Evaluation of the jont impact of river floods and storm surges on flood risk in an ungauged coastal river basin

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1. Introduction

In coastal river basins, inundation can potentially result from the interaction of several factors such as heavy rainfall-induced river floods, and high storm surges during severe hurricanes, typhoons, or cyclones. In developing countries, many data-scarce and ungauged river basins/coastal river basins are still available. The lack of observed data is a big challenge for modelers as these data are required to validate hydrodynamic models.

In this study, an integrated modelling system was employed and developed to simulate inundation in Tra Bong River Basin, which is considered as an ungauged coastal river basin in Central Vietnam. In the basin, the main stream meanders around 69 km from the west to the east through a high terrain (1,500 m) towards a gulf thus creating the large drainage basin of nearly 700 km^2, in which the delta area is about 270 km^2. The river network density is about 0.43 km/km^2 and the average river slope is approximately 10.9 % (Fig. 1).

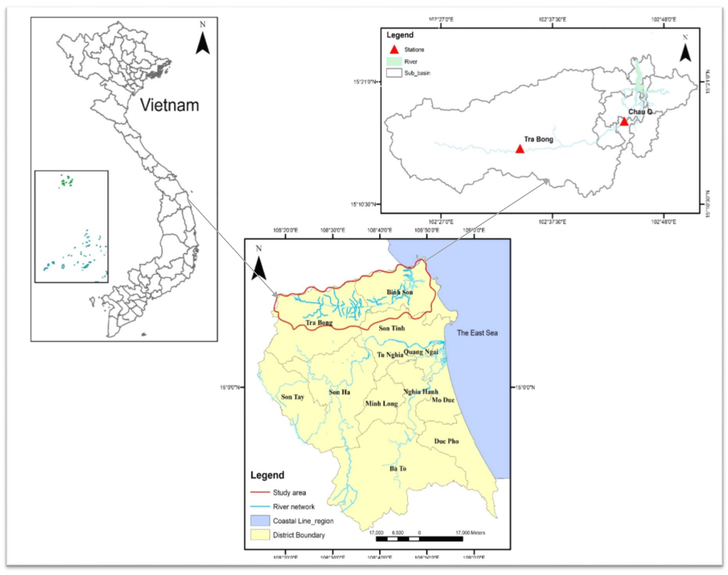

Fig.1 Map of the study area

2. Method and Approach

The below flowchart (Fig. 2) describes the approach of modelling the combined impact of river floods and storm surges induced by typhoons.

Many types of hydrological and hydraulic models have been widely applied in solving water issues in Vietnam, especially, the MIKE model packages have gained popularity lately. The models have been developed by the Danish Hydraulic Institute (DHI). In this work, the rainfall-runoff model MIKE11 NAM and the 1D and 2D hydrodynamic models MIKE11 and MIKE21, as well as the coupling tool MIKE Flood were applied.

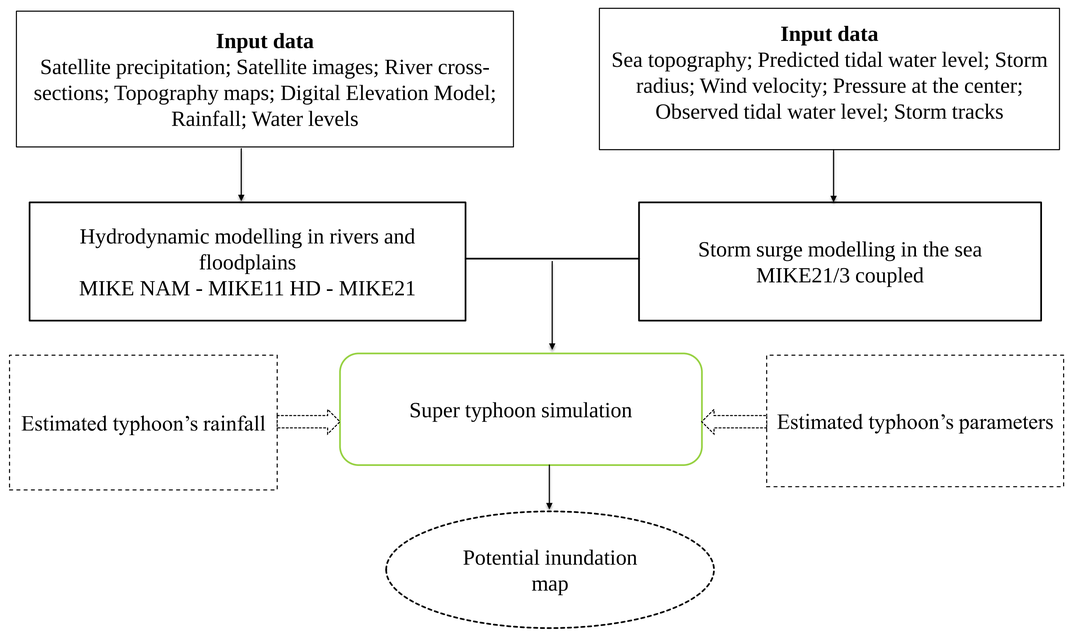

Fig.2 Methodology and approach flowchart

3. Results and discussion

3.1 Storm surges modelling

The model domain was the entire area of the sea (Fig. 3). Due to the lack of observed tidal data in the basin, the model was calibrated and verified against the observed water level at surrounding gauging stations. Two historical typhoons were selected for the processes of model verification including Nari occurred in 2013 and Ketsana occurred in 2009. Fig.3 presents the model domain, wind speed, pressure gradient, and the path (white dots) of Typhoon Ketsana (2009).

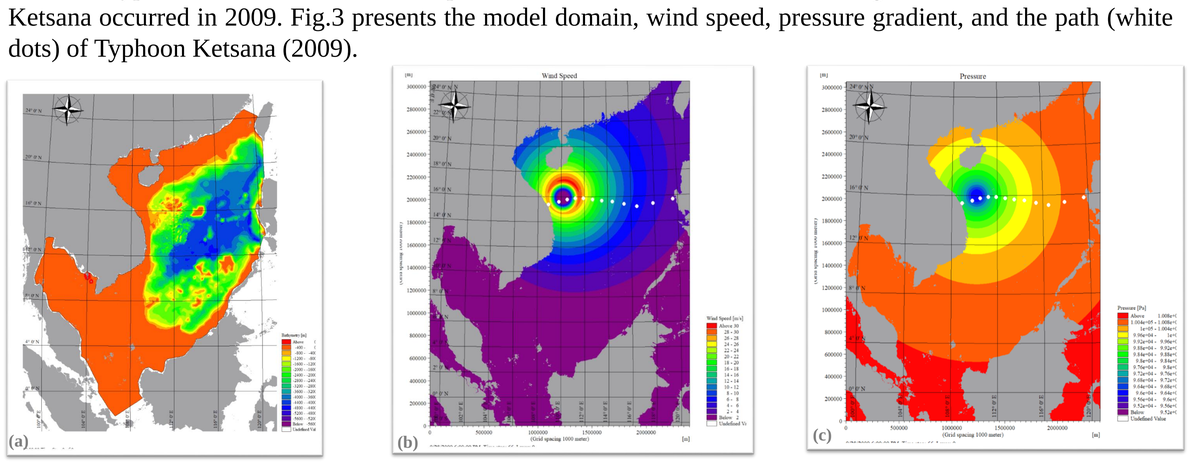

Fig.3 Model domain (a), wind speed (b) and pressure gradient (c) induced by Typhoon Ketsana (2009)

The validated storm surge model was then applied to examine storm surge heights in the past from 1982 to 2017 and computed the maximum surge height for each typhoon. We found that the specific typhoons with direct landfall on the study area always induce severe storm surges. While the other typhoons, which hit the adjacent areas and have perpendicular or parallel paths to the shoreline of the region, also create storm surges but with lower heights.

3.2 River flood modelling

Rainfall-runoff model was used for the simulation of the rainfall-runoff process to generate input data for the 1D and 2D models (Fig. 4). To define the values of the model parameters for the basin, regionalization method was applied. Due to the unavailability of observed rainfall and the coarse resolution of time interval at the rain gauges, the remote sensing precipitation product (CMORPH_CRT) used for the simulations.

Sentinel-1A product including high-resolution images (10 m) of Level-1 Ground Range Detected (GRD was downloaded from Sentinel Data Hub and employed to derive flood extent for flood model calibration.

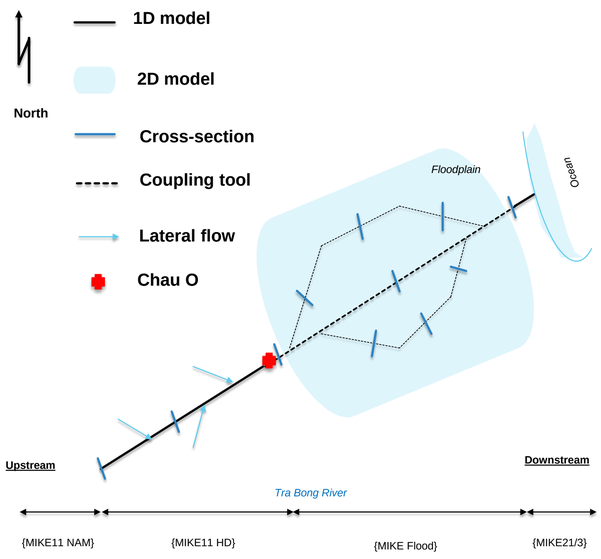

Fig.4 Hydraulic schematization

3.3 Evaluation of combined impacts

Based on the simulation results (Fig. 5a) we found that the combined effect of fluvial floods and storm surges slightly increased up to 10% of the total inundated area as well as the maximum water depth. The river runoff from heavy rainfall is the major factor that mainly induces flood inundation for the study area when occurring the combined impact.

We assumed that a super typhoon or a violent typhoon would occur and have landfall on the study area in the future. The results indicated that the super typhoon would result in more significant inundation in the low-lying areas and along the river banks. The inundation area and the maximum depth for the super typhoon are 71.2 km^2 and 6.5 m. Approximately 80% of the floodplain areas would be inundated from 12 to 48 hours. Some areas in the low-lying part of the floodplains would be flooded above 48 hours (Fig. 5 b,c).

4. Conclusion

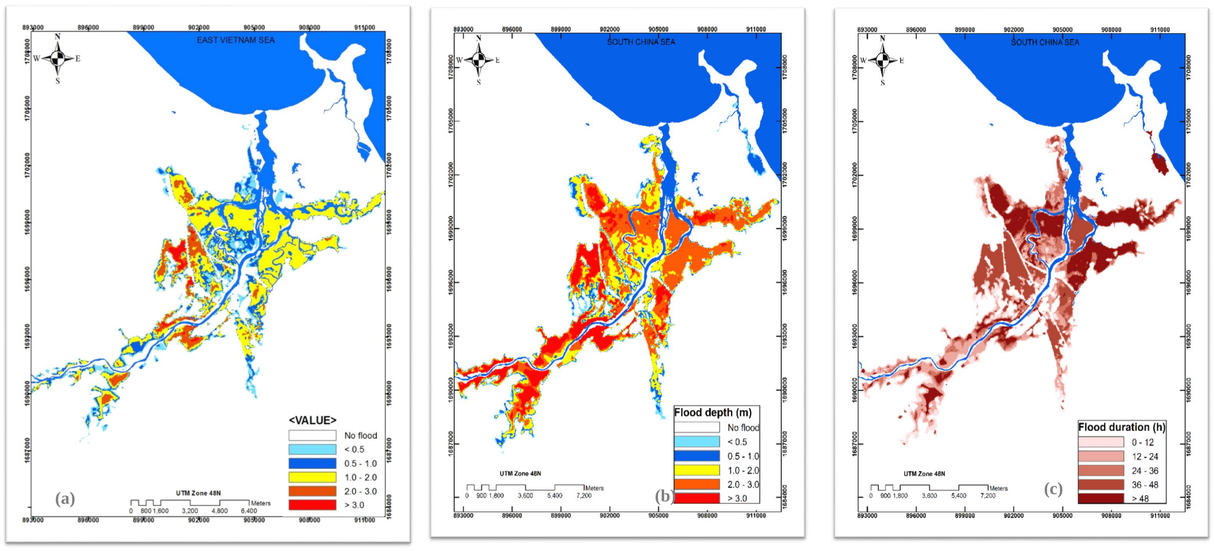

Fig.5 Flood mapping induced by Typhoon Ketsana (a) and super typhoon (b,c)

The modelling system including the rainfall-runoff model, the one-dimensional and two-dimensional models, and the coupled model was sucessfully developed and analyzed to simulate storm surges and fluvial flooding in the rivers, the floodplains, and the sea of the ungauged basin.

The study found that Typhoon Ketsana (2009) generated the maximum height of storm surge (1.31 m) in the past. Typhoons with direct landfall on the river estuary will probably induce the most severe storm surges. The joint effect in case of the super typhoon would properly produce the most extreme inundation for the basin.

The fluvial flooding is the major factor creating inundation in the study basin, while storm surges will enhance flood risk. Thus, joint impacts in such basins need to be considered to avoid underestimation of flood risk.

Sea level rise and the joint probability of fluvial floods and storm surges were not evaluated in this study. Therefore, they need to be understood in future studies to predict more accurately flooding and inundation for the Tra Bong River basin.

5. References and citations

Cuong HD, Thuy NB, Huong N Van, Tien DD .(2017). Assessment of the risk of typhoons and storm surge in coastal areas of Vietnam. Journal of Hydro-Meteorology 12:1–9

DHI .(2011). MIKE11 - A modelling system for Rivers and Channels. Denmark

DHI .(2019a). MIKE 21 Flow Model FM Hydrodynamic and Transport module. Demark

DHI .(2019b.) MIKE Flood- Modelling of River Flooding. Denmark

Trinh, M.X., Molkenthin, F. Flood hazard mapping for data-scarce and ungauged coastal river basins using advanced hydrodynamic models, high temporal-spatial resolution remote sensing precipitation data, and satellite imageries. Nat Hazards 109, 441–469 (2021). https://doi.org/10.1007/s11069-021-04843-1

Makungo R, Odiyo JO, Ndiritu JG, Mwaka B. (2010). Rainfall-runoff modelling approach for ungauged catchments: A case study of Nzhelele River sub-quaternary catchment. Physics and Chemitry of the Earth 35:596–607. https://doi.org/10.1016/j.pce.2010.08.001

Neumann JE, Emanuel KA, Ravela S, et al. (2015). Risks of coastal storm surge and the effect of sea level rise in the Red River delta, Vietnam. Sustainability (Switzerland) 7:6553–6572. https://doi.org/10.3390/su7066553

World Bank and GFDRR. (2017). Vietnam's coastal development between opportunity and disaster risk. https://openknowledge.worldbank.org/handle/10986/34639.

Zellou. B, Rahali H. (2019.) Assessment of the joint impact of extreme rainfall and storm surge on the risk of flooding in a coastal area. Journal of Hydrology 569:647–665. https://doi.org/10.1016/j.jhydrol.2018.12.028

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