CLIMATE CHANGE AND POTENTIAL FLOOD RISK IN DOWNSTREAM SAI GON-DONG NAI RIVER BASIN IN VIETNAM

NGUYEN THU PHUONG

MASTER OF SCIENCE

IN

NATURAL RESOURCES AND ENVIRONMENTAL MANAGEMENT

SCHOOL OF SCIENCE

MAE FAH LUANG UNIVERSITY

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ABSTRACT

Ho Chi Minh City (HCMC), located in the downstream of Sai Gon-Dong Nai river basin in Southern Vietnam, is identified as one of the top Asian coastal megacities most vulnerable to climate change. The city has been adversely affected by flooding annually. The unexpectedly big flooding in Bangkok, Thailand in 2011, mainly due to the extreme widespread rainfall of some 40% above normal condition in the whole watershed, can provide a good lesson for HCMC because of the similarities of both natural and socio-economic conditions. Previous assessments of flood risks, generally and for HCMC particularly, are mainly conducted for damage and economic losses, rather than for social vulnerability implications. This study aims at social vulnerability assessment for HCMC to flooding under the high rainfall scenario similar to the 2011 flood in Bangkok. Flood flows in the Sai Gon-Dong Nai watershed are simulated by applying the rainfall-runoff model (MIKE NAM) and hydrodynamic model (MIKE 11). These outputs are then overlaid with the digital elevation map (DEM) to create the inundation maps, followed by the flood hazard assessment with the effects of flood depth and duration, and finally by social vulnerability assessment with various social factors at the district level such as numbers of females, children and elderly and poor households. The flood risk maps are determined for each district in HCMC to specify the districts that are likely to be most socially vulnerable to potential flooding although some of which are not necessarily to be of high hazards. This paper will serve a starting point for proper actions to reduce these risks. Further research studies on other flooding scenarios and at more refined geological scales are needed for more effective reduction of flood risks.

Keywords: Extreme rainfall/Inundation map/Flood hazard/Social vulnerability/ Flood risk

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ABBREVIATIONS

ADB	Asian Development Bank
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
GIS	Geographic Information System
HCMC	Ho Chi Minh City
HI	Hazard Index
ICEM	International Centre for Environmental Management
IHEC	Institute of Hydrology, Environment and Climate Change
IPCC	Intergovernmental Panel on Climate Change
MSL	Mean Sea Level
NCFHF	National Centre for Hydro-meteorological Forecasting
RI	Risk Index
RS	Remote Sensing
SIWRP	Southern Institute of Water Resources Planning
SoVI	Social Vulnerability Index
SVEAI	Social Vulnerability for Evacuation Assistance Index

CHAPTER 1

INTRODUCTION

1.1 Background

Water is one of valuable natural resources, which plays a vital role for human being. It not only supplies for domestic human life, but also provides benefits for agriculture, aquaculture, industry, hydropower, etc. For these reasons, civilizations usually occur on the riverside. However, behind these advantages are these adverse disasters such as floods and droughts. Flooding is one of these most risks which cause vast of damages, including loss of human lives and disruption to livelihood. In the recent years, flood is becoming more serious and complex due to climate change which is recognized as one of the most high profile problems facing a globalized world. In fact, accelerated sea levels rise, intensification of tropical and extra tropical cyclones and storms altered precipitations and runoffs are the climate-related factors which cause the increase of intensity and frequency of extreme floods. Consequently, the cities which located in both of the downstream of watersheds and coastal areas are severely affected by unexpectedly floods and sea level rises. More seriously, these mega cities, where also are highly population and core socio-economic development concentrated, are much vulnerably affected by these severe floods.

As a stark example in the region, the unexpectedly big flooding in Bangkok, Thailand in 2011, which caused serious damages for several areas, was identified, mainly due to the extreme widespread rainfall of some 40% above the normal condition in the whole watershed (Tokyo Climate Center, 2011). This flooding affected 65 of Thailand’s 76 provinces and the estimate economic loss of this flooding is USD 45 billion (Aon Benfield, 2012). The issue, can be lesson learn to other neighboring countries who share similar climate, culture and socio-economic condition, including Vietnam.

As a coastal city located in the downstream of the Sai Gon-Dong Nai river basin in Southern Vietnam, Ho Chi Minh City (HCMC) is the major city covering an area of 2,095 km^2, with high dense population (approximately 3,400 person/km^2 as estimated in 2009). The city is the major economic base to the national GDP with a high rate of annual economic growth over the last couple of decades. However, being located in the low-lying area without a dyke system of the river, HCMC has been adversely affected by annual flooding. This is because the city is affected by both of upstream flooding, heavy local rainfalls and high sea tides. Further, as considered as one of the top Asian megacities most vulnerable to climate change as well as the top population exposed to the effect of climate change (World Bank, 2010), HCMC is becoming highly vulnerable to climate-related risks in the near future.

After the big flooding occurred in Bangkok 2011, lots of Vietnamese experts worry about the potential of the similar flooding will be happened in HCMC, because of the similarities of topography, climate and also socio-economic conditions between two cities. For example, HCMC and Bangkok are both coastal megacities located in low-lying areas and in the downstream of large river basins. Besides, both of two cities have non-dyke systems of the rivers and also are highly affected by the high tide regime from the sea. Thus, this unexpected flooding could become serious concerns to HCMC. Thus, the questions that “Will the extreme flood be occurred in the near future under the high precipitation scenario and how severe of this flooding?” are the great interests of most researchers and citizens in the area.

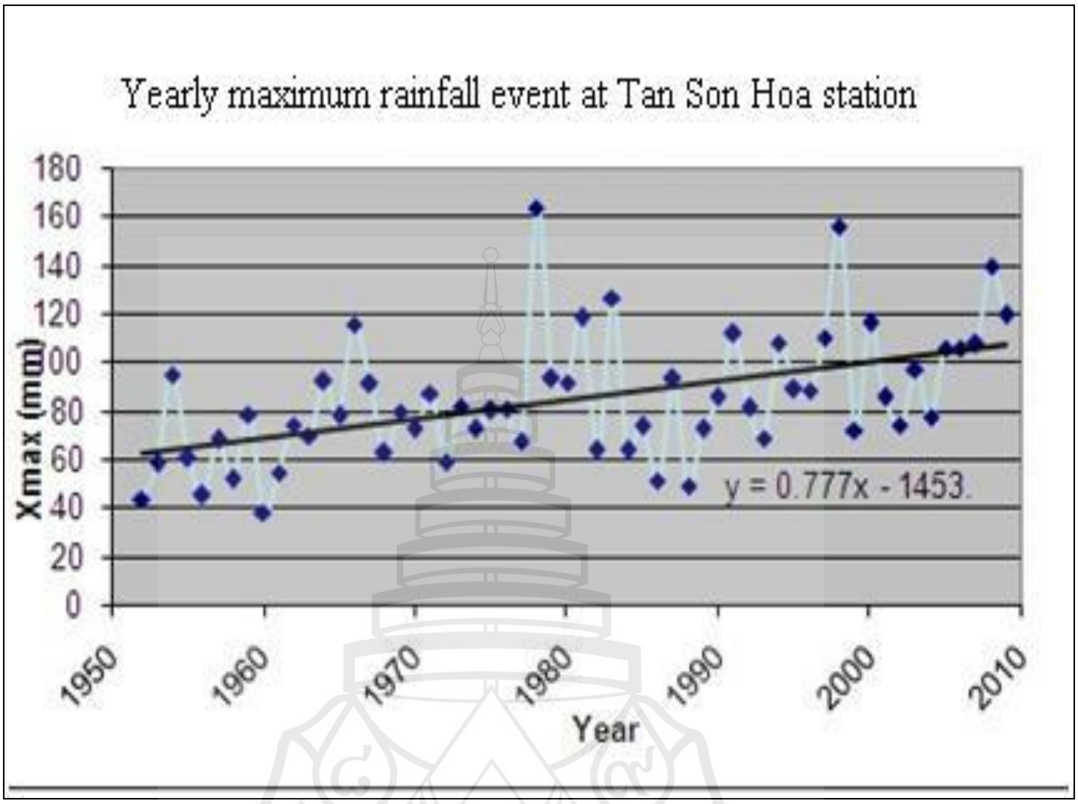
There are several research studies conducted for flood risk for HCMC, for example, by Asian Development Bank (ADB) in 2010 and World Bank in 2010, but the extreme rainfall conditions in the whole watershed are not updated accordingly, and the social risk assessment from potential flooding is not considered for various vulnerable groups of people. Thus, the ultimate purpose of this study is to assess social risks in HCMC from potential flooding that is caused by high upstream rainfall condition (namely 40% above the normal) and historical high tidal conditions. This is done by several steps, starting from developing the flood hazard and inundation map, using MIKE 11 and MIKE 11 GIS, followed by assessment of social vulnerability at the district level with a focus on the four groups of people, namely the children, the elderly, the women, and the poor households. Implications for flood risk reduction are also discussed, along with needs for considering more flooding scenario.

1.2 Problem Statement

In recent years, in Sai Gon-Dong Nai delta, particularly HCMC, the occurrence of flooding is more frequent. The inundation duration and intensity also increase. Climate-related factors such as rainfall increase and high sea level time have altered the temporal and spatial pattern of flooding in this area. The consequences of flooding increasingly impact on many aspects such as human lives and their livelihoods, both of economic and social sectors. There are several research studies on flood risk in HCMC, however, almost previous studied are conducted for damages and economic losses, rather than for social vulnerability implications.

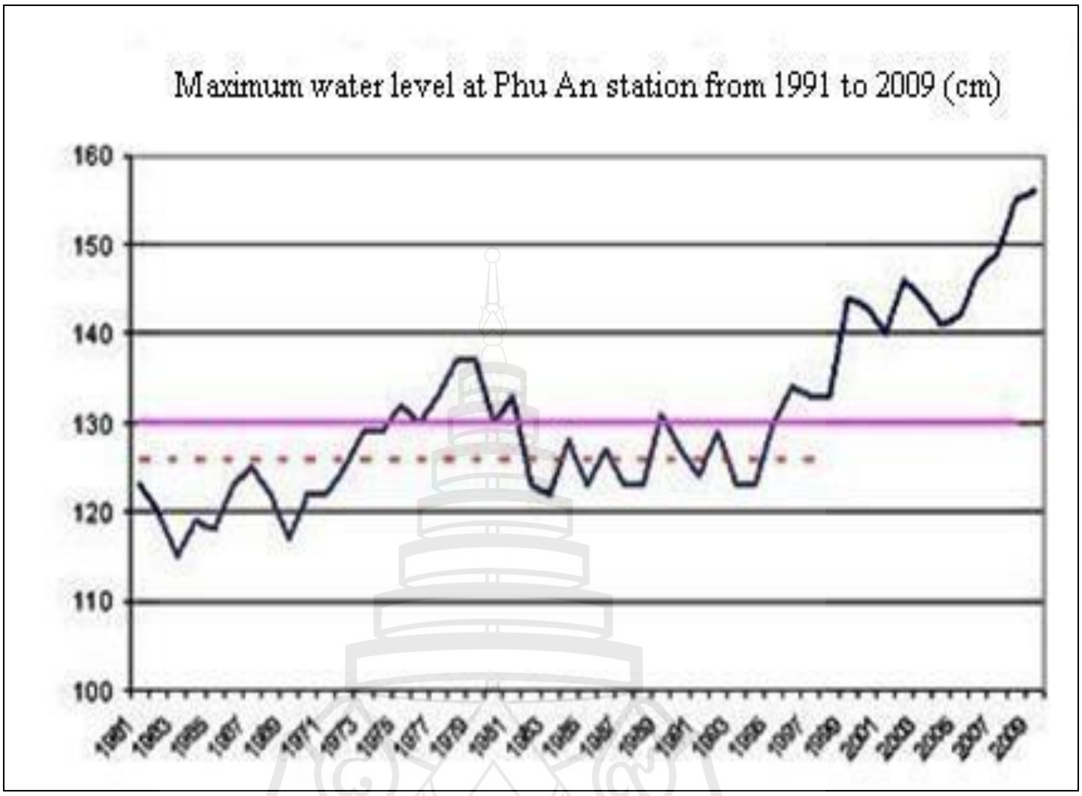
According to the report of ADB 2010, between 1997 and 2007, almost all of the districts of HCMC were directly affected by natural disasters. For example, in 2007, there are about 154 communes (from a total of 322 communes of HCMC) affected by flooding. Most of the damage was concentrated in the vulnerable rural districts of Can Gio and Nha Be, toward the mouth of the Sai Gon - Dong Nai watershed. More specific, in the center of HCMC, there are normally about 30 inundation points within HCMC during the wet season, and up to above 100 serious flooded locations after the heavy rainfall event (127 mm, 16 May 2004) (Phi, 2008).

The flooding issue in HCMC is likely worse and worse in the future due to the extreme of climate and hydrodynamics in the area. Storms, storm surges, and tidal flooding are expected to be more severe (ADB, 2010). In recent decades, there is an upward trend of precipitation pattern in the area. Phuoc (2012) shows that the annual average precipitation in HCMC in the recent period from 1993 to 2007 was estimated about 1618mm, increasing 76 mm compared with that in the long period from 1978-1992. In addition, Phi (2012) indicates that the amount of yearly maximum rainfall events was increased 46 mm approximately in the long-term period of 60 years from 1950 to 2010, which can see in Figure 1.1. Moreover, sea level rise is one of the most aspects which suffer to the clearly upward trend. For example, tidal inundation increases 7% compared the period 2009-2010 with 2000-2008, which is seen in Figure 1.2.



Source Phi (2012)

Figure 1.1 Upward Trend of Rainfall Patterns in HCMC



Source Lan & Hanh (2010)

Figure 1.2 Upward Trend of High Tide in HCMC

Flooding and inundation are critical and challenging issues in HCMC which have existed for decades, so there have been several research studies conducted for this issue by lots of experts on water engineering in Vietnam as well as the international organizations such as ADB (2010) and World Bank (2010). The simulated flooding scenarios, non-structure and structure measures considered are provided, however, the problems have not solved yet and flooding is still remaining. Besides, the consequences of flooding increasingly impact on many aspects such as human lives and their livelihoods, economic sectors such as industrial zones, agricultural production and social sectors like healthcare, culture, etc. So, there are also several studies on these impacts of flooding for preparedness, adaptation purposes. However, almost previous studied are conducted for damages and economic losses due to the flooding, rather than for social vulnerability implications which become more and more risky due to the dramatic increase of population in the area.

Therefore, this study aims at social vulnerability assessment for HCMC to potential flooding under the updated high rainfall scenario similar to the 2011 flood in Bangkok.

1.3 Research Questions

The general research question is: “What are the potential flood risks in HCMC in the lower Sai Gon-Dong Nai river basin during the flooding season, under the extreme scenarios of high precipitation (40% increase over the normal condition) and high sea tide?” To answer this question, we need to consider these following specific related sub-questions under the scenario:

1.3.1 Where are possible flood inundated areas in HCMC?

1.3.2 What are flood risks to HCMC at district level?

1.3.3 What are policy recommendations to reduce the flood risk?

1.4 Objectives

The main proposes of the research are to assess the flood risks (including social vulnerability) in HCMC from potential flooding (from high rainfall scenario of 40% above the long-term average in the whole watershed and historical high sea tide conditions)

The sub-objectives are as follows:

1.4.1 To construct the inundation maps for HCMC under the new rainfall scenario

1.4.2 To assess the flood risk in HCMC at district level under the potential flooding above

1.4.3 To propose some policy recommendations on flood risk reduction

1.5 Expected Outcomes

The following outcomes, under the scenarios of both rainfall increasing 40% and high sea tide, are expected from this research:

1.5.1 Inundation maps in HCMC

1.5.2 Flood risk maps in HCMC

1.5.3 Initial recommendations on flood risk reduction strategies

1.6 Scope and Limitations

The total area of Sai Gon-Dong Nai river basin is 37,400 km^2, belongs to 11 relevant provinces and cities, which is seen in Figure 1.3. However, the scope of study will be narrowed as follows:

1.6.1 Inundation maps are developed in HCMC only

1.6.2 Flood hazard, social vulnerability and flood risk maps are conducted for HCMC at district level only, because of data unavailability

1.6.3 In terms of the upstream boundary, only two main dam (Dau Tieng and Tri An reservoirs) in the upstream watershed are considered.

The main limitations of the current study are described as follows:

1.6.4 For topography condition, only Digital Elevation Model (DEM) of 90m x 90m is used, and land use changes are still not considered

1.6.5 Administrative scale is only at district level, due to data unavailability and time constraint.

1.6.6 In terms of flood hazard assessment, due to data availability, only flood depth and duration are considered, rather than velocity of flood flow, etc.

1.6.7 Regarding social risk assessment, only four major vulnerable target groups (namely children, elderly, women and poor households) are considered.

Source Center for Environmental Monitoring Portal (2012)

Figure 1.3 Sai Gon-Dong Nai River Basin

1.7 Conceptual Framework

The study research framework as outline in Figure 1.4 shows the steps taken to pursue the objectives through literature review and methodology. Understanding both natural and socio-economic conditions is the first necessary step to identify flooding problems at the study site. Flood hazard and social vulnerability are two specific concepts are considered in term of flood risk assessment. Finally, flood risk maps in the study area are conducted, followed by conclusions and recommendations on flood risk reduction.

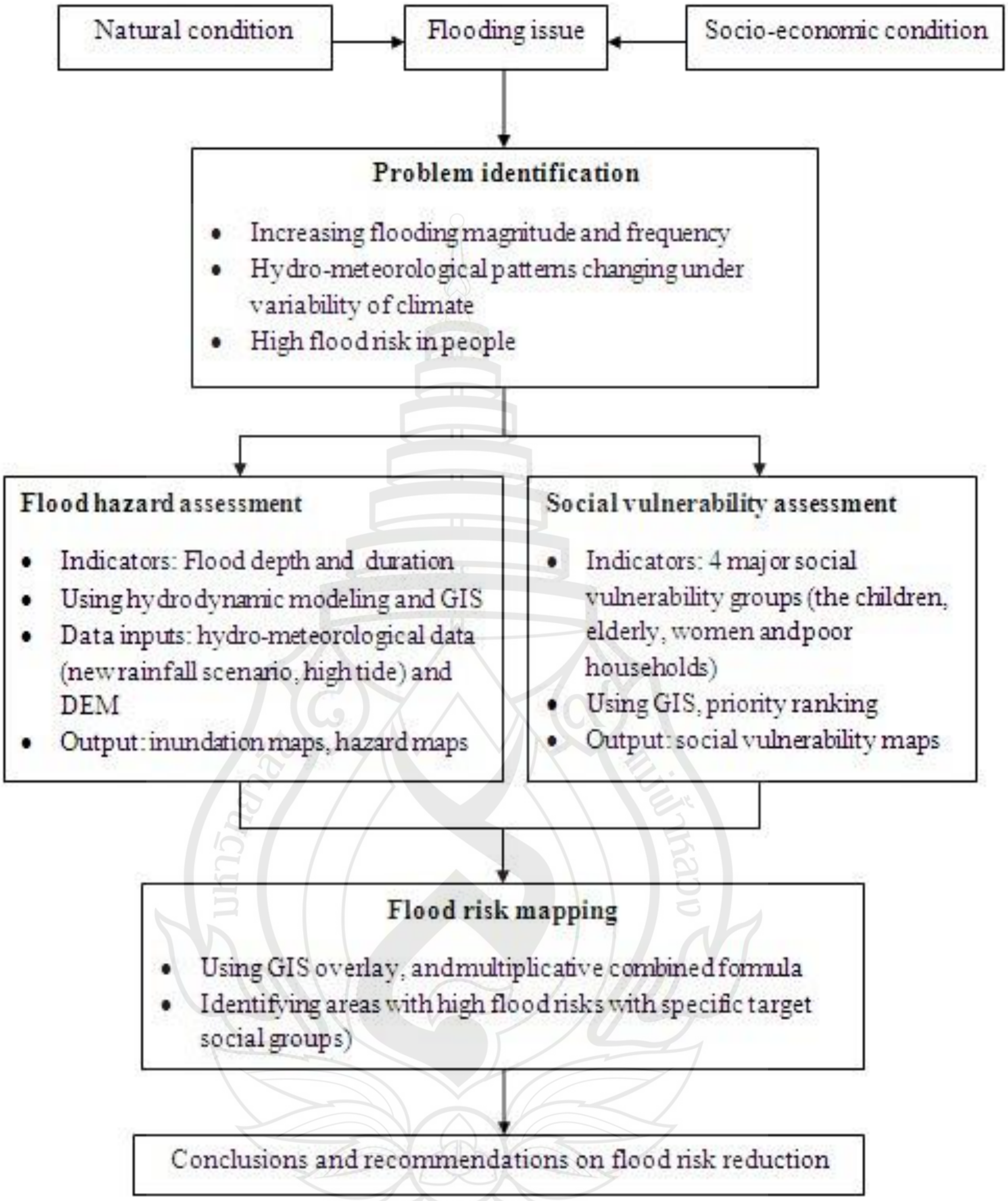


Figure 1.4 Research Framework

CHAPTER 2

LITERATURE REVIEW

2.1 Flood Risk Concept

2.1.1 Risk

The term risk has been analyzed from very diverse points of view. The different meanings often reflected by the needs of particular decision markers, leading to the several meanings and multiple dimensions relating to safety, economic, environmental and social issues (Castillo, Baldwin, Casarin, Vanegas & Juarez, 2012).

In terms of damages and losses perspective, risk involves an ‘‘exposure to a chance injury or loss’’ (Morgan & Henrion, 2003). Expected losses (of lives, persons injured, property damaged, and economic activity disrupted), due to a particular hazard, for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability (Department of Humanitarian Affairs, 1992). Risk is the actual exposure of something of human value to a hazard, and is often regarded as the combination of probability and loss (Smith, 2003). Risk means the expected number of lives lost, persons injured, damage to property, and disruption of economic activity due to a particular natural phenomenon, and is consequently the product of specific risk and elements at risk.

Total risk can be expressed in pseudo-mathematical form as: *Risk (total) = hazard × elements at risk × vulnerability* (Granger, Jones, Leiba & Scott, 2003).

Risk is the probability of a loss, and depends on three elements, hazard, vulnerability, and exposure (Crichton, 2008).

Risk might be defined simply as the probability of the occurrence of an undesired event [but] be better described as the probability of a hazard contributing to a potential disaster. Importantly, it involves consideration of vulnerability to the hazard (Stenchion, 2003).

Risk is also defined as the function of three factors, including hazard, exposure and vulnerability as: *Risk = hazard × exposure × vulnerability* (Peck, Subhankar & Slobodan, 2007).

Risk is defined as a function of the probability of the hazard, of exposure to the hazard, and the vulnerability of receptors to the hazard (Thywissen, 2006).

Risk = impact of hazard × elements at risk × vulnerability of elements at risk (Kelman, 2003).

Risk = hazard × vulnerability × value of the threatened area/ preparedness (Cruz-Reyna, 2003).

Risk is the combination of the probability of occurrence of harm and the severity of that harm (SO/EC, 2005).

Risk is a compound measure combining the probability and magnitude of an adverse effect (Adams, 2003).

Risk is the probability of hazard occurrence, where hazard is the potential threat to humans and their welfare (Brooks, 2003).

Risk is function of probability and magnitude of different impacts (Intergovernmental Panel on Climate Change [IPCC], 2003).

Risk is the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted, or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions (Gouldby & Samuels, 2005).

Risk is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components: the chance (or probability) of an event occurring and the impact (or consequence) associated with that event (Wallingford, 2005).

Sayers, Gouldby, Simm, Meadowcroft & Hall (2003); Gouldby & Samuels (2005); Helm (2003); Safecoast (2008) and Bellomo (2008) defined risk is a multiplicative function of the probability of the hazard and its consequences as the function below:

$$Risk = probability \times consequence$$

Risk is the function of the probability that a risk event occur and the consequence associated with that event. Practically, risk is made up of four major building blocks: the probability of flooding, the exposure of the elements-at-risk to a flood with certain characteristics, the value of these elements-at-risk, and the vulnerability of these elements-at-risk (ADAPT project, 2008).

Depended on specific purposes, the risk function can be adjusted for the rationality of each study. In this research, with the social vulnerability focused under the flooding, the risk concept consists of two factors, including hazard and social vulnerability. The function is described as follows:

$$Risk = Hazard \times Social\ Vulnerability$$

2.1.2 Flood Hazard Assessment

The concept of hazard is defined as the potential damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environment degradation (United Nations International Strategy for Disaster Reduction [UNISDR], 2004).

Flood hazard maps are detailed flood plain maps complemented with type of flood, the flood extent; water depths or water level, flow velocity or the relevant water flow direction (Panayotis, 2008 & World Bank, 2011).

The categories of flood depth are generated based on the magnitude of the impacts of the possible flood depth. For instance, Samarasinghe et al. (2010) describes that flood hazard is categorized based on the level of difficulties in daily life and/or damage to properties. Flood depths are ranked as 3 levels, from under or equal 1 meter, 1 meter to 3 meter, and above 3 meter. Another example, Tu (2009) develops the categories of flooding depth as four levels (from under or equal 0.5 meter, 0.5 meter to 1.5 meter, 1.5 meter to 3 meter, and above 3 meter).

To sum up, in order to assess flood hazard, there are some main indicators such as flooding depth, flooding duration, velocity of flood flow, timing and frequency of occurrence. In this study, flood depth and duration are two indicators which are used for hazard assessment.

2.1.3 Social Vulnerability Assessment

Social vulnerability describes those characteristics of the population that influence the capacity of the community to prepare for, respond to, and recover from hazards and disasters. Social vulnerability interacts with natural processes and the built environment to redistribute the risks and impacts of natural hazards and in this way creates the social burdens of hazards (Cutter, Emrich, Webb & Morath, 2009). Social vulnerability helps to explain why some communities experience the hazard differently, even though they experience the same level of flooding or storm surge inundation. Understanding the differential impact of hazards as a product of the social vulnerability of a place, rather than exposure, is a critical element in formulating comprehensive mitigation plans (Morrow, 2008).

Social vulnerability groups

Within the social science and disasters literature, there is a rich tradition of research focused on those social factors that increase or decrease the impact of specific natural hazard events on the local population. Some broad indicators appear repeatedly in social vulnerability analyses, although it is possible to choose different proxies or variables to represent them. Those characteristics most often found in the literature include socioeconomic status (wealth or poverty); age; special needs populations; gender; and finally, race and ethnicity (Tierney, Lindell & Perry, 2001; Heinz Center, 2002; National Research Council, 2006; Bates & Swan, editors, 2007) (see Table 2.1).

Table 2.1 Selected Population Characteristics Influencing Social Vulnerability

Concept or Characteristic	**Proxy Variable**	**Effect on Social Vulnerability**
Socioeconomic status	% poverty	Increases
	Per capita income	High decreases; low increases
Gender	% female headed households	Increases
Race and/or ethnicity	% African Americans	Increases
	% Hispanic	Increases
Age	% elderly	Increases
	% under 18	Increases
Housing tenure (ownership)	% renters	Increases
	% homeowners	Decreases
Employment	% unemployed	Increases
Occupation	% agricultural workers	Increases
	% low skilled service jobs	Increases
Family Structure	% Single parent households	Increases
	Large families	Increases
Education	% Less than high school	Increases
Population growth	Rapid growth	Increases

Table 2.1 (continued)

Concept or Characteristic	Proxy Variable	Effect on Social Vulnerability
Access to medical services	Higher density of medical establishments and services	Decreases
Special needs populations	Homeless, tourists, transients, nursing home residents	Increase
Social dependence	% social security recipients	Increase

Source Cutter et al. (2009)

Socioeconomic status influences the ability of individuals and communities to absorb the losses from hazards (Peacock, Morrow & Gladwin, editors, 2000; Masozera, Bailey & Kerchner, 2007). In general, people living in poverty are more vulnerable than the wealthy to hazard impacts (Fothergill & Peek, 2006). Poor people have less money to spend on preventative measures, emergency supplies, and recovery efforts. Although the monetary value of the economic and material losses of the wealthy may be greater, the losses sustained by the poor are far more devastating in relative terms. Poor people are more likely to live in substandard housing, which can be a major disadvantage when disasters occur (Long, 2007), and during disasters, are less likely to have access to critical resources and lifelines, such as communications and transportation. Some research suggests that working class families tend to experience long-lasting impacts from disasters (Dash & Morrow, 2007).

The confluence of race and class (socioeconomic status) has a long history of producing social inequalities (Fussell, 2007; Germany, 2007). Nowhere were these inequalities than in the differential impact of and response to Hurricane Katrina (Cutter et al., 2006; Elliott & Pais, 2006; Logan, 2006; Pastor et al., 2006; Elder et al., 2007; Brunsma, Overfelt & Picou, editors, 2007; Potter, editor, 2007). Many scholars refer to Hurricane Katrina as an "unnatural disaster" (Dyson, 2006; Hartman & Squires, editors, 2006; Laska & Morrow, 2006) inferring that the impacts associated with it were more related to the underlying socioeconomic inequalities within the affected population rather than the hurricane's intensity. In the United States, racial and ethnic minorities are more vulnerable to hazards because minorities are more likely to live in poverty (Peacock et al., editors, 2000). Discrimination also plays a major role in increasing the vulnerability of racial and ethnic minorities (Fothergill, Maestras & Darlington, 1999; Bolin, 2006). In particular, real estate discrimination may confine minorities to certain hazard-prone areas or hinder minorities in obtaining policies with more-reliable insurance companies (Peacock & Girard, 1997). Ethnic communities are often geographically and economically isolated from jobs, services and institutions. Where minorities are immigrants from non-English-speaking countries, language barriers can greatly increase vulnerability to a disaster and recovery (Peguero, 2006; Leong, Airriess, Li, Chen & Keith, 2007; Trujillo-Pagan, 2007).

Social vulnerability index

While the theoretical underpinnings of vulnerability science progressed over the past two decades, advancements in methods for measuring vulnerability have lagged. While there is significant policy interest in such efforts, there is less agreement on the appropriate methods for creating social vulnerability indices. The methodological development of social vulnerability indices are focused around three major decisions: (1) the scale of the index; (2) the explicit proxies (or variables) included in the index; and (3) the method of aggregation (Adger, Brooks, Bentham, Agnew & Eriksen, 2004; Gall, 2007, Barnett, Lambert & Fry, 2008). Variations in the development of the index inevitably produce different outcomes.

In 2000, Cutter, Mitchell and Scott operationalized the Hazards-of-Place model to reveal the vulnerability of populations living inside hazard zones for Georgetown County, South Carolina. To quantify social vulnerability, nine indicators were chosen deductively, based on a priori knowledge from the existing literature. These included total population and total housing units (i.e. proxy of people/ structures at risk); number of females, number of nonwhite residents, number of people under age 18, and number of people over age 65; mean house value (i.e. proxy for wealth, resilience); and number of mobile homes (i.e. proxy level of structural vulnerability). Indicators were collected for block groups using 1990 US Census Statistics. Rather than using simple percentages to represent indicators, each social variable was standardized by determining a ratio of that variable in each census block to the total value of that variable for the entire county to create a comparative proportion for each variable in each block. To produce an aggregate value for social vulnerability, standardized values were summed for each block. This score was then combined with the aggregate values for biophysical vulnerability (derived from frequency of hazard occurrence) using a GIS. Lacking the reliable theoretical or statistical evidence needed to assign weights, all indicators had the same relative importance (equal weight) within the GIS.

Chakraborty, Montz and Tobin (2005) used those methods developed by Cutter et al. (2000) to develop the Social Vulnerability for Evacuation Assistance Index (SVEAI) for block groups in Hillsborough County Florida. SVEAI used ten indicators, similar to those chosen by Cutter et al. (2000) with some minor changes to reflect those populations that may have special evacuations needs (i.e. disabled) and those who have differential access to evacuation resources inside their home (i.e. no telephone or vehicle).

Rather than simply summing the standardized variables, values were averaged yielding aggregate vulnerability normalized between zero and one. In further contrast from Cutter et al.'s (2000) metric, Chakraborty et al. (2005) presented four alternative approaches for grouping the variables to calculate social vulnerability for evacuation and for examining the spatial distribution of each approach within the study area. These characteristics are listed below, along with the number of variables associated with each approach: Approach 1: Population and structure (three variables); Approach 2: Differential access to resources (three variables); Approach 3: Special evacuation needs (four variables); and Approach 4: All three characteristics (all 10 variables). Each approach addresses a specific dimension of evacuation assistance need that can be examined and visualized independently, a process that recognizes the different issues that local emergency managers face in developing evacuation plans. Using the methods of Cutter et al. (2000), SVEAI was combined with a geophysical risk index (hurricane risk and flooding). The resultant values indicate overall evacuation assistance need.

In 2003, Cutter, Boruff and Shirley developed the Social Vulnerability Index (SoVI). Based on the social dimensions of the Pressure and Release and Hazards-of-Place models (See Conceptual Frameworks, Section 1), SoVI is a multidimensional, scale dependent, spatially reliant algorithm for quantifying the relative socio-economic and demographic quality of a place as a means of understanding vulnerability. Using an inductive factor analytic approach, 42 socioeconomic variables (derived from US Census and County Data Books) reduced to 11 statistically independent factors, which accounted for about 76 percent of the variance at the county level for the entire United States. These factors were aggregated using a simple additive model to compute a summary score (i.e. the SoVI score) (Cutter et al., 2003). Again, no *a priori* weights were assigned during any point of aggregation. Those factors that contribute to the overall score often are different for each county, underscoring the interactive nature of social vulnerability—some components increase vulnerability while others reduce or moderate the SoVI score. SoVI attempted to uncover places having an uneven capacity for preparedness and response; places where resources might be used most effectively to reduce the pre-existing vulnerability). Unlike previous indices, SoVI is designed as a stand-alone indicator. This is concurrent with the accepted theoretical understanding that social vulnerability is independent of hazard type. Zones of differential exposure to any or all hazards combine with SoVI to create place vulnerability (for example see Borden, Schmidtlein, Emrich, Piegorsch & Cutter, 2007; Burton & Cutter, 2008; Wood, Burton & Cutter, 2009). Though Cutter et al.'s SoVI (2003) was applied to all counties in the U.S., sensitivity testing suggests that the developed methods are both scalable and transportable throughout the U.S. (Schmidtlein, Deutsch, Piegorsch & Cutter, 2008) and other developed countries (Boruff & Cutter, 2007).

From these seminal works come many variations in the development of social vulnerability metrics. Rygel, Sullivan and Yarnal (2006) employ similar methods to those published by Cutter et al. (2003) the main deviation being the assignment of weights for aggregation, based on a ranking of the factors. Cox, Rosenzweig, Solecki, Goldberg and Kinney (2007) apply a weighting schema based on the percent variance explained by each factor. Other metrics suggest the use of weights based on *a priori* comprehension of differential hazards risks and the potential for damage (Montz & Evans, 2001; Myers, Slack & Singlemann, 2008).

A common critique of comparative statistical research, particularly those focused on national level analyses, is that it fails to capture the sub-national spatial and social differentiation of vulnerability and local conditions that mediate the capacity to adapt. Such macro scale analyses though, easily sacrifice detail for common patterns and potentially fail to detect the heterogeneity of vulnerability at a subscale level (Eyles & Furgal, 2002; Adger et al., 2004; Barnett et al., 2008). In contrast, sub-national level indices capture sufficient detail useful for exploring intervention tools to ameliorate adverse vulnerability. The drawback of micro level studies, however, is that a high level of local detail limits the chance for generalizations and application in other regions (Eyles & Furgal, 2002). These critiques are important to consider, because social vulnerability is place-sensitive, so the selection of the places (or units of analysis) for comparisons is important.

To sum up, social vulnerability is determined by a host of social as well as physical factors such as gender, race, ethnicity, age and social class.

Based on these researches above in term of social vulnerability and data availability, the social indicators which are used in the study include the four vulnerability group, namely the children, the elderly, the women and the poor households. These groups likely experience the most consequences of flooding and the less ability against the hazard.

Social vulnerability mapping

Social vulnerability as a comparative metric means little without a method of visualization. As a utility for identifying and locating sensitive populations, vulnerability maps allow for the estimation of anticipated community needs at differing levels of disaster response (Morrow, 1999). The literature explicitly discussing vulnerability mapping is relatively sparse, yet most assessments provide a map depicting the geographic variability in social vulnerability (Cutter et al., 2000; Chakraborty et al., 2005; Rygel et al., 2006; Borden et al., 2007; Boruff & Cutter, 2007; Cox et al., 2007; Wood, Burton & Cutter, 2009; Burton & Cutter, 2008). Using vulnerability maps as planning tools, emergency managers can address the root causes of vulnerability, which will inherently change from place to place. At the local scale, planners and managers can look beyond geographical exposure to understand how unique social and political patterns facilitate the attenuation of risk (Frazier, Wood & Yarnal, 2008; Yarnal, 2007). The concentration of high-risk areas can be highlighted in communities or states so that emergency management plans can be customized and disaster relief distributed based on need as determined by the social vulnerability.

Adherence to basic cartographic design and principles is evident in the outputs from social vulnerability indices. Choropleth mapping, a method by which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed, is widely used to depict the "saturation" of vulnerability in a given area. In the examples cited above, vulnerability is a single standardized value or score, which is classified using objective schema, such as standard deviations or quantiles (Cutter et al., 2003; Chakraborty et al., 2005; Rygel et al., 2006). Mapping using a geographic information system (GIS) allows for the ease of data editing, analysis, transport, storage, and visualization (DeMers, 2005).

2.2 Researches on Flood Risk Assessment

Peck et at. (2007) studied on study analyzes flood risk and vulnerability in the Upper Thames, England. Vulnerability is considered by both of physical, economic, infrastructure and social component. The study considered ‘exposure’ separately from ‘vulnerability analysis’ and used it as a weight in the calculation of risk, which was obtained as the product of vulnerability, exposure and hazard values

Kannami (2008) studied on establishment of country-based flood risk index. Flood Risk Index considers five aspects of flood risk; Hazard, Exposure, Basic Vulnerability, Capacity soft countermeasures and Capacity hard countermeasures.

Manandhar (2010) studied on the flood plain and risk assessment in Lothar Khola in Nepal. Floodplain was studied by HEC-RAS model. The flood risk map is carried out by the relationship between landuse classification and flood depth.

Masood (2008) studied the flood hazard and risk assessment in Dhaka, Bangladesh. In this study, depth of inundation is assigned as hazard index and percentage area of landuse covered is considered for vulnerability index.

Samarasinghe et al. (2010) also analyzed the flood risk as both of hazard and vulnerability in Kalu-Ganga river basin in Sri Lanka by applying remote sensing and GIS. For the hazard mapping, the depth of flooding was considered for hazard assessment. For the vulnerability analysis, population data, building data and a comprehensive household vulnerability survey were considered.

Sengtianthr (2007) studied flood risk map using RS & GIS, in Champhone District Savannakhet, Laos. Flood hazard is defined by satellite image. Landuse and infrastructure is considered to assess the vulnerability.

Shantosh (2011) studied on GIS based flood hazard mapping and vulnerability assessment of people due to climate change in Kankai watershed, Nepal. HEC-RAS model is used for flood simulation. Risk assessment identified the flood prone areas, also the vulnerability in terms of the type of land use affected and hazard related to the return period of flooding and flood water depths. The social approach was participatory vulnerability assessment by survey, including agriculture, infrastructure, forest, biodiversity and settlement.

Surjit (2012) studied on assessment of the risk and vulnerability based on multi-criteria assessment. In this study, Rank Sum method is used to calculate the weights of factors contribute to flood hazard. The environmental factors such as hydrology, slope, soil type, drainage density, landform and land use/ land cover were considered to propose a Flood Risk Index.

Tu (2009) studied on flood inundation, damage and risk assessment for Hoang Long river in Vietnam. Flood inundation was studied by MIKE 11, MIKE 11 GIS model. For the hazard assessment, two important parameters including flood depth and duration were considered to create the hazard indices. For the vulnerability assessment, population density was considered to determine the vulnerability index.

2.3 Existing Flooding Researches on HCMC

2.3.1 Research on Climatic Factors Contributing to Flooding

HCMC is subject to both regular and extreme flooding. Regular floods refer on a daily and seasonal basis. Some of the main climatic factors that contribute to it include seasonal monsoonal rainfall and tide. Extreme flooding occurs when tropical storms and storms surges combine with tide influences and monsoon rainfall to create extreme weather conditions. Storm surge has been identified as a key driver for extreme events in HCMC. With an extensive area subject to regular flooding, it is not surprising that more extensive flooding can be induced by tides, storm surges, heavy rainfall on city directly or in the upper watershed, or combination of those events associated with the typhoon (World Bank, 2010).

Upstream rainfall is not expected to be a major cause of flooding in HCMC in the future, because the HCMC watershed is intensely managed. But localized flooding from a more intense monsoon rainfall within the city area will be a major threat (ADB 2010).

2.3.2 Researches on Flood Hazard and Risk Assessment in HCMC

According to ADB report (2010), Would Bank (2010) and International Centre for Environmental Management [ICEM] (2009), there were researches on flood impacts and vulnerabilities estimation in case of HCMC. The study assessed both regular and extreme flooding for the current and in the future in 2050. When assessing the impact of extreme flooding in HCMC, the study considered both high rainfall pattern and sea level rise scenarios, with the extreme (1-in30 year) flooding events under the current and the A2 scenario (Intergovernmental Panel on Climate Change [IPCC] scenario) in the future. The results were the flood hazard mapping for HCMC and the vulnerability on both of natural, social and economic systems. The main findings from this study show that the flooding in 2050 scenario will suffer the significant increase in both flood depth and duration, dramatically increase in the number of people affected in which the poor are the most vulnerable to flooding and the highly industrial zones are at risk of flooding which causes the huge losses in term of damage and economic losses.

Hung (2010) studies on the effects of climate changes on natural disaster situation and adaptation solutions for HCMC, developing the inundation maps of the flooding event in 2000 and under the scenario of sea level rise (100cm increased).

Phi (2012) also provided the inundated point map for HCMC (in 2003 and 2011) under the capacity storm under sewer overloaded and high tide.

Phu and Hiep (2012) study on application of GIS and remote sensing for indentifying flood risk in HCMC. The flooded areas are indentified by the remote sensing analysis.

Tu (2010) studies on adaptation on flood risk in HCMC, focusing on the relationship among hazard, vulnerabilities to that hazard, and capacities to cope with that hazard in order to reduce the vulnerabilities and enhance the adaptation capacities.

There are also other researches on flooding simulation under the sea level rise scenarios to assess the flood hazard in HCMC and researches on structure measures to reduce the flooding, however, the flooding problems in the area still remain and need to more further researches to solve the issues.

This study has proposed the potential flooding under high rainfall scenarios based on the main causes of the flooding in Bangkok 2011. Further, the flood risk will be assessed and mapped for HCMC, however, focus on the social risk assessment from potential flooding which is not considered deeply for various vulnerable groups in these previous researches.

CHAPTER 3

METHODOLOGY

3.1 Study Area

3.1.1 Overview of the Study Site

Sai Gon-Dong Nai watershed located in Southern Vietnam is the third largest river basin in the country as shown in Figure 3.1. The watershed covers 43,450 km^2 (not including the area of Cambodia). It shares to 10 provinces (Dak Lak, Lam Dong, Binh Phuoc, Binh Duong, Tay Ninh, Long An, Dong Nai, Ba Ria - Vung Tau, Ninh Thuan, Binh Thuan) and HCMC. Geographically the watershed lies between $105^0$03'21''E and $109^0$01'20''E, and $10^0$19'55''N and $12^0$20'38''N. HCMC is coastal city located on the estuary of the watershed, which covering an area of about 2095 km^2.

Topographic feature in the study area is divided to three forms: mountainous in the north, basaltic plateau in the south, and a transition zone of alluvial valleys between them. The watershed is generally flat with an average slope of the river basin at only 4.6% which reduced from North-East to South-East. While the mountainous highland areas upstream go up to 1,700 m, the downstream areas of the watershed are rather low, so subject to annual flooding in the wet season and salinity intrusion in the dry season. Almost half of HCMC areas in this watershed are very low. Namely, as reported in the HCMC (ADB, 2010), about 40-45% of land cover in HCMC is at an elevation of below 1 m, 15-20% of between 1 and 2m and very little land sits about 4m.

HCMC has a tropical monsoon climate with pronounced wet season and dry season. There is a large variation in monthly precipitation, but relatively constant daily temperatures. The annual average temperature in HCMC is 26–27^{o}C, and the fluctuation between months of the year differ by just 4-5^{o}C. In recent years, the annual average temperature has increased at a rate nearly double that of the increase in the surrounding Mekong Delta region. The higher temperature increase in HCMC since the 1990s has coincided with the accelerated urbanization in the area (ADB, 2010).

Source ADB (2010)

Figure 3.1 Sai Gon-Dong Nai Watershed and HCMC

Sai Gon-Dong Nai river basin is originated in Lang Biang High plateau (Lam Dong province). Depending on the topographical condition, the basin flows in North-East to South-West and North to South directions though almost provinces of Southern Vietnam. Totally the river basin consists around 266 rivers and streams which are greater than 10km length. The density of the river basin network is moderate, approximately 0.64 km/km^2. There are two main outlets, including Ganh Rai and Soai Rap which flow to the South China Sea.

The watershed has five major sub-watersheds: the Dong Nai mainstream, Be, Sai Gon, La Nga, Vam Co Dong and Vam Co Tay as major tributaries which are described in Table 3.1. However, each major sub-watershed can be divided to smaller sub-watersheds in order to estimate rainfall distribution and corresponding flood flow for minor sub-watershed. There are about 25 sub-watersheds in the upstream Sai Gon-Dong Nai river basin as estimated.

Table 3.1 Major Sub-watersheds in Sai Gon-Dong Nai River Basin

Sub-watershed	Area (km^2)	Length of mainstream (km)
Dong Nai mainstream (upstream)	14,800 (to Tri An)	470
Be	7170	344
La Nga	4100	290
Sai Gon	4710	256
Vam Co Dong	4270	283
Vam Co Tay	2430	235

Source Trinh & Hung (2004)

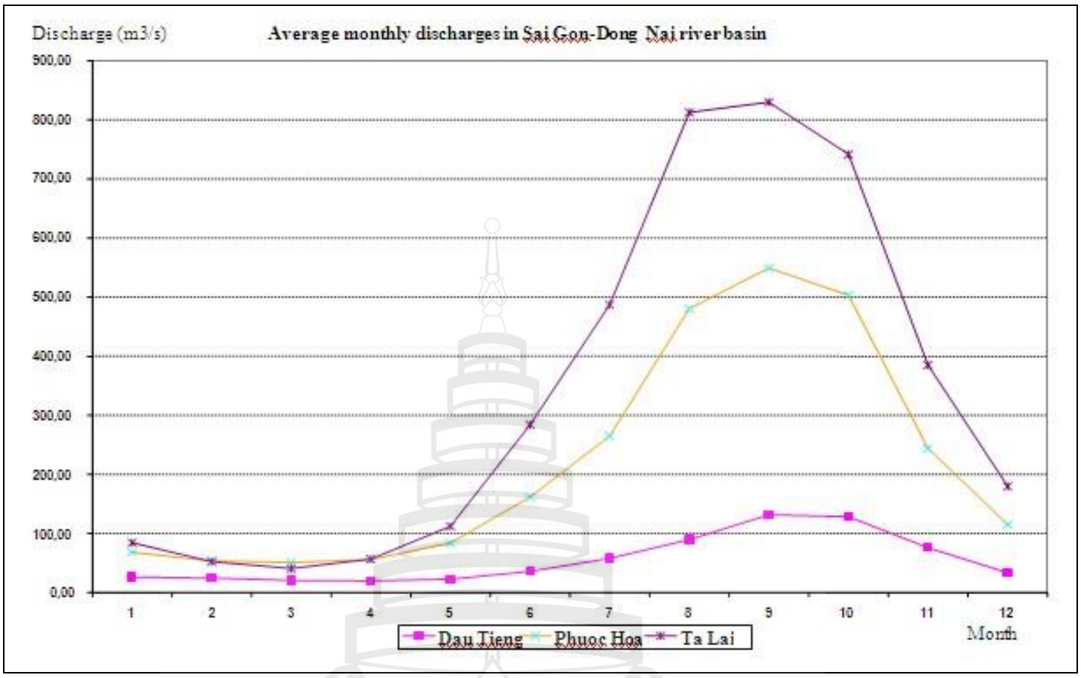
According to the previous researches, the total annual runoff of Sai Gon-Dong Nai watershed is approximate 36.6 billion m^3, in which total capacity inside of Vietnam is 32 billion m^3 (making 89%). (Center for Environmental Monitoring Portal, 2012). Table 3.2 shows the annual runoffs of the sub-rivers in Sai Gon-Dong Nai river basin.

Table 3.2 Annual Runoff of Sub-rivers in Sai Gon-Dong Nai River Basin

Rivers	Total annual runoff (billion m^3)
Dong Nai (including La Nga river)	33.622
Be	8.047
Sai Gon	2.948
Vam Co Dong	5.353

Source Center for Environmental Monitoring Portal (2012)

Flow in the Sai Gon-Dong Nai river basin is dominated mainly by rainfall regime and therefore it varies accordingly in terms of in space and time. The flooding season, which occurs from June to November, begins approximately one to two months after the rainy season which contributes 80% of the total annual flow. The dry season lasts over six months from December to May, with lowest flow in March or April or even in May. Generally, monthly flow records indicate highest totals in the August-October months, which are shows in the Figure 3.2.



Source Southern Institute of Water Resources Planning [SIWRP] (2009)

Figure 3.2 Average Monthly Discharges in Sai Gon-Dong Nai River Basin

3.1.2 The Feathers Related to Hydrodynamic Modeling

There are above 20 hydro-meteorological gauging stations spatially distributed in the watershed, which had been observed from 1978 until now. Table 3.3 indicates hydro-meteorological observations in Sai Gon-Dong Nai river basin.

Table 3.3 Hydro-meteorological Observations in Sai Gon-Dong Nai River Basin

ID	Station	Type of observed data	Period of data observation
1	Binh Long	Daily rainfall	1978-2007
2	Phuoc Hoa	Daily rainfall	1978-2008
		Daily water level	1976-2007
		Daily discharge	1980-2007
3	Phuoc Long	Daily rainfall	1978-2007
		Daily discharge	1988-1991
4	Dau Tieng	Daily rainfall	1978-2007
		Daily discharge	1976-1978
5	Loc Ninh	Daily rainfall	1978-2007
		Daily discharge	1975-1983
6	Can Dang	Daily rainfall	1978-2007
		Daily discharge	2000-2007
7	Tay Ninh	Daily rainfall	1978-2007
8	Moc Hoa	Daily rainfall	1978-2008
9	Tan An	Daily rainfall	1978-2007
		Hourly water level	1980-2007
10	Tan Son Nhat	Daily rainfall	1978-2007
11	Bien Hoa	Daily rainfall	1978-2007
		Hourly water level	1980-2007
12	Thong Nhat	Daily rainfall	1978-2007
13	Ta Lai	Daily rainfall	1978-2007
		Daily water level	1978-2005
		Daily discharge	2001-2006
14	Tri An	Daily rainfall	1979-2007
		Daily water level	1995-2007

Table 3.3 (continued)

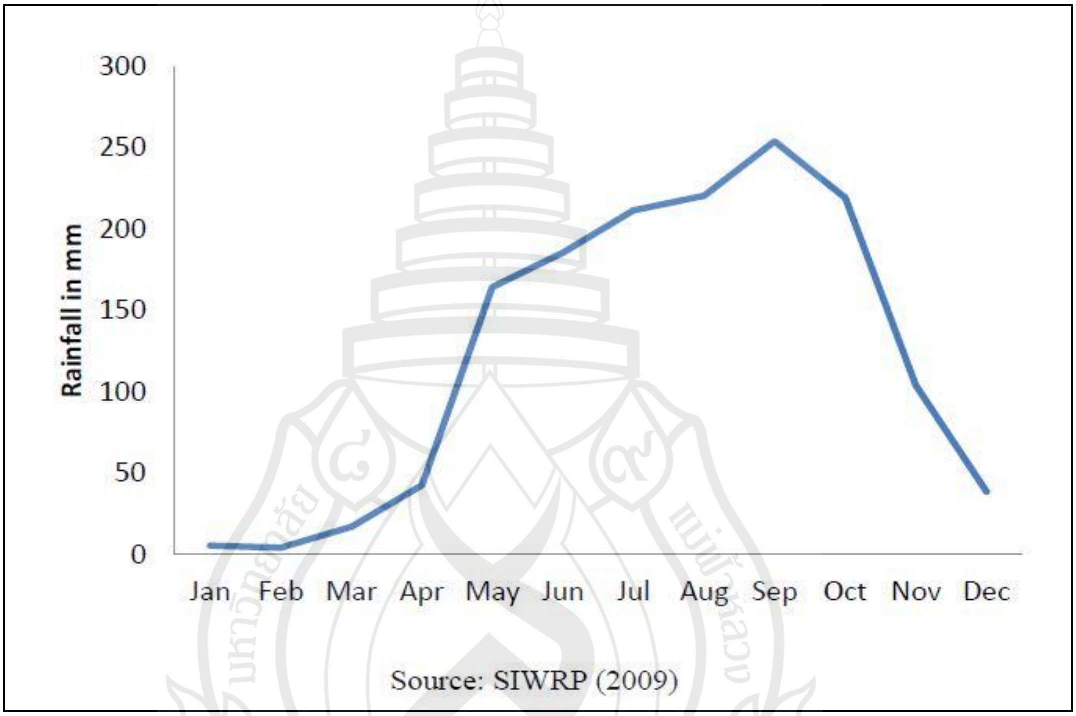
ID	Station	Type of observed data	Period of data observation
15	Ta Pao	Daily rainfall	1979-2007
		Daily water level	2002-2006
		Daily discharge	1981-2007
16	Bao Loc	Daily rainfall	1978-2007
17	Dac Nong	Daily rainfall	1978-2007
		Daily discharge	1981-2007
18	Da Lat	Daily rainfall	1978-2007
19	Dong Phu	Daily rainfall	1978-2007
20	Lien Khuong	Daily rainfall	1978-2007
21	Vung Tau	Daily rainfall	1978-2007
		Hourly water level	1980-2007
22	Phu An	Hourly water level	1980-2007
23	Nha Be	Hourly water level	1981-2007
24	Thu Dau	Hourly water level	1980-2007
25	Ben Luc	Hourly water level	1980-2007
26	Tan An	Hourly water level	1980-2007

Source Institute of Hydrology, Environment and Climate Change [IHEC] (2012)

Rainfall patterns

Rainfall is normally greater in the upstream area and the central area of the watershed (ranging from 2,200 to 2,800 mm) while is lower near the coastline (from 800 to 1,400 mm). The average annual rainfall in the basin is about 2,000 mm in the region and about 1,500 mm in the coastal area.

Rainfall is divided into two seasons; the rainy season represents approximately 87-93% of the annual total while the dry season is only 7-13%. The rainy season normally starts in May and ends in November, lasting approximately 7 months and reaching a peak during September to October. Figure 3.3 shows the average monthly rainfall in the watershed.



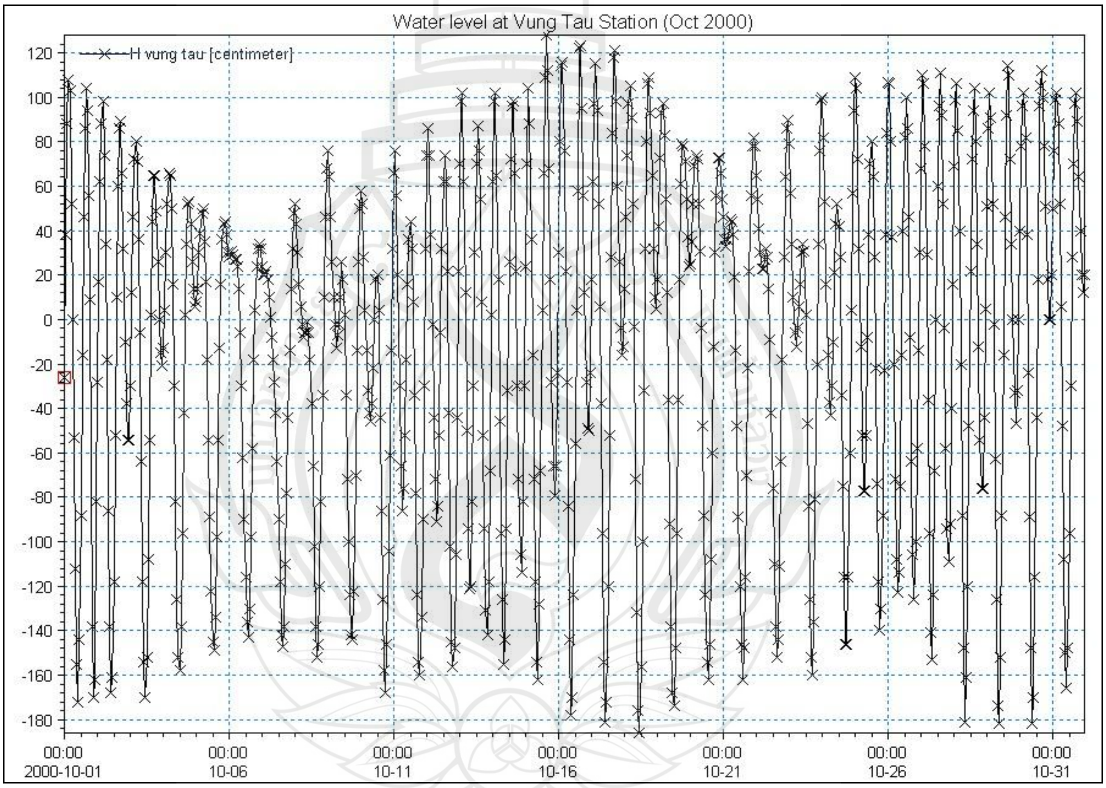
Source SIWRP (2009)

Figure 3.3 Average Monthly Rainfall from 1990 to 2006

Tide regime

The region is affected by irregular semi-diurnal tidal flow regime. It means that the tide flow suffers mostly 2 times rising and falling per day. The maximum water level reaches about 3.0m to 4.0m above MSL.

In term of temporal pattern, the highest water level occurs in October and November and the lowest water level occurs in June and August. Tide data is observed at Vung Tau station. Figure 3.4 shows the water level observed on October 2000 at Vung Tau station.



Source IHEC (2012)

Figure 3.4 Sea Water Level at Vung Tau Station

Reservoir systems

There are lots of existing and under-construction reservoirs in the upstream of the watershed, including irrigated reservoirs and hydropower dams. Dau Tieng in the upper Sai Gon tributary is the largest irrigated reservoir in Vietnam, covering a large area of 2,700 km^2. With the volume is 105 million m^3, it supplies water for irrigation and a clean water supply in Tay Ninh province and HCMC. The existing hydropower dams include Thac Mo, Da Nhim-Dai Ninh, Dong Nai 3, Ham Thuan-Da Mi and Tri An dams. Several additional reservoirs are also currently under construction. In which, Dau Tieng and Tri An reservoirs are two largest dams in the watershed, which are described in Table 3.4.

Table 3.4 Main Parameters of Dau Tieng and Tri An Reservoirs

Parameter	Dau Tieng reservoir	Tri An reservoir
Area (km^2)	2,800	14,800
Flood design frequency (m)	P = 0.1%	P = 0.1%
Normal water elevation (m)	24.4	62
Surcharged water elevation (m)	25.1	65.2
Dead water elevation (m)	17.0	50
Crest of dam elevation (m)	28.0	65
Total volume of water storage (bil.m^3)	1.58	2.74

Source SIWRP (2009)

3.1.3 Socio-economic Conditions

Social condition

The total population in the whole watershed is about 20 million people with average density of 296 people/km^2. In the lower watershed (including Long An, Tay Ninh, HCMC and Vung Tau), total population in the area amounts to more than 9 million inhabitants.

HCMC is the major city located on the estuary of the watershed, which the population is more than 7 million people with the highest density of 3,399 person/km^2 (2009), about 8.34% of the total population of Vietnam, making it the highest population-concentrated city in the country. As of the end of 2012, the total population of the city was 7,750,900 people, an increase of 3.1% from 2011. Table 3.5 shows the population indicators of HCMC

Table 3.5 Population Indicators in HCMC

Indicators	Ratio
Average annual growth rate (1999-2009)	3.5%
Sex ratio (the number of males per 100 females) in 2009	92.7
Population density (in 2009)	3,399 person/km^2
Urban population rate (in 2009)	83.2%

Source General Statistic Office (2009)

The city has been divided into twenty-four administrative divisions since December 2003. Five of these (area of 1601 km^2) are designated as rural. The rural districts are Nha Be, Can Gio, Hoc Mon, Cu Chi, and Binh Chanh. The other districts (area of 494 km^2) are designated urban. This includes Quan1, Quan 2, Quan 3, Quan 4, Quan 5, Quan 6, Quan 7, Quan 8, Quan 9, Quan 10, Quan 11, Quan 12, Tan Binh, Binh Thanh, Phu Nhuan, Thu Duc, Binh Tan, Tan Phu and Go Vap. The majority of the population is ethnic Vietnamese at about 93.52%, followed by Chinese with 5.78%, Khmer 0.34% and Cham 0.1%.

Economic condition

The Sai Gon-Dong Nai river basin is the economic center of the country in Southern Vietnam.

In the lower delta of the watershed, Long An and Tay Ninh have important agricultural production areas. Agriculture production is highly diversified, with products ranging from staple crops like rice, to raw materials for the local industry such as sugarcane, to high-valued crops like vegetables and fruits.

Industry and services are the key economic growth sectors. There are many industrial zones concentrated in the middle and lower river basin, including HCMC and such provinces like Dong Nai, Ba Ria-Vung Tau and Binh Duong.

HCMC accounted for over 23% of the country’s GDP in 2006 (ADB 2010). Rapid economic growth (11.3% annually between 2000 and 2007) has been the central driver behind the city’s expansion, as the increasing number and magnitude of income earning opportunities attract migrants from throughout Vietnam. There are about 30,000 factories in the industrial sector, including many large enterprises, high-technology, electronic, processing, light industries, construction, building materials and agro-products. Currently, HCMC has 15 industrial parks (IP) and export-processing zones. Export - Import Turnover through HCMC ports took 29 billion USD, or 40% of the national total. Ho Chi Minh City has also contributed about 30% to the national budget's revenue annually.

3.2 Methodology

3.2.1 Methodology Framework

Figure 3.5, Figure 3.6 and Figure 3.7 describe methodologies of the research.

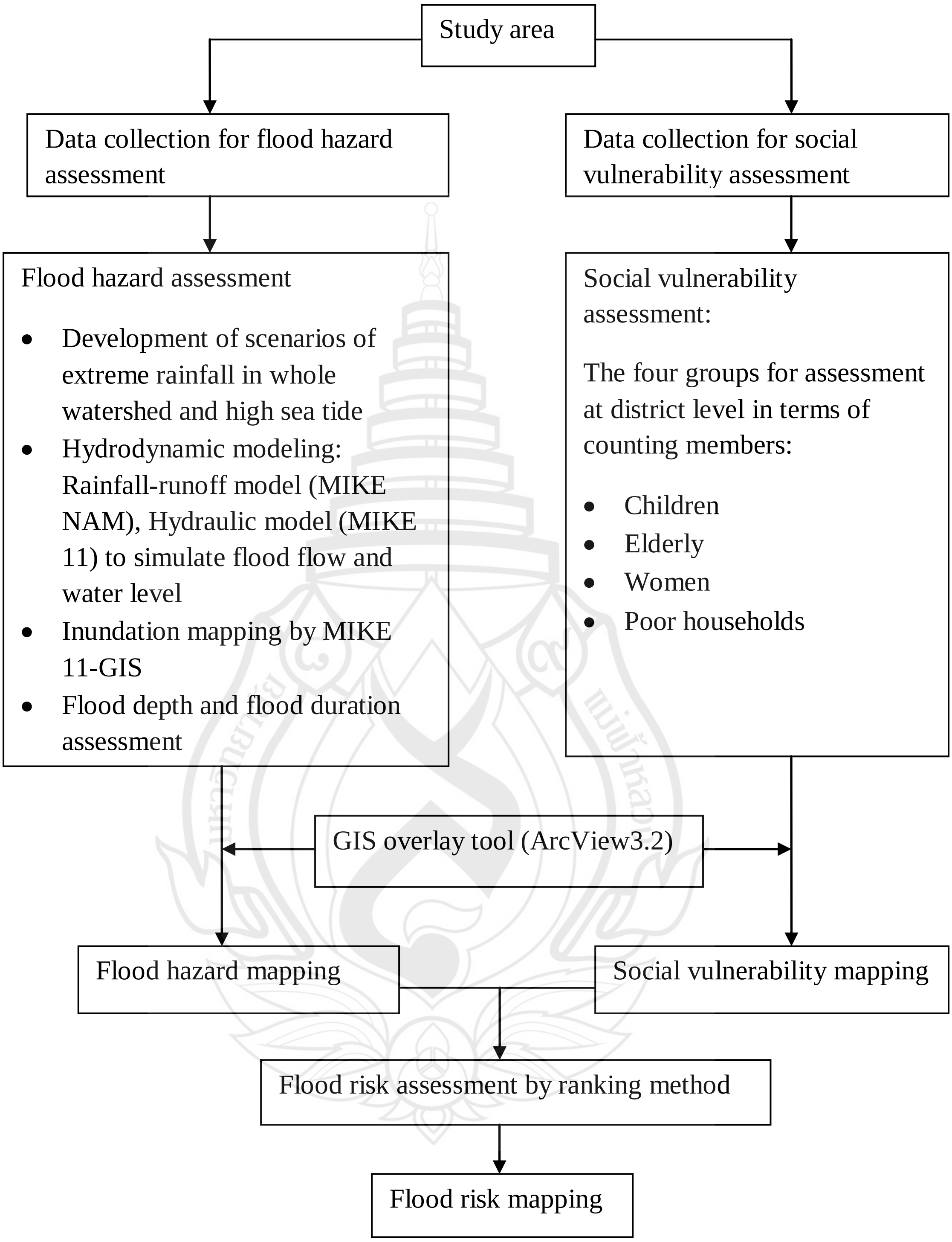


Figure 3.5 General Research Methodology

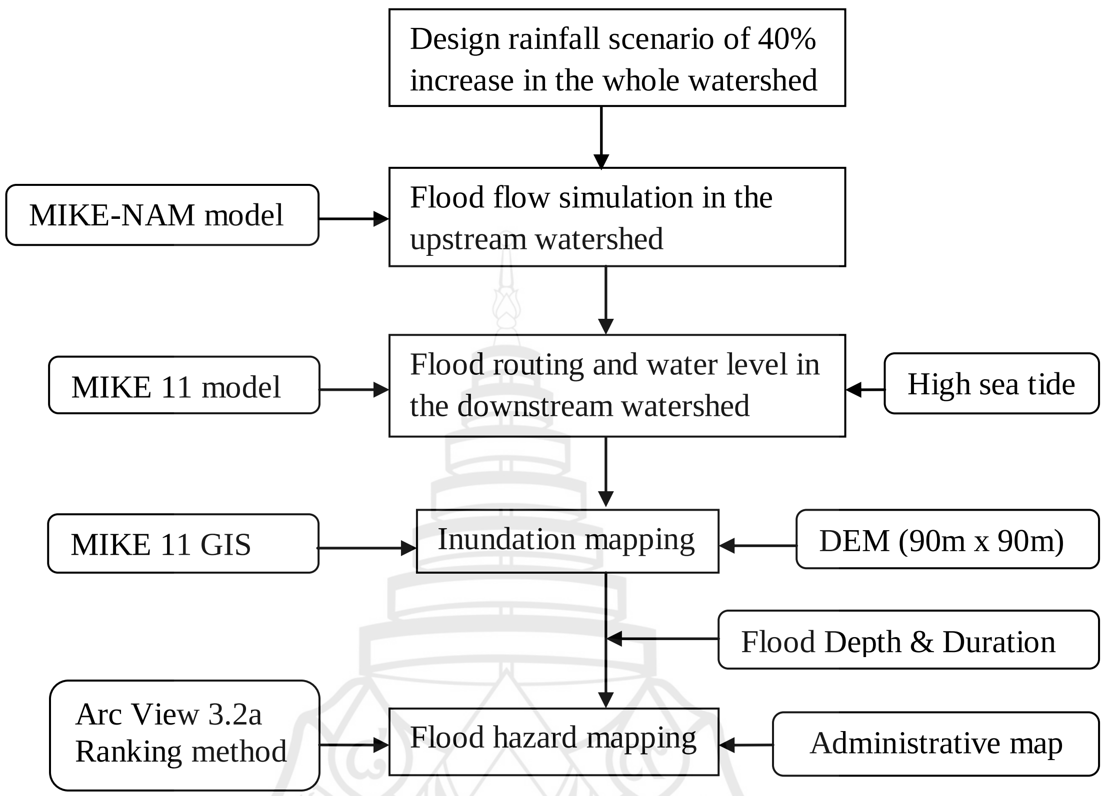


Figure 3.6 Methodology for flood hazard assessment

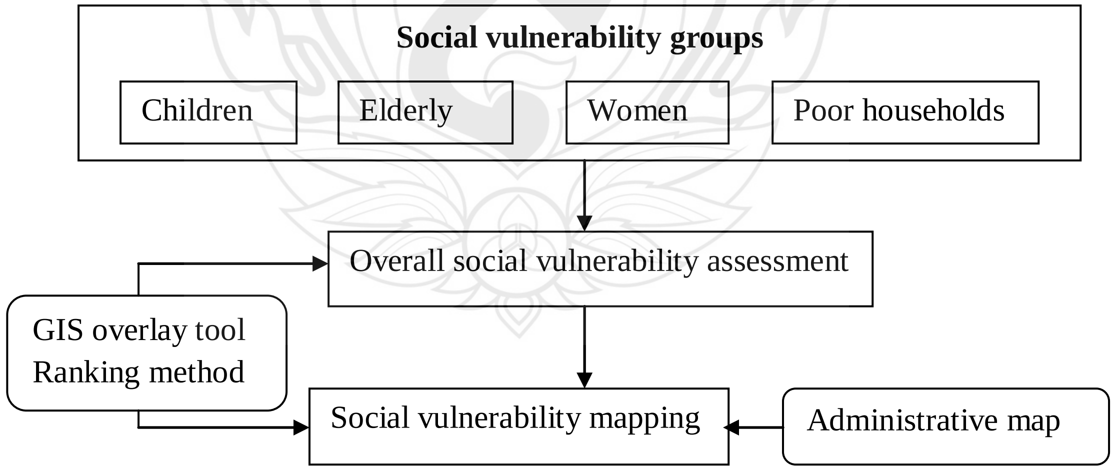


Figure 3.7 Methodology for Social Vulnerability Assessment

3.2.2 Method for Flood Hazard Assessment

3.2.2.1 Developing design hyetographs

Developing design hyetographs at each gauging station

Choosing a measured rainfall time-series (hyetograph) which has total rainfall is similar to design rainfall. The design hyetograph is obtained by using the following ratio:

$$R_{\mathrm{r}} = \frac{\mathrm{X}_d}{X_a}$$

Where:

R_r is the rainfall ratio

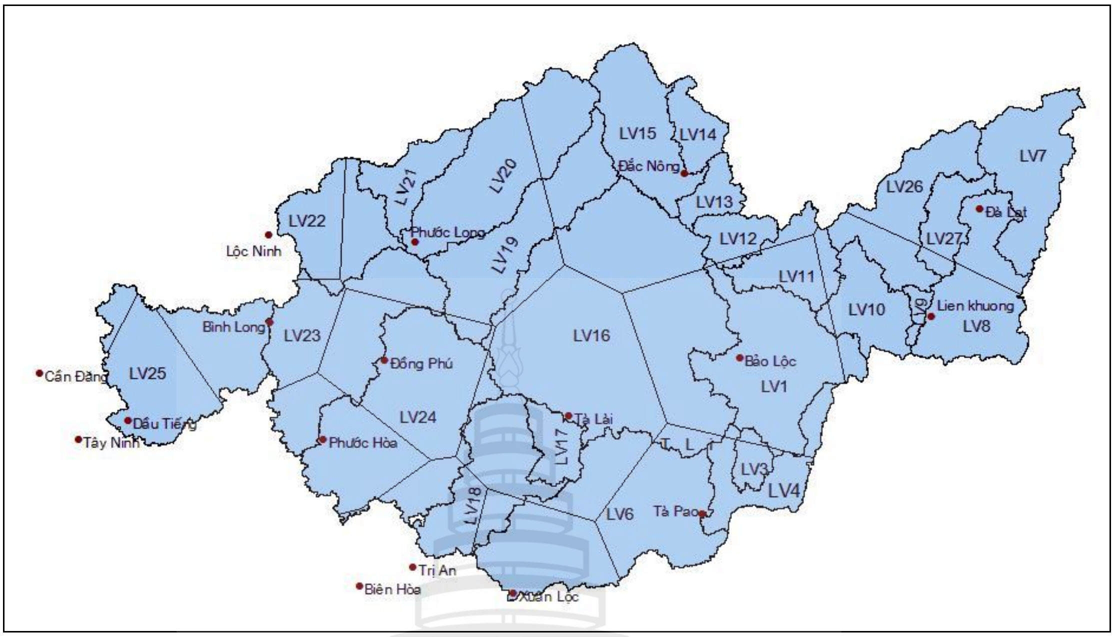
X_a is the total actual rainfall in a period.

X_d is the total design rainfall as the same period of actual rainfall.

Then, design hyetograph (X_d) = Actual hyetograph (X_a) × Ratio (R_r).

Estimating rainfall distribution at each sub-watershed

Thiessen method is used for estimation of the spatial distribution of rainfall. This method assigns weight at each gauge station in proportion to the catchment area that is closest to that gauge. Figure 3.8 shows the Thiessen polygon for rainfall distribution estimated of 25 sub-watersheds in the upstream Sai Gon-Dong Nai river basin. The weights are assigned from previous study from Hydrology, Environment and Climate Change Institute (IHEC), Hanoi Water Resources University of Vietnam, which are given in Appendix A2-1.



Source IHEC (2012)

Figure 3.8 Thiessen Polygon for Rainfall Distribution in Upper Sai Gon-Dong Nai River Basin

3.2.2.2 Method for developing design hydrographs

MIKE-NAM (DHI, 2007) is one of rainfall-runoff model; it can simulate runoff at any sub-watershed in the whole river basin. Adjusting parameters of MIKE NAM model which are already calibrated and verified by the observed data (according to IHEC, Hanoi Water Resources University of Vietnam), this model can be applied for estimating design discharge hydrographs. Design rainfall in the upstream Sai Gon –Dong Nai river basin. Information of NAM model is described in Appendix A.

3.2.2.3 Method for flood flow simulation

To simulate the flood flow in river basin network, MIKE 11 (DHI, 2007), the hydrodynamic model, is calibrated and verified by using collected data in the study area.

The upstream hydrographs corresponding obtained from output of MIKE-NAM are input at upstream boundary conditions of MIKE 11. The water levels at outlet stations are the input at downstream boundary condition. The outputs of model are the water level and discharge at every cross-sections. Parameters of MIKE 11 model which are already calibrated and verified by the observed data (according to IHEC, Hanoi Water Resources University of Vietnam) are adjusted. Information of MIKE 11 model is described in Appendix A.

3.2.2.4 Method for constructing inundation map

The results of maximum water levels at nodes along the rivers obtained from output of MIKE 11 and digital elevation map (DEM of 90m x 90m grid data for land elevation) are used for illustration the inundation maps by MIKE-11GIS (DHI, 2001).

MIKE 11 GIS constructs a grid based on water surface and compares this data with the developed DEM to produce flood depth map. So, flood inundation maps in HCMC will show the depth of flood water in low lying areas

3.2.2.5 Flood hazard assessment and mapping

Flood hazard assessment is estimated for the overall adverse effects of flooding, based on flood depth and duration, with the equal weight being used in this study. The intensity of flood hazard is ranked by a relative scale and is described as a hazard index (HI) as assumed in Table 3.6. The flood depth ranking is based on previous studies (e.g., Samarasinghe, 2010 and Tu, 2009). The flood duration is ranked by the study, which depended on the effect of high tide from sea.

Table 3.6 Hazard Index for Flood depth and Flood duration

Flood Depth (m)	Flood depth hazard index	Flood Duration (day)	Flood duration index
$0.1 < y \leq 0.5$	1	$1 < t \leq 3$ days	1
$0.5 < y \leq 1$	2	$3 < t \leq 21$ days	2
$1 < y \leq 1.5$	3	$21 < t \leq 30$ days	3
$y > 1.5$	4		

The final hazard index for each district is then normalized relatively to the maximum value. Five levels of hazard to present the hazard magnitude are used, as in Tu (2009), starting from Very low (0% < HI ≤ 20%), to Low (20% < HI ≤ 40%), then Medium (40% < HI ≤ 60%), and High (60% < HI ≤ 80%), and Very high (80% < HI ≤ 100%).

3.2.3 Social Vulnerability Assessment and Mapping

Based on data availability, the social vulnerability assessment is only conducted at the district level. All 24 districts in HCMC are considered in terms of major vulnerable social groups, namely (1) the children (population under 15 years of age), (2) the elderly (population over 65 years of age), (3) the women (female population), and (4) the poor households (low income households). Important justifications for selecting these indicators are provided in Table 3.7.

Table 3.7 Social Vulnerability Indicators

Indicator	Description (for each district)	Key justifications
Children	# of people under 15 years old	Physically weak; susceptible to health related problems; limited mobility; incapability/difficulties in decision making and disaster response
Elderly	# of people over 65 years old	Limited mobility; more reluctant to leave home; less informed; no one to aid them; suffering more health related issues; physically weaker
Women	# of females	Physically disadvantaged; slower recovery; higher domestic labor; increased stress and emotion; more likely to be poor
Poor households	# of poor households	Differential access to resources; higher financial instabilities from damages

Note Adapted from Peck et al. (2007)

For each social indicator above, its value is ranked by a common score scale (from 1 to 5). The overall social vulnerability index (SoVI) is evaluated as the average of all the social indicator values; and then normalized relatively to the maximum value for percentage ranking. Similarly to the hazard index, social vulnerability is categorized into 5 levels from Very low (0% < SoVI ≤ 20%), to Low (20% <SoVI ≤ 40%), and Medium (40% < SoVI ≤ 60%), then High (60% < SoVI ≤ 80%), and Very high (80% < SoVI ≤ 100%).

3.2.4 Flood Risk Assessment and Mapping

Flood risks in this study are considered as the multiplicative combination of both the flood hazard and social vulnerability, which is widely used in the literature; and are assessed for each district in HCMC, as expressed in terms of percentage, in the following formula.

$$Risk\ index\ (RI) = Hazard\ index\ (HI) \times Vulnerability\ Index\ (SoVI)$$

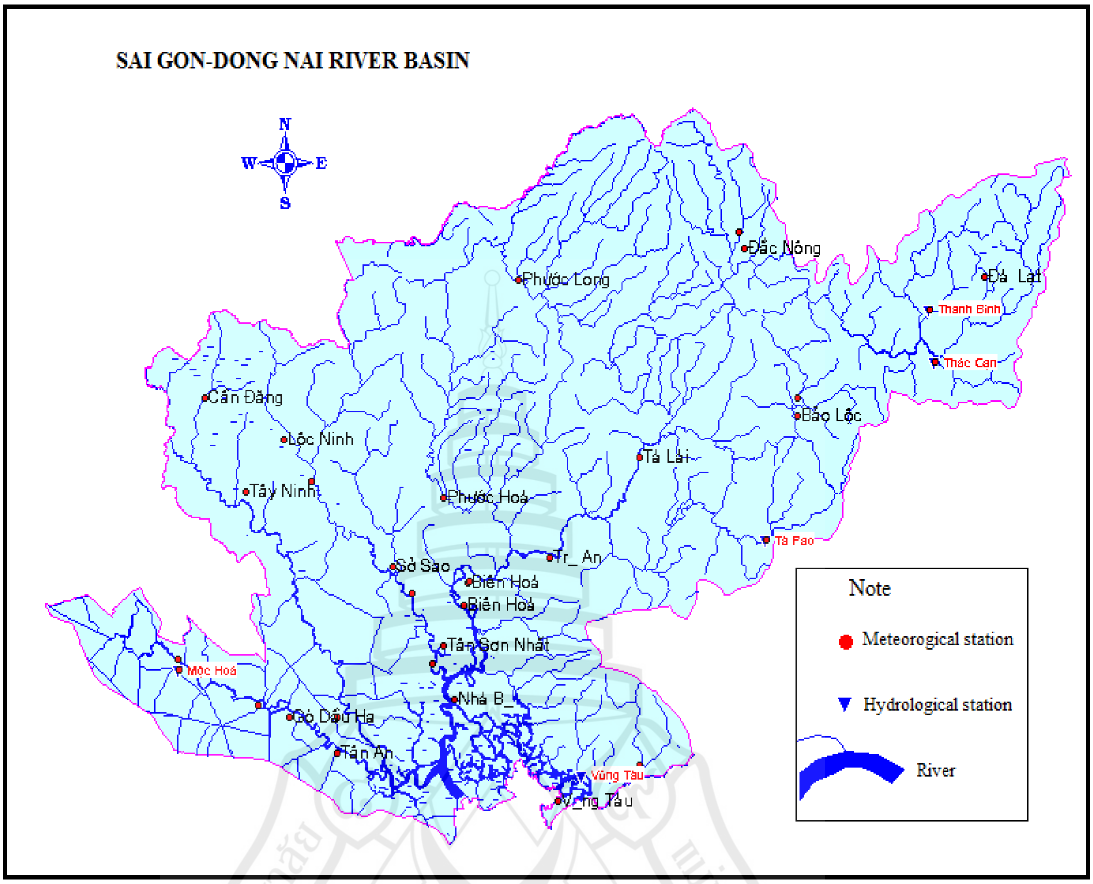
The risk index, for simple priority, is then categorized into five equal-interval levels (Very low, Low, Medium, High, and Very high).

3.3 Data to be Used

3.3.1 Physical Data

3.3.1.1 Hydro-meteorological data, maps and modeling parameters

Data inputs to the hydrodynamic model for simulating flood flows consist of design daily rainfalls data of the scenario of 40% rainfall increase from the average in the whole watershed, which is assumed and designed for each gauging station from available 21 gauged stations for 30 years (from 1978 to 2007), water level data from the sea (based on the maximum value occurred in the past for flooding months), and river geometry. All of the gauge datums are referred to Mean Sea Level (MSL). Figure 3.9 shows the gauging observation network in Sai Gon-Dong Nai river basin. Sea water level data inputs and downstream Sai Gon-Dong Nai river network are given in Figure 3.10 and Figure 3.11.



Source National Centre for Hydro-meteorological Forecasting [NCFHF] (2012)

Figure 3.9 Gauging Stations in Sai Gon-Dong Nai Watershed

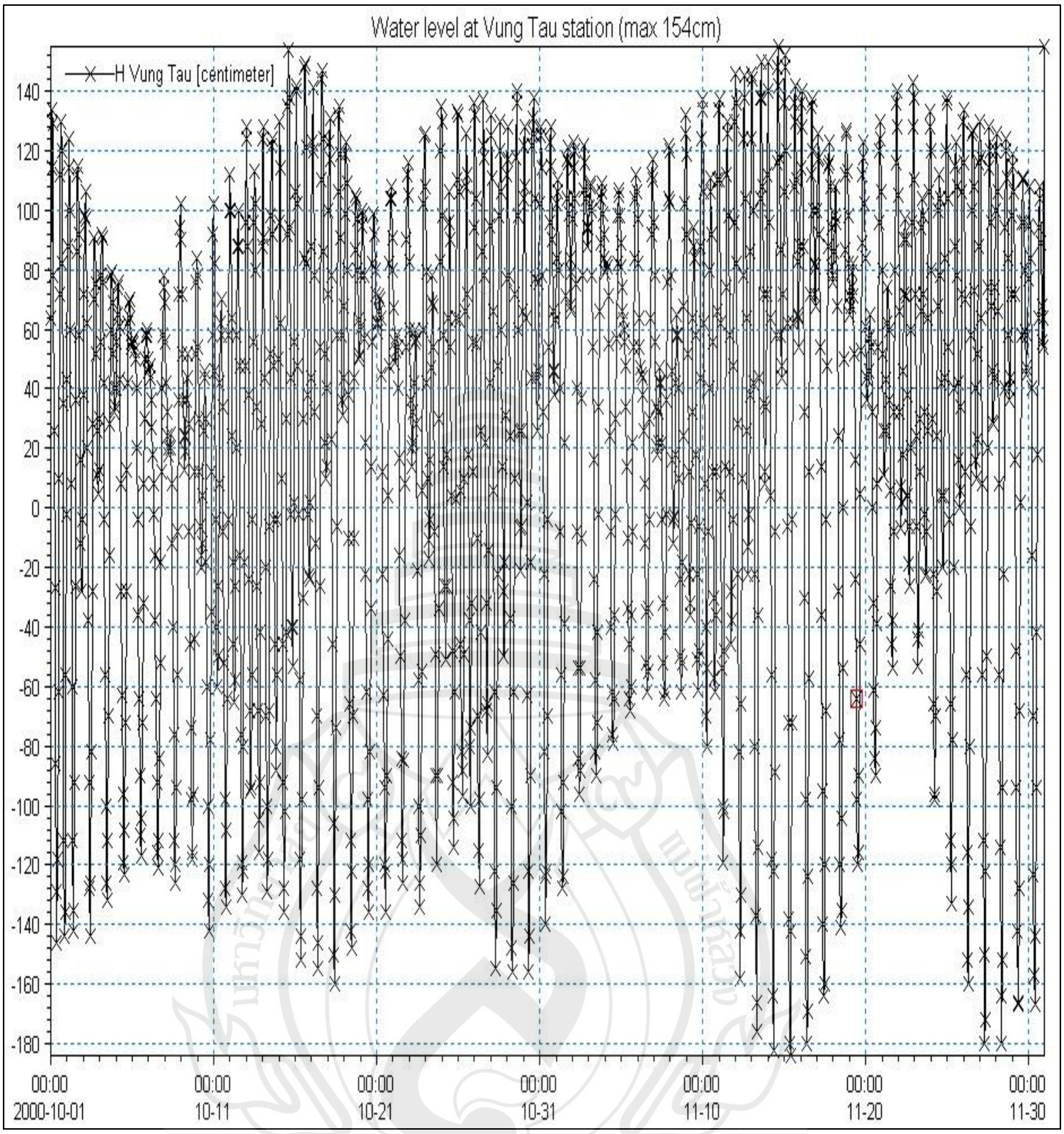
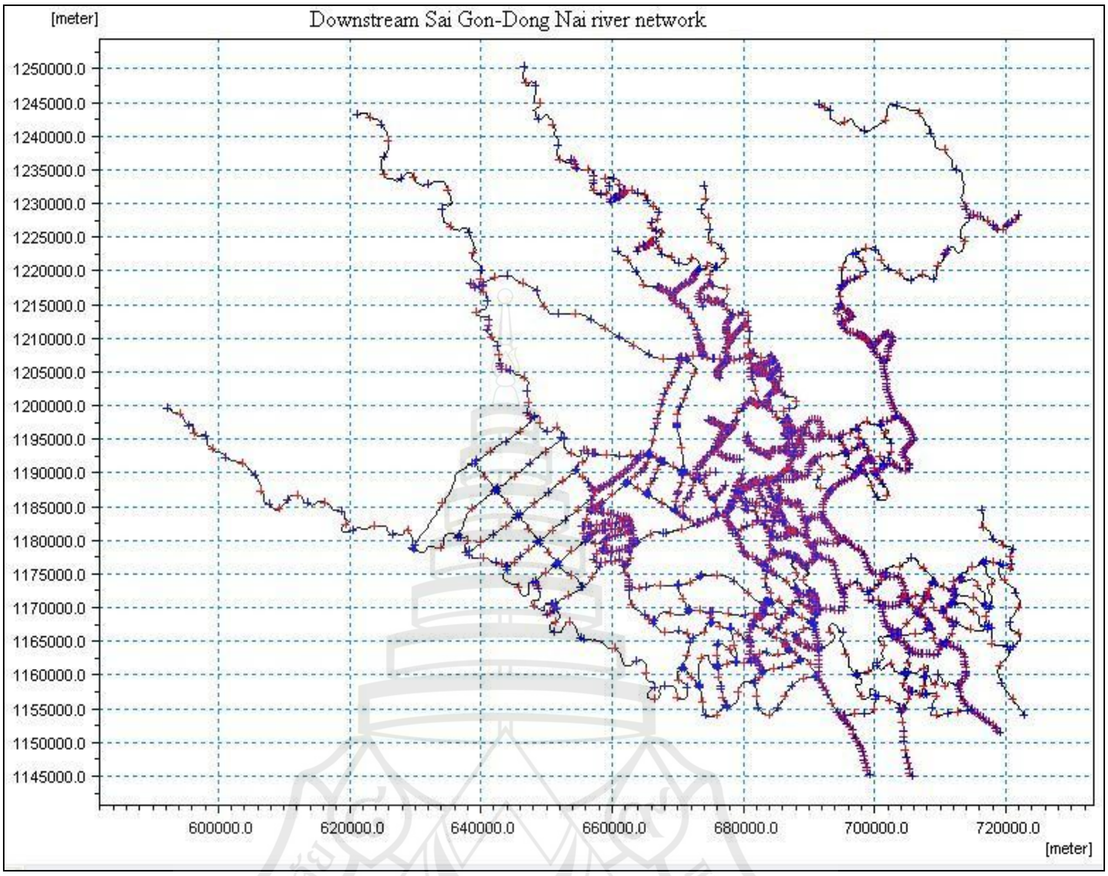


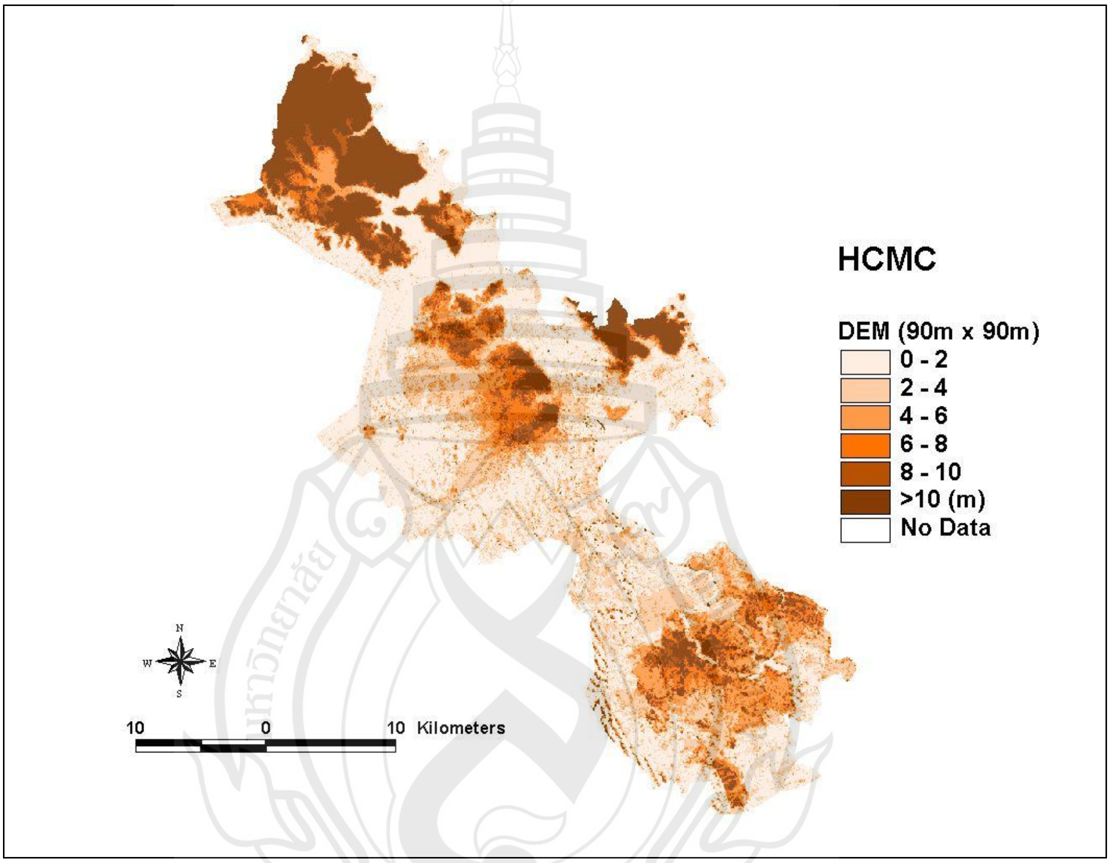
Figure 3.10 Scenario of Sea Water Level at Vung Tau Station



Source IHEC (2012)

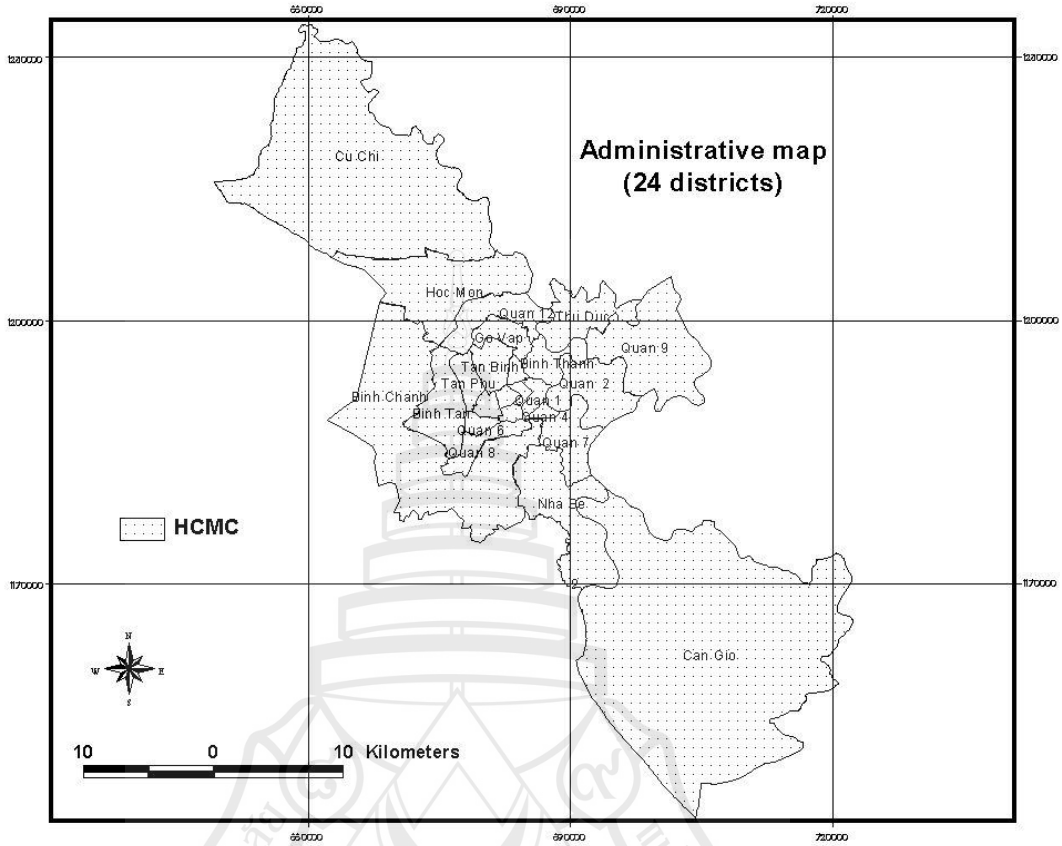
Figure 3.11 Downstream Sai Gon-Dong Nai River Network

Digital Elevation Model (DEM) of 90m x 90 m for HCMC used for generating inundation maps and Digital administrative maps with scale 1:700,000 used as the baseline for hazard, social vulnerability and risk maps are shown in Figure 3.12 and Figure 3.13.



Source IHEC (2012)

Figure 3.12 Digital Elevation Model (DEM) of HCMC



Source IHEC (2012)

Figure 3.13 Administrative Map of HCMC's Districts

All these data above are collected from the Institute of Hydrology, Environment and Climate Change (IHEC), Hanoi Water Resources University of Vietnam.

The parameters of hydrodynamic model (MIKE NAM and MIKE 11) are adapted from on the previous research studies (from IHEC, Hanoi Water Resources University, Vietnam) which are given in Appendix B.

3.3.1.2 Historical floods and reservoirs information

Reports on historical floods in October in 2000 and 2007 are also reviewed for reference, together with the regulation information for the two largest reservoirs upstream (Dau Tieng and Tri An reservoirs). These data are collected from and Southern Institute of Water Resources Planning (SIWRP) of Vietnam.

3.3.2 Social Data

All 24 districts in HCMC are considered in terms of major vulnerable social groups, namely (1) the children (population under 15 years of age), (2) the elderly (population over 65 years of age), (3) the women (female population), and (4) the poor households (low income households). The first three data groups are based from the Census data in 2009 collected from General Statistics Office of Vietnam, while the last one from the previous study as by Cuong (2009). Data of population and poverty of HCMC are given in Appendix C.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Inundation Assessment

Inundation assessment for HCMC is done gradually by four steps, namely (1) designing new rainfall scenarios, (2) calculating flood flow from the upstream, (3) simulating flood routing and water level in the downstream and (4) constructing inundation maps. The detail results for these steps are described as following.

4.1.1 Developing Design Rainfall Scenarios

The design new rainfall scenario of 40% increase in the whole watershed during the rainy season (from May to November) over the average of 30 years (from 1978 to 2007) is designed at each gauging station, which is illustrated in Figure 4.1. This figure also shows the variety of spatial rainfall distribution in the whole watershed.

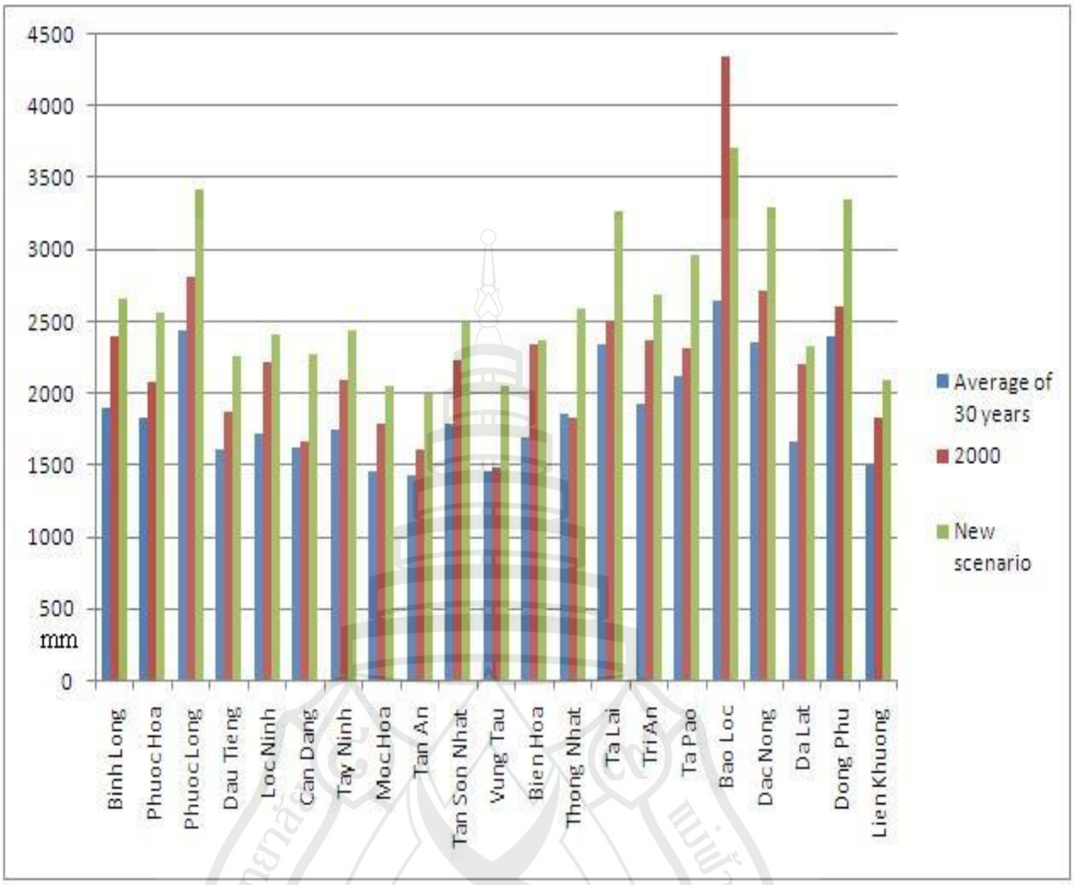


Figure 4.1 Accumulated Rainfall Scenario During Rainy Season at Gauging Stations

Table 4.1 describes the design rainfall scenario of 40% above the average for each gauging station, based on the actual rainfall (from 1 May to 31 October in 2000). For modeling calculation, design hyetographs are then developed for one month (daily rainfall from 1 Oct to 31 Oct). Hyetograph is a measured rainfall time-series which has total rainfall is similar to design rainfall. These design hyetographs will be used an input to flood flow simulation.

Table 4.1 Design Rainfall Scenario at Gauging Stations in the Whole Watershed (mm)

ID	Station	Accumulated rainfall from May to November (mm)		Ratio (X_d/X_a)
		Actual rainfall (X_a) (in 2000)	Design rainfall (X_d)	
1	Binh Long	2392	2660	1.11
2	Phuoc Hoa	2072	2559	1.23
3	Phuoc Long	2812	3421	1.22
4	Dau Tieng	1867	2252	1.21
5	Loc Ninh	2219	2411	1.09
6	Can Dang	1659	2270	1.37
7	Tay Ninh	2087	2438	1.17
8	Moc Hoa	1792	2047	1.14
9	Tan An	1609	2002	1.24
10	Tan Son Nhat	2232	2496	1.12
11	Vung Tau	1485	2048	1.38
12	Bien Hoa	2346	2369	1.01
13	Thong Nhat	1831	2593	1.42
14	Ta Lai	2510	3274	1.30
15	Tri An	2365	2689	1.14
16	Ta Pao	2314	2970	1.28
17	Bao Loc	4341	3713	0.86
18	Dac Nong	2711	3293	1.21
19	Da Lat	2199	2332	1.06
20	Dong Phu	2600	3348	1.29
21	Lien Khuong	1834	2098	1.14

4.1.2 Caculating Flood Flow from Upstream

The design flood flows are simulated for one month (from 1 Oct to 31 Oct). By using rainfall-runoff (MIKE NAM) model, with the input of design hyetographs for upstream of the watershed, the corresponding design upstream hydrographs are determined, as illustrated in Figure 4.2.

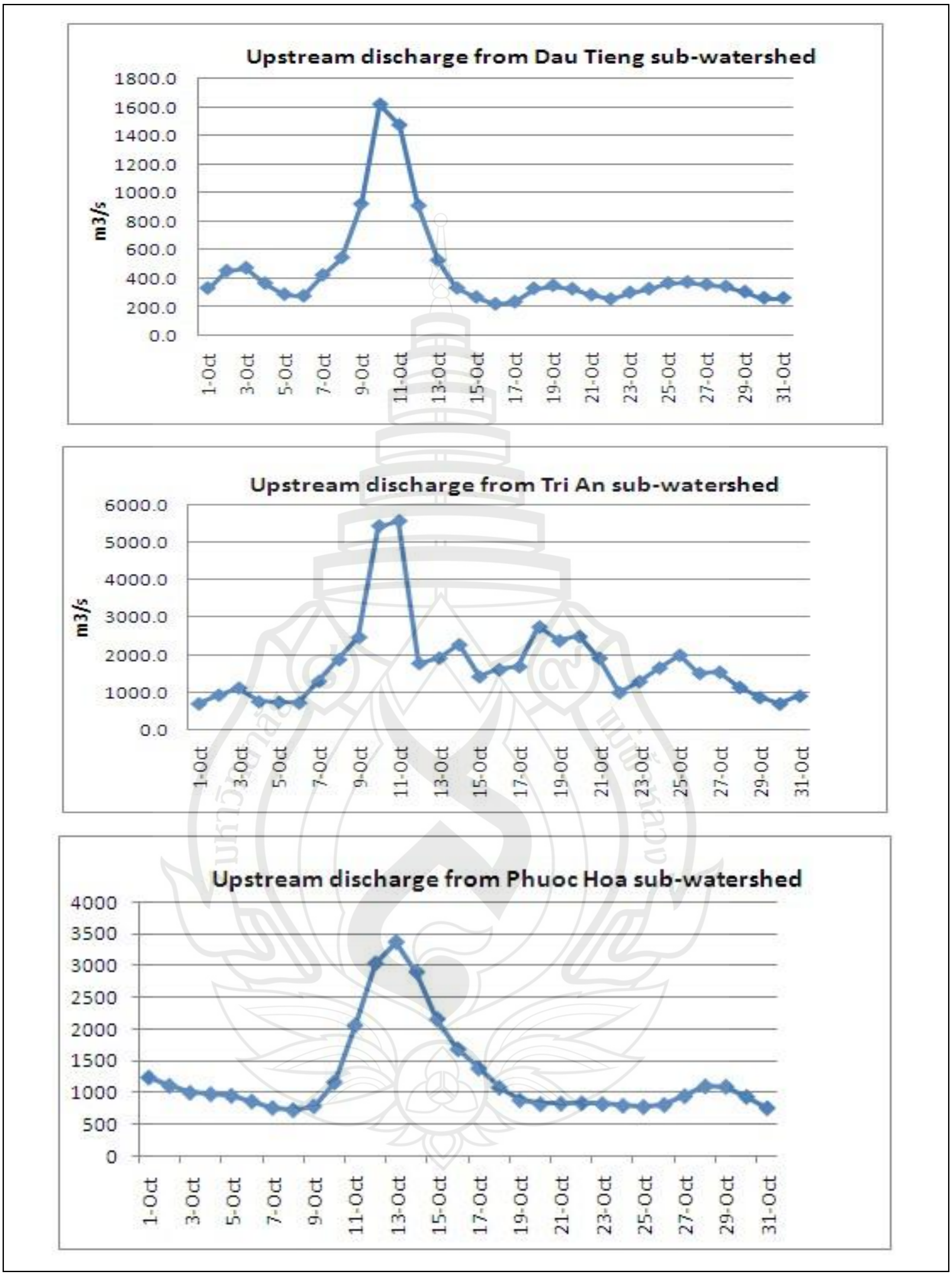


Figure 4.2 Design Upstream Hydrographs from MIKE NAM Model Results

These upstream hydrographs above then are regulated by Dau Tieng and Tri An reservoirs. To refelect upstream flood flows after two reservoirs, the two typical cases are considered for simulation, namely Case 1 (non-regulated reservoirs) to present equality between the inflows and outflows at these resevoirs, and Case 2 (reulated reservoirs) to reduce the peak of flood outflows to downstream, which is regulated from 5500 m^3/s to 4000 m^3/s at Tri An reservoir, and from 1600 m^3/s to 800 m^3/s at Dau Tieng reservoir, as indicated in Figure 4.3 (for the regulated reservoirs scenarios).

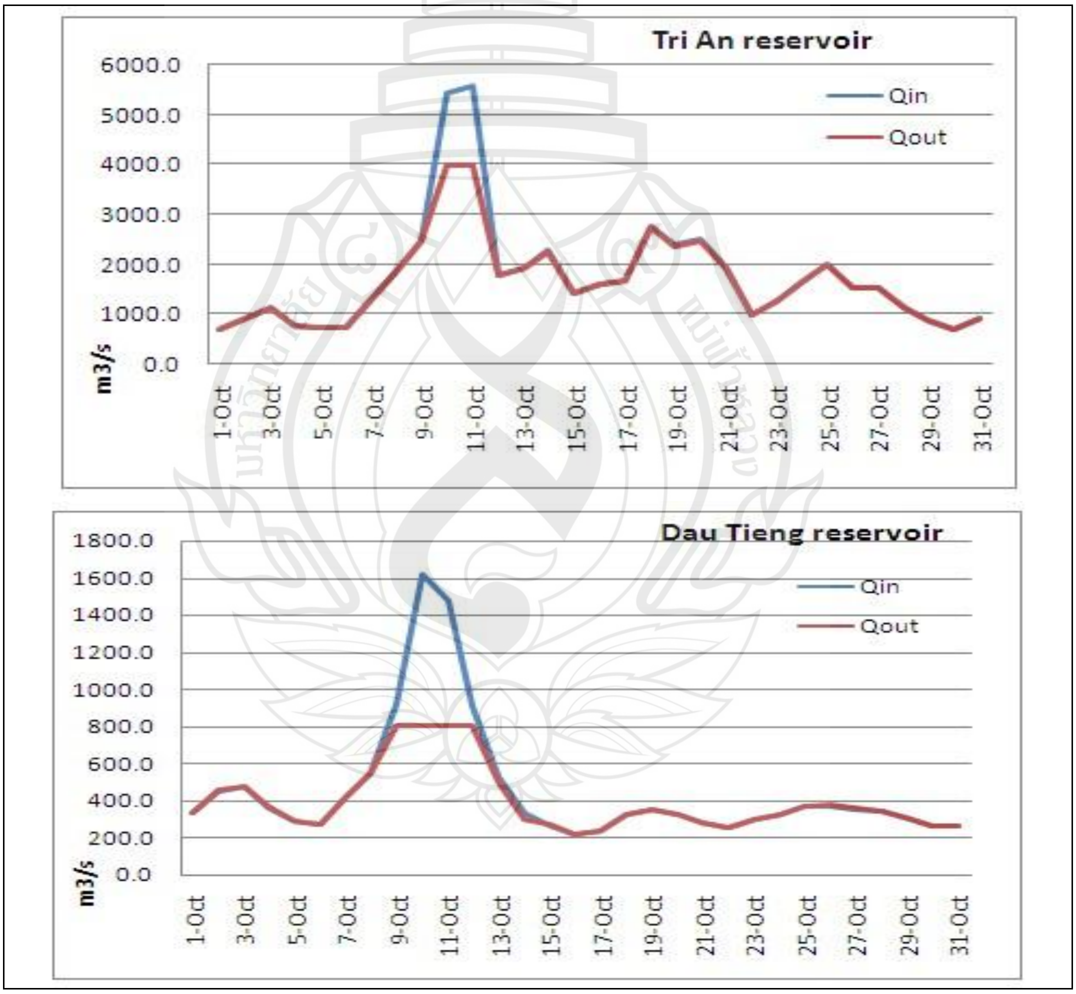


Figure 4.3 Regulated Flows Scenarios at Tri An and Dau Tieng Reservoirs

4.1.3 Simulating Flood Routing and Water Level in the Downstream

By using hydrodynamic (combination of MIKE NAM and MIKE 11) models, with the inputs of upstream boundary (flood flow from upstream), downstream boundary (high sea tide level) and design hyetographs of local rainfall, the corressponding discharges and water level at difference points in the downstream are calculated.

4.1.4 Inundation Mapping

Inundation maps, based on the outputs from the hydrodynamic model (discharges and water levels) and the DEM, are shown in Figures 4.4 for Case 1 (non-regulated reservoirs) and Case 2 (regulated reservoirs), which already acount for the new design rainfall sceario, assumed discharges from upstream and under another boundary condition of the high sea tid for HCMC. The comparison indicates that reservoirs regulations help reduce remarkedly the peak of water levels downstream of reservoirs at some dowstream locations not too far from the resevois (namely, from 3m to 1.72m at some points in Cu Chi district in terms of the maximum flooding depth). However, no significant reductions are seen in other inundated zones, which is mainly because of additonal impacts from the high tides.

The total flooding areas are then computed, based on the maximum water level computed by the model overlaid with the area map, and resulted at about 1,318 km^2 (63% HCMC's area) in Case 1 (non-regulated reservoirs) and 1,257 km^2 (60% of HCMC's area) in Case 2 (regulated reservoirs), which are higher than the baseline data in the year 2000 with the total inundated area of only 50%. These figures are considered as rough estimation only (due to the rough DEM being available for use), and no significant difference between the two cases are observed because only the inundated areas are considered rather than the actual flood depth variations. Table 4.2 shows the flooded areas of districts in HCMC in Case 1. Due to located at the lowland areas, Nha Be, Can Gio, Quan 7, Quan 8, Quan 4, Quan 1, Quan 2 and Binh Thanh are districts which almost areas are flooded. Furthermore, the number of downstream communes affected by flooding, through overlay techniques, is assessed at about 185 (accounting for 57.4 % from a total of 322 communes in HCMC).

Table 4.2 Flooded Areas at Districts in HCMC in Case 1 (Non-regulated Reservoirs)

ID		Total area (km^2)	Flooded area (km^2)	Percentage (%)
1	Can Gio	704	600	85
2	Nha Be	100	91	91
3	Binh Chanh	253	195	77
4	Binh Tan	52	25	48
5	Quan 7	36	36	100
6	Quan 8	19	19	100
7	Quan 6	7	3	47
8	Quan 5	4	1	14
9	Quan 4	4	4	100
10	Quan 3	4	2	46
11	Quan 1	8	8	100
12	Quan 2	50	43	86
13	Binh Thanh	21	17	82
14	Quan 12	53	16	31
15	Thu Duc	48	13	27
16	Quan 9	114	73	64
17	Cu Chi	435	84	19
18	Hoc Mon	109	36	33
19	Tan Binh	22	0	0
20	Tan Phu	16	0	0
21	Quan 11	5	0	0
22	Quan 10	6	0	0
23	Phu Nhuan	5	0	0
24	Go Vap	20	0	0
	HCMC	**2095**	**1318**	**63**

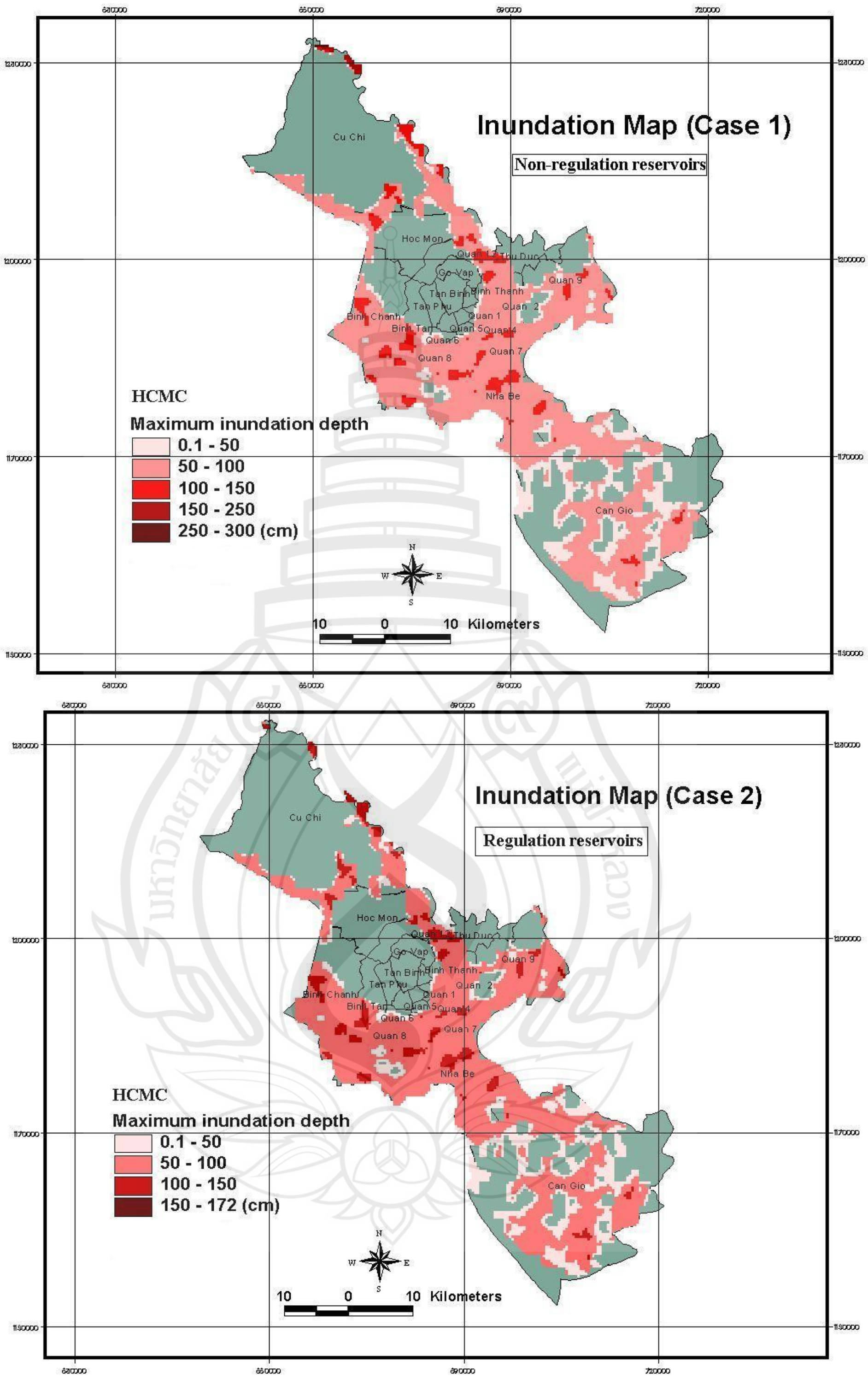


Figure 4.4 Inundation Maps for HCMC (under High Rainfall and High Tide)

4.2 Flood Hazard Assessment

Flood hazard maps are developed for each district of HCMC under the combination of three factors (new rainfall scenario, upstream flooding and high sea tide). It is noted that the flood hazards for Case 1 (non-regulated reservoirs) and Case 2 (regulated reservoirs), after caculation, are not of significant diffirence in terms of the specified hazard indices at a district level. Thus, only Case 1 is used for subsequent assessment of flood hazard and then flood risks. Flood hazard maps are generated by overlaying flood hazard index at the district level and administrative maps.

4.2.1 Compution of Flood Hazard Index

Based on the categorized hazard indices which are mentioned in 3.2.2.5, the results of weighted hazard index of flooding depth for each district are shown in Table 4.3. There are 18 districts which are flooded and suffer different level of flooding depth. Mostly these districts experience the depth from 0.5 to 1m. However, there are some points (in Cu Chi and Quan 12 districts) are up to very high level of flood depth (from 1.5 to 3m), due to the effect of flooding from upstream. Table 4.4 describes the weighted hazard index of flooding duration and overall flood hazard index for each district. The cause of differences on flooding duration is due to the influence of high tide regime. The districts located near the coastal line suffer shorter flooding duration than the districts located far to the sea. Finally, Table 4.5 shows the overall flood hazard index and hazard zone for districts in HCMC.

4.2.2 Flood Hazard Mapping

The result of flood hazard mapping for all 24 districts in HCMC is presented in Figure 4.5.Almost districts suffer the very high level of flood hazard, especially, these four highest ones (including Quan 7, Quan 4, Nha Be and Binh Chanh), which are located in the West-South of the city center, experience both high level of flood depth and duration.

Table 4.3 Weighted Hazard Index of Flood Depth

ID	District	Percentage of area categorized following flood depth (%)				Weighted hazard index of flood depth
		$0.1<y<50$ cm HI = 1	$50<y<100$ cm HI = 2	$100<y<150$ cm HI = 3	$150<y<300$ cm HI = 4	
1	Quan 5	10.7	3.6	0.0	0.0	0.18
2	Quan 3	25.0	21.4	0.0	0.0	0.68
3	Can Gio	30.5	53.0	1.5	0.0	1.41
4	Quan 6	14.3	32.7	0.0	0.0	0.80
5	Quan 2	11.7	74.1	0.0	0.0	1.60
6	Quan 8	10.3	89.0	0.7	0.0	1.90
7	Quan 1	5.4	94.7	0.0	0.0	1.95
8	Quan 9	6.8	52.9	4.3	0.0	1.25
9	Binh Thanh	7.5	66.0	8.2	0.0	1.64
10	Hoc Mon	4.1	25.3	3.9	0.0	0.67
11	Quan 4	0.0	100.1	0.0	0.0	2.00
12	Binh Chanh	4.6	65.1	7.6	0.0	1.57
13	Nha Be	2.0	82.1	7.1	0.0	1.88
14	Binh Tan	4.9	33.3	9.9	0.0	1.01
15	Thu Duc	0.9	21.7	4.5	0.0	0.58
16	Quan 7	2.0	82.3	15.7	0.0	2.14
17	Cu Chi	2.5	12.9	2.7	1.2	0.41
18	Quan 12	1.3	16.5	12.9	0.3	0.74
19	Tan Binh	0	0	0	0	0
20	Tan Phu	0	0	0	0	0
21	Quan 11	0	0	0	0	0
22	Quan 10	0	0	0	0	0
23	Phu Nhuan	0	0	0	0	0
24	Go Vap	0	0	0	0	0

Table 4.4 Weighted Hazard Index of Flood Duration and Overall Flood Hazard Index

ID	District	Weighted hazard index of flood depth	Weighted hazard index of flood duration			Overall flood hazard index
			1-3 days HI = 1	3-21 days HI = 2	30 days HI = 3	
1	Quan 5	0.18	1			0.59
2	Quan 3	0.68				0.34
3	Can Gio	1.41		2		1.71
4	Quan 6	0.80		2		1.40
5	Quan 2	1.60		2		1.80
6	Quan 8	1.90		2		1.95
7	Quan 1	1.95		2		1.97
8	Quan 9	1.25		2		1.63
9	Binh Thanh	1.64		2		1.82
10	Hoc Mon	0.67			3	1.83
11	Quan 4	2.00			3	2.50
12	Binh Chanh	1.57			3	2.29
13	Nha Be	1.88			3	2.44
14	Binh Tan	1.01			3	2.01
15	Thu Duc	0.58			3	1.79
16	Quan 7	2.14			3	2.57
17	Cu Chi	0.41			3	1.71
18	Quan 12	0.74			3	1.87
19	Tan Binh	0				0
20	Tan Phu	0				0
21	Quan 11	0				0
22	Quan 10	0				0
23	Phu Nhuan	0				0
24	Go Vap	0				0

Table 4.5 Overall Flood Hazard Index and Hazard Zone for Districts in HCMC

ID	District	Overall flood hazard index	Normalized overall flood hazard index (%)	Flood hazard zone
1	Tan Binh	0	0	No hazard
2	Tan Phu	0	0	No hazard
3	Quan 11	0	0	No hazard
4	Quan 10	0	0	No hazard
5	Phu Nhuan	0	0	No hazard
6	Go Vap	0	0	No hazard
7	Quan 5	0.59	23	low
8	Quan 3	1.34	52	medium
9	Quan 6	1.40	54	medium
10	Quan 9	1.63	63	high
11	Cu Chi	1.71	66	high
12	Can Gio	1.71	67	high
13	Thu Duc	1.79	70	high
14	Quan 2	1.80	70	high
15	Binh Thanh	1.82	71	high
16	Hoc Mon	1.83	71	high
17	Quan 12	1.87	73	high
18	Quan 8	1.95	76	high
19	Quan 1	1.97	77	high
20	Binh Tan	2.01	78	high
21	Binh Chanh	2.29	89	very high
22	Nha Be	2.44	95	very high
23	Quan 4	2.50	97	very high
24	Quan 7	2.57	100	very high

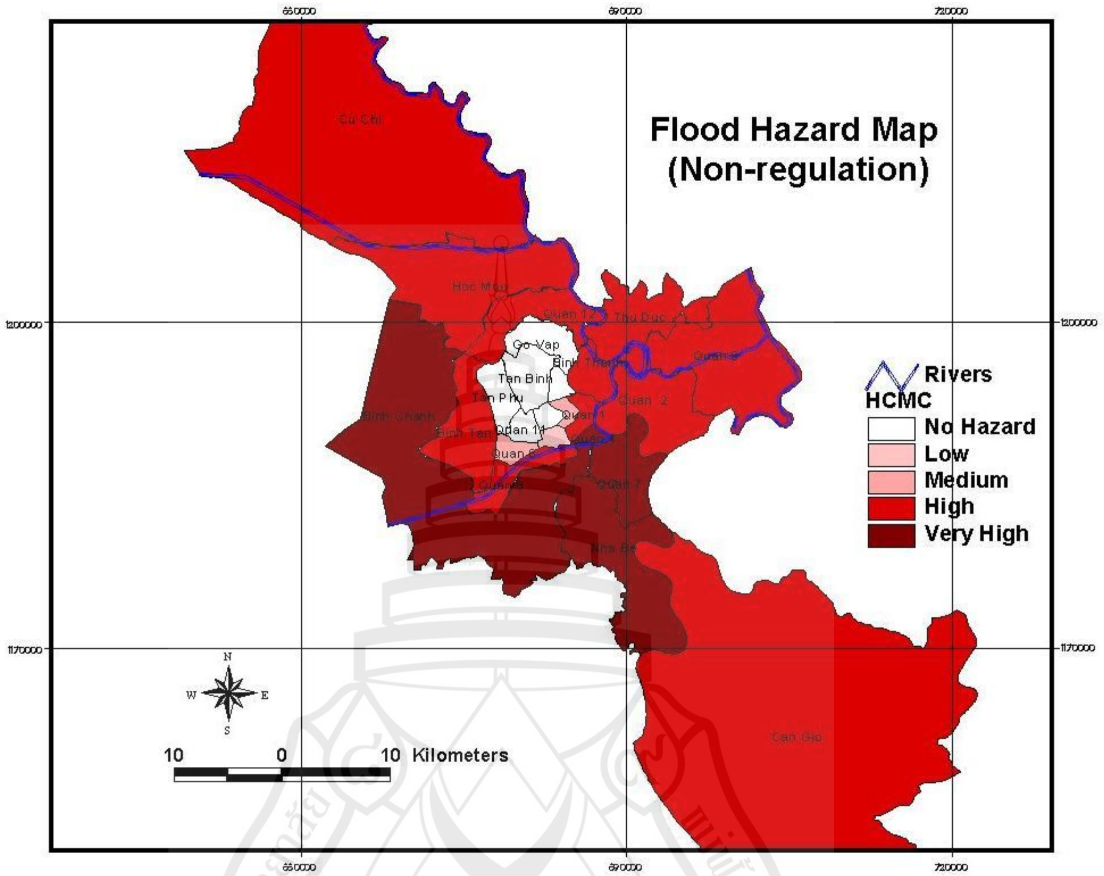


Figure 4.5 Flood Hazard Map for HCMC (under High Rainfall and High Tide)

4.3 Social Vulnerability Assessment

Social vulnerability for districts in HCMC is assessed, based on the combined assessment of 4 vulnerability groups (children, elderly, women and poor households). The groups are considered with different weights contributing to the overall social vulnerability index. The results are presented below.

4.3.1 Social Vulnerability Groups Assessments

Social indicators values are ranked by a common score scale (from 1 to 5), which are described in Table 4.6, Table 4.7, Table 4.8 and Table 4.9.

Table 4.6 The Children Indicator Index

ID	District	# of children (< 15 yrs)	Interval	Ranking
1	Can Gio	2809	0	1
2	Binh Chanh	3523		
3	Hoc Mon	3759		
4	Cu Chi	3905		
5	Nha Be	5572		
6	Quan 5	31132	24000	2
7	Quan 2	31954		
8	Phu Nhuan	33193		
9	Quan 1	35253		
10	Quan 3	35801		
11	Quan 4	37427		
12	Quan 10	42590		
13	Quan 7	46855		
14	Quan 11	48196	48000	3
15	Quan 9	52511		
16	Quan 6	54242		
17	Thu Duc	80085	72000	4
18	Tan Binh	83908		
19	Tan Phu	85415		
20	Binh Thanh	87046		
21	Quan 12	87982		
22	Quan 8	88418		
23	Go Vap	103389	96000	5
24	Binh Tan	111324		
	HCMC	**1196289**		

Table 4.7 The Elderly Indicator Index

ID	District	# of elderly (> 65 yrs)	Interval	Ranking
1	Can Gio	609	0	1
2	Binh Chanh	705		
3	Cu Chi	880		
4	Hoc Mon	1255		
5	Nha Be	1265		
6	Quan 2	6577	5000	2
7	Quan 7	8606		
8	Quan 9	9881		
9	Quan 4	11072	10000	3
10	Quan 5	12419		
11	Quan 12	12865		
12	Phu Nhuan	13434		
13	Tan Phu	13819		
14	Quan 1	14110		
15	Quan 11	14131		
16	Binh Tan	14266		
17	Quan 6	14664		
18	Thu Duc	14683		
19	Quan 3	15165	15000	4
20	Quan 10	15653		
21	Quan 8	20551	20000	5
22	Tan Binh	21425		
23	Go Vap	22302		
24	Binh Thanh	27552		
	HCMC	**287889**		

Table 4.8 The Women Indicator Index

ID	District	# of females	Interval	Ranking
1	Can Gio	34222	0	1
2	Nha Be	50769		
3	Quan 2	74829	60000	2
4	Quan 5	92294		
5	Phu Nhuan	93665		
6	Quan 4	95761		
7	Quan 1	98500		
8	Quan 3	103082		
9	Quan 11	119628		
10	Quan 10	123164	120000	3
11	Quan 9	128870		
12	Quan 7	128998		
13	Quan 6	131062		
14	Cu Chi	178031		
15	Hoc Mon	178716		
16	Tan Phu	205385	180000	4
17	Quan 12	206340		
18	Binh Chanh	211228		
19	Quan 8	213655		
20	Tan Binh	219133		
21	Thu Duc	230676		
22	Binh Thanh	241968	240000	5
23	Go Vap	272449		
24	Binh Tan	294705		
	HCMC	**3727130**		

Table 4.9 The Poor Households Indicator Index

ID	District	# of poor households	Interval	Ranking
1	Phu Nhuan	1803	0	1
2	Quan 3	2101		
3	Quan 1	2428		
4	Quan 5	2593		
5	Quan 10	2635		
6	Quan 2	3300	3000	2
7	Quan 7	3765		
8	Tan Binh	3929		
9	Quan 4	4164		
10	Quan 11	4616		
11	Quan 6	4837		
12	Nha Be	4890		
13	Quan 9	5142		
14	Binh Thanh	5498		
15	Can Gio	6321	6000	3
16	Go Vap	6428		
17	Tan Phu	6436		
18	Quan 12	7202		
19	Hoc Mon	8841		
20	Thu Duc	9038	9000	4
21	Quan 8	10056		
22	Binh Tan	11944		
23	Cu Chi	13116	12000	5
24	Binh Chanh	17692		
	HCMC	**148775**		

The overall social vulnerability indices are calculated for five cases. Specifically, Case 1 shows that the overall index is contributed by the equal weights of four social indicators, while other 4 cases (Case 2, Case 3, Case 4, Case 5) describes that the overall index are contributed by the variety of these social indicators weighted. Specifically, poor household, children, women and elderly are these groups arranged according to priority as the highest weights in Case 2, Case 3, Case 4 and Case 5. Table 4.10 below shows the detail weighted contribution for each case.

Table 4.10 Weighted Contribution of Social Vulnerability Groups

Case	**Weighted contribution of social vulnerability groups**			
	Children	**Elderly**	**Women**	**Poor household**
Case 1	0.25	0.25	0.25	0.25
Case 2	0.3	0.2	0.1	0.4
Case 3	0.4	0.2	0.1	0.3
Case 4	0.2	0.2	0.4	0.2
Case 5	0.2	0.4	0.1	0.3

Table 4.11 shows the results of the overall social vulnerability indices after normalized for each district for five cases. However, as the results after calculating, it is noted that there is not significant differences of these overall indices between five cases. In addition, as considered in the historical flood events in HCMC, the impacts of flooding to these vulnerability groups are not so much differences. Thereby, Case 1 (equal weights) is used for further consideration of overall social vulnerability index and social vulnerability zone in HCMC. Table 4.12 shows the details of social

vulnerability group indices for Case 1 (equal weights). The overall social vulnerability index and zone for Case 1 (equal weights) are illustrated in Table 4.13.

Table 4.11 Overall Social Vulnerability Index under Different Weighted Contribution

ID	District	Normalized overall social vulnerability index (%) for 5 cases				
		Case 1	**Case2**	**Cass 3**	**Case 4**	**Case 5**
1	Nha Be	28	33	30	26	30
2	Can Gio	33	43	36	30	36
3	Quan 1	44	43	43	43	48
4	Quan 2	44	48	45	43	45
5	Quan 5	44	43	43	43	48
6	Phu Nhuan	44	43	43	43	48
7	Hoc Mon	44	48	41	48	41
8	Quan 3	50	48	48	48	57
9	Quan 4	50	52	50	48	55
10	Quan 7	50	50	48	52	48
11	Quan 9	56	57	55	57	52
12	Quan 10	56	50	50	57	59
13	Quan 11	56	60	57	52	59
14	Cu Chi	56	67	59	57	55
15	Quan 6	61	62	57	61	61
16	Binh Chanh	61	69	61	65	57
17	Quan 12	78	81	80	78	75
18	Tan Phu	78	81	82	78	75
19	Tan Binh	83	81	80	83	86
20	Thu Duc	83	90	86	83	82
21	Binh Thanh	89	83	84	91	89
22	Quan 8	94	100	95	91	100
23	Binh Tan	94	100	98	96	89
24	Go Vap	100	100	100	100	100

Table 4.12 Social Vulnerability Groups Index for Districts in HCMC

ID	District	Children	Elderly	Women	Poor households	Overall social vulnerability index (equal weights)
1	Nha Be	1	1	1	2	1.25
2	Can Gio	1	1	1	3	1.5
3	Quan 1	2	3	2	1	2
4	Quan 2	2	2	2	2	2
5	Quan 5	2	3	2	1	2
6	Phu Nhuan	2	3	2	1	2
7	Hoc Mon	1	1	3	3	2
8	Quan 3	2	4	2	1	2.25
9	Quan 4	2	3	2	2	2.25
10	Quan 7	2	2	3	2	2.25
11	Quan 9	3	2	3	2	2.5
12	Quan 10	2	4	3	1	2.5
13	Quan 11	3	3	2	2	2.5
14	Cu Chi	1	1	3	5	2.5
15	Quan 6	3	3	3	2	2.75
16	Binh Chanh	1	1	4	5	2.75
17	Quan 12	4	3	4	3	3.5
18	Tan Phu	4	3	4	3	3.5
19	Tan Binh	4	5	4	2	3.75
20	Thu Duc	4	3	4	4	3.75
21	Binh Thanh	4	5	5	2	4
22	Quan 8	4	5	4	4	4.25
23	Binh Tan	5	3	5	4	4.25
24	Go Vap	5	5	5	3	4.5

Table 4.13 Overall Social Vulnerability Index and Zone for Districts in HCMC

ID	District	Overall social vulnerability index	Normalized overall social vulnerability index (%)	Social vulnerability zone
1	Nha Be	1	28	low
2	Can Gio	2	33	low
3	Quan 1	3	44	medium
4	Quan 2	4	44	medium
5	Quan 5	5	44	medium
6	Phu Nhuan	6	44	medium
7	Hoc Mon	7	44	medium
8	Quan 3	8	50	medium
9	Quan 4	9	50	medium
10	Quan 7	10	50	medium
11	Quan 9	11	56	medium
12	Quan 10	12	56	medium
13	Quan 11	13	56	medium
14	Cu Chi	14	56	medium
15	Quan 6	15	61	high
16	Binh Chanh	16	61	high
17	Quan 12	17	78	high
18	Tan Phu	18	78	high
19	Tan Binh	19	83	very high
20	Thu Duc	20	83	very high
21	Binh Thanh	21	89	very high
22	Quan 8	22	94	very high
23	Binh Tan	23	94	very high
24	Go Vap	24	100	very high

4.3.2 Social Vulnerability Mapping

Social vulnerability risks are then mapped for each district of HCMC by combining all social vulnerability indicators. Figure 4.6 illustrates various degrees of social vulnerability across districts. There are 6 districts (including Tan Binh, Thu Duc, Binh Thanh, Quan 8, Binh Tan and Go Vap) located in the North-East and around the city center, which suffer the highest level of social vulnerability.

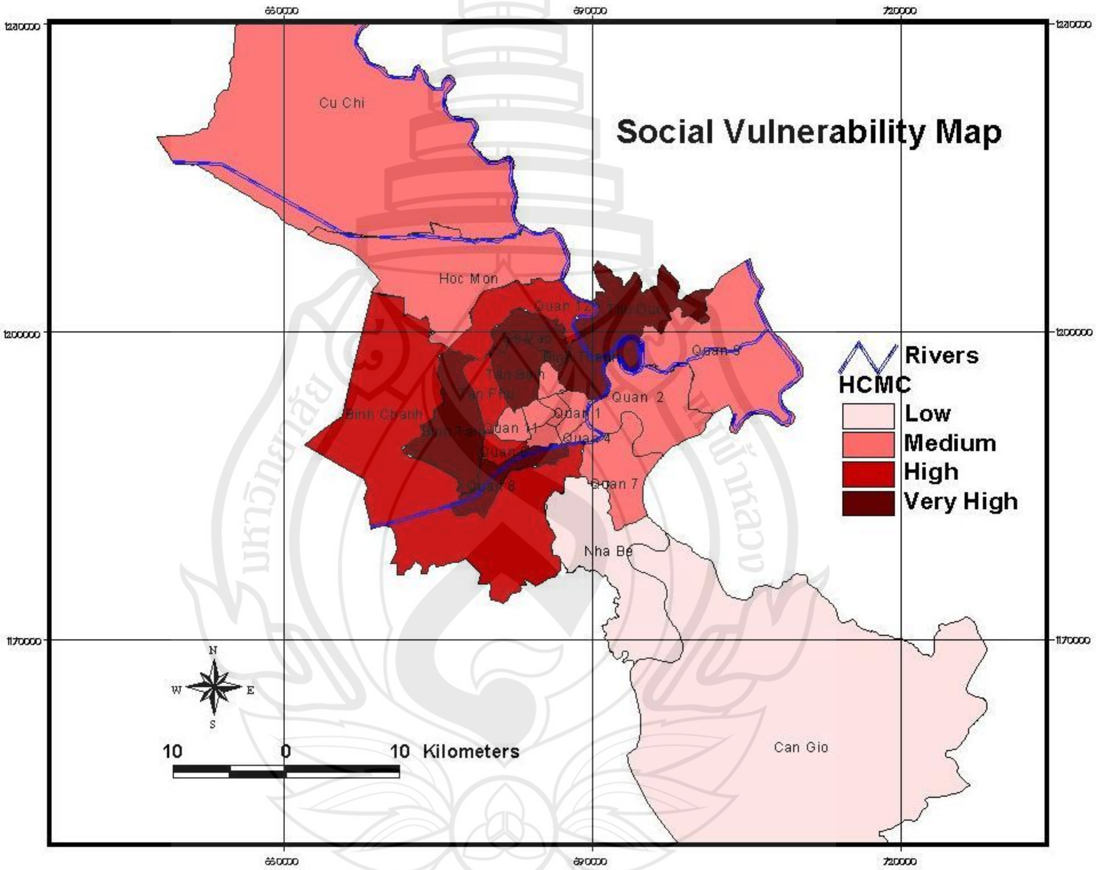


Figure 4.6 Social Vulnerability for HCMC

4.4 Flood Risk Assessment and Mapping

Flood risk index is then estimated by multiplying hazard index and social vulnerability index, which are described in Table 4.14. The final flood risk map under new rainfall scenario and high sea tide for HCMC at district level is developed as seen in Figure 4.7. These most at- risk districts are located surrounding the city center.

Table 4.14 Flood Risk Assessment for Districts in HCMC

ID	District	Flood Hazard Index	Social Vulnerability Index	Flood Risk Index	Normalized Flood Risk Index	Flood Risk Zone
1	Binh Tan	78	94	73	100	very high
2	Quan 8	76	94	71	97	very high
3	Binh Thanh	71	89	63	86	very high
4	Thu Duc	70	83	58	79	high
5	Quan 12	73	78	57	78	high
6	Binh Chanh	89	61	54	74	high
7	Quan 7	100	50	50	68	high
8	Quan 4	97	50	49	67	high
9	Cu Chi	66	56	37	51	medium
10	Quan 9	63	56	35	48	medium
11	Quan 1	77	44	34	47	medium
12	Quan 6	54	61	33	45	medium
13	Hoc Mon	71	44	31	42	medium
14	Quan 2	70	44	31	42	medium
15	Nha Be	95	28	27	37	low
16	Quan 3	52	50	26	36	low
17	Can Gio	67	33	22	30	low
18	Quan 5	23	44	10	14	very low
19	Tan Phu	0	78	0	0	no risk
20	Tan Binh	0	83	0	0	no risk
21	Quan 10	0	56	0	0	no risk
22	Quan 11	0	56	0	0	no risk
23	Phu Nhuan	0	44	0	0	no risk
24	Go Vap	0	100	0	0	no risk

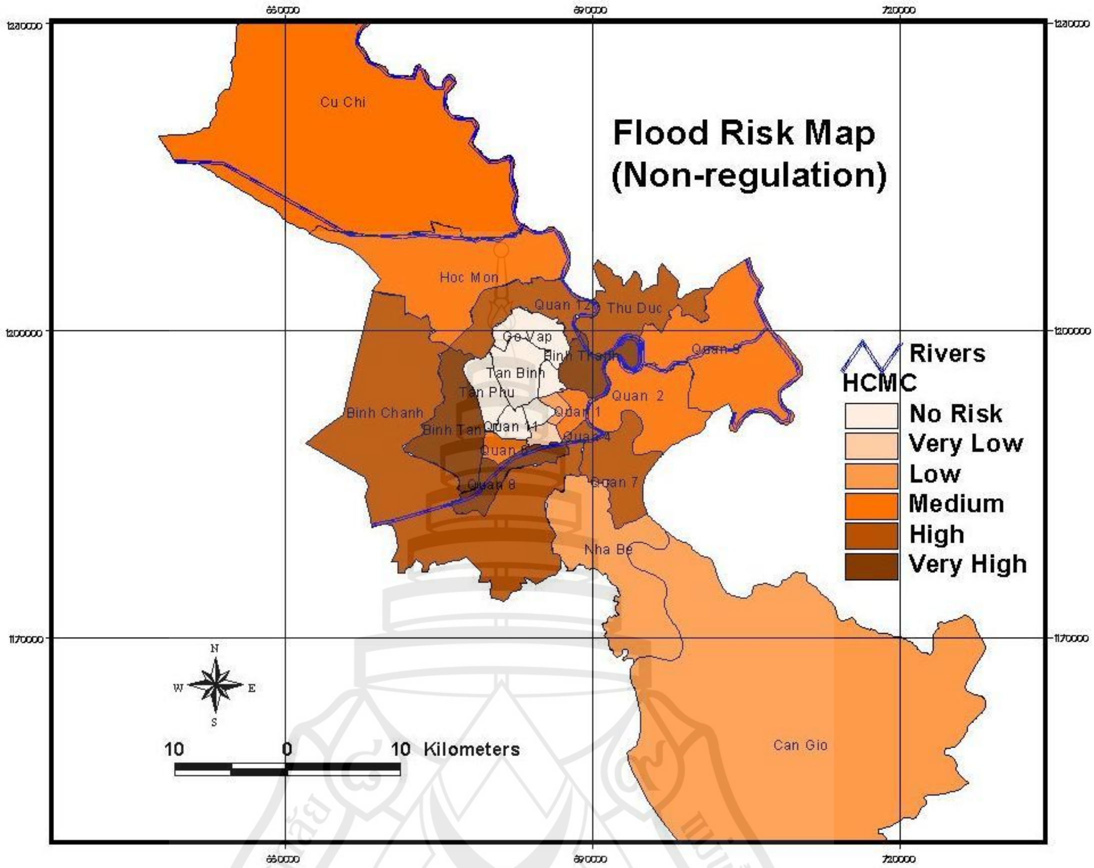


Figure 4.7 Flood Risk Map for HCMC (under High Rainfall and High Tide)

As seen from the flood hazard and social vulnerability maps, there is a significantly different distribution between hazard and social vulnerabilities in HCMC. It is interesting to observe that hazard and social vulnerability are not always in parallel. For example, some districts such as Go Vap, Tan Phu and Tan Binh without hazards, however, still suffer from the high and very high social vulnerability. Likewise, Nha Be district with a very high level of hazard is of low social vulnerability. Some other districts will suffer very high levels and magnitudes of both hazard and social vulnerability (such as Binh Tan, Quan 8 and Binh Thanh), which are of course assessed as to be of the highest risk in HCMC that need special priority consideration to address flooding risk reduction.

From the Table 4.15, it is noted that six districts, including Binh Tan, Quan 8, Binh Thanh, Thu Duc, Quan 12 and Binh Chanh, suffering the highest flood risk due to the large numbers of social vulnerability groups which are likely to expose to the high level of flood hazard. At-risk population of these districts makes up nearly 40% of total population of HCMC (including 41.9% of total children, 34.2% of total elderly, 37.6% of total women and 41.3% of total poor households).

Table 4.15 Top Six Potentially Highest Flood Risk Districts in HCMC

ID	District	Total population	Social vulnerability groups (the actual value)			
		(people)	Children	Elderly	Women	Poor households
1	Binh Tan	572132	111324	14266	294705	11944
2	Quan 8	408772	88418	20551	213655	10056
3	Binh Thanh	457362	87046	27552	241968	5498
4	Binh Chanh	420109	46855	8606	213655	17692
5	Quan 12	405360	87982	12865	206340	7202
6	Thu Duc	442177	80085	14683	230676	9038
Total		**2705912**	**501710**	**98523**	**1400999**	**61430**
% (of HCMC)		**37.8**	**41.9**	**34.2**	**37.6**	**41.3**

This current study, due to time and data constraints, should be considered as a preliminary assessment, but it still can provide important insights of potential flood risks under the typical extreme climate condition for HCMC. It also indicates that some districts with low economic losses as indicated in previous research studies on flood risks in HCMC (e.g., World Bank, 2010) are likely to experience highly social risks based on our study (such as the three districts of Binh Tan, Binh Thanh, Quan 8).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

HCMC is frequently affected by flooding due to the combination of local heavy rainfall and high tide from sea almost every year during the rainy reason. Further, flooding is becoming more and more severe due to the uncertainly under climate change. In addition, as considered as a major city with high socio-economic concentrated, HCMC suffer the both highest of urbanization rate (57.1%) and population growth rate (3.5%) in Vietnam. Thus, social factor become the critical issue under the impact of flooding. Thereby, it is necessary to have the flood risk assessments which are focused on various social vulnerability groups, in order to contribute the planning and preparedness for human to reduce the social flood risk. Therefore, flood hazard, social vulnerability and risk assessments under the new increasing rainfall scenario which is based big flooding in Bangkok 2011 are considered in this city. The research process can be summarized as follows:

1. Based on the data of average rainfall of 30 years and distribution of an actual rainfall in October 2000, the new rainfall scenarios of 40% increase are designed for the whole Sai Gon-Dong Nai watershed.

2. Applying rainfall-runoff model (MIKE NAM), with the input of designed hyetographs of new rainfall scenarios, the corresponding hydrographs are determined for every sub-basin of Sai Gon-Dong Nai river basin. After regulated by Dau Tieng and Tri An reservoirs, the assumed discharges are then inputs for the hydrodynamic model (MIKE 11), the corresponding water level hydrographs corresponding at various stations are determined.

3. Based on the computed water level hydrographs from MIKE 11 model and ground elevation map (DEM) of 90 m x 90 m resolution in HCMC, inundation maps under the new rainfall scenario combined with high tide are developed by MIKE 11-GIS model.

4. Flood hazards are assessed based on flood depth and flood duration at district level only. Categories of flooding depth (below 0.5 meter, 0.5 to 1.0 meter, 1 to 1.5 meter and 1.5 meter to 3.0 meter) and flooding duration (under 3 days, 3 to 21 days, almost 30 days) are determined, following by flood hazard mapping.

5. Social vulnerabilities are assessed for 24 districts in HCMC, based on the real number of four major vulnerable social groups, namely (1) children (population under 15 years of age), (2) elderly (population over 65 years of age), (3) women (female population), and (4) poor households (low income households), following by social vulnerability mapping.

6. Finally, flood risks for HCMC at district level are developed. There are top six potentially highest risk districts in HCMC.

The results from the above research process can be highlighted as below:

7. 63% of total HCMC area is flooded under the new rainfall scenario of 40% above average and the high sea tide. The inundated depth fluctuates between 0.5m to 3m. In which, the most flooded areas are under range of 0.5 to 1 (m), however, some flooded zones are up to the range of 1 to 1.5 (m), and some points reach to the very high depth of 1.5 to 3 (m). Due to the confluence of tide regime, almost districts suffer the long duration of flooding.

8. There are 18 flooded districts (from the total of 24 districts) which almost will suffer high and very high level of flood hazard, in which, the highest ones are 4 districts of Quan 7, Quan 4, Nha Be, Binh Chanh. Amost areas of these districts are flooded, witnessing the both very high level of flood depth and duration.

9. In addition, each district witnesses the different level of social vulnerability, depended on the actual number of vulnerable groups exposed to the hazard. Specifically, there are 6 districts (including Tan Binh, Thu Duc, Binh Thanh, Quan 8, Binh Tan and Go Vap) located in or near the center of HCMC, which will be of the highest level of social vulnerability.

10. The final flood risk assessment is done for districts in HCMC. There are 6 districts (including Binh Tan, Quan 8, Binh Thanh, Thu Duc, Quan 12 and Binh Chanh) around the city center, which will be likely at the highest flood risk due to the large numbers of social vulnerability groups which are likely to expose to the high level of flood hazard, which makes up nearly 40% of total population of HCMC.

11. There are the difference distributions between flood hazard and social vulnerability across districts. They are not always in parallel.

12. Some districts with low economic losses are likely to experience high social risks, such as the three districts of Binh Tan, Quan 8 and Binh Thanh.

This current study should be considered as a preliminary assessment, but it still can provide important insight of potential flood risks under the typical extreme climate condition for HCMC. Further, this sort of our study can help compliment conventional flood risk assessment to provide more comprehensive risks for better effective decision making (for example, from awareness and preparedness to warning, evacuation, response and recovery), especially in risk reduction for the most vulnerable groups of at-risk people and the poor households who are likely to be directly exposed to the risks.

This study, although based on well-integrated modeling approaches (hydrodynamic modeling and GIS), still remains some key limitations in terms of flooding scenarios and geographical scale. Firstly, only some typical scenarios of flooding are considered (40% rainfall increase and historical high tide). Secondly, it has high level of aggregation of administrative scale (only considering at district level) and limitation of topographical condition (due to low-resolution of DEM used and less consideration on land use).

5.2 Policy Recommendations for Flood Risk Reduction

The results from flood risk assessment and mapping being for each district in HCMC are very useful to identify the districts that are likely to be most socially vulnerable to potential flooding although some of which are not necessarily to be of high hazards, which will serve a starting point for proper actions to reduce these risks.

The top 6 potentially highest at-risk districts (including are Binh Tan, Quan 8, Binh Thanh, Thu Duc, Quan 12 and Binh Chanh) need special attention by the HCMC authority to reduce risks. In which, each district should focus on its most social vulnerable groups. According to the results of Table 4.15, Binh Tan district has the highest number of children and women so that the authority of this district should prioritize these two subjects first. Binh Thanh district has the highest number of elderly, thus, the old people should be considered most. Binh Chanh district has the highest number of poor households, so the poverty issue should be more concerned in this district.

In addition, the study could provide some initial recommendations for flood risk reduction for each vulnerability group throughout phases of hazard (from awareness and preparedness to warning, evacuation, response and recovery), in order to contribute the more effective decision making for human-related risks reduction. The details are described as follows:

5.2.1 Awareness and Preparedness

Firstly, children and women are the priority subjects who need to be informed about the hazards, their impacts and the ways to prepare and solve with the hazards. Specifically, children should be provided knowledge about flooding by schools, popular media, training programs, in order to gain the basic preparedness and response skills, so that they can handle emergency situations. In addition, women play pivotal roles in family life and their extensive social networks based on neighborhood parenting, school and work, thus, they also need to be enhanced information of hazard awareness and preparedness, by directly consulting with local woman groups or via TV, Internet, etc.

Secondly, the elderly should be updated the new information, for example, by the local volunteer groups and also should prepare their own lifebuoys at home. For poor households, each household should upgrade their houses or dwellings, as well as prepare stockpile food, water, medication and other emergency supplied before the flooding season.

Thirdly, at policy level, the government should make good plans to support these above vulnerable groups with clear measures and responsibility. They should specially focus on development of more care centers, schools, nursing houses, securing shelters, emergency response guidelines and evacuation plans.

5.2.2 Warning

Both of these vulnerability groups above should be prioritized in disaster warning. Specifically, children are less level of independence or resources available as adults, thus, they need to be guided by parents, guardians and schools for the warnings and evacuation messages. Elderly, who often are less likely to receive warnings than young people due to social networks diminished, low rate of information and limited physical, so that they need to be specially cared by families and local communities. Women should be considered as the informal network for communicating and interpreting to disaster warnings through local woman groups.

At policy level, schools and children centers are needed to be early warned by disaster warning organizations to take care of the children. Moreover, district and city authority levels should provide necessary and proper warning systems to lower level.

5.2.3 Evacuation

During the flooding, evacuation becomes the critical issues. The government should make a good plan to evacuate all vulnerable groups, specially focus on transportation assistance and evacuation care centers (including clinics, relocation and resettlement, etc.)

5.2.4 Response

Basic need for all vulnerable groups should be provided (including foods, drinking water, cloths, hygiene, healthcare, etc.)

Opportunities should be created for all of vulnerability groups to participate to the degree feasible in all facets of emergency response and preparedness programs at the local level.

5.2.5 Recovery

The government needs to make clear recovery plans for specific flooded districts and each specific vulnerable group, including sufficient subsidizes for at-risk people.

Finally, strong and sustained commitment is required from all levels of government (including specific agencies responsible for flood risk control) to make and implement the policy effectively.

5.3 Recommendations for Further Research

As mentioned in 5.1, this present study is still limited due to time and data constraints. Thereby, in order to gain more significant application of the study, further researches required are indicated as below:

1. Additional flooding scenarios, including different scenarios of rainfall increase (i.e., 45%, 50%, etc., rainfall increase above normal), additional scenarios of high sea tides and regulated reservoirs will be further conducted.

2. High-resolution of DEM (i.e., DEM of 20m x 20m, 10m x 10m) and land use should be considered to improve the accuracy of inundation assessment.

3. Additional sensitivity analyses and more social vulnerability groups (such as disability, health, family structure, etc.) will be assessed to complete the comprehensive social vulnerability assessment.

4. Administrative scale will be downscaled to commune level for more detail assessment and risk reduction planning.

As flooding risks in a large watershed as in HCMC and with many contributing factors become so complicated to assess, more research studies in this line are really needed for more accurate and detailed assessments to serve as more concrete inputs to help reduce overall flooding risks in general, and social risks in particular.

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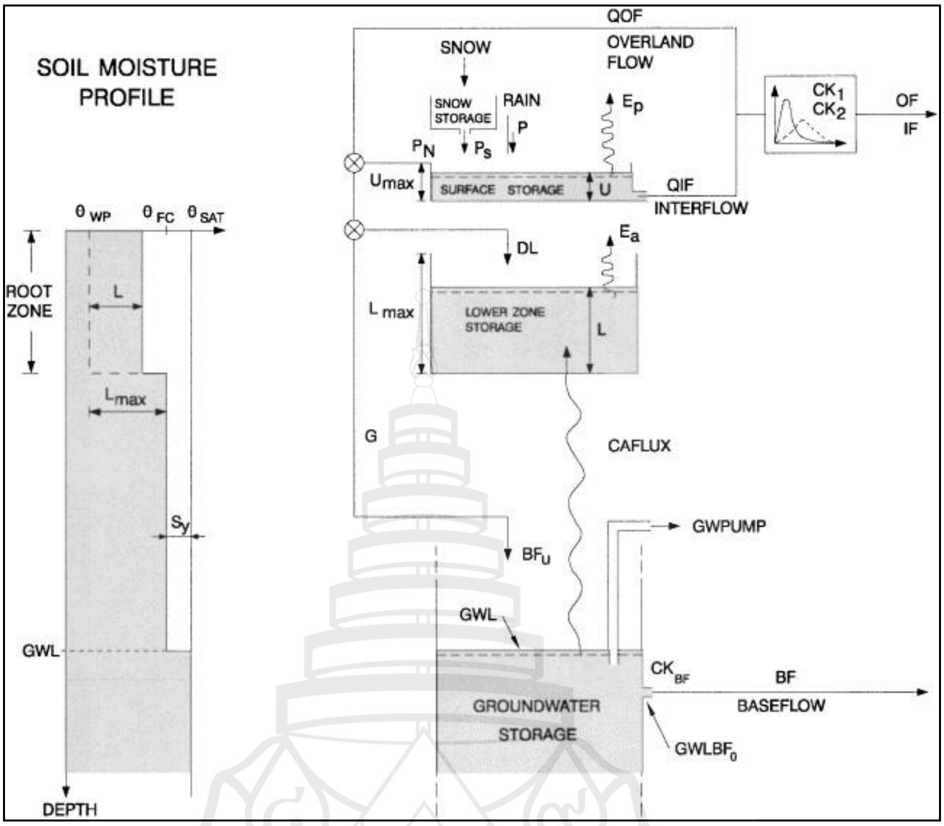
APPENDICES

APPENDIX A

OVERVIEW OF HYDRODYNAMIC MODELING

1. MIKE NAM

NAM model is developed for estimating runoff in a rural catchment by Neilson and Hansen (1973). It requires moderate input data. NAM model has been applied to study flows in many catchments in different regions. NAM represents various components of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages. These storages are Snow, Surface, Root Zone and Ground Water Storages. (DHI, 2007).



Source Madsen (2000)

Figuer A.1 NAM Model Structure

NAM model-specific parameters involve: Surface, Root-zone, Snow melt data, Ground water data, Initial Conditions, Irrigated Area. The basic parameters and their short description is given in Table A.1.

Table A1 NAM parameters

Parameter	Definition
Umax	Maximum contents of surface storage
Lmax	Maximum contents of root zone storage
CQOF	Overland flow coefficient
CKIF	Time constant for interflow
TOF	Root zone threshold value for overland flow
TIF	Root zone threshold value for interflow
TG	Root zone threshold value for recharge
CKBF	Time constant for routing base flow
CK1,2	Time constant for routing overland flow

2. MIKE 11

The hydrodynamic module (MIKE 11 HD) is commonly applied as a flood management tool simulating the unsteady flow in branched and looped river networks and quasi two-dimensional flow on floodplains.

MIKE 11 is based on an efficient numerical solution of the complete non-linear St. Venant equations for 1-D flows.

The Saint Venant Equations:

Continuity:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

Momentum:

$$\frac{\partial Q}{\partial t} + \frac{\partial (\frac{\alpha Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0$$

Where

Q: discharge, (m^3/s)

A: flow area, (m^2)

q: lateral inflow, (m^2/s)

h: stage above datum, (m)

C: Chezy resistance coefficient, ($m^{1/2}/s$)

R: hydraulic or resistance radius, (m)

α: momentum distribution coefficient

The four terms in the momentum equation are local acceleration, convective acceleration, pressure, and friction (Source: www. dhigroup.com).

In MIKE 11, a network configuration depicts the rivers and floodplains as a system of interconnected branches. Water levels and discharges (h and Q) are calculated at alternating points along the river branches as a function of time. It operates on basic information from the river and floodplain topography to include man-made features and boundary conditions.

APPENDIX B

PARAMETERS FOR HYDRODYNAMIC MODELING

1. Weighted Rainfall Distribution in the Upstream of Sai Gon-Dong Nai River Basin

There is divided to five main sub-watersheds in the upstream of the river basin, including Dau Tieng (2700 km^2), Phuoc Hoa (5193 km^2), Tri An (14800 km^2), upstream of Vam Co Dong river (2700 km^2) and upstream of Vam Co Tay river (1000 km^2). In which, due to the large area, Tri An and Phuoc Hoa sub-watersheds are continuously divided to 17 minor sub-watersheds and 6 minor sub-watersheds.

In order to weight the spatial distribution of rainfall for each sub-watershed above, Theisson method is used to estimate the weighted distribution of rainfall which is illustrated as the table below:

Table B1 Weighted Rainfall Distribution of Sub-watersheds in the Upstream Sai Gon-Dong Nai River Basin

Sub-watershed	**Minor sub-watershed**	**Area (km^2)**	**Weighted rainfall distribution**			
Dau Tieng		2700	Binh Long	Dau Tieng	Loc Ninh	
			0.4	0.3	0.3	
Phuoc Hoa	LV19	1074	Dak Nong	Dong Phu	Phuoc Long	
			0.33	0.05	0.62	
	LV20	1332	Dak Nong	Phuoc Long		
			0.8	0.2		
	LV21	402	Phuoc Long			
	LV22	748	Binh Long	Phuoc Long	Loc Ninh	
			0.03	0.42	0.55	
	LV23	1469	Phuoc Hoa	Phuoc Long	Binh Long	Dong Phu
			0.2	0.2	0.3	0.3
	LV24	2022	Ta Lai	Tri An	Phuoc Hoa	Dong Phu
			0.04	0.12	0.34	0.5
Tri An	LV1	769	Bao Loc	Lien Khuong		
			0.8	0.2		
	LV3	670	Ta Pao	Bao Loc		
			0.8	0.2		
	LV6	2000	Ta Pao	Ta Lai		
			0.7	0.3		
	LV7	844	Da Lat			
	LV8	968	Da Lat	Lien Khuong		
			0.34	0.66		
	LV9	74	Lien Khuong			
	LV10	514	Bao Loc	Lien Khuong		
			0.05	0.95		
	LV11	500	Dak Nong	Lien Khuong	Bao Loc	
			0.17	0.17	0.66	
	LV12	255	Dak Nong	Bao Loc		
			0.93	0.07		
	LV13	213	Dak Nong			
	LV14	268	Dak Nong			
	LV15	826	Dak Nong			

Table B1 (continued)

Sub-watershed	Minor sub-watershed	Area (km^2)	Weighted rainfall distribution			
Tri An	LV16	3620	Dak Nong	Phuoc Long	Bao Loc	Ta Lai
			0.24	0.08	0.25	0.43
	LV17	367	Ta Lai			
	LV18	923	Tri An	Ta Lai		
			0.4	0.6		
	LV26	845	Da Lat	Lien Khuong		
			0.63	0.37		
	LV27	328	Da Lat	Lien Khuong		
			0.85	0.15		
Vam Co Dong		2700	Can Dang	Tay Ninh	Loc Ninh	
			0.45	0.2	9.35	
Vam Co Tay		1000	Moc Hoa			

2. Parameters of MIKE NAM Model

Table B2 Parameters of MIKE NAM Model for Upstream Catchments

Parameter	Catchment						
	Dau Tieng, Vam Co Dong, Vam Co Tay	Phuoc Hoa	Tri An				
			LV3,6	LV7,8,9, 10,11,26, 27	LV12,13,14,15	LV16,17, 18	LV1
Umax	13	14.1	13.3	13.5	14.5	19.9	19.3
Lmax	176	201	100	146	213	287	268
CQOF	0.605	0.92	0.98	0.809	0.72	0.597	0.528
CKIF	494.6	452	467	423.7	421.2	452.5	417
CK1,2	45	49	15.6	19.9	32.2	35.3	41.6
TOF	0.588	0.97	0.051	0.041	0.089	0.228	0.051
TIF	0.432	0.63	0.267	0.287	0.481	0.17	0.267
TG	0.227	0.06	0.256	0.251	0.89	0.25	0.256
CKBF	2858	1428	2000	1876	2000	2138	2000

Table B3 Parameters of MIKE 11 Model in the Downstream Sai Gon-Dong Nai River Basin

ID	River	Chainage	Resistance	ID	River	Chainage	Resistance
1	sgon 0	0	0.033	26	vcod 0	106995.8	0.027
2	Nha Be 1	0	0.026	27	vcod 0	110697.9	0.027
3	vct 1	0	0.025	28	vcod 0	113026.7	0.028
4	RLangThe	7132.641	0.025	29	vcod 0	116180.4	0.027
5	RLangThe	0	0.025	30	vcod 0	117514	0.026
6	thi tinh	25000	0.026	31	vcod 0	117865.3	0.026
7	vcod 0	0	0.03	32	vcod 0	120058.2	0.027
8	vcod 0	5264.388	0.03	33	vcod 0	124577	0.027
9	vcod 0	17668.02	0.03	34	vcod 0	128688	0.027
10	vcod 0	23144.65	0.03	35	vcod 0	130165	0.026
11	vcod 0	31767.53	0.03	36	vcod 0	135577	0.026
12	vcod 0	39984.37	0.03	37	vcod 0	137607	0.026
13	vcod 0	47319.52	0.027	38	vcod 0	145770	0.027
14	vcod 0	50084.99	0.029	39	vcod 0	150077	0.027
15	vcod 0	53013.62	0.03	40	vcoc 2	6000	0.03
16	vcod 0	59285.92	0.03	41	vcoc 2	11500	0.028
17	vcod 0	61127.79	0.026	42	vcoc 3	2500	0.026
18	vcod 0	64763.49	0.026	43	vcoc 3	4500	0.028
19	vcod 0	68584.61	0.03	44	vcoc 4	12100	0.028
20	vcod 0	75163.14	0.03	45	vcoc 4	16300	0.03
21	vcod 0	79143.67	0.026	46	srap 1	25632	0.028
22	vcod 0	84825.45	0.026	47	srap 1	27985	0.026
23	vcod 0	88993.63	0.026	48	srap 1	31876	0.028
24	vcod 0	94735.68	0.029	49	srap1	39616	0.027
25	vcod 0	102555.9	0.027	50	sgon 0	5770	0.033

Table B3 (continued)

ID	River	Chainage	Resistance	ID	River	Chainage	Resistance
51	sgon 0	13771	0.027	76	t duc 10	0	0.026
52	sgon 0	26738	0.028	77	t duc 10	100	0.026
53	sgon 0	28017	0.03	78	t duc 10	150	0.025
54	sgon 0	28892	0.025	79	t duc 10	300	0.024
55	sgon 0	33732	0.029	80	t duc 10	500	0.023
56	sgon 0	36958	0.025	81	t duc 10	1000	0.022
57	sgon 0	39400	0.03	82	t duc 10	1500	0.02
58	sgon 0	42745	0.026	83	t duc 10	1700	0.02
59	SGON 0	50960	0.028	84	Dong Nai1	3000	0.026
60	sgon 0	58400	0.029	85	dong nai 1	3200	0.027
61	sgon 0	61756	0.028	86	dong nai 1	3300	0.028
62	sgon 0	73230	0.028	87	dong nai 1	3400	0.028
63	sgon 0	84485	0.028	88	t duc 10	2000	0.024
64	sgon 0	95540	0.027	89	t duc 10	2100	0.024
65	sgon 0	98440	0.027	90	t duc 10	2500	0.026
66	sgon 0	99451	0.027	91	t duc 10	2700	0.027
67	sgon 0	6038.079	0.03	92	t duc 8	1000	0.027
68	sgon 0	13926.78	0.03	93	t duc 8	1200	0.027
69	sgon 0	21356.27	0.03	94	t duc 8	1500	0.027
70	sgon 0	26669.01	0.03	95	dong nai 1	88600	0.026
71	sgon 0	29035.25	0.03	96	dong nai 1	88900	0.025
72	sgon 0	33063.73	0.03	97	dong nai 1	89000	0.023
73	sgon 0	33614.58	0.03	98	dong nai12	9800	0.026
74	sgon 0	36889.76	0.03	99	dong nai12	10000	0.027
75	sgon 0	32288.63	0.026	100	dong nai 1	36480	0.0245

APPENDIX C

SOCIAL DATA IN HCMC

Table C1 Population in HCMC (source: Census data in 2009)

ID	District	Area (km^2)	Population	Density (person/km^2)
1	Can Gio	704	68846	97.7926
2	Nha Be	100	101074	1010.74
3	Quan 2	50	147490	2949.8
4	Quan 5	4	171452	42863
5	Phu Nhuan	5	174535	34907
6	Quan 1	8	180225	22528.1
7	Quan 4	4	180980	45245
8	Quan 3	5	190553	38110.6
9	Quan 11	5	226854	45370.8
10	Quan 10	6	230345	38390.8
11	Quan 7	36	244276	6785.44
12	Quan 6	7	249329	35618.4
13	Quan 9	114	256257	2247.87
14	Cu Chi	435	343155	788.862
15	Hoc Mon	109	349065	3202.43
16	Tan Phu	16	398102	24881.4
17	Quan 12	53	405360	7648.3
18	Quan 8	19	408772	21514.3
19	Binh Chanh	253	420109	1660.51
20	Tan Binh	22	421724	19169.3
21	Thu Duc	48	442177	9212.02
22	Binh Thanh	21	457362	21779.1
23	Go Vap	20	522690	26134.5
24	Binh Tan	52	572132	11002.5
	HCMC	**2096**	**7162864**	**3417.4**

Table C2 The Number of Poor Households and the Poverty Density of Districts in HCMC (source: Cuong, 2009)

District	No. of sampled households	Total households	Area (km2)	% of poor households	No. of poor households	Poverty density (no. of poor households per km2)
1	4490	44231	7.74	5.5	2428	314
2	3106	30616	48.89	10.8	3300	68
3	3576	42180	4.75	5	2101	443
4	2635	34100	4.06	12.2	4164	1026
5	3455	36020	4.08	7.2	2593	635
6	3734	47792	6.97	10.1	4837	693
7	4211	37348	34.6	10.1	3765	109
8	3902	71673	18.79	14	10056	535
9	4496	50958	111.96	10.1	5142	46
10	3630	47478	5.62	5.6	2635	469
11	3703	44555	4.98	10.4	4616	927
12	4332	70468	51.64	10.2	7202	139
Go Vap	4007	106079	19.59	6.1	6428	328
Tan Binh	3820	87110	22.12	4.5	3929	178
Tan Phu	4396	83365	15.47	7.7	6436	416
Binh Thanh	3844	88541	20.44	6.2	5498	269
Phu Nhuan	4126	37477	4.71	4.8	1803	383
Thu Duc	4221	86657	47.29	10.4	9038	191
Binh Tan	3750	105137	50.98	11.4	11944	234
Cu Chi	4254	70515	424.98	18.6	13116	31
Hoc Mon	4039	52943	106.94	16.7	8841	83
Binh Chanh	4318	77192	247.55	22.9	17692	71
Nha Be	3054	16277	98.32	30	4890	50
Can Gio	3268	14730	732.55	42.9	6321	9
HCMC	92367	1383442	2095.01	10.8	148775	71

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