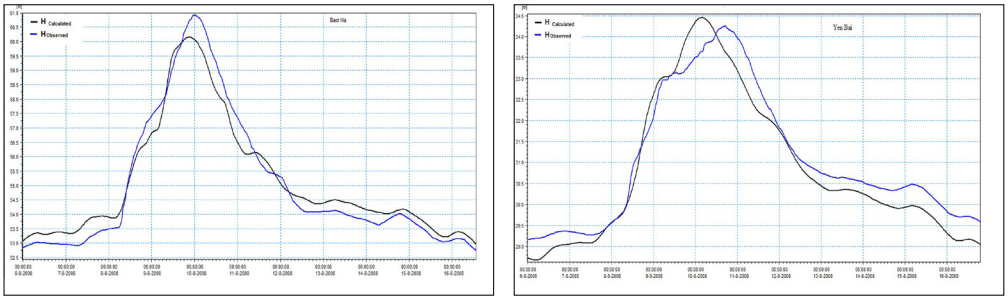

Figure 7. Observed and calculated water level at Bao Ha station and Yen Bai station on Thao River, August 2008

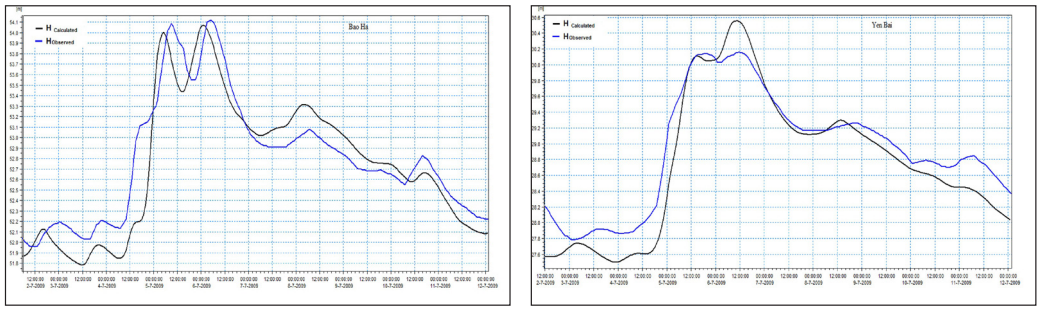

Figure 8. Observed and calculated water level at Bao Ha station and Yen Bai station on Thao River, July 2009

The figures show that the results of flood calculation on Thao River with the floods of August 2008 and July 2009 are relatively consistent between the measured and calculated water level. The Nash indicator of the validation has value from 0.76 to 0.98 showing the satisfactory of the model performance. The peak error at Bao Ha station is small at 5cm while the value at Yen Bai station is more than 0.4m. However, the simulated flood peak is larger than the observed data. Consequently, the set of MIKE 11 hydraulic parameters is acceptable and can be applied for the next calculation steps.

4.3. Creation 2D Grid

In this study, the computational grid was set up with triangular and square grids. Square grids were used to simulate flood-blocking objects such as roads, dikes, and other things. The remaining areas were modeled according to triangular grids. The regions located along both sides of the river and have high intensity population have average size of the grid around 50 m while another areas have the average grid size is about 200 m.

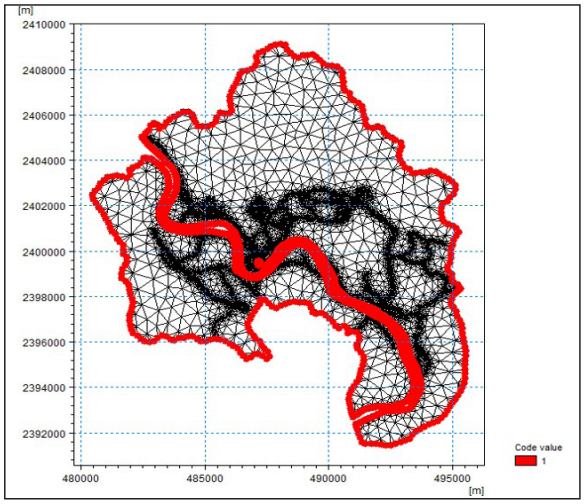

Figure 9. 2-D grid of Yen Bai city area

4.4. 2D simulation results evaluation

After calculating flood and creating calculation grid for the area, the study used MIKE FLOOD model to simulate flooding for Yen Bai city.

The calculation results of the 2-D flood inundation simulation were reviewed based on the data of flood tracks that were surveyed and collected in the submerged areas in response of the biggest flood in 2008.

Figure 10 and Table 2 show the results of comparision between flood survey data at 18 flood tracks in the calculation domain and flood simulations. The results show that the flood calculation results are quite suitable.

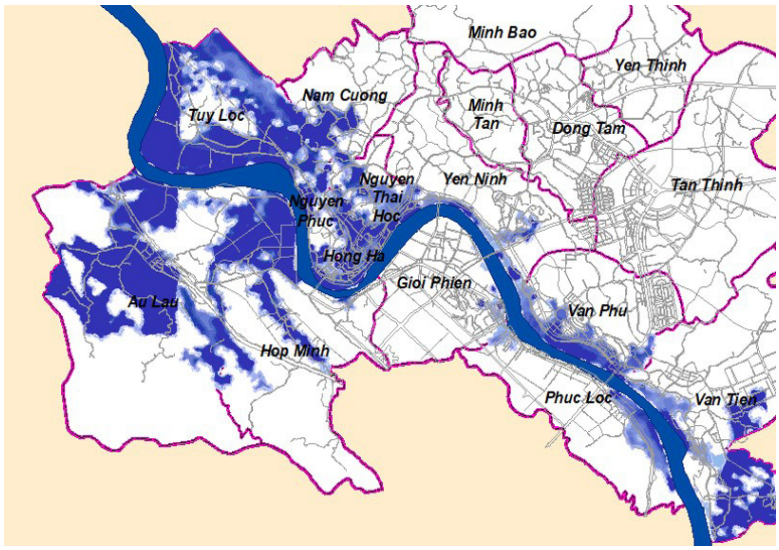

Figure 10. Results of the flood inundation simulation of 2008 flood in Yen Bai city

Table 2. Comparison of investigated flood tracks and results of 2D hydraulic model

No.	Point name	VN2000, meridian 104°45'		Z (m)		Difference (m)
		X coordinate (m)	Y coordinate (m)	Survey 2008	Calculate	
1	YBVL-T01	2,407,761.629	507,278.444	36.46	Not in the domain	
2	YBVL-T02	2,405,532.896	508,864.292	35.59	35.455	0.135
3	YBVL-T03	2,402,816.175	510,721.916	34.936	35.351	0.415
4	YBVL-T04	2,402,133.089	511,734.421	33.994	34.46	0.466
5	YBVL-T05	2,400,261.572	512,647.396	33.86	33.96	0.1
6	YBVL-T06	2,401,504.695	514,303.179	33.021	33.6	0.579
7	YBVL-T07	2,400,632.078	515,570.507	32.721	32.786	0.065
8	YBVL-T08	2,399,529.103	516,114.626	32.29	32.25	0.04
9	YBVL-T09	2,398,842.06	517,199.018	32.429	32.25	0.179
10	YBVL-T10	2,397,999.136	518,381.482	32.257	31.78	0.477
11	YBVL-T11	2,396,873.772	519,144.666	31.85	31.0	0.85
12	YBVL-T12	2,394,609.041	519,420.39	30.875	30.5	0.375
13	YBVL-P13	2,405,509.02	507,174.853	35.867	Not in the domain	
14	YBVL-P14	2,403,029.46	508,526.387	34.801	34.7	0.101
15	YBVL-P15	2,401,309.74	509,863.965	34.712	34.57	0.142
16	YBVL-P16	2,400,345.994	511,193.892	34.731	35.01	0.279
17	YBVL-P17	2,399,188.693	512,807.308	33.585	33.68	0.095
18	YBVL-P18	2,399,941.882	515,084.192	33.389	33.1	0.289
19	YBVL-P19	2,398,857.99	515,839.002	33.339	32.921	0.418
20	YBVL-P20	2,397,099.696	515,894.386	32.224	Not in the domain	
21	YBVL-P21	2,394,442.669	518,694.084	30.143	30.358	0.215

5. Results and discussion

Yen Bai hydrological station is situated in Thao River. Therefore, in this study, we consider calculating simulation and making flood maps for Yen Bai city according to the scenarios based on water level alarm at Yen Bai hydrological station incorporate with the realistic floods. Responding to 3 alarm levels, the study generated flood inundation maps of four floods, including:

- Scenario 1: Simulation of the 2009 flood (corresponding flood BD1 +0.15 m);
- Scenario 2: Simulation of the 2015 flood (corresponding flood BD2 +0.17 m).
- Scenario 3: Simulation of the 2018 flood (corresponding flood BD3 +1.12 m)
- Scenario 4: Simulation of the 2008 flood (especially large flood, corresponding alarm 3 +2.17 m).

Table 3. Statistic of flooded area corresponding to flood levels under 4 scenarios

Flood depth	Flooded area (ha)			
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
<0.5 m	35.478	140.621	231.708	307.175
0.5 - 1.0 m	14.068	67.701	166.038	193.369
1.0 - 1.5 m	9.361	43.344	121.342	174.401
1.5 - 2.0 m	10.096	41.682	96.981	192.666
2.0 -2.5 m	8.055	27.937	80.13	162.619
2.5 - 3.0 m	5.224	21.362	64.814	138.679
3.0 -3.5 m	4.462	17.709	54.914	319.931
>3.5 m	11.812	30.802	194.043	806.152
Total (ha)	**98.556**	**391.158**	**1,009.97**	**2,294.992**

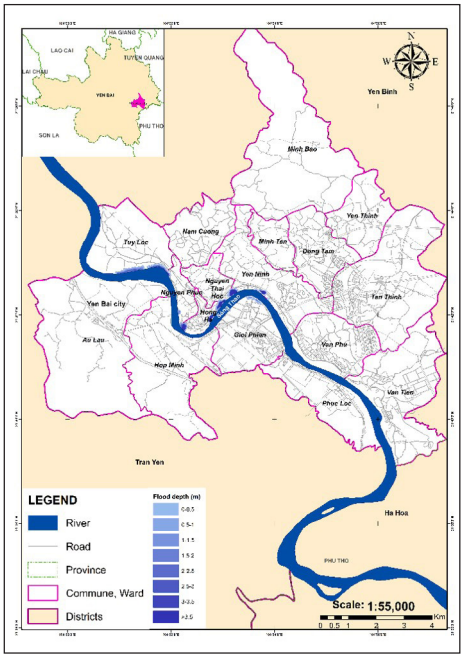

Figure 11. Inundation map of Yen Bai city in 2009 flood (Scenario 1)

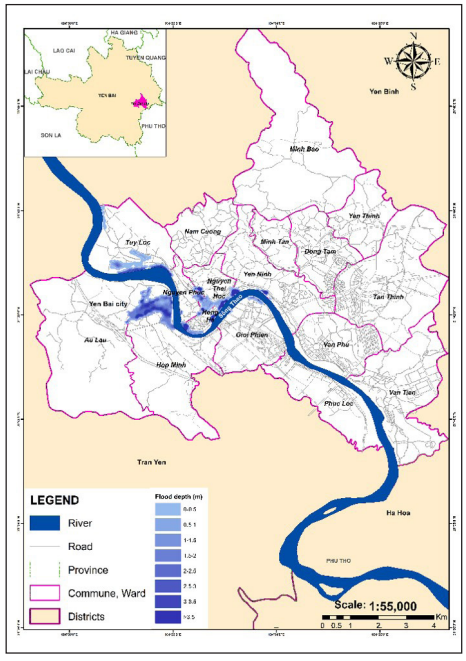

Figure 12. Inundation map of Yen Bai city in 2015 flood (Scenario 2)

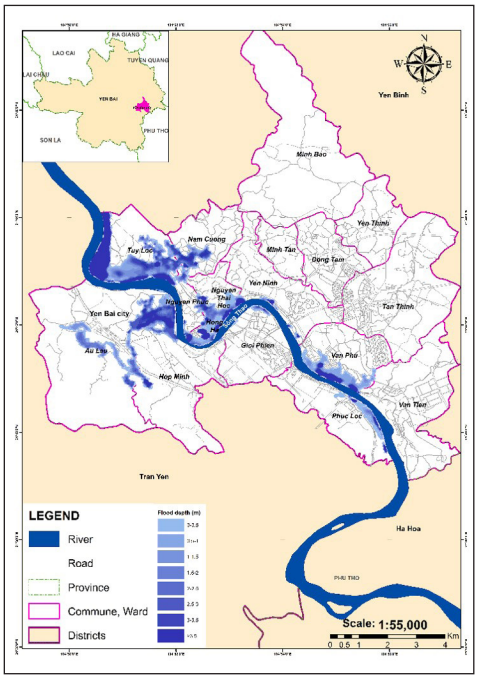

Figure 13. Inundation map of Yen Bai city in 2018 flood (Scenario 3)

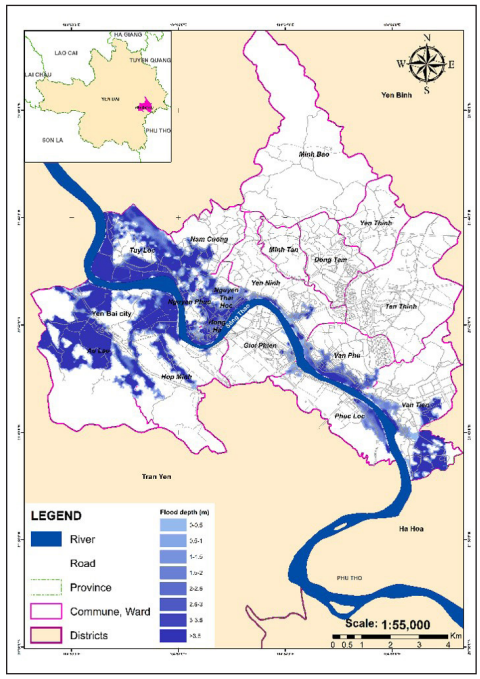

Figure 14. Inundation map of Yen Bai city in 2008 flood (Scenario 4)

Discussion:

- According to the calculation results, the flooding (inundation depth, flooded area) of Yen Bai city increased gradually according to the disadvantages of the scenarios corresponding to the water level alarm levels at the Yen Bai hydrological station.

- Corresponding to the scenarios, flooding occurs mostly in communes/wards located along both sides of Thao River.

- The total flooded area of Yen Bai city corresponded to the incremental scenarios from scenario 1 to scenario 4.

- Inundated depths had all levels of alarm. Especially in scenario 4, the extreme flooding occurred in 2008 with flood depth >3.5 m.

+ *For Sc1*: In Yen Bai city, flooding occurred with a negligible area. The flooded area was in 5/17 communes with 100 ha and happened on the left bank of Thao River. The largest flooded area corresponds to the inundation depth <0.5m which mainly occured in communes and wards: Tuy Loc, Hong Ha, Nguyen Thai Hoc

+ *For Sc2*: In the whole city of Yen Bai, the number of flooded communes increased to 8/17. The inundated area was 400 ha with large scale both in terms of area and depth. The regions which had a depth less than 0.5 m were the largest flooded area and concentrated in 4 communes and wards: Au Lau, Hop Minh, Tuy Loc and Hong Ha.

+ *For Sc3*: Considering the whole city of Yen Bai, the flooded communes have increased to 8/17 communes, the flooded area is about 400 ha. In flooded communes, flooding has occurred on a large scale both in terms of area and depth, with a depth of less than 0.5 m still having the largest flooded area. The flooded area is concentrated in 4 communes and wards: Au Lau, Hop Minh, Tuy Loc and Hong Ha.

+ *For Sc4*: The flood map according to scenario 5 for Yen Bai city is clearly different from the three previous scenarios. The flood water spread from the Thao River into the city, only 5/17 communes and wards located in mountainous areas far from the river were not flooded. The total flooded area of the city was nearly 2,300 hectares with flood depth > 3.5 m had the largest area. Flooding time in all 12/17 affected communes and wards lasted from 5 to 6 days.

6. Conclusions

The study used the MIKE FLOOD model to simulate flooding in Yen Bai city. The MIKE 11 1D hydraulic model was calibrated and validated against observed data at Bao Ha and Yen Bai stations. The 2D hydraulic model was set up with and a grid and topography based on topographic maps of 1/5000 and 1/1000 scale which was released by the Data Center for Geodetic and Mapping Data of the Department of Surveying and Information in Viet Nam. The 2D calculation results were validated with the survey data of historical floods in the calculated area to ensure high reliability and can be used to simulate the corresponding level of different inundation scenarios. Inundation maps of 4 scenarios for Yen Bai city were created based on water level alarm levels at Yen Bai hydrological station combined with selected flood data to choose five floods in 2008, 2009, 2015 and 2018.

According to the flood calculation results of 4 scenarios, the inundation level (inundation area and inundation depth) of Yen Bai city increased gradually according to alarm level and disadvantage, magnitude of the floods that occurred. Flooding areas occurred mainly in communes wards located in both sides of Thao River. With level 1 alert, the flooded area is not considerable, mainly located along the Thao River. At the level 2 alert, the flooded area started to expand widely, mainly in 4 communes and wards: Au Lau, Hop Minh, Tuy Loc and Hong Ha. However, with the flood occurring in 2008 (the peak water level is +2.17 m higher than the level 3 warning level), the flood level is much higher than the two scenarios above. Flooding occurs in all communes and wards on both sides of the river and then expanded to the city, except for communes and wards located in mountainous areas far from the river.

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