NUMERICAL MODELLING OF EXTREME FLOODING FOR FLOOD RISK ASSESSMENT IN THE TRA BONG RIVER BASIN, VIETNAM

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1- Study area

- The total river system basin area **is over 700 km²**, of which more than 80% is mountainous or hilly.

- The river has a length of **59 km** and its network density is about **0.43 km/km²**, the average altitude is 196 m and the average river slope is 10.9%.

- Tropical climate and yearly total rainfall **2200 to 2500 mm**.

- The overall **topography changes rapidly** from the upper part in the West to the lower part in the East of the study area.

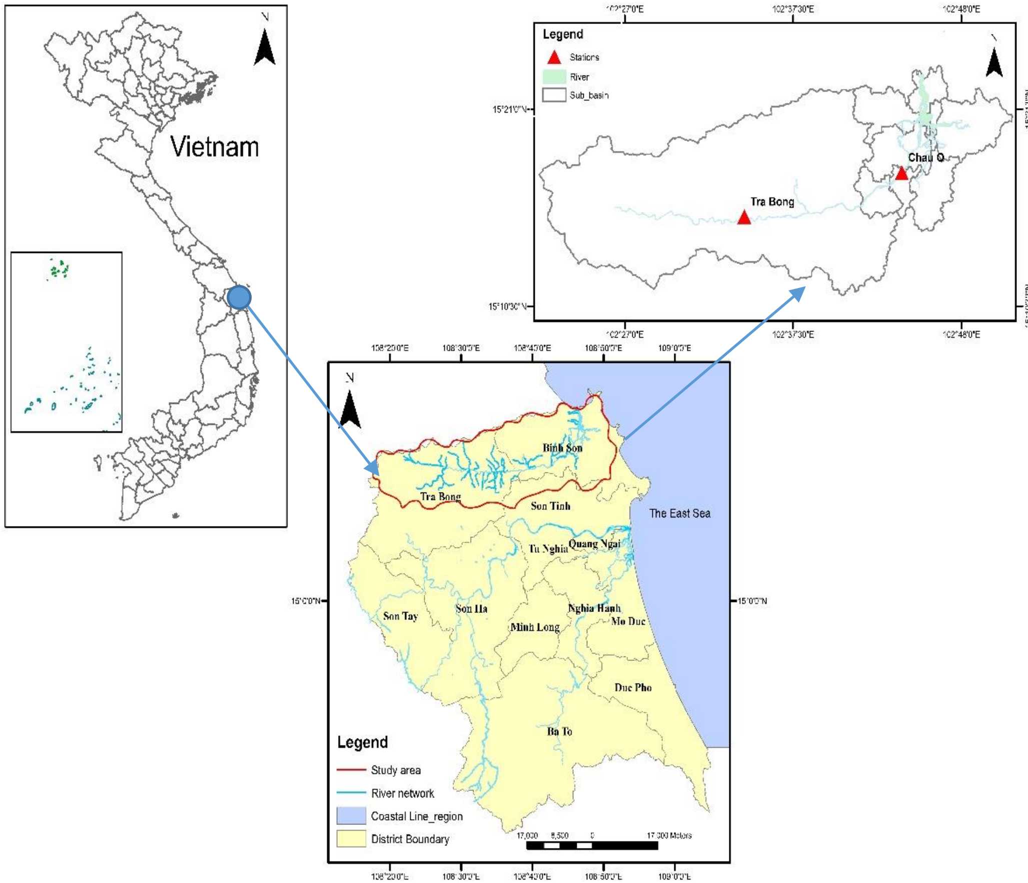


Fig. 1 Map of the study area in Quang Ngai province

Due to the topographic and rainfall characteristics, floods are very unpredictable and severe in this area.

2- Problem statements

- The basin is constantly effected by heavy rains and typhoons and the annual inundations that cause considerable **damages to people and infrastructure.**

- The basin is **lack of hydrological information**.

- Typically, the **2003 flood event** occurring from the 16th to the 17th of October caused the water level in the Tra Bong River to rise over the Alarm 3 level of 1.20 to 2.02 meters. During the flood event, **total 7 deaths and a hundred of households were inundated** due to water depths of 1 to 3.5 meters.

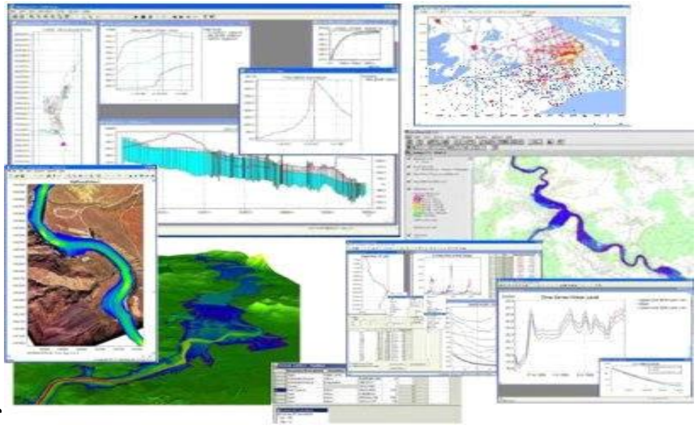
- Annually, many floods with different magnitudes happen in this area. Hundreds of local families have to **move their households to safe places**, while some even avoid the flood disaster by **climbing on the roofs of their houses in hope of finding help from others.**




(Source:www.quangngai.org.vn)

Considering the impacts of flooding in this river plays an important role in mitigating and adapting to flood risk.

3- Material and Methodology



3.1. Material

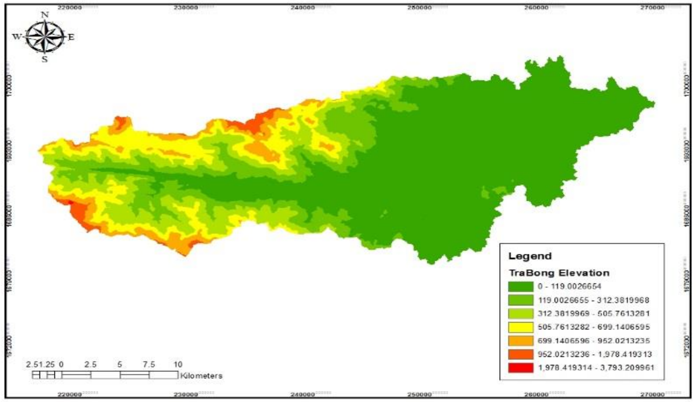
- Hydro-meteorological data: Rainfall
- Geometry and Land-use: Cross-sections, Digital Elevation Map, land uses map, etc.
- Numerical models:

+ Rainfall-runoff model (MIKE NAM);

+ Hydrodynamic model 1D (MIKE 11 HD);

+ Hydrodynamic model 2D (MIKE 21 FM);

+ Coupling model (MIKE Flood).

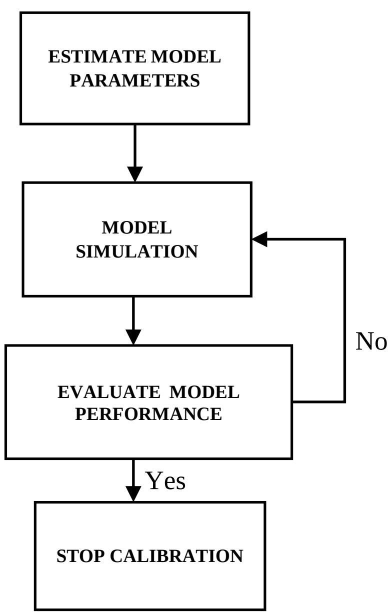


Applying numerical modelling for extreme flooding simulations in the ***ungauged basin (No discharge data)***

3- Material and Methodology

3.2. Methodology

- The **regionalization method** (Physically similarity and Spatial proximity) was applied for modelling rainfall-runoff.
- The **Rainfall Based method** was applied for the design flood.
- To evaluate the model performance, the **Nash Sutcliffe coefficient** of efficiency, peak flow error, peak time rate, volume error, and correlation coefficient were used.
- The **trial and error method** was implemented to calibrate these models.



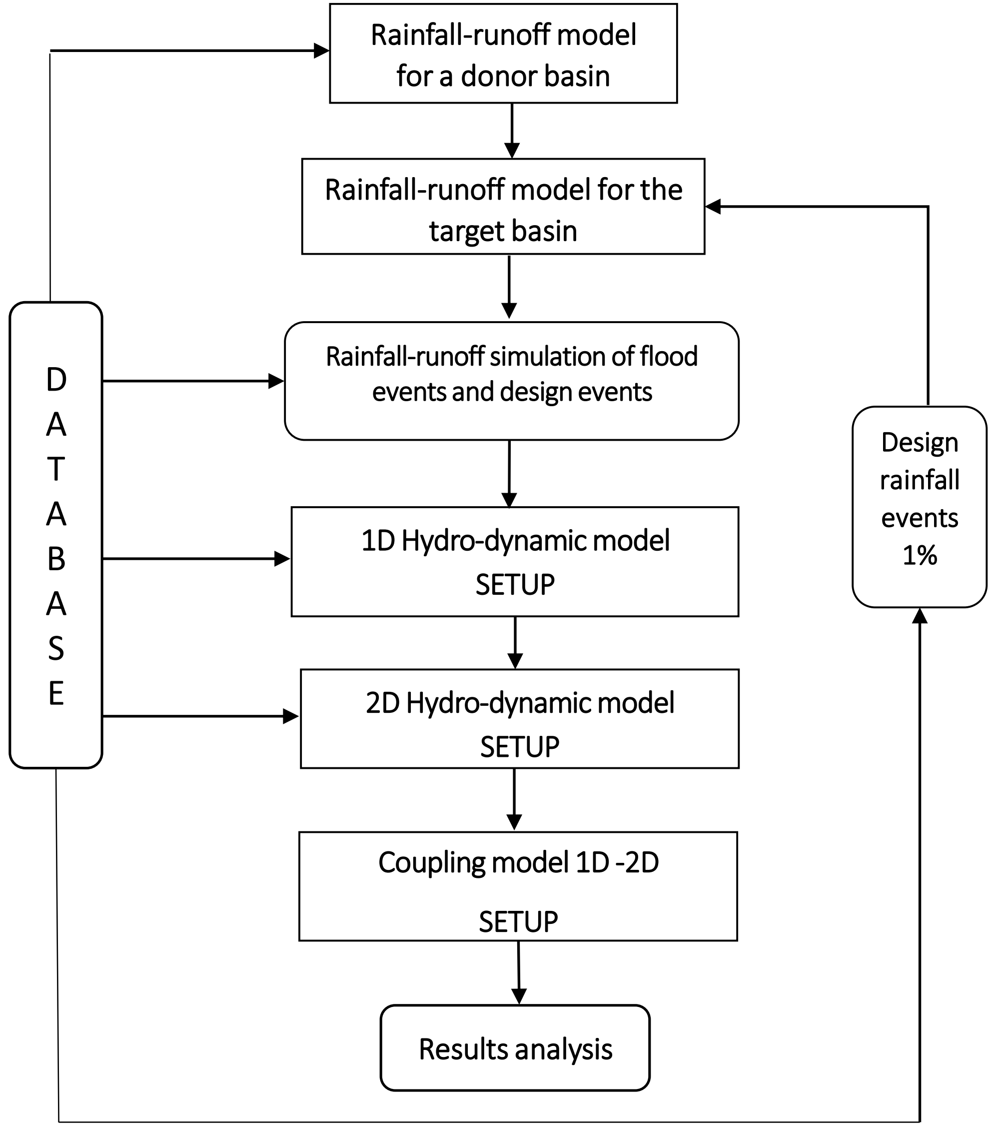


Fig 2: The model application approach

4- Rainfall-runoff model

Due to a lack of sufficient hourly discharge data in the Tra Bong catchment, the regionalization method was applied. The An Chi catchment was selected.

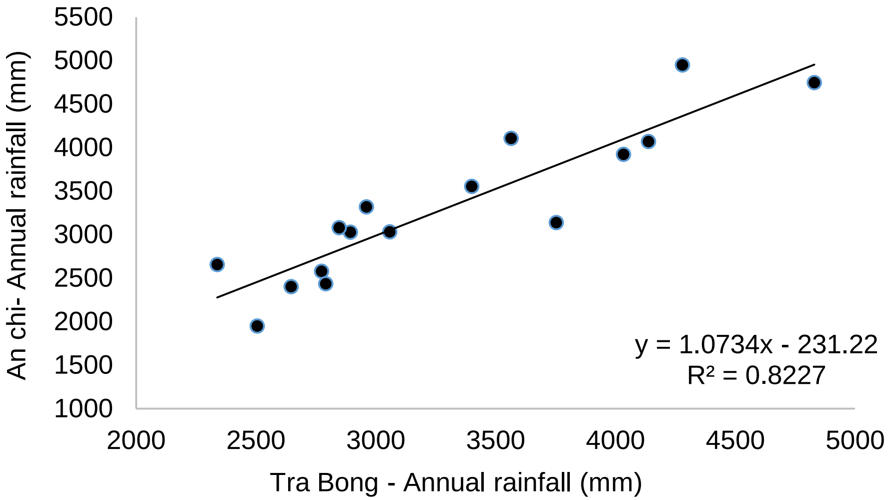


Fig. 4 Annual rainfall relationship between two basins

No.	Attributes	Donor basin	Target basin
1	Drainage Area (km^2)	764	700
3	Catchment slope	0.086	0.097
4	River slope	0.002	0.003
5	Main river length (km)	58.7	40.2

Table. 1 Geographic characteristics of two basins

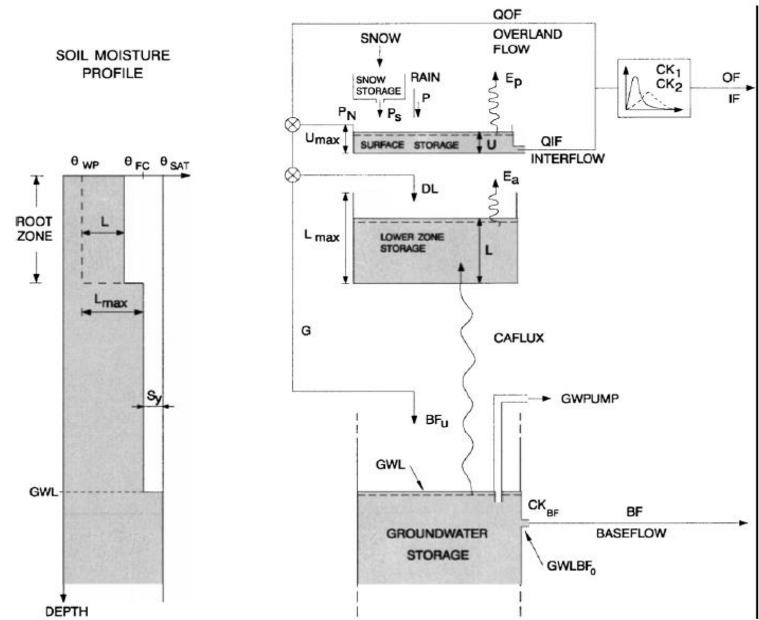


Fig. 3 MIKE 11 NAM structure (DHI,2011)

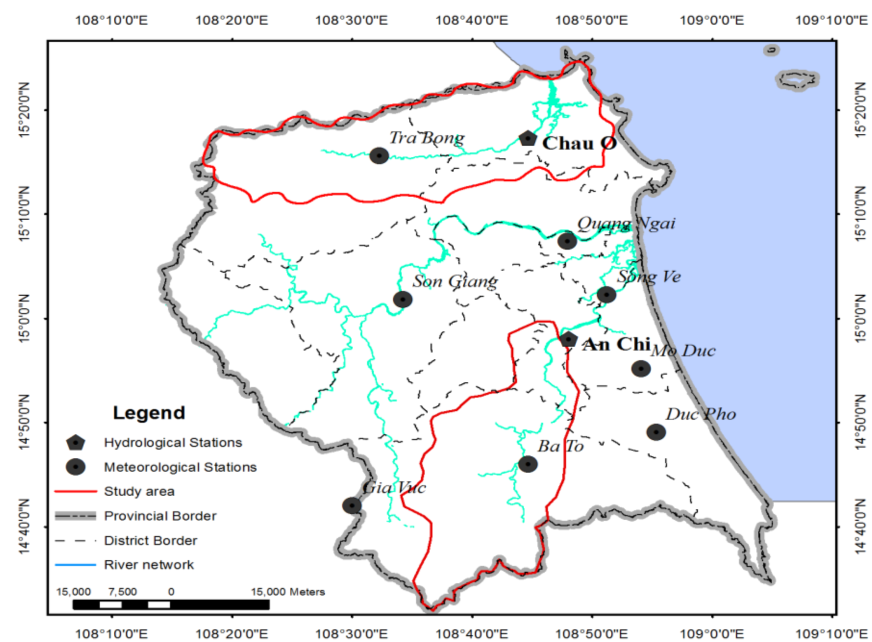


Fig. 5 Map of the location of two basins

4- Rainfall-runoff model

The hourly discharge time series and hourly rainfall time series in the year of **1999 and 2003** were used to calibrate and validate respectively due to synchronous data and typical extreme flood events in both years.

Gauging stations	An Chi	Ba To	Gia Vuc
Weighted average	0.118	0.614	0.268
Observed station	An Chi		
Calibration period	11/01/1999 – 12/31/1999		
Validation period	09/01/2003 – 10/30/2003		
Simulation interval	1 hour		

Table 2. The Thiessen polygon approach

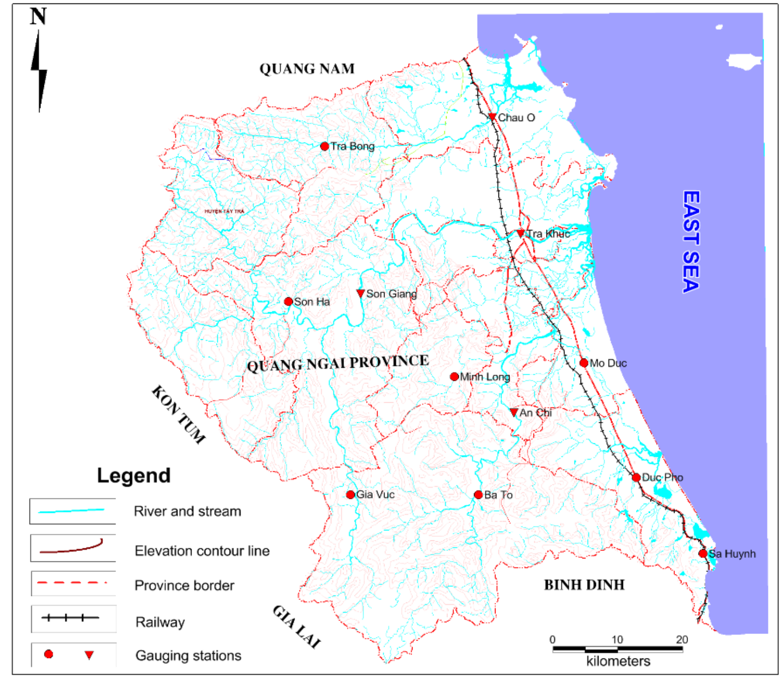


Fig. 6 River network and gauging stations

Parameter	Description	Parameter	Description
QOF	The part of P_N that contributes to overland flow	θ_{SAT}	Saturation zone
QIF	Interflow contribution	U_{max}	Upper limit of the amount of water in the surface storage
OF	Overland flow	P	Precipitation
IF	Interflow	E_p	Potential evapotranspiration
CK_1	Inflow hydrograph	P_N	Excess water that gives rise to overland flow
CK_2	Outflow hydrograph	P_S	Excess melt water contribution
S_y	Specific yield	E_a	Actual evapotranspiration
L_{max}	Upper limit of the amount of water in root zone storage.	DL	Portion of the water available for infiltration
G	Groundwater recharge	CAFLUX	Capillary flux
CKBF	Time constant for routing baseflow	GWL	Groundwater table below the ground surface
BF	Baseflow	GWL_{BF0}	The maximum groundwater table depth
L	Depth of the lower zone storage	GWPUMP	Net groundwater abstraction
θ_{wp}	Wilting point	CQOF	Overland flow runoff coefficient
θ_{FC}	Field capacity	CKIF	Time constant for interflow from the surface storage
TG	Threshold value for recharge	CK1,2	Time constant for overland flow and interflow routing
TOF	Threshold value for overland flow	TIF	Threshold value for interflow

Table 3. Description of the MIKE 11 NAM model parameters (DHI, 2011)

09 major parameters representing the hydrological characteristics of the surface zone, the root zone and the groundwater zone: Lmax, Umax, Ck1,2, CQOF, TOF, TIF, CKIF, and CKBF.

4- Rainfall-runoff model

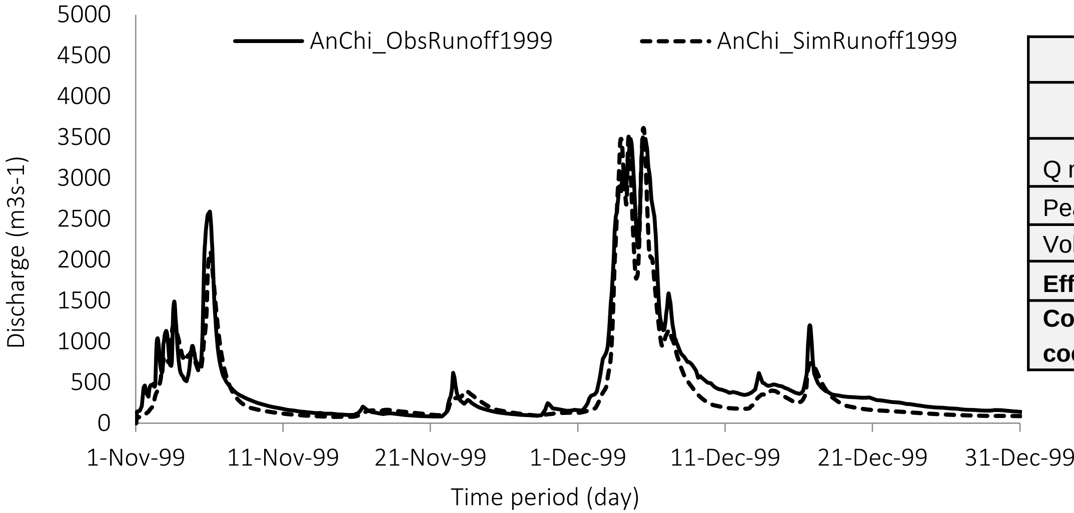


Fig. 7 The observed and simulated runoff in case of the model calibration in the year of 1999

Periods	1999		2003	
Criteria	Simulation	Observation	Simulation	Observation
Q max (10^3 m^3/s)	3.54	3.48	2.80	3.02
Peak error (%)	3.13		3.11	
Volume error (%)	26		35	
Efficiency index	**0.89**		**0.87**	
Correlation coefficient	**0.96**		**0.91**	

Table 4. Error criteria of the model calibration and validation

Parameters	Values	Representation of parameters
L_{max}	100	Maximum water content in surface zone storage
U_{max}	10	Maximum water content in root zone storage
CQOF	0.75	Overland flow coefficient
TOF	0.9	Root zone threshold value for overland flow
TIF	0.6	Root zone threshold value for interflow
TG	0.9	Root zone threshold value for groundwater recharge
CKIF	700	Time constant for routing interflow
CK1,2	40	Time constant for routing overland flow
CKBF	1800	Time constant for routing base flow

Table 5. Major model parameters obtained from the donor basin

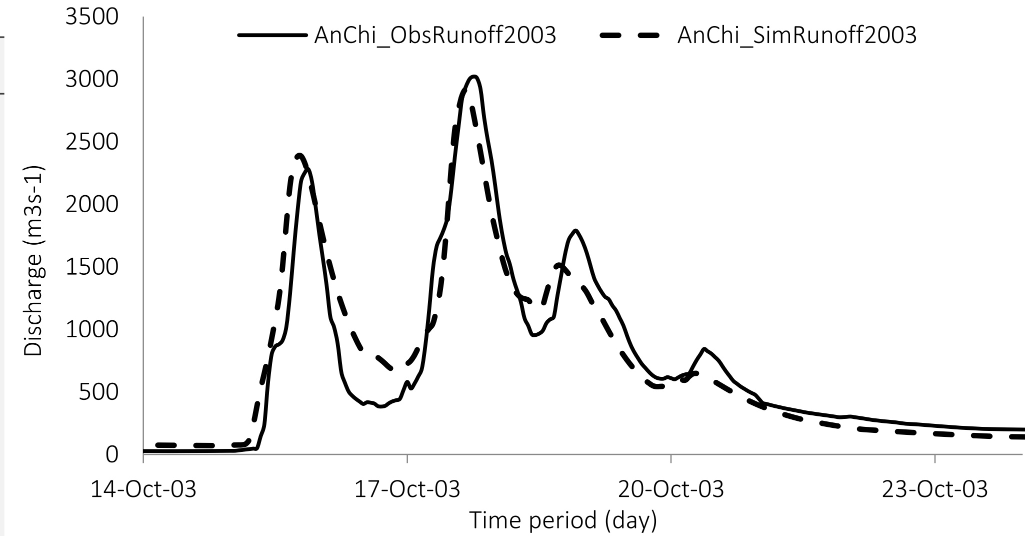


Fig. 8 The observed and simulated runoff in the case of the model validation in year of 2003

5- 1D and 2D models

Hydro-dynamic models 1D (MIKE 11 HD)

- 01 main river
- 02 tributaries
- 80 cross-sections
- Observed point: Chau O (Water level)
- Upstream boundary: Output from the Rainfall-runoff model
- Downstream boundary: Tidal data at the estuary of the river
- Manning number: n

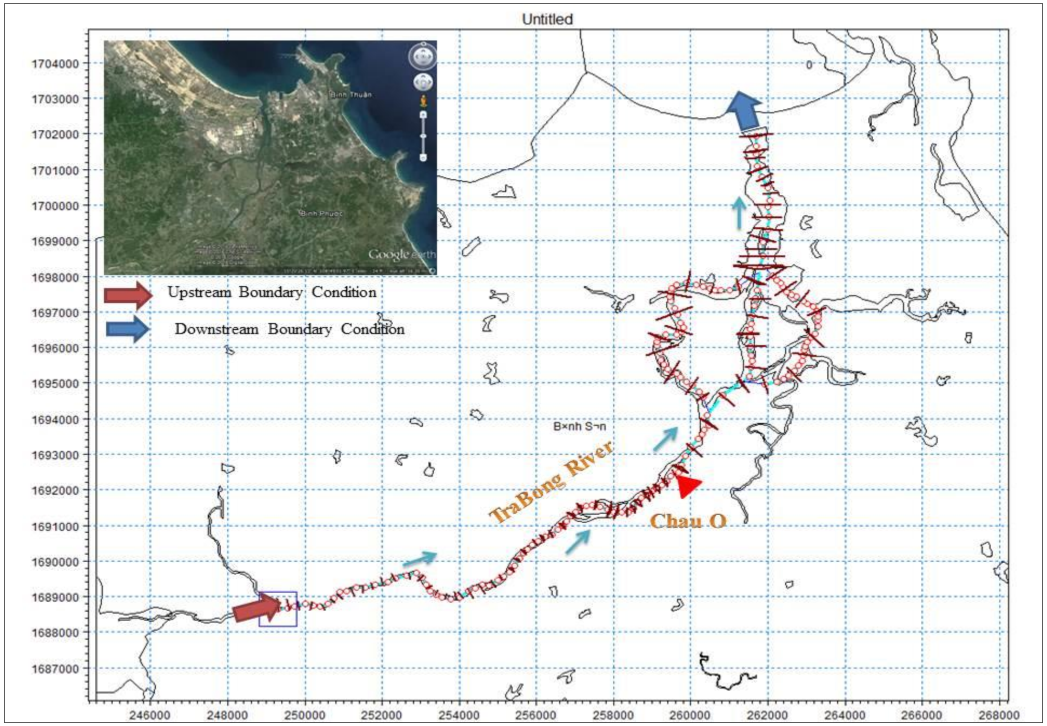


Fig. 9 Numerical MIKE 11 HD model schematization of the Tra Bong River

The Manning roughness that is defined for each cross section. Initially, the Manning values are varying from **0.03 to 0.12 $sm^{-1/3}$ for river banks and channel sections.**

Several cross sections were extracted beyond the **Digital Elevation Model (DEM) of 10 meter** grid size by setting perpendicular lines to each branch in the GIS software.

Rivers	No. of cross sections	River Length (Km)	Description
Tra Bong	61	23.3	Main reach
Tributary 1	8	3.5	Right side
Tributary 2	11	5.2	Left side

Table 6. The river and cross-sections statistics

5- 1D and 2D models

Hydro-dynamic model 2D (MIKE 21 FM)

- DEM (10 x 10 m)
- UTM WG84 ZONE 48N
- Mesh nodes (9,224),
- Mesh elements (17,921),
- Mesh maximum area (16,073 m^2)
- Mesh average area (8,701 m^2)

The domain or floodplain area was determined based on the **highest water level**, which was previously obtained at the Chau O station and to identify the flooded area.

In order to get a stable model, the mesh should obtain triangles without **small angles and smooth boundaries**.

The domain is designed with the mesh in the floodplain and **without the mesh in the river bed** aiming to couple the MIKE 11 HD model with the MIKE Flood model and to reduce the computation time.

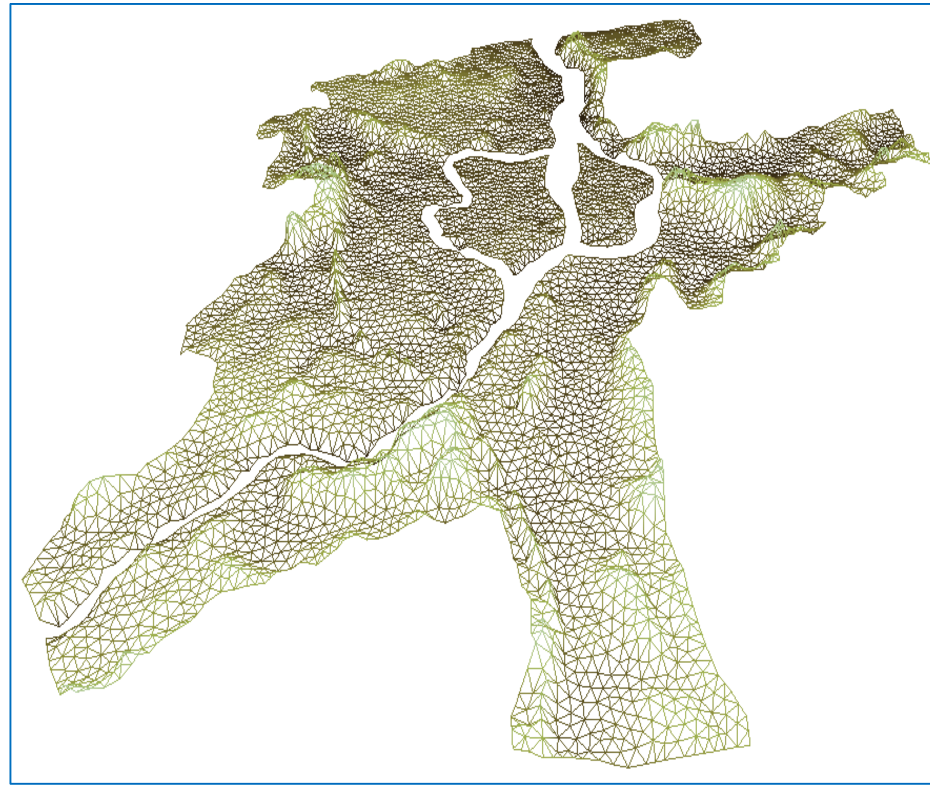


Fig. 10 The domain mesh of the floodplain

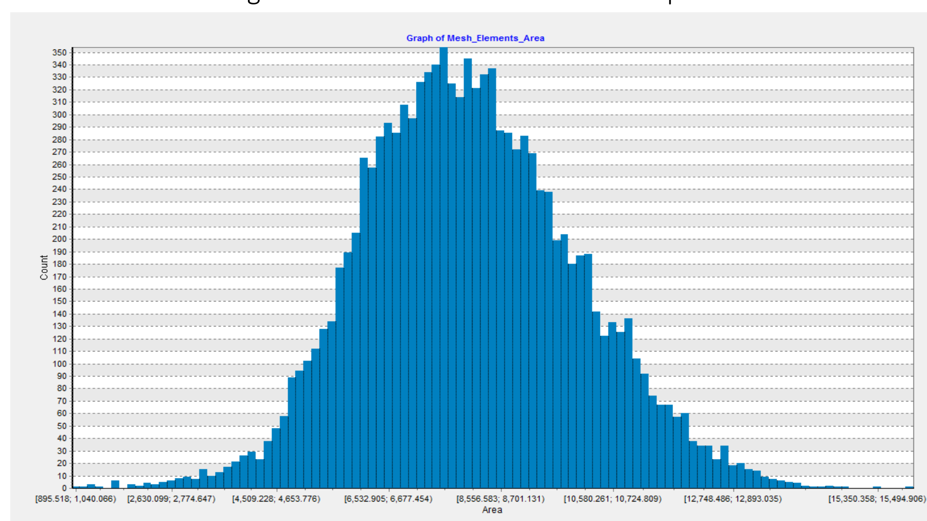


Fig. 11 Mesh element areas distribution

5- 1D and 2D models

Hydro-dynamic model 2D (MIKE 21 FM)

- The MIKE 21 FM was not created with boundary conditions.
- The Manning roughness coefficients were reclassified from the land use map/ Land cover and other parameters are used as default values in the model.
- A manning value is assigned to each element in the mesh domain based on the suggested values for the overland surface from McCuen (1998).

Surface description	Manning's n
Asphalt	0.012
Concrete	0.013
Wood	0.014
Open surface	0.018
Short grass/Lawn	0.15
Dense grass/Light woods	0.2
Woods with underbrush	0.4

Table 7. Manning's n values derived for the domain

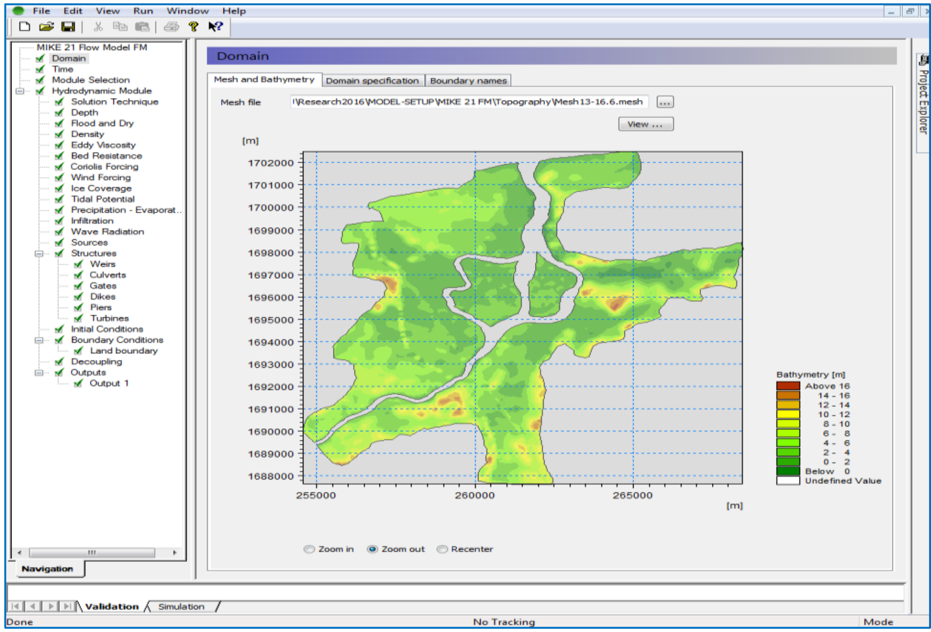


Fig. 12 The MIKE 21 FM setup for the floodplain

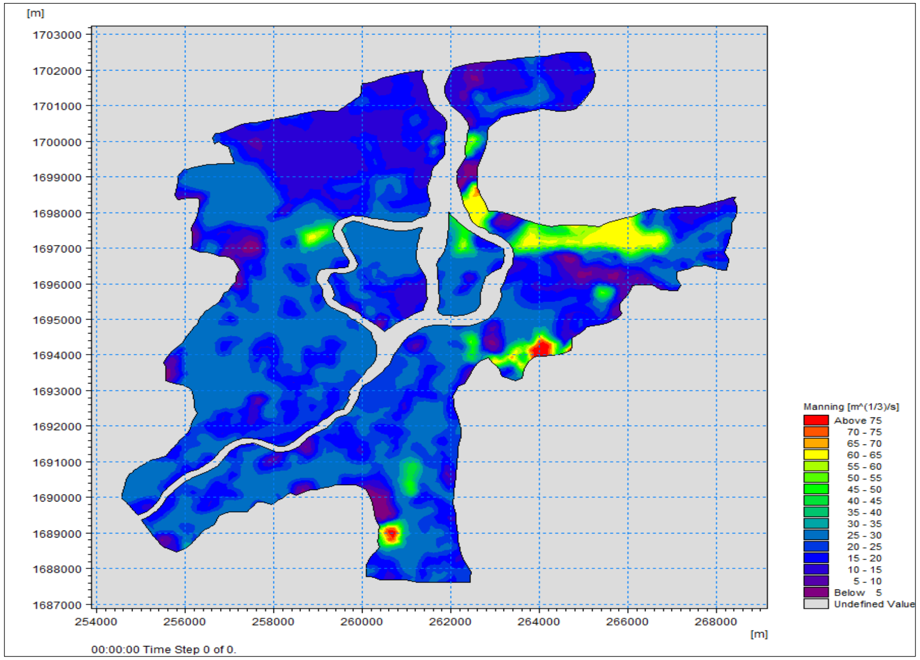
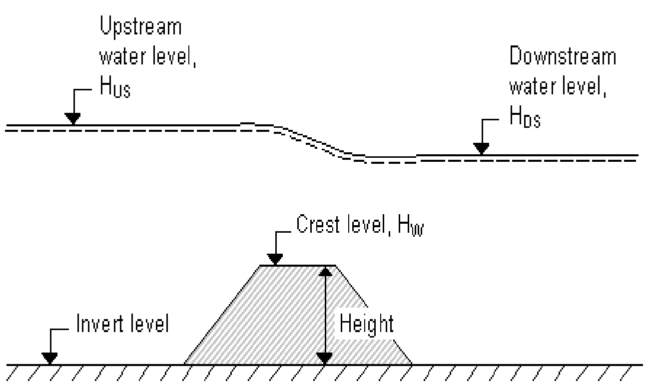


Fig. 13 Manning values varying in the domain

6- The coupling model

Coupling model (MIKE Flood)

- MIKE 11 and MIKE 21 FM models were coupled externally.
- Types: Lateral links
- Structure formula: Weir Formula 1



$$q = WC(H_{us} - H_w)^k[1 - \frac{H_{ds} - H_w}{H_{us} - H_w}]^{0.385}$$

Where: q is the discharge through the structure; W is the width, C is the weir coefficient, k is the weir exponential; H_{us} is the upstream water level; H_{ds} is the downstream water level and H_w is the weir level.

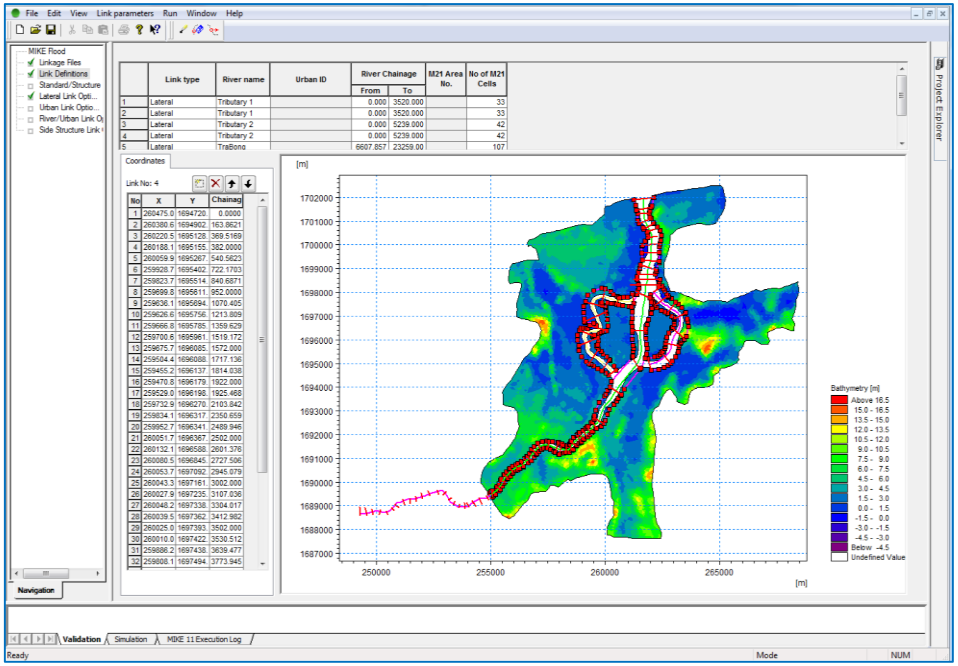


Fig. 14 The coupling model MIKE Flood for the Tra Bong River

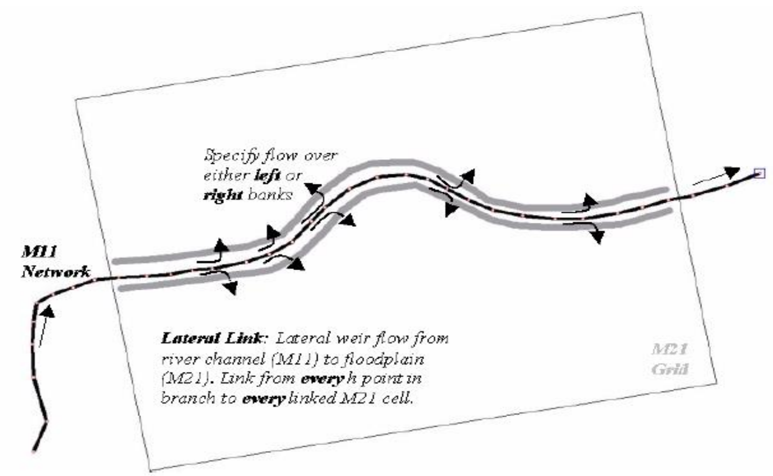


Fig.15 Application of lateral links (DHI, 2011)

7- Simulations and Results

Hydro-dynamic model calibration and validation

- The flood events from 15th October 2003 to 20th October 2003 and from 27th September 2009 to 2nd October 2009 were used for the model calibration and validation.
- A series of statistical evaluations were applied based on a visual comparison.
- To achieve model accuracy and stability, a ten second computation time step was set up for the calculation. A 360 storing factor of time step, equivalent to one hour of storing result was chosen.

Gauging station	Period	Peak error	Volume error (%)	Correlation coefficient	Nash
Chau O	15/10/2003 – 20/10/2003	0.013	10	0.81	0.63
Chau O	27/9/2009 – 2/10/2009	0.012	20	0.92	0.70

Table 7. Model performance of the MIKE Flood

*The model performance is relatively **satisfactory** for both calibration and validation. The results above indicate that this model is **suitable for flood risk assessment** in this basin.*

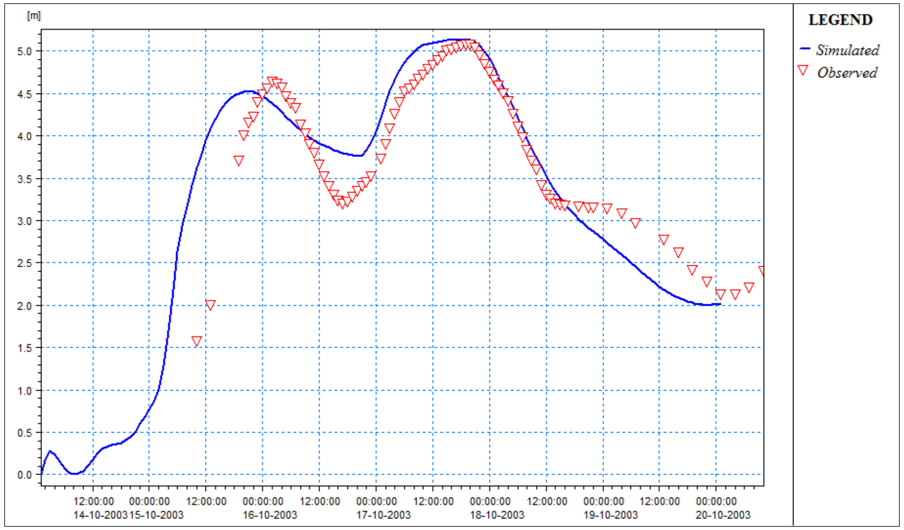


Fig. 16 The observed and simulated water levels for the 2003 flood event in case of the calibration

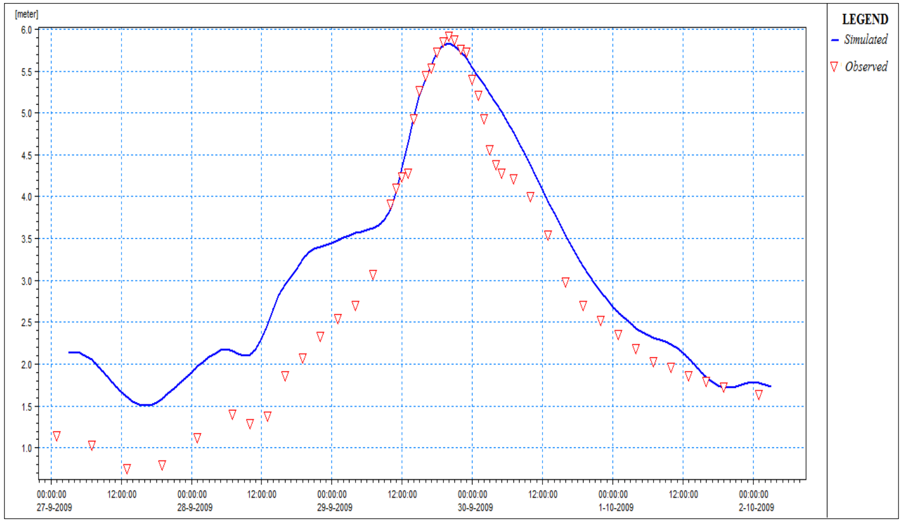


Fig. 17 The observed and simulated water levels for the 2009 flood event in case of the validation

7- Simulations and Results

Simulation of the 2009 flood event- Flood mapping

The flood events from 27th September 2009 to 2nd October 2009, which was one of the extreme floods, were used for flood mapping

No	Communes	2009 flood event	
		Flooded area (Km²)	Proportion (%)
1	Binh Chanh	4.9	10.7
2	Binh Chuong	3.5	7.6
3	Binh Dong	1.4	3.1
4	Binh Duong	6.6	14.4
5	Binh Long	2.0	4.4
6	Binh Minh	1.5	3.3
7	Binh Nguyen	6.2	13.5
8	Binh Phuoc	4.5	9.8
9	Binh Thanh	2.1	4.6
10	Binh Thoi	3.5	7.6
11	Binh Thuan	0.1	0.2
12	Binh Tri	1.2	2.6
13	Binh Trung	7.5	16.4
14	Chau O	0.8	1.7
	Total	45.8	

Table 8. Statistics of flood areas caused by the 2009 flood event

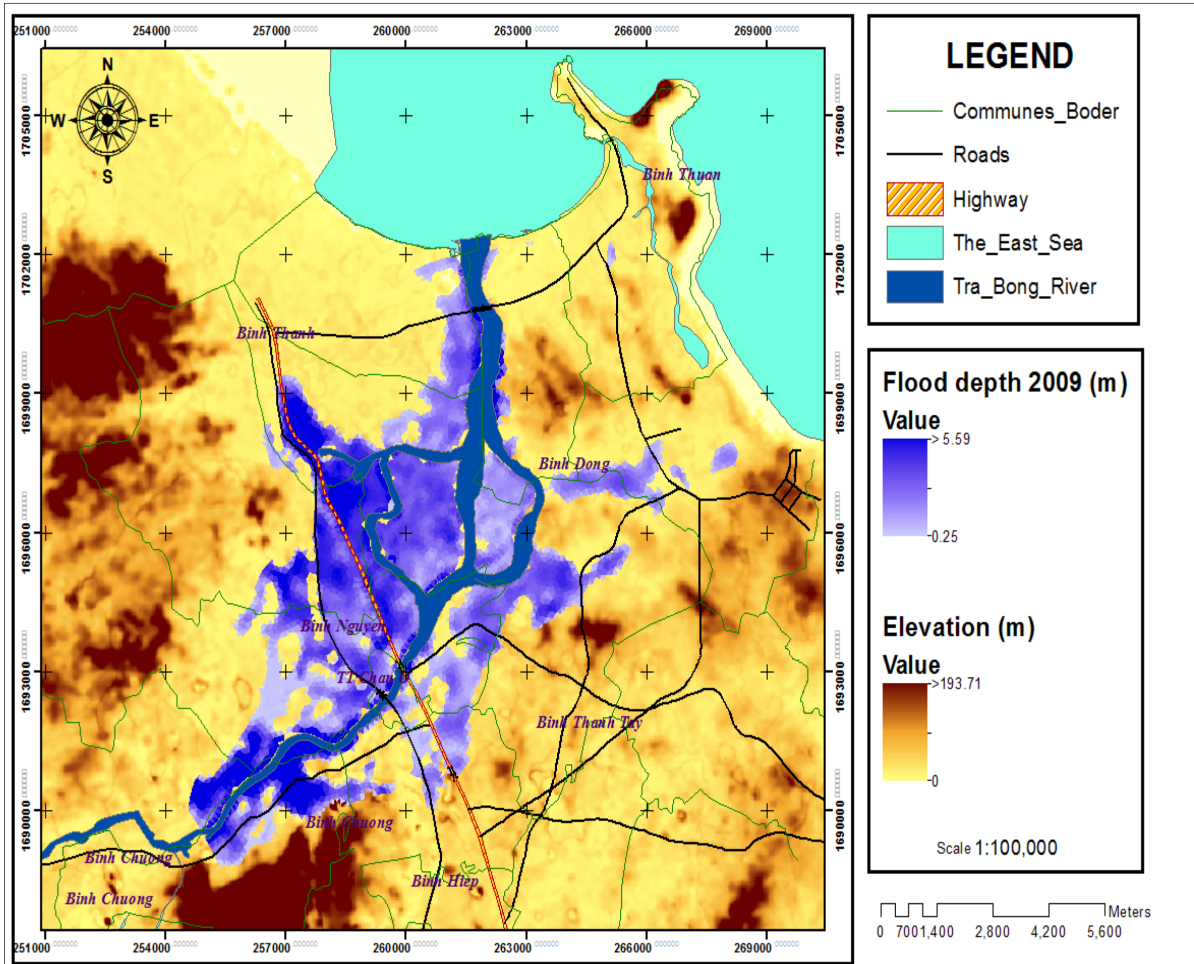


Fig. 18 Visualization of the flooding in the Tra Bong river flood plain at 23:00 9/29/2009

7- Simulations and Results

Simulation of the scenario flood event (100 year return period)- Flood mapping

- Due to lack of available historical records of flood event, **the method of rainfall based** was implemented to carry out the creation of design flood event.
- The design rainfall of 100 year return period was identified by using the **Weibull probability.**

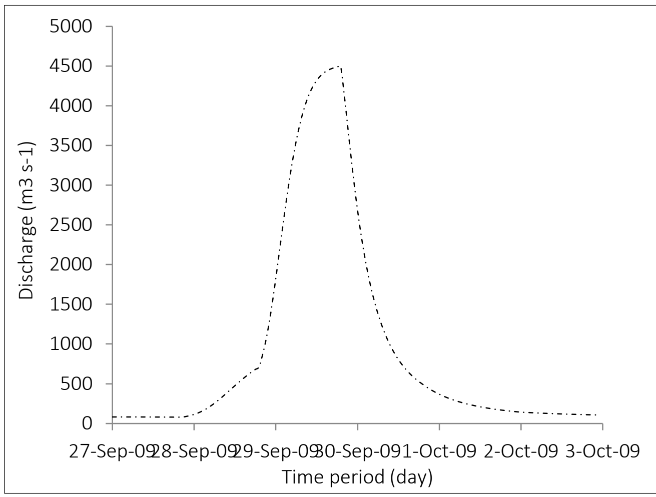


Fig 20: Hydrograph of the design flood

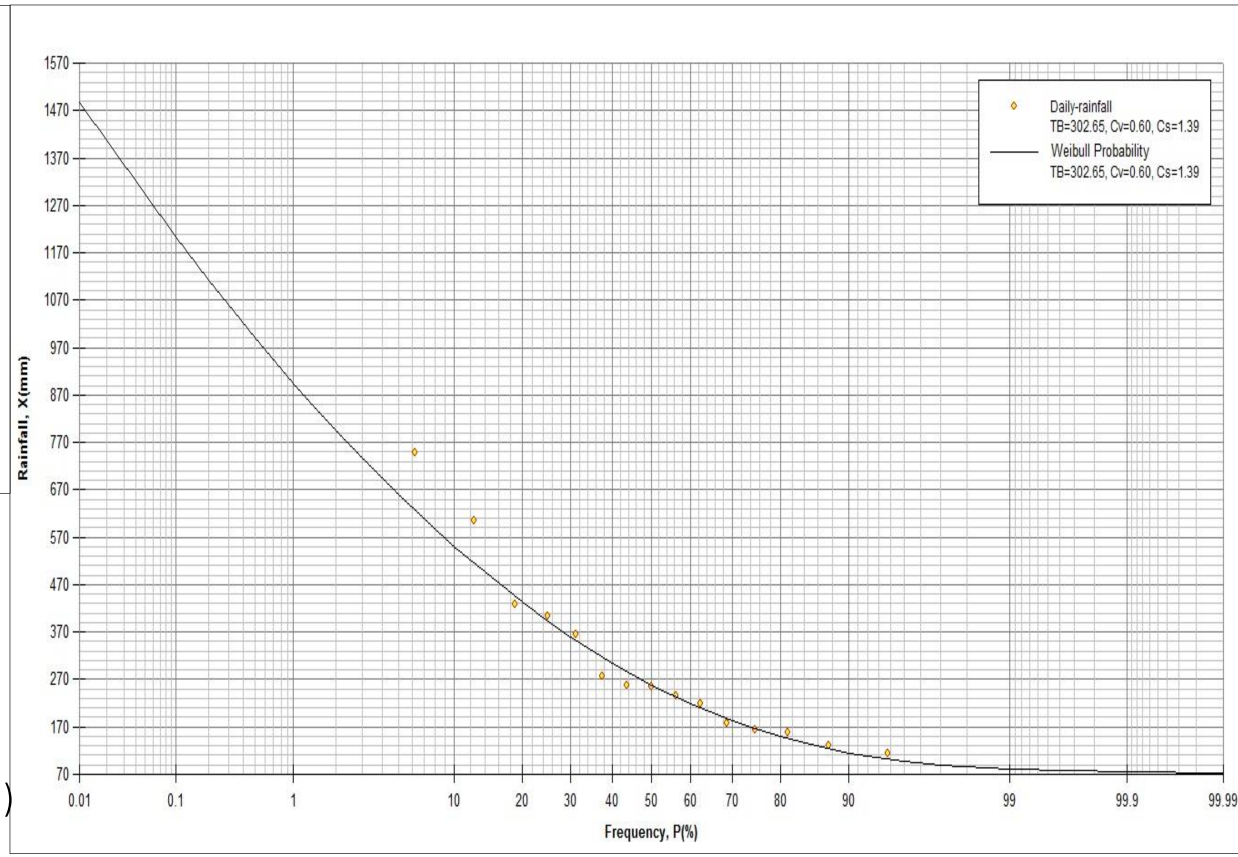


Fig. 19 Frequency curve of maximum daily rainfall

Frequency coefficients

-Cv (dispersion): 0.6

-Cs (Partial): 1.39

-Average daily rainfall: 302 (mm)

-100 year return period rainfall: 700 (mm)

7- Simulations and Results

Simulation of the scenario flood event (100 year return period)- Flood mapping

No	Communes	Design flood	
		Flooded area (Km²)	Proportion (%)
1	**Binh Chanh**	**5.9**	**10.8**
2	Binh Chuong	4.0	7.3
3	Binh Dong	1.6	2.9
4	**Binh Duong**	**7.0**	**12.8**
5	Binh Long	3.2	5.9
6	Binh Minh	1.6	2.9
7	**Binh Nguyen**	**7.3**	**13.4**
8	**Binh Phuoc**	**5.4**	**9.9**
9	Binh Thanh	2.6	4.8
10	Binh Thoi	4.2	7.7
11	Binh Thuan	0.1	0.2
12	Binh Tri	1.6	2.9
13	**Binh Trung**	**9.0**	**16.5**
14	Chau O	1.1	2.0
	Total	54.6	

Table 9. Statistics of flood areas caused by the design flood event

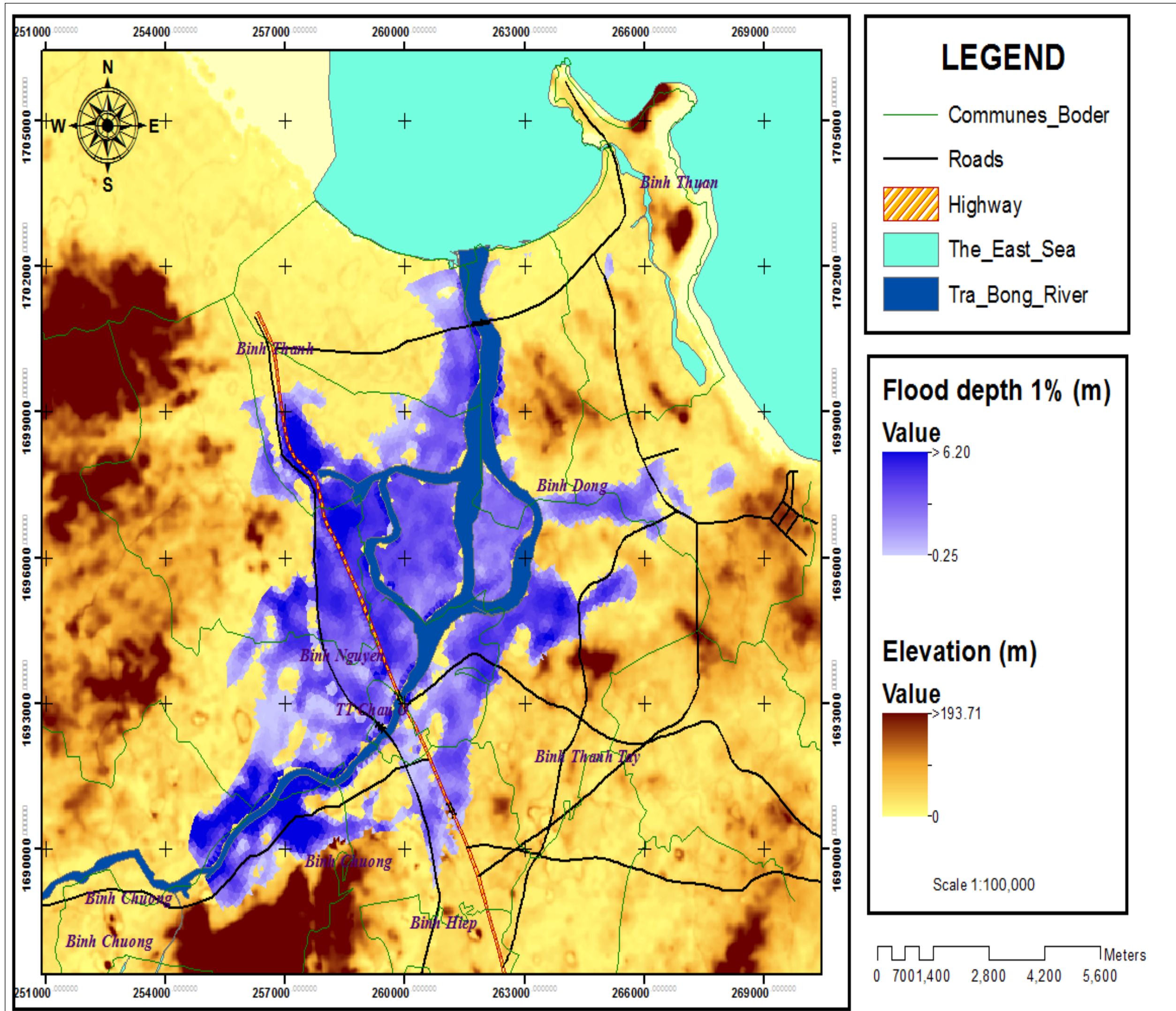


Fig 20: Visualization of flooding in the Tra Bong river flood plain in case of the 1% design flood

8- Conclusions

- *The Tra Bong river basin is an ungauged basin. Therefore, in order to apply several numerical modellings for simulating extreme flood events, many methods are required.*
- *The regionalization method (Physically similarity and Spatial proximity) was significantly used to generate runoff from rainfall. A set of model parameters obtained from donor basin was well applied in the target basin.*
- *The rainfall based method was implemented in order to determine the flood scenario for the ungauged basin.*
- *The hydrodynamic models were successfully applied into the floodplain of the river basin. The calibration and validation of those models were implemented by making a comparison between the observed and simulated hydrographs at the Chau O gauging station. The simulation results show that the model performances are fairly good and acceptable.*
- *The two flooding maps for 2009 and 100 year return period were created. According to the maps, more than 80% of the floodplain area was and would be flooded. Many flooded areas would be under high and very high risk based on the flood depth.*
- *The model performances indicate that flood risk assessment and management can be conducted in this area.*

THANK YOU!