MAPPING ENVIRONMENTAL RISKS - QUANTITATIVE AND SPATIAL MODELLING APPROACHES

Flood impact in the Mekong Delta, Vietnam

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The Vietnamese Mekong Delta (VMD) has an important role in terms of food security and socio-economic development of the region. The VMD is a densely populated area and is a social and economic hotspot for coastal hazard risks and vulnerability. The amount of people exposed to flooding, storm surges and seasonal river floods in VMD is estimated to increase as the sea level rises, land-use changes and urbanization in flood-prone areas is growing. Therefore, it is necessary to focus on assessing and mapping flood hazard, risk and vulnerability of the Mekong delta. There are many flood hazard and risk studies carried out in the VMD, however very little is done with respect to vulnerability. The region is facing a rapid economic growth and vulnerability to floods becomes an important issue to be addressed.

The study presented here focuses on mapping of the vulnerability of the VMD, based on the situation in the area and on the available data. The study evaluates the VMD districts from vulnerability point of view and presents maps, which will be helpful to the decision makers who need to take measures on how to reduce and mitigate the flood impact in the area. Collaboration between deltas’ administrations, multiple stakeholders and organizations, at national and international level (delta alliances), has to be undertaken to support the most vulnerable areas and to learn from each other. Mapping vulnerability offers the opportunity to get a broad overview on affected areas and on possible adaptation options that could be applied, directing resources at more in-depth investigation of the most promising adaptation strategies. Moreover, at a later stage, it can also serve to evaluate the effectiveness of the adaptation measures.

The present study presents a map of flood vulnerability for the VMD for the years 2000 and 2050 (see Main Map). The map is created by applying Coastal Cities Flood Vulnerability Index (CCFVI) methodology; the flood map will overlay flood hazard in order to create flood risk maps using tools such as ArcGIS.

\textbf{Keywords:} Mekong; delta; vulnerability; hazard; risk; floods

1. Introduction

Worldwide, due to climate change and an increased spread of human settlement and development activities, delta areas are vulnerable to flood hazards (Centre for Research on the Epidemiology of
This increasingly likely hazard has created a growing need to inform the decision makers, deltas’ administrations, multiple stakeholders and organizations, at national and international level (delta alliances), about their current flood vulnerability in order to help and facilitate them in the process of taking measures on how to reduce and mitigate flood impact. Deltas are biologically rich and diverse systems with waterflows, fish and vegetation, and they support a large economic system based on tourism, agriculture, hunting, fishing, harbor and industry development (Prakasa and Murty, 2005). Deltas can be seen as a set of interconnecting subsystems; the subsystem is composed of interacting elements where different processes are carried out using various types of resources. The subsystems which characterized deltas are reflected by its elements, and it is surrounded within its own environment. The natural subsystem refers to the physical, chemical and biological processes which are taking place into the deltas; the socio-economic subsystem includes the societal (human) activities related to the use of the natural delta system.

Therefore there is a growing need not only to revisit the knowledge base of coastal areas but also the flood risk and vulnerability in general in order to gain a better understanding of all interaction between systems. The gained insight should help to contribute to appropriate decision making for the local administration for better flood management.

To date, many studies and models have been developed to assess the extent of past floods in different areas in the world (Gichamo, Popescu, Jonoski, & Solomatine, 2012; Hartanto, Beevers, Popescu, & Wright, 2011; Kafle, Hazarika, Shrestha, Prathumchai, & Samarakoon, 2006; Moya Quiroga, Popescu, Solomatine, & Bociort, 2012; Popescu, Jonoski, van Andrei, Onyari, & Moya Quiroga, 2010), and consequently many studies have been conducted in the VMD as well (Hoanh, Jirayoot, Lacombe, & Srinetr, 2010; Johnston & Kummu, 2011). However, there are only few studies that assess the hazard, vulnerability and risk of floods resulting from Sea Level Rise (SLR) due to climate changes. Wassmann, Nguyen, Chu, and To (2004) and Dinh, Balica, Popescu, and Jonoski (2012) developed flood vulnerability maps under SLR scenarios in some parts of the VMD, but not for the whole VMD area. Flood risk management in a restricted sense is the procedure of managing an existing flood risk situation (Plate, 2002), and in a broader sense, it includes the planning of a system, which will reduce the flood risk. The characteristics of flood risk management include complexity, large spatial scales, inter-temporal issues, plural values and conflicts of interests. With regard to natural disasters, risk is described as the probability that natural events of a given magnitude and associated with a given loss will occur. Therefore, risk encompasses two aspects: hazard and vulnerability (Merz, Thieken, & Gocht, 2007) and is described as follows:

\[
\text{Floodrisk} = f(\text{floodhazard}; \text{vulnerability})
\]

The probability of the occurrence of potentially damaging flood events is called flood hazard (Messner & Meyer, 2006). Potentially damaging means that there are elements exposed to floods which may be harmed. Vulnerability is considered as defined by Balica and Wright (2010) to be ‘the extent to which a system is susceptible to floods due to exposure, a perturbation, in conjunction with its ability (or inability) to cope, recover, or basically adapt’.

2. Calculating flood vulnerability

Currently, there is a need for a readily calculated and easily understood method to calculate flood vulnerability in deltas and coastal areas. The CCFVI can be used to identify the most vulnerable delta zones, develop adaptation measures for them and assess the effects of future change scenarios. Up to present, all methods to map flood vulnerability are using indicators-based
methodology. The first step in an indicator-based vulnerability assessment is to select appropriate indicators. Since the development of the CCFVI involves the understanding of different relational situations and characteristics of a coastal system exposed to flood risks, a deductive approach to identify the best possible indicators has to be used, based on existing principles and the conceptual framework of vulnerability.

For mapping vulnerability to flooding in the VMD, a survey of the literature identified a range of factors that are relevant to developing socio-economic and physical vulnerability indicators. Indicators ranged from age and gender, social status, income, geographic location, education, health status and special needs, and household arrangement. Some indices are described in more detail below.

The first coastal vulnerability index (CVI) was developed by Gornitz (1990). In this index the six variables are related in a measurable way that manifests the relative vulnerability of the shore to physical changes due to sea-level rise (Dinh et al., 2012). This technique emphasizes areas where the diverse effects of sea-level rise may be at the peak; the Sensitivity Index (SI), developed in particular for Ireland, and Erosion Hazard Index. The coastal vulnerability index (CVI) is computed as the square root of the multiplication of the ranked variables divided by the total number of variables. The vulnerability classification is based upon the relative contributions and interactions of the six risk variables: geomorphology; shoreline erosion/accretion rate; coastal slope; elative sea-level rise rate; mean wave height; and mean tide range. The CVI ranges (from low (0–0.25) to very high (0.75–1.00)), each computed value falls into the relevant quartile and the coastal region is then characterized accordingly.

A multi-scale coastal vulnerability index developed by McLaughlin and Cooper (2010) uses a function of the ‘physical nature of the coast (which controls its ability to respond to perturbation), the nature (frequency and magnitude) of the perturbation (the forcing factor) and the degree to which such changes impact on human activities or property’. The coastal vulnerability can then be shown by using three elements and 17 variables, 7 for coastal characteristics (solid and drift geology, shoreline type, river mouths, elevation, orientation, inland buffer), 4 for coastal forcing (significant wave height, tidal range, difference in storm and modal wave height, storm, frequency) and 6 for socio-economic factors (population, cultural heritage, roads, land use, railways and conservation status). Vulnerability is a function of coastal characteristics (resilience and susceptibility); coastal forcing and socio-economic factors. The total CVI is computed as a summed up of the three components and then divided by 3. The values are presented between a range of 1 to 5, where 5 represents strong contribution to vulnerability and 1 the least contribution. Balica, Wright, and van der Meulen (2012) developed a Flood Vulnerability Index methodology, now applied to coastal cities, based on three factors of vulnerability: exposure, susceptibility and resilience; these factors are interlinked with the three components: hydro-geological (sea level rise, storm surge, number of cyclones, river discharge, foreshore slope, soil subsidence, coastal line), socio-economic (cultural heritage, population close to coastal line, growing coastal population, shelters, awareness/preparedness, disable people, km of drainage, recovery time) and politico-administrative (uncontrolled planning zones, flood hazard maps, institutional organizations and flood protection). Pethick and Crooks (2000) proposed ‘a simple and preliminary’ coastal vulnerability index relating to relaxation time over the return interval. Eight different types of shoreline where used cliffs, beaches, sand dunes, mudflats, spits, salt marshes, estuaries and shingle ridges. A coastal vulnerability index build up from different coastal forms gives a first-order suggestion of the sensitivity of the landform to slight changes in its environment.

Mapping vulnerability will help to better understand risk and its perception. In order to show the applicability of the technique, the past flood of the year 2000 is simulated and used for map representation of the flood extent in the area. The thematic maps are classified according to the calculated flood vulnerability. Flood hazard is computed by modeling water levels of the flood
recorded in the year 2000 and then overlaying the two, flood vulnerability and flood hazard, to map flood risk using GIS techniques.

3. Study area

Mekong River is one of the greatest rivers in Asia, which is one of the 12th longest rivers of the world (Mekong River Commission, 2009), flowing through six countries: China, Myanmar, Thailand, Laos, Cambodia and Vietnam (White et al., 2005). The source of the Mekong River is located in the snow-capped Tibetan mountains. The Mekong River has a total length of 4,800 km, draining an area of 795,000 km² and discharging 135,475 km³ of water annually. The Mekong Delta begins in the city of Phnom Penh, where the river divides into its two main distributaries, the Mekong and the Bassac. The Mekong then divides into six main channels and the Bassac into three to form the ‘Nine Dragons’ of the outer delta in Viet Nam (Dac, 2005; Huy & Toan, 2010). The main delta is made up of a vast triangular plain which is lower than five meters above sea level, large areas of which are flooded every year. Two-third of the Mekong Delta is situated in the southern part Vietnam (3.9 million ha) and one third in Cambodia (1.6 million ha), (ASEAN Regional Center for Biodiversity Conservation, 2012), (see Figure 1).

VMD is one of the most productive and intensely cultivated areas in Asia. The VMD consists of 13 provinces with 105 districts and 21 urban areas, which cover an area of 40,500 km²; constituting 12.1% of whole country’s area (General Statistics Office of Vietnam, 2010). Vietnam is a major producer of rice and contributes 22 million tons (60%) to world rice production. The VMD is Vietnam’s rice bowl and accounts for 90% of the country’s rice exports (General Statistics Office of Vietnam, 2010; Hoanh et al., 2010). Within the delta which is dominated by rice, nowadays the farming system also includes activities related to aquaculture, such as fish, crustaceans, molluscs and aquatic plants, but also rearing of animals, inland fisheries, cash crops and fruit trees. Fresh and saline water shrimp are raised within the paddy rice fields (Devendra & Gardiner, 1995). In 2008, the area of aquaculture product was 0.75 million ha, contributing to 71% of the total area of VMD and provides 59% of the demands of Vietnam (General Statistics Office of Vietnam, 2010).

Figure 1. Location of the study area.
The VMD experiences a monsoonal climate, with the seasonal precipitation as the primary source for river runoff. The wet season lasts from mid May to October, and accounts for over 90% of annual precipitation in the area (Kingston, Thompson, & Kite, 2011). Peak river flow at the head of the delta (Phnom Penh) usually occurs in September or October, with the high flow season extending from June to November. Annual minimum flows occur in March or April. Flooding is a major problem of the VMD and severely affects the region. There are two types of flooding that are affecting the VMD: first type causes floods from the upstream Mekong Delta, which are long time flood inundation (from 2 to 6 months) (Mekong River Commission, 2010) and second type is the tidal-induced flood triggered by the tidal regimes in the East and West Sea. Large parts of the delta are flooded in the wet season, forming the Plain of Reeds. The discharge of the Mekong river at the most upstream point of the delta varies from 2100 to 40,000 m³/s occurring on April and December, with a peak in September (Hoa, Nhan, Wolanski, Tran, & Haruyama, 2007).

4. Methodology

This research focuses on mapping flood vulnerability of the VMD. A sequence of steps needs to be followed in order to map the vulnerability of floods (See Figure 2).

Firstly, in order to map flood hazard, a 1D-hydrodynamic model (ISIS) was used to simulate the 2000 flood extent of the VMD. The ISIS 1D software is used to simulate the water levels and the depth of flooding in the area along the distributary channels of the VMD. The 1D model used for determining the flood extent in the VMD area has limitations, such as the difficulty to determine flow velocity, duration of flooding and rate of water rise for the overland flow. However, the flood flow velocity and the rate of water rise are normally low over the study area. The region is quite flat terrain, mostly of average height of 0.7 to 1.2 m, except for the mountainous area in the Northwest and along the coast (2003 Digital Terrain Model of the Mekong delta). Along the

![Figure 2. Mapping the impact of floods in Vietnamese Mekong Delta methodology.](image-url)
Cambodian border, the terrain is highest, from 2.0 to 4.0 m above sea level, then lower to the central plains, from 1.0 to 1.5 m high, and 185 only 0.3 to 0.7 m in the tidal and coastal areas. The slope of the region is less than 2%.

The present study only considers flood depth as the hazard indicator. The flood hazard map developed divides the study area into cells (that are inundated) using a uniform grid, (100 m × 100 m) and records the hazard for each cell, based on its flood depth. Digital Elevation Model (DEM) with the resolution 100 m × 100 m of the Vietnamese Mekong Delta has been obtained from Mekong River Commission Secretariat (MRCS). The hazard zone scale is made by transforming the interval of flood depth into an interval from 0 to 1.

**The maps** (see Main Map) show clearly the spatial distribution of the flood hazard (low, medium, high and very high hazard regions) to the affected people and decision makers (Merz et al., 2007). **The maps** can be used for flood control and floodplain management. By applying the before mentioned method the flood hazard maps for the flood event of the year 2000, were created, using the well-known GIS software, the ArcGIS of ESRI. The resulting flood depth of the simulation was used to prepare inundation maps and to analyze flood hazard in the region. Flood hazard classification into five categories (very low, low, medium, high and very high), as defined by Tingsanchali and Karim (2005), is used in order to determine the hazard of a computational cell. The ranges for the classification are shown in Table 1. Secondly, in order to map flood vulnerability, CCFVI method (Balica et al., 2012) was applied for the VMD for the year 2000. CCFVI is an indicators based-methodology. The index can be used to identify the most vulnerable coastal areas, develop adaptation measures for them and assess the effects of future change scenarios. The methodology, in principle, involves two concepts. First, vulnerability, which covers three related concepts called factors of vulnerability: exposure, susceptibility and resilience. The other concept concerns the actual flooding; understanding which elements of a system is suffering from this natural disaster. Four main components of a system are recognized which are affected by flooding: socio-economic and hydro-geological components. The methodology recognizes different characteristics for deltaic areas, allowing a more in depth analysis and interpretation of local indicators.

| Flood Depth (m) | Hazard Ranking | Definition of Hazard Zone |
|-----------------|----------------|--------------------------|
| 0.0–0.2         | 0.0–0.04       | This is the case in which the damage to property is expected to be very low |
| 0.2–0.5         | 0.04–0.1       | This is the case in which the number of causalities due to floods, in terms of death or injuries, is insignificant, and the damage to property is expected to be relatively low. Moreover, in this case vehicles movement are affected, but wading is safe. |
| 0.5–1.0         | 0.1–0.2        | This is the case in which causalities, in terms of death and injuries, are considerable, relatively to the number of people leaving in the area under study. Moreover the property damage is expected to be high. Vehicles movements and wading are not safe. |
| 1.0–2.0         | 0.2–0.4        | This is the case in which damage to property is quite extensive and the probability of having dead and injured people is high. The social disruption is also very high. |
| > 2.0           | 0.4–1.0        | This is the case in which, at all levels, severe damages are expected. Buildings and houses are the most affected and nothing is safe any longer. |
The CCFVI is used to compute flood vulnerability based on a selected set of indicators belonging to the hydro-geological, social and economic components of a coastal system. Vulnerability assessment was done by gathering data and values on the selected indicators for the 105 districts and 21 urban areas of the VMD. The procedure for calculating the CCFVI starts by converting each identified indicator into a normalized one, on a scale from 0 to 1, (see Table 2), which is a dimensionless number using its minimum and maximum values as the normalization limits. The CCFVI of each coastal component (hydro-geological, social and economic) is computed based on the general flood vulnerability index (FVI) given by the equation (2):

$$FVI = \frac{E \times S}{R}$$

The indicators of exposure and susceptibility are multiplied and then divided by the resilience indicators, because indicators representing exposure and susceptibility increase the flood vulnerability; they are therefore placed in the nominator. The resilience indicators decrease flood vulnerability and thus are part of the denominator.

The total CCFVI is computed as a summation of the three CCFVI s of the coastal components of the system (Eq.(3)):

$$\text{TotalCCFVI} = \text{CCFVI}_{\text{Hydrogeological}} + \text{CCFVI}_{\text{Social}} + \text{CCFVI}_{\text{Economic}}$$

The CCFVI is therefore a method which combines multiple aspects of a system into one number. For purposes of comparison, the final CCFVI results are again normalized on a scale between 0 and 1; with 1 being the highest vulnerability found in the samples studied and 0 the lowest. The CCFVI values are grouped into five categories, as shown in Table 2, to represent five vulnerability zones. The flood vulnerability maps are constructed using ArcGIS tools based on the CCFVI results for the VMD districts and urban areas. Several data sources are used in order to assess flood vulnerability indicators for each of the districts (Table 3).

Thirdly, flood risk is expressed for the VMD delta for each of the computational cells considered during the flood hazard mapping. For each cell, the flood hazard factor is calculated as the product of the expected level of damage to properties and the loss of human lives in that area. The magnitude of risk, also known as the risk factor, is computed as a product of the vulnerability factor of the corresponding area and the hazard factor. Flood hazard maps together with flood vulnerability maps using ArcGIS overlie to determine flood risk maps. The study presented herein classifies risk of flood based on predicted flood depths. The risk value of each unit is ranging from 0 to 1; where 0 is the lowest risk value while 1 is the highest risk value. After that the risks were categorized into five types, namely very low, low, medium, high and very

| Vulnerability zones | CCFVI |
|---------------------|-------|
| Very low            | 0 – 0.2 |
| Low                 | 0.2 – 0.4 |
| Medium              | 0.4 – 0.6 |
| High                | 0.6 – 0.8 |
| Very High           | 0.8 – 1 |
For the year 2050, the same methodology is used: the ISIS 1D model is calibrated for the last major flood, from 2000, and then used to predict flood hazard in the year 2050. Observations of the 2000 flood are used for calibrating the hydrodynamic model. The model of 2050 is subsequently built, applying the climate change assumptions for the SLR as they have been defined by Ministry of Natural Resources and Environment (MONRE). The assumptions for the boundary conditions for the year 2050 are driven by climate change scenarios, i.e. an increase in water level due to predicted SLR at the downstream end of the river.

On the basis of assumptions about changing socioeconomic factors coupled with the hazard analysis, flood vulnerability maps are built for the year 2050. The 2050 flood vulnerability scenario is developed based on water discharge of the upstream Mekong Delta and sea level rise. The river discharge indicator for 2050 was determined from the output of the ISIS model after simulating the flood event of 2050. The projected sea level rise (increase up to 30 cm of scenario B2 (Intergovernmental Panel on Climate Change, 2007) for the both East and West Sea with

### Table 3. Flood vulnerability indicators and data sources.

| Sub-Index       | Indicators                  | Factor of | Unit          | Source                                                                 |
|-----------------|-----------------------------|-----------|---------------|------------------------------------------------------------------------|
| 1 Hydro-Geological | Sea Level Rise              | Exposure  | mm/year       | Impact of SL on coastal zone of Vietnam (MONROE, 2009)                 |
| 2               | Storm Surge                 | Exposure  | m             | Economics of adaptation to Climate Change, McElwee, 2010               |
| 3               | #Cyclones                   | Exposure  | #             | World Bank Country Report 1999 for Vietnam                            |
| 4               | River Discharge             | Exposure  | m³/s          | ISIS model                                                             |
| 5               | Foreshore Slope             | Exposure  | %             | DEM                                                                    |
| 6               | Soil Subsidency             | Exposure  | mm/year       | Sinking Deltas (James P.M. Syviski)                                    |
| 7               | Coastal Line                | Exposure  | km            | Google Earth                                                           |
| 8               | Cultural Heritage           | Exposure  | #             | http://gis.chinhphu.vn/                                               |
| 9               | Population Close to CL      | Exposure  | people        | General Statistics Office (GSO2011) and Vietnamese Census             |
| 10              | Growing Coastal Population  | Exposure  | %             | General Statistics Office (GSO2011) and Vietnamese Census             |
| 11              | Shelters                    | Susceptibility | # | Vietnamese Census (counting schools, hospitals & pagodas)       |
| 12              | %Disable People             | Susceptibility | % | http://thongtinphapluaodansu.edu.vn/2008/12/30/2161/             |
| 13              | Awareness/Preparedness      | Resilience | -             | Scaled by Balica, Douben, and Wright (2009)                           |
| 14              | Recovery Time               | Resilience | days          | Southern Institute of Water Resources & Planning, Vietnam             |
| 15              | Drain                       | Resilience | Km            | River network                                                          |

### Table 4. Risk zones.

| Risk zones            | Risk factor |
|-----------------------|-------------|
| Very Low              | 0–0.008     |
| Low                   | 0.008–0.04  |
| Medium                | 0.04–0.12   |
| High                  | 0.12–0.32   |
| Very High             | 0.32–1.0    |
reference to the one in 2000) in combination with the discharge projected according to the adjusted regional climate model with developments in the Upper Mekong Basin after 2030. We acknowledge that some of the indicator values for the year 2050 could only be computed based on assumptions.

5. Results and observations

It is observed from ISIS simulation of 2000 year flood that the extent of the inundated area is 37,420 km², which covers 96% with respect to total VMD area (including very low, low, medium, high, and very high hazard were 2.6%, 9.7%, 31.0%, 36.1%, and 16.6%). Northern part of the VMD (An Giang, Dong Thap, Kien Giang, Long An) and along Bassac and Mekong River is considered having high and very high hazard areas, while there is little hazard in the coastal area. The areas with no hazard cover 3.9% and they are situated in Ca Mau Peninsula or in areas with high topography. Flood hazard assessment for the year 2050 was done based on classifications introduced in Table 1.

The flood hazard area is 97.6% (about 38,038 km²) of the VMD area. Mainly, flood hazard would expand till Ca Mau Peninsula. The areas under very low, low, medium, high and very high hazard category are 518, 1695, 13,510, 20,251, 2026 km² corresponding to 1.3%, 4.4%, 34.7%, 52.0% and 5.3% of the total area, respectively. The remaining 911 km² (2.3% of total VMD area) is found to be non-flooded. There are 22,313 km² (57.3% of total area) within high and very high hazard zones. From the 2000 year flood vulnerability map can be seen that 10.2% of the whole VMD represent very high (204 km²) and high (3804 km²) vulnerability to floods, mainly districts situated along the rivers and the coast. The highly vulnerable to floods is the district of Than Chau, followed by An Phu, Tinh Bien, Mo Cay Bac, Phong Dien, Hong Ngu, Nga Bay, Chau Thanh, Cau Duoc, Can Giuoc, Cu Lao Dung, Cho Gao, Go Cong Tay, Tien Can, Cau Ngang and Binh Minh. The remaining majority of districts represent medium-vulnerability to floods (14,964 km², 38.1% of the total VMD). These districts are situated along the Bassac and Mekong River banks and on the Northern and North-Eastern sides of the delta. The 51.8% (20,349 km²) of the whole VMD represents low vulnerability to floods. The least vulnerable districts are the ones from Ca Mau Peninsula. The 2050 year flood vulnerability map shows that the low vulnerability areas will increase with 4.1% compare with 2000 year flood vulnerability, the medium vulnerability areas with 0.8%, the high and very high with 3% and 1%, respectively. In 2050, the very high vulnerable to floods will be following districts: Tan Chau, Ninh Kieu, Nga Bay, Cu Lao Dung, My Thi and Vinh Long, situated along the rivers banks. The 2000 year risk map was prepared classifying risk into five distinct risk zones, corresponded to very low, low, medium, high and very high-risk areas where risk was calculated as the product of hazard (i.e., depth of inundation) and vulnerability (i.e., the exposure of people or assets to flood, their susceptibility and their resilience). It is observed that very high (847 km²) and high-risk (13,036 km²) zone covers few areas, mainly on the Northern side of the VMD, and it is located mostly adjacent to the two rivers. The high and very high-risk districts are the followings: Tan Chau, An Phu and Hong Ngu. In this area, risk is high because high vulnerability and high hazard, high river discharge, population density is also high; huge damage for infrastructure and building may occur. High-risk area is the area where people are more exposed to hazard.

The medium flood risk represents the higher value, 16,483 km², 42.3% of the total VMD. The 22.0% of the VMD is under very low, low and no risk to floods. It is also observed that, in some parts of the Ca Mau Peninsula, there is no inundation, so the risk is zero (1529 km², 3.9% respectively), even if the area is densely populated. The 2000 year flood risk map shows that 78.0% of the whole delta is under medium to very high-risk zone. From 2050 year flood risk map can be
observed that comparing with 2000 year flood risk map, the very high and high-risk areas are decreasing with 1.2% and 1.9% respectively, however medium-risk areas will increase by 16.2% (6295 km²), the whole Northern and North-Eastern part of the delta is under the medium-risk zone; the low and very low-risk areas are covering 6.6% of the total VMD, with an area of 2572 km². The 2050 year flood risk map shows that 91.1% of the total VMD is found under very high, high and medium-risk conditions.

6. Conclusions
The VMD flood hazard map provides residents and government with the information on the choice of possible damage and the disaster prevention measures. The effective understanding of hazard map can decrease the extent of disasters. However, the flood hazard map is not sufficient for decision-making. It has always to be used in combination with a vulnerability map in order to determine the risk.

The CCFVI is limited by the accuracy and availability of good datasets. A number of the indicators are very hard to quantify especially when it comes to the social indicators. On the other hand, such a model can give a simplified way of characterizing what in reality is a very complex system. Such results will help to give an indication of whether a system is resilient, susceptible or exposed to flooding risks. And help identify which measures would reap the best return on investment under a changing climate and population and development expansion. However, the advantage in using ISIS 1D models is their high capability for prognosis and forecasting, and their disadvantage is the high input data demand. The ISIS 1D model has a better science base (bigger datasets), but limited evaluation of vulnerability. Therefore, using CCFVI as a parametric model to overlay it with the ISIS 1D deterministic model will help in understanding and assessing the flood risk and vulnerability in the VMD area.

The VMD flood vulnerability map provides useful information for both inhabitants and government about the vulnerability, and the policy makers and water authorities can define better measures to prepare and deal from/with floods (Muste et al., 2010; Quinn, Hewett, Popescu, & Muste, 2010). Government can use the flood vulnerability map for ensuring the proper agricultural planning of the high and very high-vulnerable areas. Agricultural planner can use this information to make economic sound land-use decisions. For the effective planning of flood defenses and the safety of the people living in high and very high-vulnerable areas, useful information can be provided using this vulnerability map.

The flood risk map provides helpful information about flood risk management and should be useful in assigning priority for the development of high and very high-risk areas. These three maps may also help the responsible authorities to better understand the inundation characteristics of the VMD, the protection of which is their responsibility.

Understanding VMD’s flood hazard, vulnerability and risk will help decision makers to frame the future delta management and development plans. The study shows the potential of using flood hazard, flood vulnerability and risk maps by the responsible authorities and decision makers, especially in highly populated areas, such as the VMD.

These may be used in the planning of adaptation and mitigation measures to reduce the negative impacts of floods in the area.

Software
ISIS model was used to simulate the flood extent and ESRI ArcGIS 9.3, with Spatial Analyst, was used for all analysis and in the production of the final map.
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