VULNERABILITY TO FLOOD IN THE VIETNAMESE MEKONG DELTA: MAPPING AND UNCERTAINTY ASSESSMENT

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ABSTRACT

The Vietnamese Mekong Delta (VMD) is located at the end of the Mekong River, one of the 10th largest rivers in the world. It plays an important role, especially in terms of food security for not only Vietnam but also the world. However, the VMD is projected to be heavily affected by the annual flood, which would be changed in terms of time and spatial distribution after the impact of climate change scenarios (i.e. sharper hydrograph with shorter flood period) and sea level rise. Such combination would result in significant changes of surface water resources, leading to consequent impacts on the existing farming systems in the VMD. Therefore, this paper presents a new approach of integrated aone-dimensional hydrodynamic model (ISIS-1D) with GIS analyses to: (i) identify priority areas for flood adaptation and mitigation; and, (ii) provide an insight to local decision-makers in the VMD in changes of future flood.

1. INTRODUCTION

The Vietnamese Mekong Delta (VMD) islocated at the end of the Mekong River (Figure 1), one of the tenth largest rivers in the world (Liu et al., 2009; MRC, 2010) and flowing through six countries (China, Myanmar, Thailand, Laos, Cambodia and Vietnam) (White, 2002). It provides annually 90% of national rice export (Chu Thai Hoanh et al., 2010; VGSO, 2010) and contributes a significant production from aquaculture for the national and international market (VGSO, 2010). The annual flood is the common natural events in the area and are classified into two types, including: (i) floods caused by the upstream discharge with long flood inundation from 2 to 6 months(ranging from July to December; Nguyễn Sinh Huy et al., 2001; Lê Sâm, 2003; Le Anh Tuan et al., 2008; MRC, 2009a; MRCS, 2009; and, (ii) tidal-induced flood driven by tidal regimes in the East and West Sea (Le Thi Tam Thien, 1999). During the flood season, water enters the VMD via the main river reaches (the Mekong and Bassac) and overflows across the Vietnam-Cambodia border (Nguyễn Sinh Huy et al., 2001; Nguyễn Tất Đắc, 2005). According to Le Thi Tam Thien (1999), the causes of flood include: (i) Flood discharge from the upstream; (ii) Local heavy rainfall (driven by monsoon or typhoons); and, (iii) High tide in the East and West Sea. The annual flood brings significant benefits to the VMD. During the flood season, the annual flood conveys about 9 to 13 tons of sediment and a large amount fish (in average, about 475.73 tons) with about 1,200 fish species in total (WB, 2004). In specific, the 2000-flood brought about 1.86 million tons of fish (approximately 2,600 million USD). Besides, annual flood plays an important role for wetland protection and biodiversity conservation (MRC, 2009a). However, such the flood also causes negative impacts on the daily life activities of local residents (e.g. losses of life and properties). For example, the 2000-flood damaged approximately 250 million USD in total.With the impacts of the global climate change, the local hydrological conditions are projected to be significantly changed, leading to a requirement of vulnerability assessment to define priority areas for flood mitigation and adaptation.

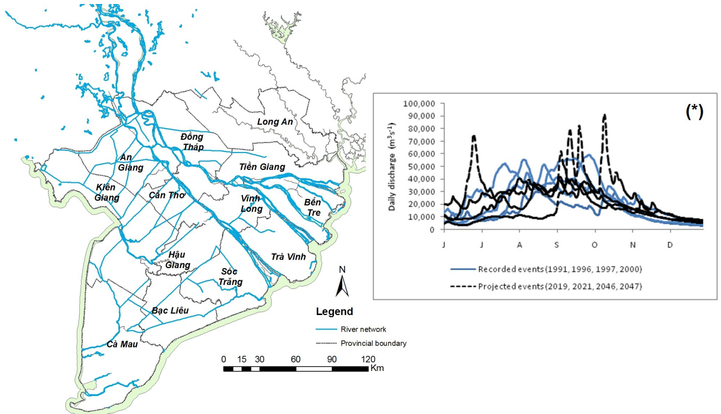

Figure 1. The Vietnamese Mekong Delta; (*) Measured and projected daily discharge in Kratie, Cambodia.

2. METHODS

2.1 Hazard maps

Flood hazard is categorized based on the level of difficulties in daily life and/or damage of properties (Tingsanchali and Karim, 2005). According to Chowdhury and Karim (1996), the hazards mapswere created after the flood depth(Table 1). Two specific days were chosen to create inundated maps, including:(i) the peak flood time based on the greatest measured stages atTan Chau and Chau Doc; and, (ii) the largest flood extentbased on the greatest measured stage in Can Tho and My Thuan.

Table 1. Classification of flood hazards

Water depth (m)	Hazard ranking	Hazard category
0-0.2	0-0.04	Very low
0.2-0.5	0.04-0.1	Low
0.5-1.0	0.1-0.2	Medium
1.0-2.0	0.2-0.4	High
>2.0	0.4-1	Very high

There were two scenarios for the future flood (in 2050) developed according to the projected entry discharge (at Kratie) and sea level rise. The later was the projected sea level rise (increase up to 30cm of scenario B2 for the both East and West sea with reference to that in 2000) while the former was the projected upstream discharge in Kratie (Scenario 1: Discharge projected according to the adjusted regional climate model without any development in the Upper Mekong Basin; Scenario 2: Discharge projected as in Scenario 1 but with the development of the Upper Mekong Basin after 2020).

2.2 Vulnerability

a. Indicators

The *Coastal City Flood Vulnerability Index* (based on exposure, susceptibility and resilience to coastal flooding indicators) (Sullivan, 2002; Sullivan and Meigh, 2005; Balica and Wright, 2010; Balica et al., 2012) were modified and applied to meet the actual conditions of the VMD with the deletion of unsuitable indicators (*e.g.* storage capacity).

b. *Calculation of vulnerability:*

The indicator values were standardized after Equation 1 and 2 for the positive and negative impacts, respectively. The standardized indicators were multiplied with weights (ranging from 1 to 10) of each indicator based on their importance to vulnerability in the VMD condition (according to the publications and local reports). All indicators of one component were then summed up to identify vulnerability of that component. Finally, the vulnerability was calculated according to Equation 3.

$$x_{standardised} = {x_i}/{x_{max}} \tag{1}$$

$$x_{standardised} = 1 - {x_i}/{x_{max}} \quad (2)$$

$$Vulnerability = Exposure + Susceptibility - Resilience \quad (3)$$

2.3 Risk and uncertainty assessment

According to UN (1991) risk value was calculated according to Equation 4,where 0 and 1 are categorised as the lowest and highest, accordingly corresponding to very low, low, medium, high and very high risk.Vulnerability uncertainty assessment was done by adjusting the applied weight (within the range of weight ±1).

$$Risk = Vulnerability * Hazard \quad (4)$$

3. RESULTS

3.1. Simulated flood

Figure 2presents the stages at Tan Chau, Chau Doc, My Thuan and Can Tho from Sept. 15th to Oct. 15th. The greatest stage in Tan Chau and Chau Doc appeared on Sept 23rd (Figure 3a) while such the greatest in Can Tho and My Thuan appeared on Sept. 28th(Figure 3b).

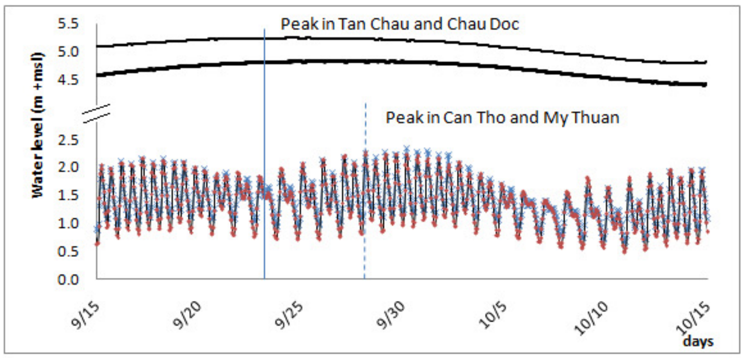

Figure 2. Simulated stages at Can Tho, My Thuan, Chau Doc and Tan Chau.

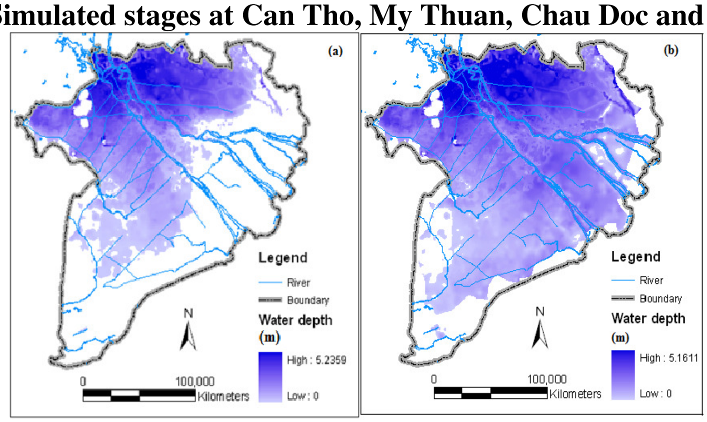

Figure 3.Inundated map at the peak flood (a) and greatest inundated area (b) in the VMD.

3.2. Hazard map

The hazard maps of flood in 2000 are shown in Figure 4. Despite peak flood time, impacted area was not the greatest (Figure 4a). Flood hazard covered about 48% total VMD area, including very low, low, medium, high, and very high hazard area (7.89%, 5.71%, 8.77%, 12.93%, and 12.71%, respectively). The high and very high hazard were mainly concentrated in the upstream, while there was improbable hazard in the coastal area. On the other hand, the medium, high, and very high hazard areas did not only increase in the upstream, but also in the coastal areas when the flood was expanded largest (Figure 4b). The influenced area were 5.98%, 12.67%, 17.84%, 25.84%, and 14.29% of total VMD area, accounted for very low, low, medium, high, and very high, respectively.

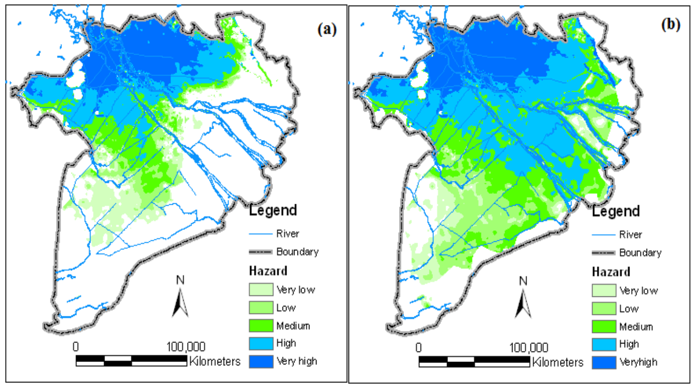

Figure 4. Hazard maps at the peak flood (a) and greatest inundated area (b).

In 2050, simulated peak flood would appear on 16/10/2050 and the flood extension would be largest in the following days. As the flood dynamics were not significantly different between the two scenarios, Figure 5 presents hazard maps of the peak flood and at the greatest extend of Scenario 1 only.At the peak flood, the hazard area would cover 60.38% of total VMD area which includethe very low, low, medium, high and very high hazard corresponding to 7.52%, 15.31%, 16.15%, 16.83%, and 4.58% of total area, respectively. The high and very high hazard would alsoconcentrate the upstream.Similarly, in scenario 2 the peak flood and largest flood extension would also appear on the same day to Scenario1. The hazard area was 59.68% of the VMD area. Particularly flood hazard would expand to the Ca Mau Peninsula.

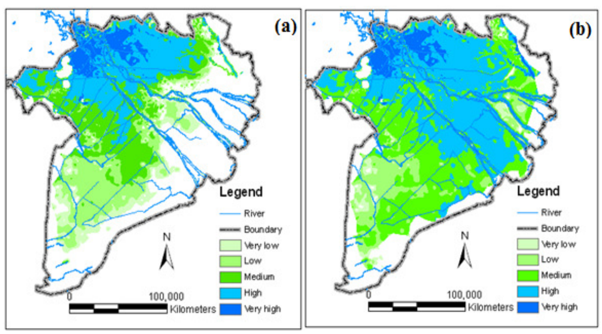

Figure 5. Hazard maps inScenario 1at the peak flood(a) and greatest flood extent in the VMD.

In comparison tothe flood in 2000, hazard areas would increase about 12.39% and 11.68% in Scenario 1 and Scenario 2, respectively. Although hazard areas would increase, very high hazard area would decrease. That could be explained by decreasing of upstream discharge. The most remained hazard ranking increased and hazard would extend to the Ca Mau Peninsula in the both scenarios because of sea level rise. At the greatest flood extent in the future, the hazard area would cover 81.45% and 79.21% (about 32,016.12 km^2 and 31,136.36 km^2) of the VMD in the Scenario 1 and Scenario 2, respectively.The high flood hazard did not only concentrate in the upstream but also in the downstream with about 30% area of the VMD.

3.3. Vulnerability

In the hydro-geological component, Soc Trang province would be most exposed to floods. That can be explained by length of coastal line, sea level rise, and large river discharge. Other coastal provinces (Ca Mau, Ben Tre, Tra Vinh and Tien Giang) would be directly affected by sea level rise. The An Giang and Dong Thap provinces were the two least affected provinces because they are far the sea leading to less impact by sea level rise and cyclones from the sea.There are insignificant differences among provinces because they located in the VMD; they have similar points such as cultural heritage, unemployment and population density. The Kien Giang, An Giang, Dong Thap, and Long An provinces were less than the others because they have good awareness for adaptation to the annual flood. The Bac Lieu province is most vulnerable to flood because of high population growing and length of drainage. Following vulnerable provinces are Can Tho and Soc Trang which also have length of drainage and less ratio of investment over the total gross domestic product. The least vulnerable province is Ben Tre because they have low population growing.

The integrated CCFVI is presented inFigure 6.Among other provinces, SocTrang province was the most vulnerable to flood because of exposure to hydro-geological factor such as large river discharge, length of coastal line. After Soc Trang, the high vulnerable provinces were Bac Lieu, Tien Giang, Tra Vinh, Ben Tre, and Ca Mau where with the existence of coast line, the impacts from sea level rise, storm surge from the East Sea was projected to be more severe. Moreover, they had little impacts (if not any) by the annual flood, so they would not have experiences for flood adaptation and mitigation. In contrast, An Giang and Dong Thap were heavily affected by annual flood in the VMD; therefore, with available experiences, they would be ableto adapt and mitigate the annual flood impacts. Additionally, they are far the sea (both East and West Sea), so they would be less affected than coastal provinces by sea level rise.

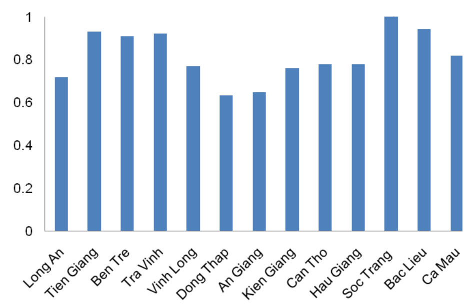

Figure 6. Integrated CCFVI of each provincein the VMD in 2000.

3.3 Risk mapping

As the flood dynamics generated for Scenario 1 and 2 were not significantly different, Figure 7 only presents the risk map of scenario 1 at the peak and the greatest flood extent. At the flood peak, the percentages of flood risk are 60.37% and 59.67% area of the VMD in Scenario 1 and 2 respectively; particularly, high risk contributed the most part. When the flood expanded largest the flood risk would be covered seemly whole the VMD. The high category of flood risk would concentrate along the Mekong and Bassac River (from the upstream to the sea). However, Tra Vinh province is needed to focus on because it had high risk to flood while it had little awareness for flood adaptation and mitigation. Besides, flood risk would also concentrate the Ca Mau Peninsula where is affected by complex interaction between East and West Sea.

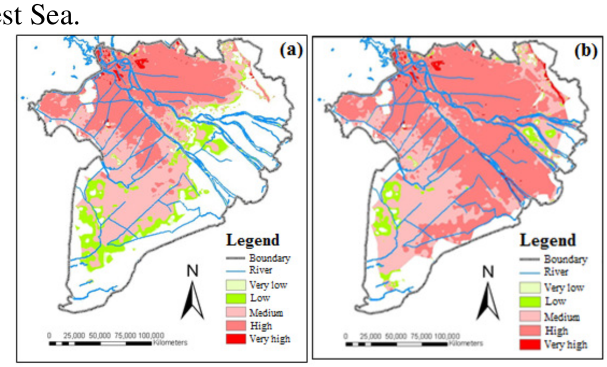

Figure 7. Risk maps of scenario 1at the peak flood(a) and greatest flood extent (b) in the VMD.

3.4 Uncertainty

The based-results of flood vulnerability were used to compare with the changes of vulnerability values (Figure 8a). Figure 8b illustrates the range of vulnerability by province after the changes of assigned weight. Soc Trang, Bac Lieu, Tien Giang, Tra Vinh and Ben Tre were considered to be highly vulnerable, while An Giang and Dong Thap were of the low vulnerability values. In comparison to based-result, there is a similar point. Although there are the changes of flood vulnerability, Soc Trang also had the highest values.

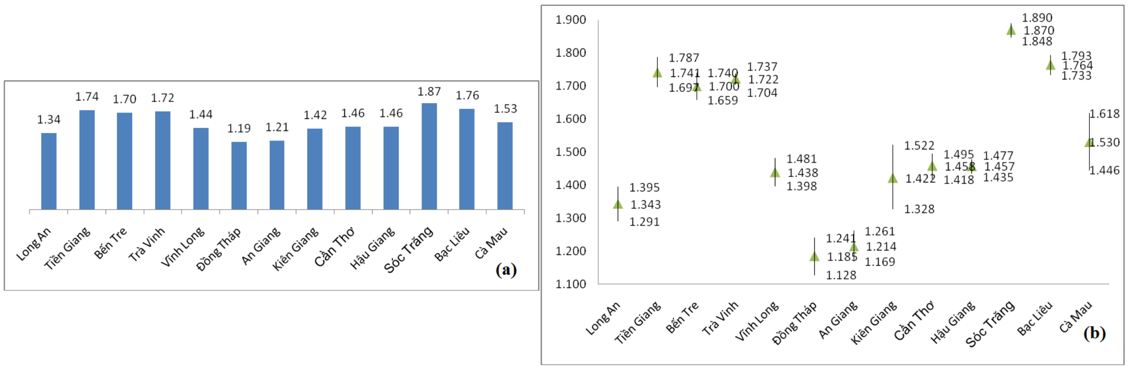

Figure 8. Calculated vulnerability of the VMD (a) and range of flood vulnerability (by province) after the changes of assigned weight (b).

4. CONCLUSIONS AND RECOMENDATIONS

The hazard in 2050 would increase, especially in the downstream of VMD due to the projected sea level rise. Results of the study would help local stakeholders and decision-makersunderstand what might be happening in the future in terms of hydrological, social and economic components as well as vulnerability of each province. The obtained results should shed light on locating areas that need specific attention for a detailed study in the future.

The coastal area, especially along the East Sea,was projected to be highly affected due to the hydrological changes while less awareness for flood mitigation and adaptation.Therefore, future researchis required to improve the indicators to better suit the VMD conditions and detailed study should be done to meet specific to local conditions.

Finally, the study paid great attention to the magnitude of flood and its impacts but did not take into account the timing distribution of flood dynamics. Such the dynamics which may have great impacts on the agri- aquaculture activities of the local residents should be studied in more details in the coming future.

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