Flood risk assessment focusing on intangible vulnerability for rural floodplain area in Central Vietnam

Pham Hong Nga

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ABSTRACT

Floodplains have traditionally supported dense population mainly engaged in intensive agriculture as a result of advantage of fertile soil and irrigation. However, the floodplains are extremely vulnerable to flooding. Deep inundation in such low-lying agricultural land can certainly cause sizable damages at local level affecting the sustainability of household livelihood. Particularly, in most rural areas of developing countries, due to poverty, flood events are dealt with in a reactive, rather than proactive, manner and little is done to be prepared for a catastrophic outcome of flood in the future and thus, the damage would be much accelerated. Therefore, to estimate the damages caused by future flood events is essential for developing long-term disaster mitigation plans at community, regional and national levels.

In general, “Disaster Risk” is the function of “Hazard”, “Exposure” and “Vulnerability”. There are several ways for risk communication, such as: index based, mapping and Average Annual Risk (AAR). Recently, the concept of AAR has been recognized as a strong synthetic indicator for a certain area showing how vulnerable it is to flood. To analyze flood disaster risk, an integrated approach is required to combine the hydrological knowledge about the frequency of flood events, the hydraulic modeling information about the inundation behavior of flood water in floodplains and socio-economic flood vulnerability knowledge, i.e. the potential damage has to be evaluated for flood events of different frequency. Based on these damage evaluations, damage – frequency curves, or also called flood risk curves (FRCs) can be constructed for a study area. FRCs can be developed for any element at risk, such as population, household property and agriculture. The area under the total risk curve is the average annual risk (AAR), which represents the expected average cost of flood induced damage every year.

The key challenge of calculating flood risk is to define flood vulnerability or potential damages as the data of past disaster damages is rather scattered, less accurate and not yet standardized, especially in the rural regions. In general, the damages induced by flood or other types of disaster can be categorized as tangible and intangible depending on whether they can be evaluated in monetary values. In

the rural area, the tangible losses usually consist of damage of cultivated products, irrigation infrastructure, housing etc. Health impacts, loss of business opportunity, environmental (soil and irrigated water) pollution, disaster compensation (loan interest exempted) that not traded directly in a market are far more difficult to assess in monetary terms and referred to as “intangible”. Due to its uncertainty and complication, intangible damage is often neglected in flood damage assessment. However, several studies emphasize the significance of intangible damage and in some cases it is even much more serious than tangible ones. As a result, the risk of flood disaster is often underestimated, especially in the rural areas. To calculate the complete loss, damage curve methodology has been developed and applied in many developed countries but far less in the developing countries.

Vietnam is characterized by dense river networks. About 70% of its population living in low-lying deltas engages in agricultural activities, which are highly vulnerable to flooding. It is important to emphasize that apart from negative consequences, from the history, it is well known that abundant water resource and seasonal flooding every year also bring rich rice field and many livelihoods for local people. Therefore, with the majority earning their livelihood by agriculture and aquaculture production, building up long term flood risk management to enhance the local resilience or so called “living with the flood proactively” strategy toward sustainable development. To achieve this goal, thorough understanding about the potential damages (tangible and intangible) as well as AAR concept is very helpful for decision makers and local authorities as it provides primary quantitative information to consider which countermeasures would be appropriate and cost effective.

This study proposes an integrated approach to derive Flood Risk Curves (FRCs) and Average Annual Risk (AAR) for a rural floodplain area based on hazard analysis of simulated flood scenarios of 100-year, 50-year. 20-year and 10-year return periods and exposure and vulnerability analysis of three groups of elements-at-risk, including direct and indirect, tangible and intangible, namely: human safety, agriculture and household properties. The risk of social safety is presented by number of people while for later two categories the risk is calculated in monetary values. Apart from being evaluated in quantitative manner, the result of AAR also demonstrates the significance of indirect tangible and intangible (both direct and indirect) damages compared to the ones that are conventionally included in post disaster reports.

The case study selected to apply proposed approach is Dien Ban District in Vu Gia –Thu Bon (VG-TB) downstream area, one of the largest river systems in Central Vietnam. VG-TB basin is characterized by far complicated hydro-morphological process causing frequent catastrophic flooding. According to the available records, during the past 20 years, flood disaster has caused approximately 780 fatalities in this basin. On the other hand, the local area undergoes rapid economic development but still poor and highly vulnerable. Like in many other parts of the developing countries, poverty is a significant contributor to people’s vulnerability to flood disaster. On the other hand, frequent flooding can eliminate the production and investment resulting in poverty. Therefore, the result of this study helps introduce an useful concept for flood risk management in the rural floodplain area and provide a kind of basic quantitative indicators for development of long term disaster management, including investment and policy framework, e.g. land use zoning, cost-effectiveness evaluation of alternative measures of flood control, disaster insurance policy etc.

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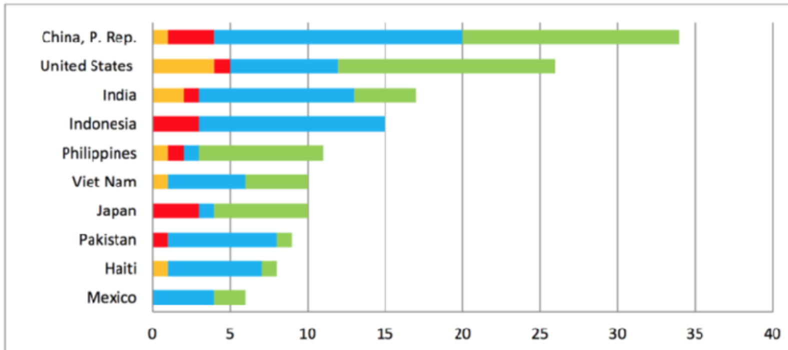
Chapter 1. INTRODUCTION

1.1 Background

The world is confronted with a rapidly growing impact of disasters, due to many factors that cause an increase in the vulnerability of society combined with an increase in hydrometerologial hazard events induced by climate change. Among these types of hazards, flood hazard is crititcal concern because of the widespread distribution of river floodplains and low-lying coasts and the attractiveness they exerted for human settlement throughout the history of mankind (Smith and Petley, 2009).

Although nowadays floods are considered not just as “acts of God” because the acts of man have changed landscape and natural water course by building flood defense and hydraulic works, indeed, flood losses are largely acts of man as it refers to the development of society along the river. Apparently, rivers and coasts have always been magnets for development as they have provided transpotation, water supply for people and agriculture, channels for sanitation etc. From the history, development in floodplains brought communities and high-value agriculture together. As populations and development grew, flood losses continued to increase. Along with opportunity, however, risk does exist and government have to incorporate risk management strategies in development planning at different levels. A new approach was needed, one that could not only identify the hazards and the consequences faced by community, but was also able to assess the relative significane of the risk faced. This new approach of flood risk management (FRM) continues to evolve, during past two decades, it has becomewidely accepted as an appropriate approach to dealing with natural disaster, one of the world’s great challenges. Figure 1.1 shows that water related disasters are most critical world wide, especially storm, typhoon and flooding (Guha-Sapir et al., 2017). Moreover, from this Figure one can easily notice that South East and East Asia countries are



	Mexico	Haiti	Pakistan	Japan	Viet Nam	Philippines	Indonesia	India	United States	China, P. Rep.
Climatological		1			1	1		2	4	1
Geophysical			1	3		1	3	1	1	3
Hydrological	4	6	7	1	5	1	12	10	7	16
Meteorological	2	1	1	6	4	8		4	14	14

Figure 1.1 Top 10 countries by number of reported events in 2016 (Guha-Sapir et al., 2017)

dominated in the list of top 10 countries by number of hazard events reported in 2016, including Vietnam, where the case study selected in this study is from, ranked at #6. UNISDIR stated in a special report for COP21 that during last two decades, flooding caused the majority of disasters, accounting for 43% of all recorded events and affecting nearly 2.5 billion people. Following is storm killing more than 244,000 people and costing US$936billion damage. Therefore, possible impacts of combined storm and consequencial flood hazard events are critically large, especially in tropical countries. Besides, studies world wide have shown that recurrent flooding has severe and long-term impacts on livelihoods and health, particularly in poor rural regions who are dependent on cultivation and natural resource exploitation to earn their living (ADB, 2013). Although these impacts are classified as direct and indirect, tangible and intangible losses and damages but the indirect and intangible ones are often neglected due to lack of data and appropriate tool.

Therefore, the question how to quantify flood consequences, especially the occurrence of human loss and indirect and intangible damages, has been an increasing concern of flood managers. To date, various methodologies have been developed to estimate the consequences of coastal and river flooding with different level of input data requirement and technical complication. However, all these methods have been developed and validated with past disaster events in developed countries, especially in UK, Netherlands, Japan etc. In developing countries, especially in rural floodplain areas, the perception of local authority and community about disaster risk is rather limited and long term consequences of flood on sustainable development is underestimated. Particularly, in most rural areas of developing countries, due to poverty, flood events are dealt with reactive, rather than proactive, manner and little is done to be prepared for a catastrophic outcome of flood in the future and thus, the damage would be much accelerated (Lotsch et al., 2010; Sayers et al., 2013).

Therefore, to estimate the damages caused by future flood events is essential for developing long-term disaster mitigation plans at community, regional and national levels. To carry out this task, recently, risk-based approach has been widely applied to provide a basis for disaster management planning, land use zoning, policy making, especially related to cost-effectiveness evaluation of alternative measures of flood control and possible insurance program for rural farming households.

This study attemps to develop an integrated approach to derive Flood Risk Curves (FRCs) and Average Annual Risk (AAR) as quantitative indicators to understand the significance of future flood events and consequencial potential damage in a rural floodplain area based on hazard analysis of flood scenarios of selected return periods and exposure and vulnerability analysis of key elements-at-risk, including direct and indirect, tangible and intangible. Based on quantitative AAR calculated, the result also demonstrates the significance of indirect tangible and intangible (both direct and indirect) damages compared to the ones that are conventionally included in post disaster reports. The case study selected to apply proposed approach is Dien Ban District in Vu Gia –Thu Bon (VG-TB) downstream area, one of the largest river systems in Central Vietnam. VG-TB basin is characterized by far complicated hydro-morphological process causing frequent catastrophic flooding. According to the available records, during the past 20 years, flood disaster has caused approximately 780 fatalities in this basin (VAST, 2012; Quang Nam, 2015). On the other hand, the local area undergoes rapid economic development but still poor and highly vulnerable. Like in many other parts of the developing countries, poverty is a significant contributor to people’s vulnerability to flood disaster. On the other hand, frequent flooding can eliminate the production and investment resulting in poverty. Therefore, the result of this study can help to raise the awareness and recommend posible countermeasures to reduce the risk that the local community confront with and thereby to enhance the resillience. Finally, the study also explain the possibility to apply this approach at larger (regional) scale, especially for assessing the progress of implmentation of international framework on disaster risk reduction.

1.2 Problem statement and objectives of the Study

1.2.1 Problem statement

Although risk based management is considered emerging approach to reduce disaster consequeces and enhance resilience, there have been entensive discussion and debate among the researcher and decision makers on the effective approaches. To analyse flood risk as function of (natural) hazard characteristics and complex social issues, an integrated approach is required which generally contains of the following steps: definition of scope, danger (threat) identification, estimation of probability of hazard occurrence, evaluation of the vulnerability of the elements at risk, consequence identification and risk estimation.

The review of literature related to flood disaster management world wide that to be discussed more in details in Chapter 2 produces several finding as following:

(i) *Knowledge gap:* The previous sections already reviewed the need of adopting risk management concept in reducing consequences caused by flood disaster and on the other hand, range of methods available to carry out the risk analysis and calculation. However, there are several problems existing that limit the effectiveness of risk based disaster management, including:

- The review of existing methods and their application in damage cost assessment for flood disaster revealed that there has been strong focus on the direct costs. By contrast, the indirect (business interruption) and intangible costs (e.g. health and environmental damages), especially the indirect intangible damages are often underestimated or even neglected entirely (Bremond et al., 2013; Abbas et al., 2014). This problem would result in incomplete cost estimates and to support decision making for effective risk mitigation measure(s).

- Although there has been great effort in developing and verifying methods used in risk analysis process, major uncertainty still remain in all steps, especially of cost assessment. In practice, the magnitude of damage is driven by various factors, not only hydraulic factors (velocity, depth) but also types of properties, flood warning etc. Moreover, it also depends on experience of local people in coping and adapting to disaster occurrence. It is very often the case that one study can aggregate all these factors in adequate way resulting in uncertainty. Another cause of increasing uncertainty is selection of appropriate method and approach. Unlike standardized hydraulic simulation has been applied and verified widely, most methods of vulnerability analysis and damage evaluation are rather site specific as they are highly dependent on socio-economic conditions and market costs and thus, adopting them from one region to another can lead to inaccurate results.
- Lack of data: The input data required in risk analysis includes two separate components: (1) hydrological time series, hydraulic parameters and spatial data of river basin for flood simulation and (2) socio-economic data and information. Unlike the data of Component 1 is relatively available and reliable, the socio-economic data, especially data on damages of past disaster events is very much scattered and inaccurate. First, the data and information on damages are often carried out as post disaster assessment using a kind of template with focus mainly in direct damages. During just a few days after the disaster occurred, it is hard to be able to collect complete information in adequate manner. The databases to store collected information are quite inconsistent and not in details from very local level.

(ii) *A need of a quantitative tool for effective disaster management:* The combination of undesirable changes of climate and socio-economic growth will influence the probability and magnitude of future natural disaster losses requiring sound understanding about all consequential risks and then, developing diversified and effective measures to mitigate these risks. To achieve this, apart from structural measures like dike, embankment, dam

and reservoir built for long history, the non-structural measures have been drawn special attention world wide as they help enhance local resilience and adaptation. However, the latter ones, like land use planning, government compensation framework, community based disaster management and more recently, insurance, require highly comprehensive tool to be able to assess quantitatively the risk of future disaster events that can include not only direct tangible but also indirect and intangible losses and damages.

(iii) *A need of improving flood disaster management to cope with climate change in Vietnam:* The impacts of natural disasters on human safety and economics are likely to accelerate in the future due to climate change and increased vulnerability. According to IPCC reports, Vietnam is one of top five countries to be prone to the effects of climate change and climate related disasters. Even though climate change impacts are expected to primarily, flooding already the critical cause to major problems in the country with 70% of its population living in coastal areas and low-lying deltas. The country undertakes impressive economic growth but not equally between urban and rural areas. Major part of population is still categorized as poor and nearly poor households, who are critically vulnerable to flood disaster as their income and livelihood are more dependent on weather; their housing and properties are less protected and they are more prone to health impacts. Poor householders also have lower capacity to recover after the disaster due to limited knowledge and financial ability. Moreover, despite the huge effort from the Government and society to reduce the consequences of flood disasters, these problems remains critical and tends to be worsen due to climate change (Bangalore et al., 2018). So far, in Vietnam embankment and dam are dominant approach to flood control and risk based management concept is still new. It is indeed a need to have a tool that can produce the answers to the questions like: How many people are exposed to the flooding for certain scenarios? What is the potential damage? Which measure should be invested for flood control from cost-benefit point of view?

To conclude, there is highly important to study a methodology and approach for flood vulnerability and risk assessment that is quantitative and applicable in rural area to support the profound disaster management practice and sustainable development of local community as determined in global framework.

1.2.2 Objectives of the Study

This study, therefore, is carried out with the aims to investigate an integrated methods to analyse and quantitatively assess the total risk induced by flooding with a focus on intangible issues in a pilot rural area in Central Vietnam. The specific objectives are as follows:

- To obtain sound understanding about flood hazard in the study area though modeling simulation of selected return periods;
- To investigate exposure and vulnerability caused by flooding for elements at risk defined in the scope of this study
- To derive the specific risk curves and then, calculate annual risks for the elements at risk defined earlier; and
- To evaluate the significance of indirect and intangible damages compared to the total risk calculated for the study area and based on that,to recommend relevant countermeasures to reduce the risk and enhance the resilience of local community.

1.3 Research methodology and structure

1.3.1 Overall methodology

In order to meet the objectives defined above, this Study utilize an integrated methodology that combines various methods and approaches as presented in Figure 1.2:

- Flood hazard analysis: the inundation maps of selected scenarios of return periods, i.e. 100-year, 50-year, 20-year and 10-year are developed using hydraulic simulation MIKE11 package and GIS mapping.
- Elements at risk indentification and exposure: the combination of approaches is utilized, including indicator based, analysis of superimposing land use maps and Google image with flood hazard maps.

- Vulnerability analysis: the losses and damages of each level of flood hazard is evaluated using different methods corresponding to the elements at risk, including conceptual formula, stage-damage function and Contingent Value Method.
- Risk analysis: The specific risks are calculated for each elements at risk as the functions of hazard probability, exposure and vulnerability. By the other words, the total risk of all elements at risk in a given area can be presented conceptually by the following basic Eq. (1-1):

Risk = Hazard * Exposure * Vulnerability * Amount of elements at risk

(1-1)

The specific risks are then plotted against return periods to produce so called flood risk curves (FRCs). Another way of risk communication is Average Annual Risk (AAR), which is an average damage induced by flooding to be expected every year. AAR is in equal to the area under the FRC. Figure 1.3 demostrates the relationship between FRC and AAR. Specifically, AAR is calculated by Eq. 1-2 (Olsen et al., 2015).

$$\Sigma \quad - \; - \quad —— \qquad (1\text{-}2)$$

Where R- specific risk; n is chosen so that all the relevant return periods are covered from negligible cost of quite frequent events to very rare events. This study selected 04 flood scenarios (i.e. n=4) to be sufficient to develop FRC.

1.3.2 Structure of the Thesis

The Thesis is presented in 08 chapters, which are structured as following (Figure 1.4):

Chapter 1: Introduction

The current Chapter describes the concepts of flood hazard, vulnerability and risk. This part also describe the gap in flood risk analysis in order to propose the improvement of methodology developed in this Study. Chapter 1 also presents the objectives, the framework of methodology and strucutre of the Thesis.

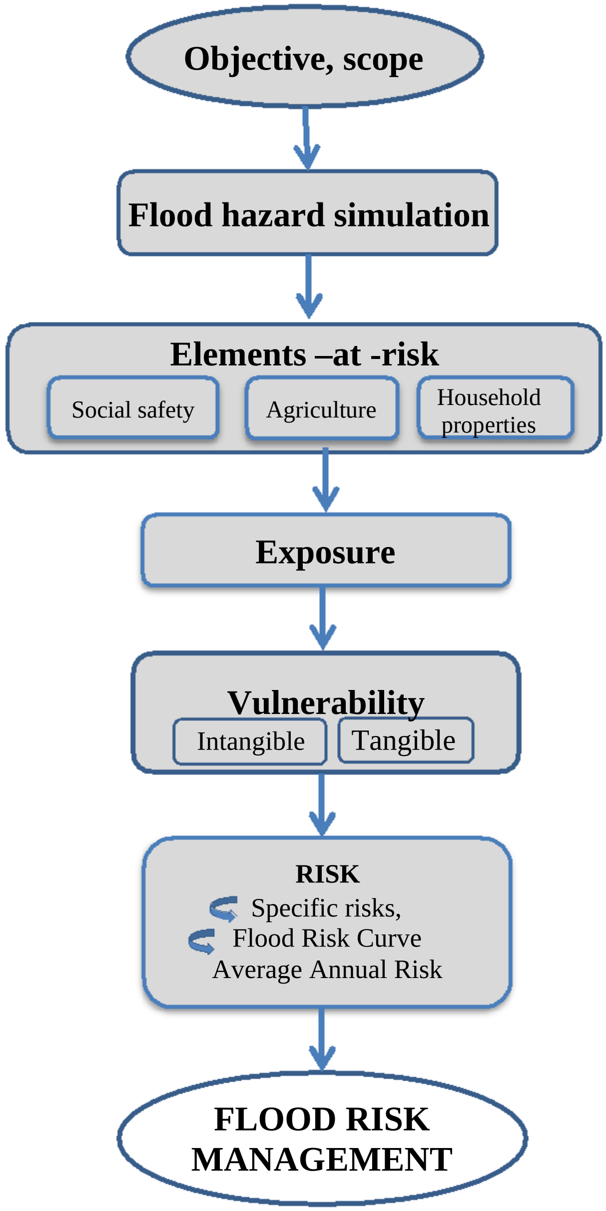


Figure 1.2. Flowchart of overall methodology

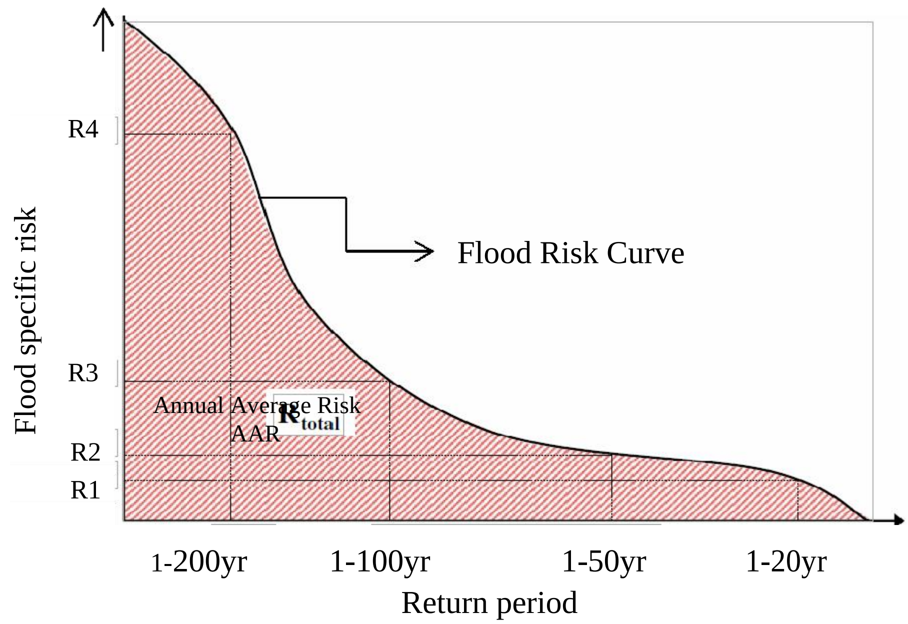


Figure 1.3 Relationship between Flood Risk Curve (FRC) and Annual Average Risk (AAR) (Messner et al., 2007)

Chapter 2: Literature review, study area and data acquisition

The first of Chapter 2 is to review the literature, including theoretical background of risk concept and risk management practice and the existing methods and approaches for flood risk analysis in some countries. The following part is to discuss the study area , i.e. the downstream of Vu Gia – Thu Bon basin, Central Vietnam with focus on flood pattern and socio-economic issues which will be the input for further analysis in following chapters. Data acquisition is also included in Chapter 2, i.e. collection and analysis of comprehensive primary and secondary data is explained, including hydrological time series record, spatial data of elevation, land use, information from household survey and interview and secondary data from statistics books and reports.

Chapter 3: Flood hazard analysis

In this Chapter, based on the collected data, the flood scenarios of 100-year, 50-year, 20-year and 10-year return periods are simulated by 1D hydrodynamic model MIKE11 package. The hazard maps with corresponding return periods are then visualized using GIS tool to indicate the level of hazard in terms of inundation depth and extension for the study area.

Chapter 4: Flood risk assessment for social safety.

Social safety is assessed for three elements at risk selected, including (1) number of effected peope, (2) number of people exposed to risk of injuries and (3) number of people exposed to risk of fatalities. In this Chapter the calculation of of social safety risk based on vulnerability analysis not only due to direct but also indirect vulnerabilities of the area and people. The flood risk curves (FRCs) and average annual risk (AAR) for these elements at risk

Chapter 5: Flood risk assessment for agriculture sector

Chapter 5 is to derive risk in terms of risk curves and annual risk as the function of hazard and vulnerability for agriculture. For each flood scenario, specific risks are calculated for elements at risk defined, including tangible and intangible, direct and indirect. The flood risk curves (FRCs) and average annual risk (AAR) is derived to show the significance of so called "hidden" risk for agriculture caused by flood disaster for the long term development in the local area.

Chapter 6: Flood risk assessment for for household properties

The methods and steps of analysis of this Chapter are similar to Chapter 5 but for household properties

Chapter 7: Flood risk management recommendation

Chapter 7 is going to discuss how risk based approach can be highly appropriate for long term flood disaster management planning. Specifically, based on the result of risk analysis obtained from Chapter 4, 5 and 6, number of proposed countermeasures are recommended.

Chapter 8: Conclusion and recommendation

The Chapter 8 is to summarise the important findings and conclusions produced in the previous chapters. The limitations of this Study and future concerns are also discussed in this final Chapter.

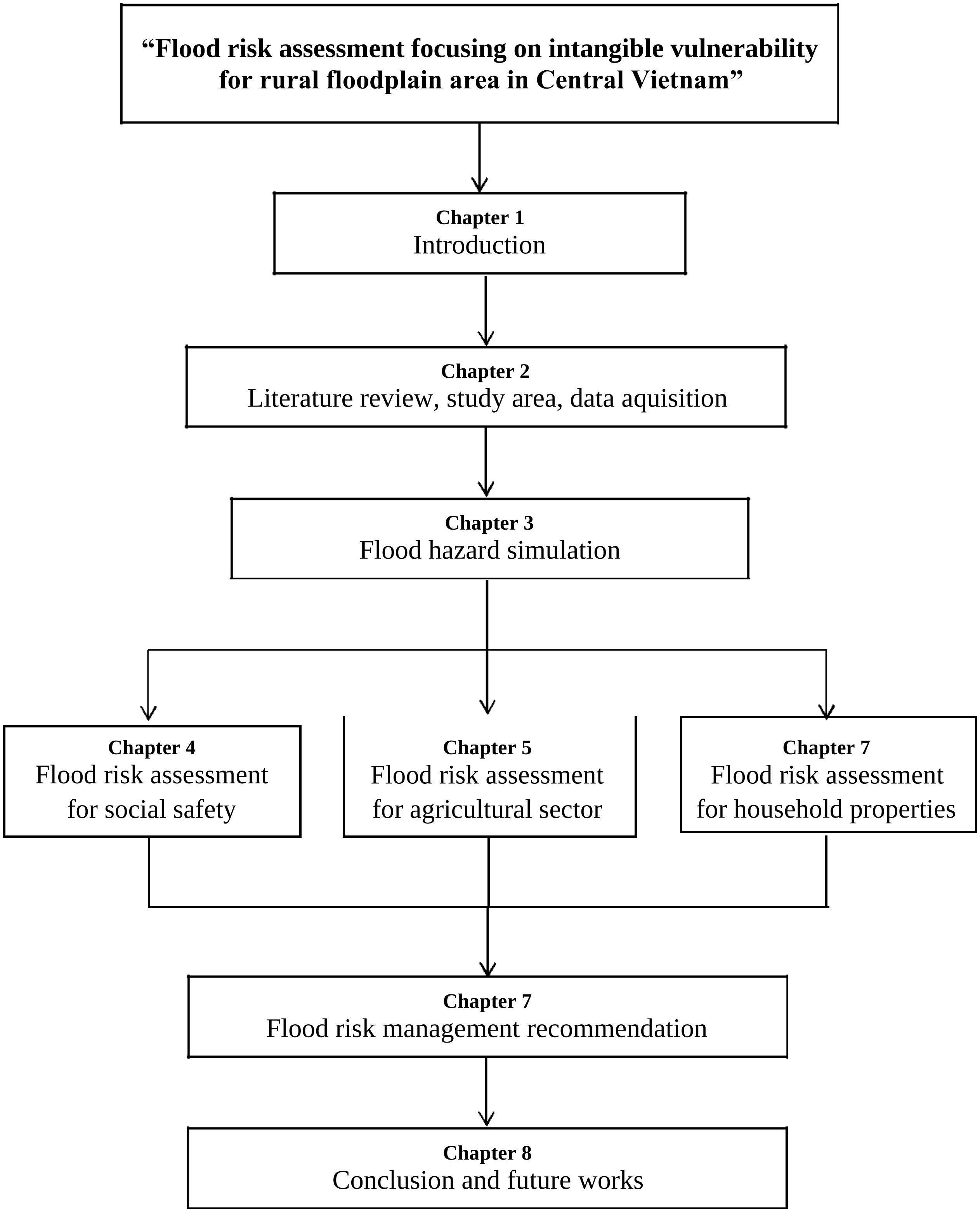


Figure 1.4. Structure of the Thesis

Chapter 2. Literature review, study area and data acquisition

2.1 Introduction

Intensive review on the theoretical background of flood risk concept and its analysis methods will the carried out in this Chapter. The following section is to describe the main characteristics, e.g. topography, climate, hydrological regime and socio-economic conditions, of the selected area for this research which is located in Vu Gia Thu Bon (VGTB) river basin, Quang Nam province, Central Vietnam. The basin comprises the entire with a total area of 10,350 km^2 extending from 14°54′N to 16°13′N and from 107°12′E to 108°44′E. The basin borders on the Huong River Basin to the north and the East Sea (South-China Sea) to the east. It shares borders with the Mekong River Basin to the west and southwest, and with the Tra Khuc River Basin to the south. In the last section, data collection and analysis required for this research will be discussed.

2.2 Literature review

2.2.1 Development of flood risk management concept

Since early civilization people prefer to settle in the river deltas to utilize the advantage of water use for their livelihood. Therefore, living with the flood has gained long history for man-kind in many regions around the world. Later, recognizing the requirement for life and livelihood protection people attempted measures to control the flood, e.g building dike, barrier, researvoirs etc. Nevertheless, as population grew and floodplains were developed, flood losses continued to increase (Lotch et al., 2013) resulting a need for more effective solution(s) in dealing with the flood as concept of risk was utilized and regularly developed to support decision making. This evolution of flood risk mamangement practice is demostrated in Figure 2.1 (Lotch et al., 2013).

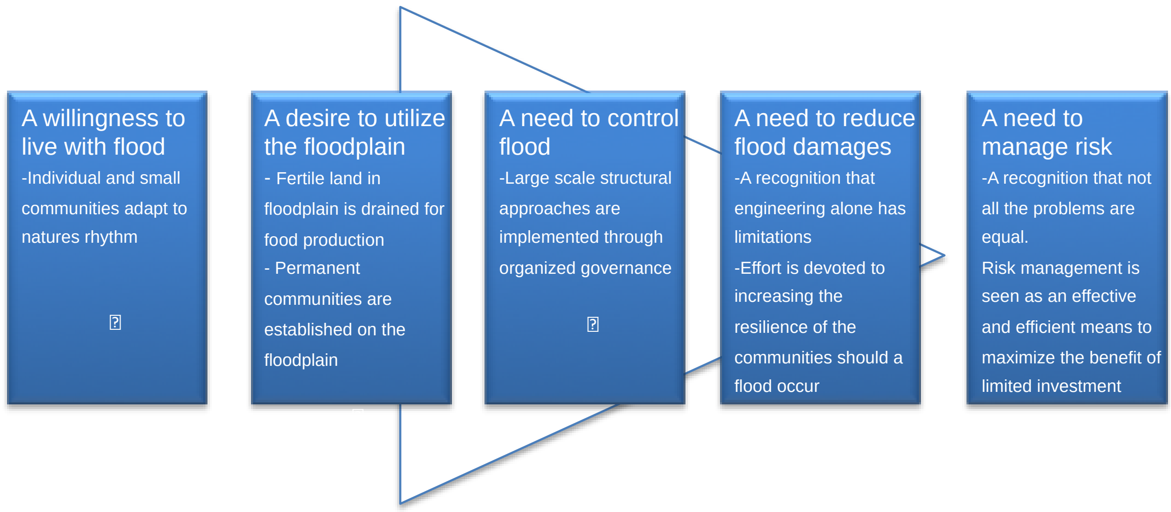


Figure 2.1 The evolution of flood risk management practice

Definition of risk: There is no consistent definition of risk as this concept has gone through an interesting evolution during the past decades. It is originally derived from the Arabic word (rizk), which means 'to seek prosperity' (ADB, 2013). In the English language the word risk was used starting in the 17^{th} century. According to Wikipedia (http://en.wikipedia.org/wiki/Risk) “Scenario analysis matured during Cold War confrontations between major powers, notably the U.S. and the USSR. It became widespread in insurance circles in the 1970s when major oil tanker disasters forced a more comprehensive foresight. The scientific approach to risk entered finance in the 1980s when financial derivatives proliferated. It reached general professions in the 1990s when the power of personal computing allowed for widespread data collection and numbers crunching.”

Recently, risk is a term that has become a part of our society and it is used in many different fields, including: business and financial risk, insurance, health, engineering and natural hazards. The study adopted the definitions from UN-ISDR about risk in disaster management: ”The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure and vulnerability” (*http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm*).

The relation among these main variables (also see Eq (1-2) are illustrated in Figure 2.2 and defined as following:

“Hazard” is a quite common word that used frequently in daily speech with different meanings. Webster’s dictionary of the English language (edition 1990) defines hazard as: “*a risk or associated with dange*. On Wikipedia we find the following entry (9 Febr. 2009): “*A hazard is a situation which poses a level of threat to life, health, property or environment. Most hazards are dormant or potential, with only a theoretical risk of harm, however, once a hazard becomes 'active', it can create an emergency situation*”. But also in scientific literature it has been used imprecisely and with different implicit meanings. For the study of hazards, a more restricted definition is required. In literature and on the internet one will find many definitions that are similar but not exactly the same. In this study, the definition by UN-ISDR (2004) will be used as “*A hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity*”. Especially the last sentence makes this definition workable, which contains four important elements: First, hazard is expressed as a probability; the likelihood that something may happen in the future. When, where and how much is not sure, but it is possible to identify areas where a hazard is more likely to occur than in other areas. Second, the hazard probability is restricted to a specified period of time; usually a year. The annual probability is the likelihood that an event will happen in the next year. Without this restriction, the probability expression would be useless. The likelihood that a floodplain will be flooded is 100%, but it could take a 1000 years before it actually

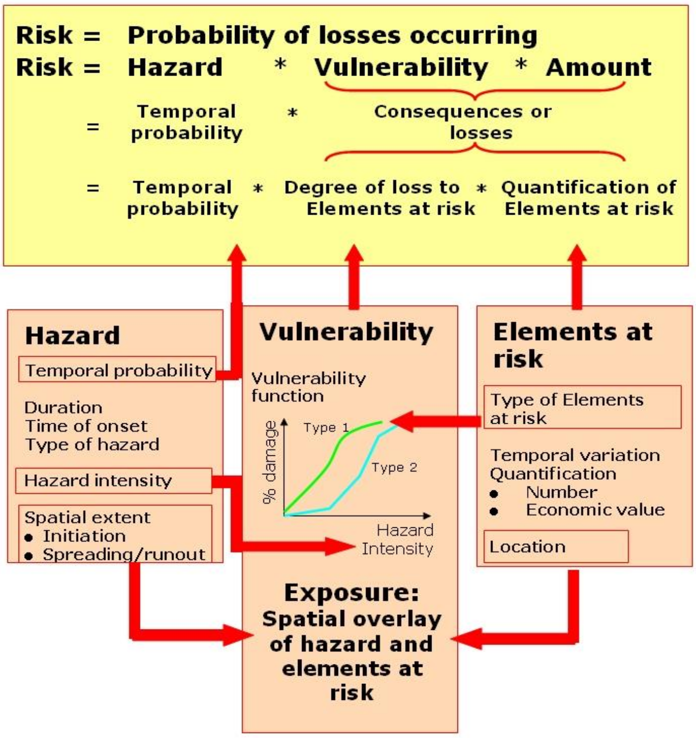


Figure 2.2 Basic components of risk (Western C.J., 2010)

happens. It is more relevant to know what the probability is that it is flooded in the coming year, or the year after etc. Third, it is valid for a specified area, e.g, floods on certain floodplains. The site specific characteristics co-define the hazard conditions. And fourth, the intensity – or magnitude – of the event. To be capable of causing loss of life or damage, the event must be of a certain intensity or magnitude.

"Exposure" indicates the degree to which the elements at risk are exposed to a particular hazard. The spatial interaction between the elements at risk and the hazard footprints are depicted in a GIS by simple map overlaying of the hazard map with the elements at risk map.

"Vulnerability" is also a complicated concept which has range of definitions. According to UNDRO, vulnerability is "the degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)". More recently, UNDP defined vulnerabiloty as "a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard" (ADB, 2013). By the other words, **vulnerability** refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Vulnerability can be classified in physical, social, economical, and environmental vulnerability based on its nature or tangible and intangible based on its units of loss and damage. To evaluate the vulnerability, one popular approach is to develop **vulnerability curves** or also called **stage – damage functions, which are** the interaction between the intensity of the hazard and the type of element-at-risk

"Elements-at-risk" are the population, properties, economic activities or any other defined values exposed to hazards in a given area. They are also referred to as "assets". Elements at risk also have spatial and non-spatial characteristics. First of all there are many different types of elements at risk and they can be classified in various ways. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The interaction of elements at risk and hazard defines the exposure and the vulnerability of the elements-at-risk.

Classification of elements-at-risk

In general, the elements-at-risk can be categorised as tangible and intangible depending on whether or not the losses can be assessed in monetary values (CONHAZ, 2011). For evaluation purposes, these two categories are furthur divided as direct and indirect losses. Direct damages occur due to physical contact of flood waters and indirect ones are induced by the direct ones and may occur after the flood events. Table 2.1 presents an example about different types of possible damages in case of flood occurrence.

Table 2.1 Classification of flood damage

	Tangible	Intangible
Direct	Physical damage to - Housing and its content - Infrastructure and public utilities - Agricultural products	Loss of life Health effect Loss of valuable properties (photos, diaries, certificates etc.) Environmental pollution and ecosystem damages Damage to cultural sites
Indirect	Temporary relocation Cleaning and sanitation Business interruption	Limited long term investment Low living standard Immigration of young people to major cities for jobs Increased vulnerability

In risk analysis, apparently the priority is given to evaluate the direct tangible elements (DEFRA, 2006). The popular method for the assessment of this type of damages is using "stage – damage curves" which present the relationship between flood level and the degree of damage in either monetary value or in damage ratios (Messner et al, 2007). Kelman and Spence (2004) point out that the most detailed studies on direct flood damage focus on the degree of the damage due to inundation level. They also emphasize that past studies have also suggested that other flood parameters, such as velocity, duration and speed of flood raising are important but not being widely used.

The assessment of direct intangible and indirect (tangible and intangible) elements is very complicated and difficult to quantify due to its subjectivity and lack of data (Lekuthai, 2002) and thus, it is generally not taken into account in a cost benefit analysis (CONHAZ, 2011). However, evaluation of intangible damages is essential as they are sometimes larger and more important, especially for the households affected, than the direct monetary losses (Green and Penning-Rowsell, 1989). Intangible elements-at-risk can be divided into two groups. The first group includes those related to security of affected people (e.g. casualties, injuries, public health etc.). The second group consists of elements to represent the damages of environment, culture, business interrruption, well-being etc.

2.2.2 A need of flood risk assessment for sustainable development

One way of dealing with natural disaster events is to ignore their threats. Until recently in many parts of the world, neither the population nor the authorities choose to take the danger of natural hazards seriously. The complacency may be due to the last major destructive event having happened in the distant past, or people may have moved in the area recently, without having knowledge about potential hazards. Alternatively, the risk due to natural hazards is often taken for granted, given the many dangers and problems confronted by people. Authorities sometimes may ignore hazards, because the media exposure and ensuing donor assistance after a disaster has much more impact on voters than the investment of funds for disaster mitigation. The past decades have witnessed a shift in focus from ‘disaster recovery and response’ to ‘risk management and mitigation’. The change was also from an approach that was focused primarily on the hazard as the main causal factor for risk, and the reduction of the risk by physica protection measures to a focus on vulnerability of communities and ways to reduce those through preparedness and early warning. Later also the capacities of local communities and the local coping strategies were given more attention. The Yokohama conference in 1994 put socio- economic aspects as component of effective disaster prevention into perspective. It was recognized that social factors, such as cultural tradition, religious values, economic standing, and trust in political accountability are essential in the determination of societal vulnerability. In order to reduce societal vulnerability, and therewith decrease the consequences of natural disasters, these factors need to be addressed. The ability to address socio-economic factors requires knowledge and understanding of local conditions, which can – in most cases - only be provided by local actors.

A general strategy for disaster risk reduction must firstly establish the risk management context and criteria, and characterize the potential threats to a community and its environment (hazard); secondly it should analyse the social and physical vulnerability and determine the potential risks from several hazardous scenarios in order to, finally, implement measures to reduce them. The final goal, reduction of disaster risk in the present and control of future disaster risk, should be achieved by combining structural and non-structural measures that foster risk management as an integrating concept and practice which are relevant and implemented during all stages of a community's development process and not just as a post-disaster response. Disaster risk management requires deep understanding of the root causes and underlying factors that lead to disasters in order to arrive at solutions that are practical, appropriate and sustainable for the community at risk (UN-ISDR, 2005).

Evidently, managing risk in this manner requires a consensual and collaborative approach. The UN-ISDR has widely advocated for new ways in which authorities, communities, experts and other stakeholders jointly diagnose problems, decide on plans of action and implement them. In other words, a new ethic of disaster risk management is emerging, based on 'informed consent' as opposed to paternalism. Risk assessment as the starting point for further risk management processes should in turn be a multifaceted activity aimed at integrating the likelihood and potential consequences of an event with subjective interpretations (perceptions) of interacting, heterogeneous actors. Therefore, this part is going to briefly introduce the general concepts of main components involved in risk assessment and then, to review existing methogologies applied world wide to evaluate the risk.

From 1990-2000 the International Decade for Natural Disaster Reduction (IDNDR) and now its successor the International Strategy for Disaster Reduction (ISDR) stress the need to move from top-down management of disaster and a cycle that stresses rehabilitation and preparedness, towards a more comprehensive approach that tries to avoid or mitigate the risk before disasters occur and at the same time fosters more awareness, more public commitment, more knowledge sharing and partnerships to implement various risk reduction strategies at all levels (UN-ISDR, 2005). This more positive concept has been referred to as ‘risk management cycle’, or ‘spiral’, in which learning from a disaster can stimulate adaptation and modification in development planning rather than a simple reconstruction of pre-existing social and physical conditions. The ISDR aims at building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development, with the goal of reducing human, social, economic and environmental losses due to natural hazards and related technological and environmental disasters, which is imcompliance with priorities of Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. Furthermore, the Sendai Framework for Disaster Risk Reduction 2015-2030 (often called in short as Sendai Framework) issued in the Third World Conference on Disaster Risk Reduction in March 2015 emphaisizes the need of managing the underlying drivers of disaster risk though enhancing understanding of disaster risk, governance for disaster risk reduction, investment and measures to strengthen resilience and preparedness for “build back better” at local level.

Therefore, we all agree that disaster risk management is included in the agenda of top summit world wide as the result of its importance to sustainable development and human well-being.

2.2.3 Review on flood risk analysis methods world wide

To analyse flood risk, an integrated approach is required which generally contains of the following steps: definition of scope, danger (threat) identification, estimation of probability of hazard occurrence, evaluation of the vulnerability of the elements at risk, consequence identification and risk estimation.

Therefore, basically, the Eq 2-1 for flood risk calculation given above is not only a conceptual one, but also be actually calculated with a set of inputs including hydraulic simulation, GIS based spatial data and social data. The scope of the analysis very much depends on extension of target area/region and the amount of elements-at-risk, such as e.g. residential housing, public facility, population, industry and trading and environmental value. Accordingly, there is a range of methods used in risk analysis that can be broadly classified into:

- Qualitative methods to produce the results in qualitative description of risk in terms of high, moderate and low.
- Semi-quantitative methods to espress risk in terms of risk indices, e.g. ranging between 0 and 1.
- Quantitative methods to calculate and espress the risk in quantitative terms either as relative or absolute losses.

For further communication, the risk calculated is presented in different forms, either matrix (mainly for qualitative methods) or map (for all three types of methods) or risk curve (used only for quantitative calculation) with the example shown in Figure 2.3

Although to date, intensive research has been carried out on this topic, especially thoese from Netherlands, Australia, New Zealand, Germany, UK, Japan etc. there are not many risk assessment studies in the literature that explicitly explain approaches for estimation of flood disaster consequences, especially in quantitative manner.

1. Quantitative methods for assessing fatalities and injuries

The history of the estimation of physical impacts on human safety due to natural hazards goes far back with some main methods and approaches as following

Friedman (1975) is one of the earliest studies, which estimated number of fatalities by the number of damaged residencies. He has developed a fatality rate per damaged residence, which is one fatality per 170 and 85 damaged households for normal floods and for flash floods, respectively. The number of people in the 13 flooded areas was estimated by assuming that each household has 3 persons based on statistics data in 1970 (cited by Dassanayake et al., 2010).

Throughout the last decades several methods have been proposed in the Netherlands for the estimation of loss of life for coastal and river floods as large part of the country could be flooded both due to coastal and river flooding. Most methods are directly or indirectly based on data on the fatalities caused by the 1953 flood disaster in the Netherlands. This event was induced by a storm surge on the North Sea that resulted in flooding in the Netherlands, the United Kingdom and Belgium. In the Netherlands large areas in the southwestern part of the country were flooded and the disaster caused enormous economic damage and 1835 fatalities. Duiser (1989) and Waarts (1992) collected data regarding the loss of life due to this disaster in the Netherlands from memorial volumes and official reports. Both reports give loss of life and hydraulic circumstances (water depth and sometimes rise rate) by municipality. Based on available descriptions, Waarts (1992) distinguished fatalities in three zones: a zone with high flow velocities, a zone with rapidly rising waters and a remaining zone. Table 2 presents the distribution of reported fatalities over the three categories and shows that most fatalities occurred in the zone with rapidly rising waters. This dataset has been used for the derivation of the methods described below.

Based on the available data with focus on data on the 1953 flood event, Waarts (1992) derived a general function for flood mortality (Fp, [—]) as a function of water depth (4 [m]): $\mathbf{F_D(h) = 0.665 * 10^{-3}\ e^{1.16h}}$ Waarts also proposed a more refined method that takes into account the effects of warning and evacuation, high flow velocities and the collapse of buildings. However, not all factors in this refined method have been specified based on historical data.

Based on Waarts' general functions, an extended method has been proposed by Vrouwenvelder and Steenhuis (1997). Especially rapidly rising floods will cause hazardous situations for people, and therefore the rate of rise of the water (w [m/h]) is included in the mortality function:

$$\mathbf{Fp=0 \quad h<3m \text{ OR } w<0.3m/h}$$
$$\mathbf{Fp(h,w) = \min(\max(8.5e^{0.6h-6} — 0.15;0).\min(\max(8.5e^{1.2w-4.3}-0.15;0),1))}$$
$$\mathbf{Fp=1 \quad h>625m \text{ AND } w>2m/h}$$

It is noticeable that this function gives Fp = 0 for h < 3m. This is in contrast with the observations from the 1953 storm surge disasters, where about one third of the fatalities occurred at locations with water depths below 3 m (Jonkman 2007). For w > 2m/h and h > 3m the function approximately corresponds to the above function of Waarts (1992). However, the limitation of these formula is that they are mainly based on single flood event and furthur application is not found in worldwide literature review.

One of the most comprehensive models is proposed by DEFRA (Penning-Rowsell et al., 2005), which estimates not only the number of fatalities but also injured people. This approach also involves important flood characteristics such as flood depth, velocity (hazard factors) and debris factor, area characteristics and population characteristics (vulnerability factors) as: **N(I) = N * X * Y w**ith **N(I)** is possible number of injuries; **N** is population of the considered area; **X** is the population who potentially expose to flood, which is calculated based on hazard rating (**HR**) and area vulnerability (**AV**). HR is then calculated as **HR= (v + 0.5) * d + DF,** with: **v** (m/s) is flood flow velocity; **d** (m) is water depth; **DF** is debris factor (0-unlikely; 1-possible and 2-likely). DEFRA proposes **AV** to consist of factors that can influent the number of injuries, including flood warning, speed of onset and nature of area. Then, **X = HR * AV. Y** is fraction of vulnerable people in the flood exposure area, which consists of three main groups: elderly people with age 75+, children with age under 6 and disable people. In particular, the method also proposes an estimation of fatality rate as: **N(D) = N(I) * 2*HR**. This method has been widely used in developed as well as developing countries (Haskoning, xxx; Tu xxx) to confirm its applicability.

The most recent development has been done by Jonkman (2008), in which possible fatalities fraction is assessed based on the magnitude and pattern of a flood event (i.e. water depth, rise rate and flow velocity) and on the other hand, coping capacity factors, including the effects of warning, evacuation and shelter. The number of exposed people and fatalities (N) can be estimated as: $\mathbf{N_{EXP} = (1 - F_E)(1 - F_S)N_{PAR} - N_{RES}}$ with N_{PAR}: the number of people in the risk area before the event; F_E: the fraction of the population that is evacuated out of the area before the flood; F_S: the fraction of the (remaining) population that has the possibility to find the shelter; N_{RES}: the number of people rescued. Then number of fatalities N is calculated as $N=F_D\ N_{EXP}$ with F_D: the fraction of mortality, which is in turn the function of flood characteristics as well as the collapse of building. The strong advantage of this method is that is determined based on advanced hydraulic simulation. Flood warning and evacuation are given more attention. One main drawbank of this method is that it has not considered age of people as key vulnerabilty factor causing bias in the result of calculated fatality number.

Some authors developed more general methods applicable to both river and coastal floods. Zhai et al. (2006) analysed data from floods in Japan to derive empirical relationship between the number of inundated houses and the loss of life based and injuries. In this study, six function of fatalities and six functions of injuries for different period from 1947 through 2001 in Japan. In these floods fatalities mainly occurred when more than 1,000 buildings were inundated and then increased as a function of the number of inundated buildings. The obtained statistical relationships show considerable variation, which might be due to the influence of other factors such as warning, evacuation, flood characteristics and the actual collapse of buildings. Table 2.2 summarizes the factors of popular methods which have been using world wide to assess the risk of social safety caused by flooding.

Table 2.2 Overview of methods to estimate loss of life and injuries caused by river flooding

Method	Data basis	Factors taken into account in loss of life estimation					
					Coping capacity & resilience		
		Water depth	Velocity	Rate of rising	Warning and evacuation	Building stability	Other
Duiser (1989)	1953 storm surge disaster in the Netherlands	x					
Waarts (1992)		x					
Vrouwenverlder and Steenhuis (1997)		x		x			
Jonkman (2001)		x	x		x	x	
Zhai et al. (2006)	Historical floods Japan					x	
DEFRA (2006)	Stability test and expert judgment	x	x	x	x	x	Population vulnerability

2. Methods for assessing economic damage

Quantitative assessment for potential economic damage aims at calculated the risk also based on Eq 1-1. In this method the combined effects in terms of losses for all possible hazard scenarios that might occur are calculated. In fact, this process is carried out through holistic approach (also see Figure…), which considers the risk of all kind of hazard types and hazard events the study region. As we mainly concern about hydro-meteorological hazards, the risk analysis process rather combines the hydrological knowledge about the frequency of hazard occurrence, the hydraulic modelling information about the extent area and thereby, potential exposure and economic damage evaluation knowledge in order to assemble so-called damage – probability curves for individual administrative regions or the whole study area. Figure 2.3 (Westen C.J, 2006) gives an example of probabilistic (risk based) assessment for building properties that are threatened to flood disaster. In this example, there are three different scenarios taken into account, each with a different probability of occurrence (e.g. 2 years, 10 years and 50 years). These scenarios are derived from hazard modelling approaches. Similarly, in this simple example, three elements at risk are defined with 2 types of houses and the construction of Type-1 houses is weaker than Type-2 ones. Based on past occurences of flooding a relation has been made between the inundation depth and the degree of damage using so called stage-damage (or fragility or vulnerability) curves. The potential damages of houses of each flood scenarios are calculated and then plotted against the probability of flood occurrence to derive risk curve(s). It means that the risk curves can be developed for specific risk of each element at risk or for total risk (of total potential damage). *The total area under the curve represent the total annual risk induced by flooding*. To calculated this highly quantitative indicator, two methods can be used: (1) Triangeles and rectangles method and (2) Simplified rectangle method with examples shown in Figure 2.4 (Westen C.J, 2006, Ward, 2011).

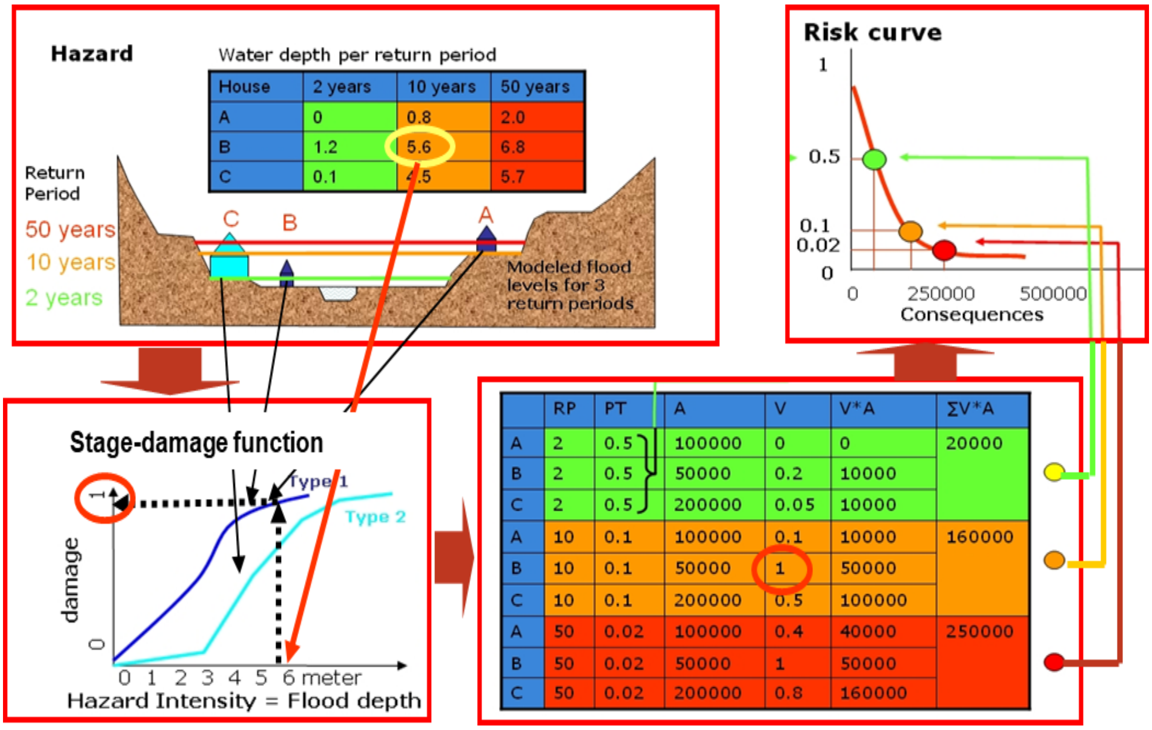


Figure 2.3 Stage-damage curves used in tangible risk analysis (Westen C.J, 2005)

Such a figure shows the amount of total damage which is to be expected if a hazard event with a specific frequency of occurrence happens. The total area under the curve represents the average total expected flood damage per year for all kind of floods. Hence, the damage – probability curve contains important risk-related information for decision making on flood risk management policy. To carry out this process of flood risk calculation, there are two separated components, including: flood hazard simulation and exposure and vulnerability assessment. For flood hazard simulation (i.e. inundation map), in most cases, a conventional method of hydraulic 2D or 3D modeling is used. However, for assessing vulnerability and potential costs of damages, a range of methods and approaches is existing depending on type of hazards, scope of assessment (or complexity of elements-at-risk) as well as availability of input

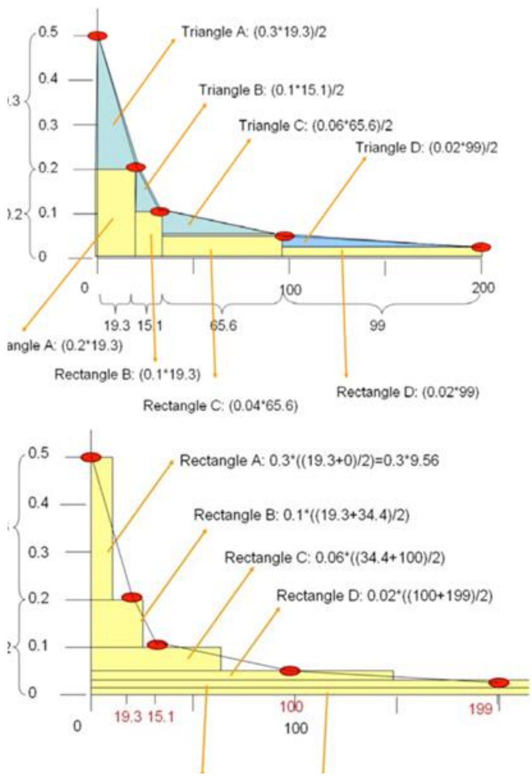


Figure 2.4 Calculation of annual risks (Ward et al., 2011)

data, requirement of accuracy or accepted uncertainty. Based on extensive review of literature, the typical methods that have been used world wide for assessing potential losses caused by flood disaster are summarized as following:

- ***Direct tangible damages:*** The most popular approach for assessing these damages is the use of stage – damage functions (or also called fragility functions), which are constructed on the basis of relation between hazard intensities and damage data in the form of a curve showing an increase in damage for a higher levels of hazard intensity (as an example shown in Figure 2.3) (Westen et al., 2010). The stage-damage functions are developed for individual types of damages or individual elements at risk, e.g. crops, urban buildings, rural residential houses, roads etc. These functions are very much dependent on the market cost and site specific characteristics and thus, they are significantly changeable from one region to the others. Over past decades, number of researches in Netherland, Germany, Australia, New Zealand, Japan etc. developed stage damage functions (Dutta et al., 2003; Forster et al., 2008; Zhai and Ikeda, 2008; NIWA, 2013). In developing countries, recently, this approach for risk assessment is also applied but still rather limited; The typical case studies were the ones carried out by Haskoning, 2009; Nhu et al., 2017.

- ***Indirect tangible damages:*** The indirect costs, such as business interruption costs, repair cost etc. can be calculated as a percentage of direct damages mainly based on firm – or household-level survey relating to single past events (CONHAZ, 2011). Some examples used this simple method are Australian flood loss model ANUFLOOD (NR&M, 2002) and Rapid appraisal model (RAM) for flood plain management (NRE, 2009). In ANUFLOOD, a ratio of 55% is used. In RAM, although different ratios are recommended depending on the certain environmental functions, an average ratio of 33% is proposed but a ratio of 20% and 45% can be used for rural area and densely populated area, respectively.

Another approach is the use of a reference value, i.e. the value is then multiplied by a number of affected persons/business (e.g. national compensation figures, yearly income…). An example of using this approach is US model Hazus-MH MR (FEMA, 2011), in which the losses dur to disruption of production processes is estimated based on relocation expenses, income losses and other costs incured. According to Meyer et al. (2013), this method has been scaled up to be econometric model by using the analysis of several events to derive the main explainatory factors for estimating the costs of future events. More recently, another approach named “Input-Output Model” is proposed to evaluate the consequences of a specific impact on one or more economic sectors on other sectors of the economy (Freeman et al., 2014). This can be achieved by applying fixed input-output coefficients to describe the relationships between various economic sectors. Due to limitation of flexibility, these two types of model are still not popular and applicable at regional/national level (Dassanayake et al., 2012; Freeman et al., 2014).

- ***Intangible (direct and indirect) damages:*** Intangible damages, e.g. those to environment, culture and health, is not expressed by direct market cost. However, to be included in a Cost-Benefit Analysis framework and to support decision making, intangible damages also have to be converted into moneytary terms. To do so, several valuation methods and approaches have been developed that can be divided into two main categories, namely (Table 2.3) (CONHAZ (2011), Meyers et al. (2013)):

- Revealed preference methods to estimate the value of a particular good based on actual market behaviour, including Hedonic prices method, travel cost method, cost of illness approach and replacement cost method.

- Stated preference: The methods in this category create a hypothetical or contigent market in a survey. They utilize willingness to pay (WTP) or willingness to accept (WTA) compensation for avoiding/repaire an environmental damage. These methods are named as Congtigent Valuation method (CVM), Choice Modelling method, Life Satisfaction method.

One of the most intensive researches for intangible damages is DEFRA (2006) in UK. DEFRA carried out a WTP survey to evaluate the mitigation of intangible effects of flooding for the target group of persons at risk and not at risk. A figure of £200 per year per household was found. The cost of illness approach of revealed preferences method was also used to evaluate working days lost due to illness and medical costs. Abbas et al. (2016) applied so called Willingness-to-Contribute (WTM), a similar approach to willingness-to-pay in CVM, in their study in Pakistan about the significance of willing in-kind contribution of local farmers in constructing structural measures to mitigate the flood risk. This study reveals the applicability of CVM in developing mitigation measures to flooding in rural areas of the developing countries where are lack of sufficient financial availability but still requiring costly structural defence work to cope with extreme flood events. On the other hand, in the context of increased frequency and uncertainty of extreme climatic events, it is believed that the disaster insurance is highly important to help with recovery and secure social stability and sustainability through mitigating financial risk. However, the implementation of this policy in most developing countries is very limited (Lotsch et al., 2010; Sayers et al., 2013). There have been several attempts were carried out by using social survey approach to seek public consent on willingness to pay for insurance. For example, Abbas et al. (2015) used CVM to collect primary data in five districts in Pakistan, the area of agricultural importance but highly affected by flooding, to evaluate the willingness to pay for flood insurance. The results showed that the driving factors of acceptability of this policy are age of household head, landownership, off-farm income sources and a perception about the effectiveness of flood insurance. In Vietnam, until now only one attempt was made to evaluate catastrophic flood risk insurance in the coastal zones using Choice Experiment Method, in which range of potential damages, including some indirect ones was covered (Brouwer et al., 2014).

Apart from these methods described above, Lekuthai et al. (2002) also developed another method named as Anxiety-Productivity–Income Interrelationship Approach (API), in which anxiety damage is presented in terms of income level. However, after that case study done in Thailand, this method has not been applied in other regions.

Table 2.3 Comparison of methods for flood damage evaluation

Method	Remarks
For direct tangible damages	
Stage – damage functions	Relation between hazard intensities and damage data in the form of a curve. Very popular to evaluate direct damages of crops, housing, infrastructure
For indirect tangible losses (e.g. business interruption etc)	
A percentage of direct tangible damage	Often used at macro (regional) level
For intangible damages (excluding fatalities and injuries)	
Revealed preference	
Hedonic pricing methods: The impacts of environemntal are estimated based on market values	✔ Estimation based on actual and relatively reliable values ✖Relatively complicated to implement and analyse. In many cases, the values must be borrowed from neighbouring area
Travel Costs method: The use values related to ecosystems or sites are estimated based on time and travel costs spent by people	✔ Estimation based on actual information of people's behaviour, inexpensive and not too complicated analysis ✖ □ Limited application, based only on travelling behaviour
Cost of Illness Approach uses the medical costs or salary/income to estimate the health impacts	✔ Estimation based on actual and quite available information of people's behaviour, inexpensive and not too complicated analysis ✖ Limited application, based only on medical services
Replacement Cost Method estimates the services of environement based on replacement cost	✔ Applicable for range of elements at risk, especially for environmental functions and infrastructure ✖Complicated analysis to obtain the cost of possible damages, often overestimation as replacement cost higher than actual lost
Stated preference	
Contigent Value Method: Social survey is carried out using questionaires and direct interview to evaluate the willingness to pay (WTP) or to accept (WTA) of people at risk	✔Enormously flexible that can be used to evaluate the economic value of range of intangible elements-at-risk ✖Hypothetical bias (often overestimation of the real economic value)

Choice Modelling Method: In the social survey, the interviewees have to chose between different alternatives (or models) with certain attributes	✔Able to obtain values for individual attributes of the good, making choices to be easier for the interviewees ✖Less direct, time consuming for analysis and choosing the model
Life Satisfation Method: In the social survey, the interviewees are asked to evaluate disaster induced impacts on their health and life quality. Then, an utility functions are used to assessed these impacts in economic value	✔Focusing on the critical element about public health and life quality ✖Limited application, highly bias

2.3 Main characteristics of Vu Gia – Thu Bon basin

2.3.1 Topography and climate

Topography: Topography of VG-TB basin is characterised by the Bach Ma Mountain Range in the north with peaks over 1000 m, by the South Truong Son mountains in the west with peaks over 2000 m, and by the Kon Tum mountain mass in the south, which runs out to the sea with Mount Ngoc Linh as the highest peak in the whole river basin (2598 m). The topography divides the area into three major landscapes from the west to the east. Based on the topographical features and major economic activities, the landscapes of the basin can be classified into highlands, midlands and lowlands (Figure 2.5).

Climate: The annual average temperature varies between 24.5 and 26.5 °C and tends to increase gradually from the west (mountainous area) to the east (coastal area). Maximum temperature occurs in June and July with maximum temperatures above 40 °C on days with dry winds from the west, and minimum temperatures in December and January. The lowest recorded daily temperatures have been as low as 10 °C, but the monthly mean temperatures are above 20 °C for all months (xxx).

Rainfall: As being influenced by the Bach Ma hill range in the north and the eastern direction of the West Truong Son mountain range, the climate in the VGTB river basin shows regional typical characteristics with relatively warm winters, dry summers affected by dry winds from the west, and a strong rainy season with typhoons lasting from September to December.

The extended dry season lasts from January to August and is regularly accompanied by droughts, which usually occur from February to April and account for 3–5% of the total annual rainfall. In May and June there is a second rainfall peak, which is more pronounced in the north-western part of the area.

Rainfall during the wet season accounts for 65–80% of the total annual rainfall, with 40–50% of the annual rainfall in October and November causing severe floods annually (LUCCi, 2017). On the other hand, the rainfall in the basin is unevenly spatially distributed and has a strong orographic component ranging from about 2,000 mm in the flood plain to more than 4,000 mm in the upper parts of the basin (Figure 2.6) (VAST, 2012). In general, during wet season, a rainfall can last over few days with an amount of of 200 to 400mm. Every year, 2-4 typhoons make landfall in this region bringing huge rainfall and whirlwind. In case the occurance of a cyclone or tropical depression coincides with a cold front from the North, the rainfall can be as torrential as up to 500 to 600mm or even 1000m (VAST, 2012)

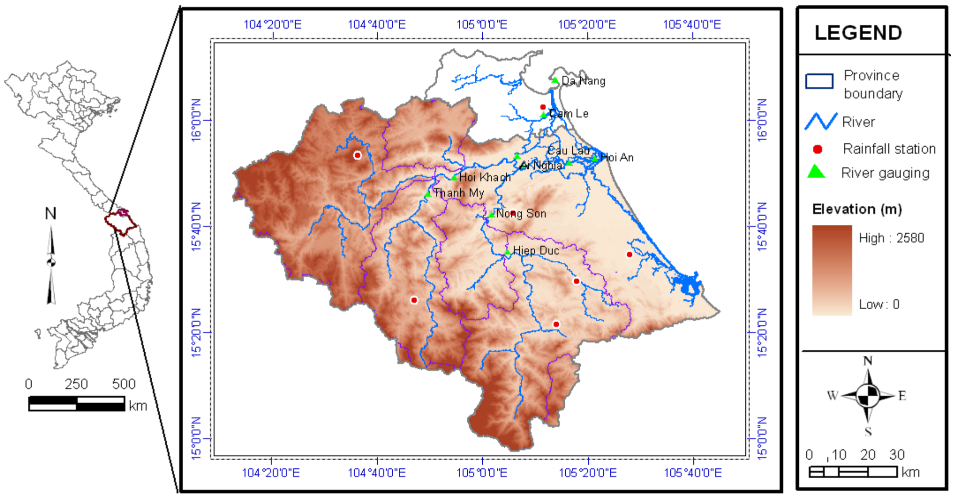


Figure 2.5 Topographic map of VG-TB Basin

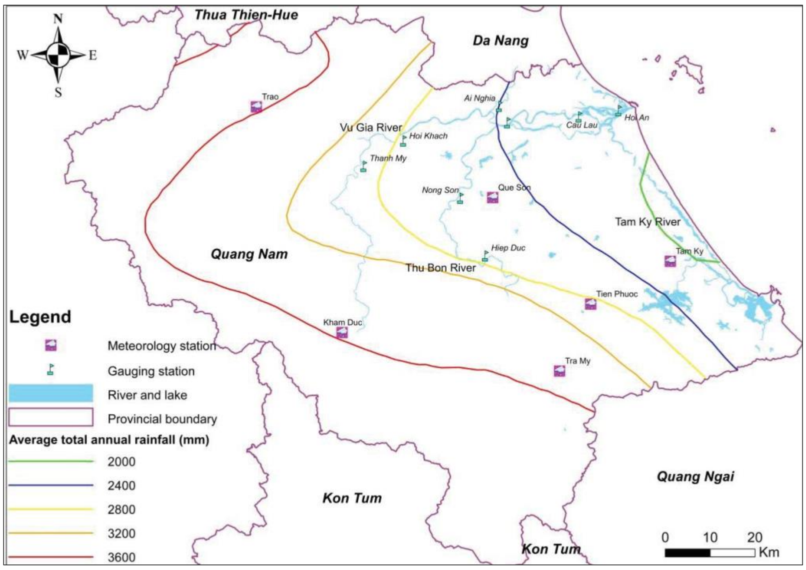


Figure 2.6. Spatial distribution of rainfall in the region of Quang Nam province

2.3.2 River system

VG-TB river system and originated in the Truong Son mountain range at the elevation of 1,600m. Being as one of the nine largest basins in Vietnam, the system is formed by two main rivers, namely Vu Gia and Thu Bon, flowing through major part of Quang Nam province and discharging into the sea at three inlets named Han, Dai va Lo. During the flood season, the two rivers interact through the Quang Hue and Vinh Dien rivers forming a braided river delta system. The total basin area is of 10,350km^2 with the length of Thu Bon river itself of 206km and tributary density of about 0.47km/km^2 creating rather complicated hydrological system. Its upper part is short and steep with a narrow riverbed, steep banks and many cascades. In the middle and downstream reaches, the riverbed is rather wide and shallow (Figure 2.5). In the downstream reach, the river bed becomes flat and the banks is low, allowing overflow into fields and villages during the flood season. The combination of high topographical slope (i.e. 25% in average) and torrential rainfall for days as described earlier VG-TB river system experiences extreme flash floods in mountainous area and deep inundation in the downstream plain and coastal area. Every year, the flood season is from September through December with multiple peaks. According to VAST (2012), the amount of surface water flowing in the basin is directly related to precipitation, which varies geographically and seasonally. The majority of rainfall occurs in the wet season (September to December), with 70 % of runoff generated during these 3 months. In contrast, during the height of the dry season (February to March) only 12% of runoff is generated. The basin has one of the longest dry seasons in Vietnam with 9 months of the year receiving only 30% of the rainfall, resulting in severe water shortages and problems with saline intrusion at the coast (LUCCi, 2017). Hydrological stations at Thanh My on the Vu Gia, and Nong Son on the Thu Bon have continuously gauged daily discharge since 1976. Figure 2.7 shows the variability of peak discharges at the main gauges of Thanh My and Nong Son. From this Figure, observed data since 1976 show that the of river discharge is high and that the Southern Thu Bon receives much more rainfall with higher discharge. The highest flow at Nong Son was 10,600 m^3/s (04-11-1999), while the lowest flow was only 4.63 m^3/s (17-08-1977).

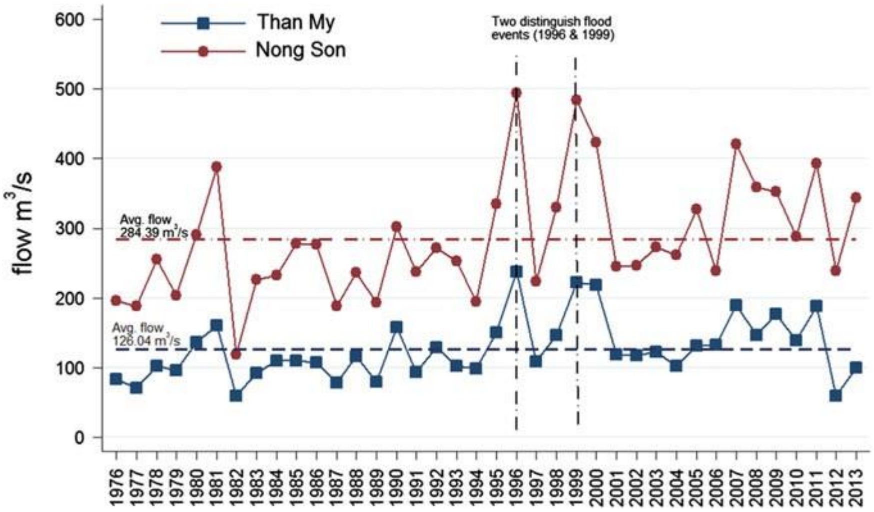


Figure 2.7 Comparision of annual discharge rates at
Nong Son (Thu Bon) and Thanh My (Vu Gia)

2.3.3 Socio-economic conditions

VG-TB basin is rural but accommodate large population of about 1.737.734 persons with the density in the downstream area as high as 1,000 people/$km^{2.}$. Although hazard analysis is often carried out for a basin extension, the risk analysis is applied for an administration area in compliance with the availability of socio-economic data and information. To be in line with this, this research selects a pilot area of Dien Ban District located in the basin downstream, near the intersection of Vu Gia and Thu Bon rivers and close to Hoi An City. This District can be considered to have most typical issues for a risk analysis case study, e.g. serious and complicated flooding pattern, high density and relative emerging economic development. Therefore, to prepar for further vulnerability and risk analysis, this part is going to focus only on the socioeconomic conditions of Dien Ban District, not the entire basin. The economy of Dien Ban District consists of 03 main sectors namely agriculture (crop cultivation, aquaculture, horticulture), manufacturing and construction and a broad range of private and public services engaging working labour of 29.2%, 36.7% and 34.1%, respectively (Figure 2.8). Recently, industrial manufacture has been significantly increased but mainly in less flood affected districts (to be discussed later in next part). Paddy cultivation and livestock farming are the two main agricultural activities in the basin. Paddy cultivation is the most important agricultural activity. Two crops of paddy are planted per year in the lowlands and areas along major rivers, where ample water resources exist for irrigation. Even in the valleys of the mountainous areas, at least one crop of paddy rice is planted per year. Other annual crops such as cassava, maize, sweet potato, peanut and sesame are also planted in the lowlands, particularly in the coastal areas. Pepper, rubber and cinnamon are the main perennial crops in the region and are planted in the upstream parts of the Thu Bon sub-basin. In agricultural sector, aquaculture has become emerging activities with relatively higher income, which has been extended in both brackish and fresh water courses with total area of approximately 130ha (Quang Nam, 2016) with average production of 1.05 tons/ha/year.

Figure 2.8 Main economic activities in Dien Ban District

Although contribution of agriculture sector to the economy in Dien Ban District dropped from 51% in 1996 to only 10% in 2016, this is most vital livelihood as around 30% of the households are still dependent on agriculture for income and food supply (Bruun et al., 2013). The population of Dien Ban District is more than 190,000, of which 13% has income less than the poverty line of US$20/person/month (Quang Nam, 2016). Such low living standard accelerates the vulnerability of local people and limits them from proactive disaster control and mitigation. Lotsch et al. (2010) explicitly emphasized that in the developing countries, especially in rural regions, poverty remains as a significant contributor to the vulnerability hen flood disaster occurs; frequent flooding in the floodplain area like Dien Ban district can in turn perpetuate the poverty.

2.3.4 Increased trend of flooding disaster and consequencial damage

Almost every year, the VGTB river basin is influenced by climate related disasters such as typhoons, tropical depressions, flooding, droughts, salinity intrusion, landslides, riverbank and coastal erosion. Flooding occurs frequently from September to December, while droughts and salinity intrusion take place during the period from February to August. However, as the droughts do not occur in the whole basin and relatively not yet to be categoried as disaster and the scope of the research defined in Chapter 1, this section will focus only in the impacts of flood disaters in the downstream area and their trends in the context of climate change.

As described earlier, due to steep terrain and “deep frying pan” shape in the downstream delta, the huge rainfall ranging from 3,000mm-4,000mm results in serious flooding in VGTB basin. According to Bruun (2013), the common characteristics of the flood events in this area are rapid rise and retreat with the rising rates in the range of 20-50cm/h. The huge volume of flood run-off overflow into crop fields and residential area in the floodplains causing inundation over the whole disctricts named Dai Loc, Dien Ban, Duy Xuyen and Hoi An. For examples, in the year of historical floods, the inundation area could be up to 452.28km2 in 1996 or 734.26km2 in 2007. As conventional way, most of rice and crop fields and aquacultural ponds are located on lowland area along the rivers for irrigation accessibility and thus, be strongly influenced by natural resources and climatic conditions and thus, highly vulnerable to natural hazards. This can be a reason to cause the study area and Quang Nam province are behind the development pace elsewhere in the country. Figure 2.9 presents the comparison of annual GDP growth rates of Quang Nam province, neighbouring Da Nang City and nation-wide (LUCCi, 2017) showing that the development of Quang Nam province have not fully kept pace with other regions of the country. Moreover, from Figure 2.9 produced by LUCCi (2017) and 2.10, it can be noticed that the decrease in annual GDP growth rate apparently relates to the years of the severe flooding events, e.g. 1998-1999, 2007-2009 and 2011-2013. A number of studies, from both local and international institutions, have been undertaken to study flood hazards and partly vulnerability in VG-TB basin (Bruun et al., 2013; VAST, 2012; LUCCi, 2017). However, none of these studies have quantified the disaster risk that the region has to confront with and more importantly, intangible impacts are completely ignored.

Although there is ongoing debate on the uncertainty of climate change scenarios and results ofthese projections, the data and information on frequency and magnitudes of flood events and consequntial damages during past decades in VGTB basin showing obvious trend of increased occurence of extreme floods and damages. In Figure 2.7, the annual peak discharges series during 1976-2017 at two main gauges were plotted showing that since 1999 serious flooding has occured much more frequently compared to the period before that. Another critical problem is increased of damages caused by flooding. Also as shown in Figure 2.10, although magnitude of flood events in the years 2011 and 2013 were less than some historical events in 1999 and 2007 the flood damages were still huge. Based on information learned from local disaster management practice, the acceleration of this problem can be explained by the high vulnerability of local community, i.e with the economic growth, while poorer households are more subject to losses from housing and personal content damage, higher income groups suffer from greater losses in production assests, e.g. crop and livestock farming, aquaculture, food processing, facilities for services (hotels, recreations), manufacture etc. Although there is a downward trend in fatalites, the indirect health impacts are believed to increased. A significant part of population still live under poverty thrshold who are unlikely able to affort disaster mitigation measures. From the institutional aspect, like other rural floodplain areas in region, the perception of local authority and community about disaster risk is rather limited. Based on learning from field survey and interviews with local authority and farmers, many accidents occurred during floods have

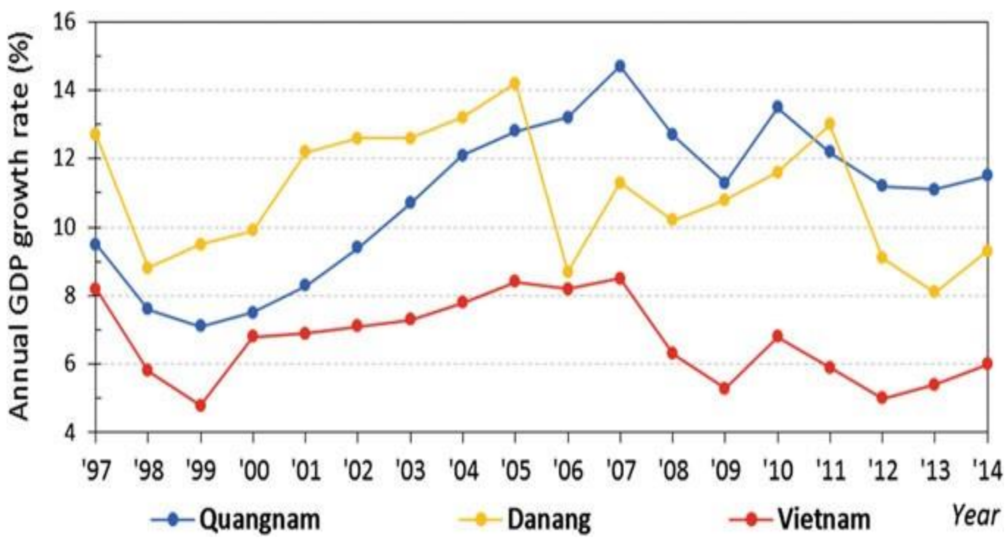


Figure 2.9 Comparison of annual GDP growth rates of Quang Nam province and nation-wide

been caused by underestimation of the disaster danger resulting in high vulnerability and risk, e.g. people keep driving or fishing during flood or refuse to evacuate etc. This issue of vulnerability will be discussed again in details in next chapters.

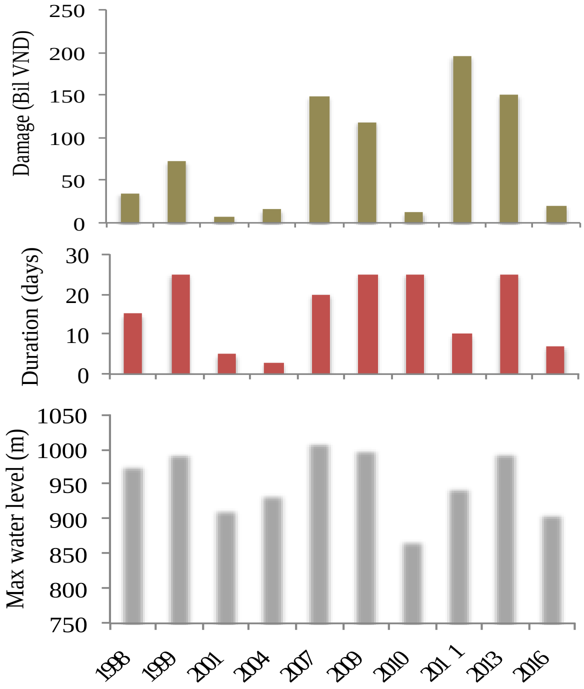


Figure 2.10 Characteristics of past flood events

2.4 Data collection and analysis

As stated earlier in Chapter 1 and Figure 1.1, risk assessment requires far wide range of data and information related to inundation hazard characteristics, land use, value of elements at risk and socio-economic statistics to derive stage-damage functions. These data and information used in this study were collected as following:

2.4.1 Meteo-hydrological and hydraulic data: To get understanding about hazard characteristics, the flood simulation is carried out, which requires four types of data, including:

(1) Time series data of rainfall, discharge and water level were obtained from National Hydro-meteorological Center of Vietnam. Figure 2.1 shows the locations of the main gauges in VG-TB downstream area.

(2) Bathymetric data of river cross sections: VG-TB basin is highly dense and hydraulically complicated system, especially in the mid- and downstream area. There is measurement of 197 cross sections over the river course length of 336km including 15 main river channels and tributaries of the system obtained from VAST (2012).

(3) Flood trace survey: With the support of JICA (Japan International Cooperation Agency) in Vietnam, 150 landmarks were installed in Dien Ban District to record the inundation levels of all flood events occurred. This data is important source for verifying the inundation maps.

2.4.2 Spatial data

- Digital Elevation Maps (DEM): Topography is frequently considered the key data set for flow routing and inundation modeling. High resolution, high accuracy topographic data are essential to shallow inundation simulations over floodplains with complex micro-topography, and such data sets are increasingly available from a variety of remotely mounted sensors. The study uses DEM of VG-TB basin developed by Vietnam Academy of Science and Technology (VAST, 2012), including: (i) DEM for the entire VG-TB basin with resolution of 30m x 30m developed from digital topographical map of scale 1:25000 in 2005 combined with 8 SPOT4 images (resolution 10mx10m); (ii) DEM for downstream area with resolution of 10mx10m developed based on digital topographical map of scale 1:10000 and a pair of SPOT-5-HRS images. The DEMs were verified by 100 checking points measured on situ by geodesy method, which showed that the average difference of these approaches is 0.45m (i.e. around 96%). Therefore, these DEMs are acceptable to use in this study. The thematic maps used in ArcGIS analysis were developed based on administration and hydrological maps.

- Google image: Google image zoomed in Dien Ban District is used to count houses and then converted into a GIS layer to superimpose over the flood inundation map for exposure analysis of both social safety (fatalities, injuries) and household properties.

- ALOS image: Another type of spatial data used in defining elements-at-risk and their exposure is land use map. Basically, in order to create the land-use maps, in-situ measurement and map correction are carried out. Recently, with the rapid development of technology, satellite images have been used as an important input in creating land-use maps. With the temporal and spatial information obtained from satellite image, land-use distribution and classification can be accurately and rapidly extracted.

This study uses two methods to extract the information from satellite image: un-supervised and supervised classification. Un-supervised classification obtains the general information of the region of interest while supervised classification classifies the objects. The optical satellite image ALOS AVNIR-2 data is used for land-use classification of Dien Ban district in Quang Nam province, Central Vietnam. The region of interest is located between the latitudes $15^0$50'N and $15^0$59'N, and the longitudes $108^0$7'30''E and $108^0$23'30''E with an area of approximately 265,391km^2. The terrain of this region is quite complicated, higher in the west and lower in the east, and it is divided into three ecological areas: mountain, midland and plain. The terrain is clustered by the basins of Vu Gia and Thu Bon river.

- Satellite image

ALOS (Advanced Land Observing Satellite), also called Daichi, is the Japanese Earth observation satellite launched in 2006 from Tanegashima, Japan by H-IIA rocket. There are 3 sensors on ALOS: PRISM, AVNIR-2 and PALSAR. PRISM (Panchromatic Remote- sensing Instrument for Stereo Mapping) is panchromatic sensor with 2.5m resolution. AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2) is a 4-band sensor with 10m resolution. PALSAR(Phased Array type L-band Synthetic Aperture Radar) is a multi-polarized radar sensor with 10m resolution. This study uses the AVNIR-2 image level 1B2 captured on March 28, 2009 with 10m resolution, radiometric and geometric corrected (see also Figure 2.11 and Table 2.3).

Table 2.3 The specifications of AVNIR-2

Number of bands	4
Wave length	Band 1 : 0.42 to 0.50 micrometers Band 2 : 0.52 to 0.60 micrometers Band 3 : 0.61 to 0.69 micrometers Band 4 : 0.76 to 0.89 micrometers
Spatial resolution	10m (at nadir)
Swath width	70km (at nadir)
S/N	>200
Focal length	800mm
Detector size	0,0115 x 0,0115mm
Number of detectors	7000/band
Pointing angle	- 44 to + 44°
Bit length	8 bits

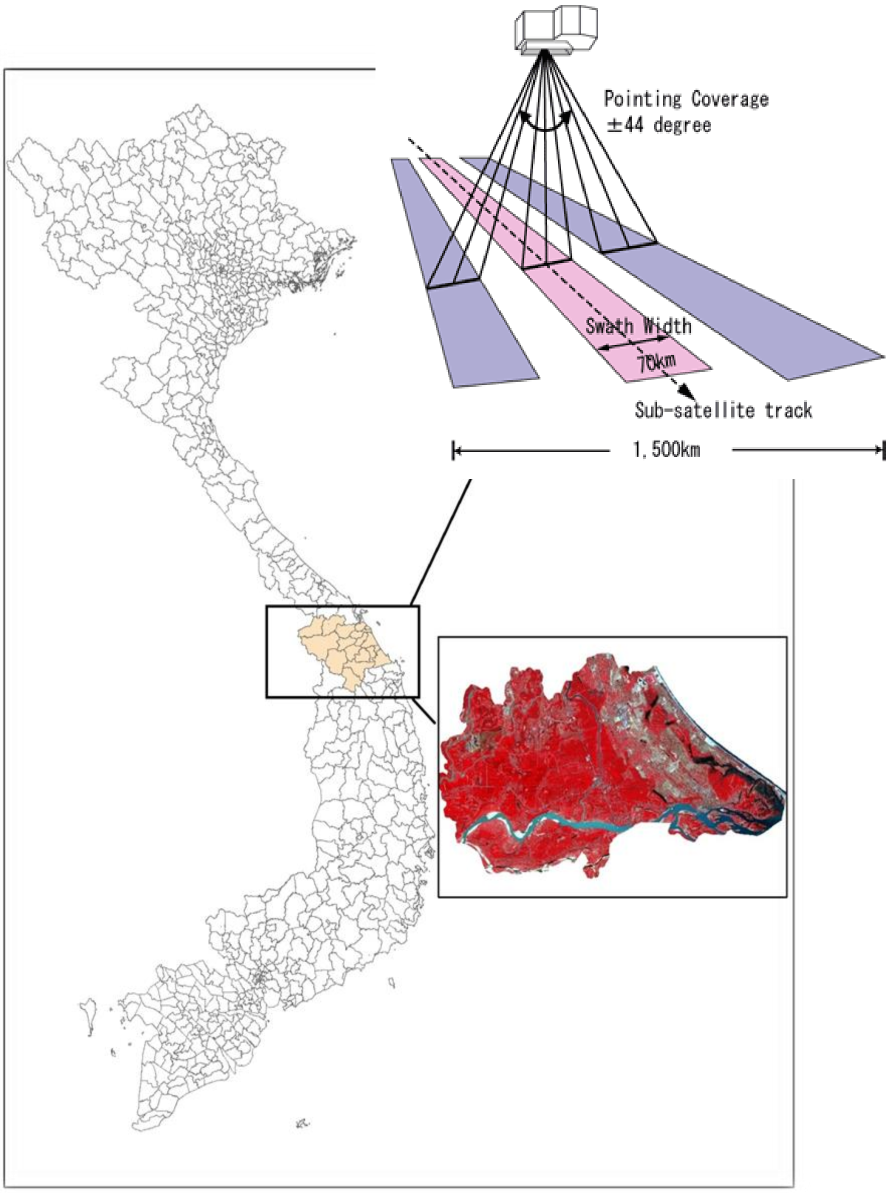


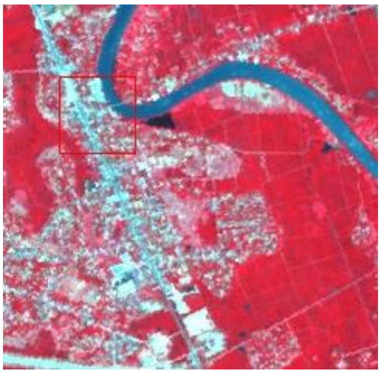
Figure 2.11 AVNIR-2 capture range with different pointing angles

(ii) Terrain map

Terrain map is published by Cartography Directorate using in-situ measurement at 1:25,000 in UTM Zone 49N co-ordinate projection and WGS84 geodetic datum.

(iii) Steps of image analysis

Step 1: Image enhancement is used to enhance the quality of the image and it makes the image interpretation easier. There are a lot of image enhancement methods, such as Linear, Gaussian, Equalization, Square root... (Figure 2.12)



(a) Image before enhancement

(b) Image after enhancement by using Equalization

Figure 2.12 ALOS AVNIR-2 before and after image enhancement

Step 2: Geometric correction is used to combine satellite image with other types of data. Satellite image is originally distorted because of the altitude, attitude and speed of satellite, the Earth's rotation, atmosphere, terrain.. For this reason, geometric correction is necessary in processing satellite image. Geometric correction includes the following steps (Figure 2.13):

- Transform (row, column) coordinate system to another coordinate system. There are 2 transformation methods: using mathematics model and using Ground Control Point (GCP).

- Calculate the pixel values in the new coordinate system by using interpolation algorithms.

In this study, the map at scale 1/25,000 is used for geometric correction on ALOS AVNIR-2 satellite image with frist-order method . 10 GCPs are used with acceptance error 2,9m (smaller than 1/2 pixel).

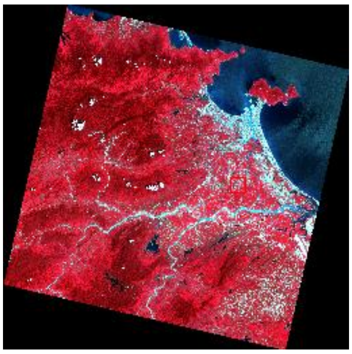
(a) True color ALOS AVNIR-2

(b) Terrain map with traffic layer

Figure 2.13 GCP on satellite and on terrain map

Step 3: Image clustering by region border

After geometric correction, ALOS AVNIR-2 image is clustered by using the border of region to reduce the unnecessary information (Figure 2.14).

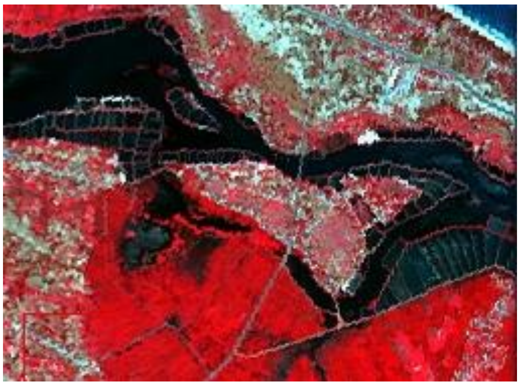


(a) A whole satellite image

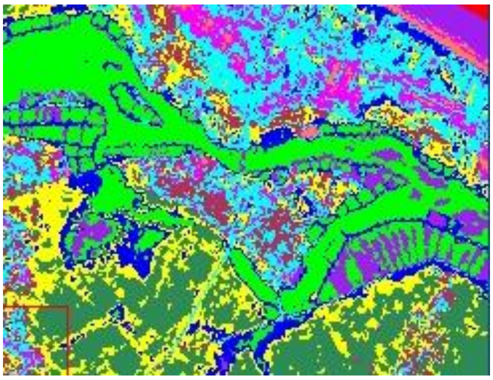
(b) Image is clustered by region border

Figure 2.14 Image clustering by region border

Step 4: Unsupervised classification is used to get general information about land cover. It will be applied to select the samples for supervised classification. Unsupervised classification is the cluster analysis, in which the pixels with similar spectral characteristic are grouped. The clustering algorithms include K-means and ISODATA (Figure 2.15).



(a) Pseudo color image



(b) Unsupervised classification ISODATA

Figure 2.15 Unsupervised classification on ALOS AVNIR-2

Step 5: Sampling

After unsupervised classification, samples for supervised classification are specified, based on the terrain map and the tone of image. These samples will be selected in the 7 following classes: river, house, cropland, bare soils, industrial land, aquaculture land and other lands. After selecting the samples, the difference among them is also evaluated.

```
Pair Separation (least to most);

House [Yellow] 215 points and Agriculture [Magenta] 337 points - 1.46588617
House [Yellow] 215 points and Bare soils [Cyan] 191 points - 1.90522731
House [Yellow] 215 points and industrial [Maroon] 79 points - 1.97215402
Aquaculture [Red] 94 points and House [Yellow] 215 points - 1.99994959
Bare soils [Cyan] 191 points and industrial [Maroon] 79 points - 1.99995172
Bare soils [Cyan] 191 points and Agriculture [Magenta] 337 points - 1.99997258
Agriculture [Magenta] 337 points and industrial [Maroon] 79 points - 1.99999673
River [Green] 1702 points and House [Yellow] 215 points - 1.99999994
Other lands [Blue] 849 points and Bare soils [Cyan] 191 points - 1.99999997
Other lands [Blue] 849 points and House [Yellow] 215 points - 1.99999999
River [Green] 1702 points and industrial [Maroon] 79 points - 2.00000000
Aquaculture [Red] 94 points and industrial [Maroon] 79 points - 2.00000000
Other lands [Blue] 849 points and industrial [Maroon] 79 points - 2.00000000
Aquaculture [Red] 94 points and Bare soils [Cyan] 191 points - 2.00000000
River [Green] 1702 points and Bare soils [Cyan] 191 points - 2.00000000
Aquaculture [Red] 94 points and Agriculture [Magenta] 337 points - 2.00000000
Aquaculture [Red] 94 points and Other lands [Blue] 849 points - 2.00000000
Other lands [Blue] 849 points and Agriculture [Magenta] 337 points - 2.00000000
River [Green] 1702 points and Agriculture [Magenta] 337 points - 2.00000000
Aquaculture [Red] 94 points and River [Green] 1702 points - 2.00000000
River [Green] 1702 points and Other lands [Blue] 849 points - 2.00000000
```

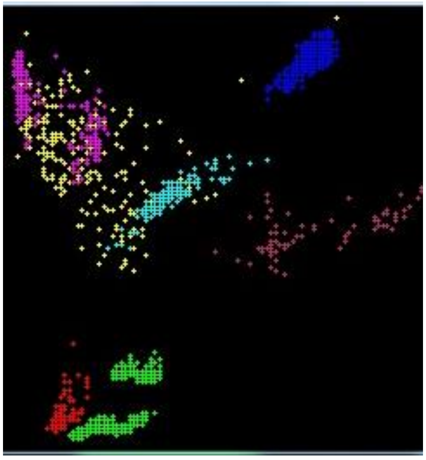


Figure 2.16 Difference among samples

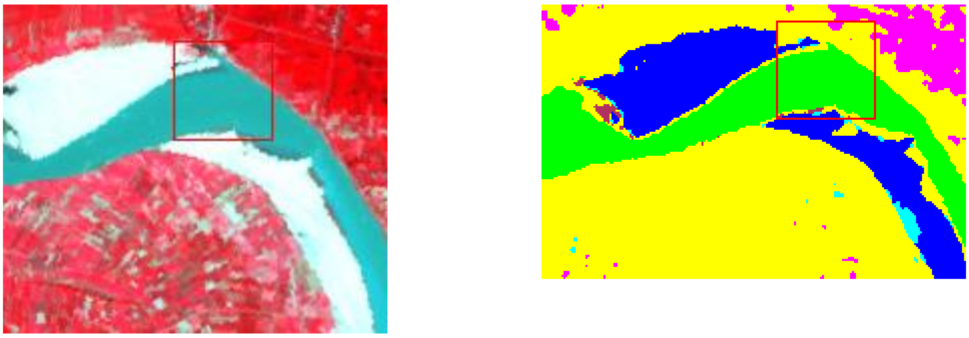
In Figure 2.16, the selected samples are quite different from each other. Only the house class and cropland class are not clearly classified. The reason is that there are still some parts of land where people are cropping in the resident land.

Step 6: Supervised classification is implemented based on the selected samples. There are several supervised classification methods, including Parallelepiped, Maximum Likelihood, Minimum Distance, Mahalanobis Distance. Every method has its own advantages, which depend on its purpose. This study uses Maximum Likelihood for classification. In this method, it is assumed that all the spectral bands have Gaussian probability distribution, and the pixels are classified based on the maximum probability. The classification is not only based on the distance but also based on the trend of brightness variance in every class (Figure 2.17).

(a) Pseudo color image (b) Supervised classification

Figure 2.17 Supervised classification

After classification, post-processing is applied for noise removal and grouping the pixels, which are alternated in other classes, to the class they belong to. Kernel Size window is used for filtering, in which the center pixel is replaced with the dominant pixel value in the filtering window (Figure 2.18).

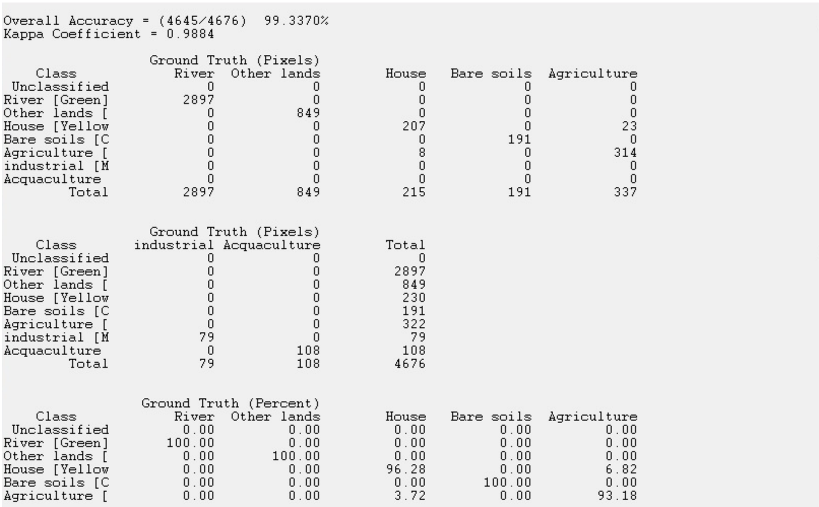


(a) Pseudo color image (b) Post-processing image

Figure 2.18 Post-processing image

The final image is exported in the vector format. The classification accuracy the most important factor, which will decide the accuracy of the land use map. In order to evaluate the accuracy of the land cover map, ground truth measurement or on-image measurement will be carried out.

The accuracy of classification is shown on the matrix table in Figure 2.19. Figure 2.20 presents the digital version of land use map of the research focus area that will be used in vulnerability analysis of agriculture in next chapters.



Overall Accuracy = (4645/4676) 99.3370%
Kappa Coefficient = 0.9884

Class	Ground Truth (Pixels) River	Other lands	House	Bare soils	Agriculture
Unclassified	0	0	0	0	0
River [Green]	2897	0	0	0	0
Other lands [	0	849	0	0	0
House [Yellow	0	0	207	0	23
Bare soils [C	0	0	0	191	0
Agriculture [	0	0	8	0	314
industrial [M	0	0	0	0	0
Acquaculture	0	0	0	0	0
Total	2897	849	215	191	337

Class	Ground Truth (Pixels) industrial	Acquaculture	Total
Unclassified	0	0	0
River [Green]	0	0	2897
Other lands [	0	0	849
House [Yellow	0	0	230
Bare soils [C	0	0	191
Agriculture [	0	0	322
industrial [M	79	0	79
Acquaculture	0	108	108
Total	79	108	4676

Class	Ground Truth (Percent) River	Other lands	House	Bare soils	Agriculture
Unclassified	0.00	0.00	0.00	0.00	0.00
River [Green]	100.00	0.00	0.00	0.00	0.00
Other lands [	0.00	100.00	0.00	0.00	0.00
House [Yellow	0.00	0.00	96.28	0.00	6.82
Bare soils [C	0.00	0.00	0.00	100.00	0.00
Agriculture [	0.00	0.00	3.72	0.00	93.18

Figure 2.19 Matrix table

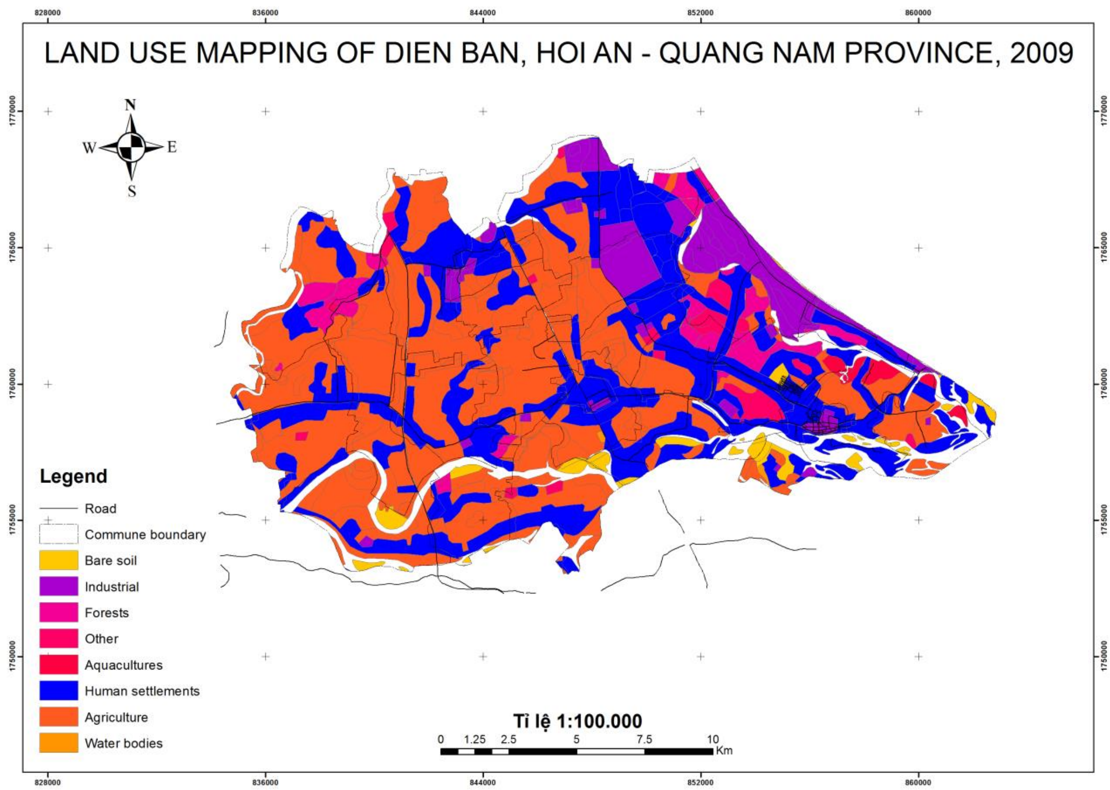


Figure 2.20 Land use map of Dien Ban district, Quang Nam province

2.4.3 Soio-economic data and household survey

(i) Statistic data: The first source of official socio-economic data is annual statistic books of Dien Ban District, which is to provide the cost units of agricultural elements at risk and other are information which provide data and information on population, gender, age, economic productions, medical care, education etc. used in social vulnerability analysis.

(ii) Household survey: to analyze direct intangible and indirect (tangible and intangible) vulnerability, this study applies Contingent Value Method (CVM) which requires far detailed information that will be collected through intensive social survey in all 16 communes of Dien Ban District.

In this survey, the households living in the villages in each commune were selected randomly with reference to the available lists of household names and addresses at the commune level. There are several methods to calculate the sample size, i.e. number of interviewees. This study applies Yamane's simplified formula with the assumption of 5% level of precision as following:

$$n = \frac{N}{1 + N(e)^2} = \frac{80.850}{1 + 80.850 * 0.05\text{^}2} \approx 400 \text{ (interviewees)}$$

Whereas:

N – population in survey area

n – sample size (i.e. no. of interviewees)

e – level of precision. The level of precision, sometimes called sampling error, is the range in which the true value of the population is estimated to be.

This sample size is structured to include 30 representatives of local authority, schools, clinics, hospital, irrigation companies, etc.) and 370 residents (including 330 farmers and 40 service providers) (see Figure 2.21).

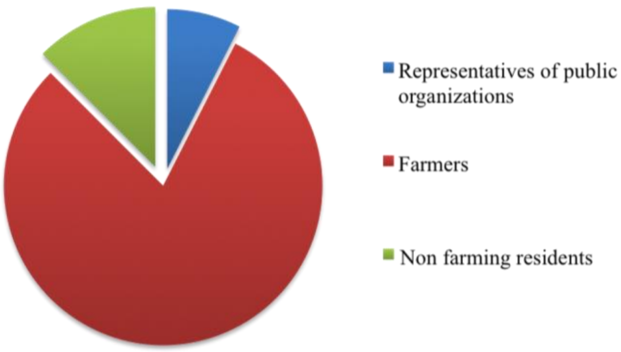


Figure 2.21 Different target groups of social survey

For CVM to yield useful information, careful design of questionnaire and survey implementation is vital. The questionnaire consists of four main parts, including:

- Part 1: collection of household socio-demographic characteristics;
- Part 2: information on household risk exposure level with focus in direct losses and other impacts related to the recent catastrophic flood events in 2007 and 2013 as well as the inundation level of moderate seasonal floods that occurs frequently.
- Part 3: 20 questions to ask the householders to evaluate the direct tangible and indirect (tangible and intangible) flood impacts on the properties, e.g. building and content, private business interruption, water quality and health impacts etc. by
- Part 4: 20 questions to ask the householders to evaluate the direct tangible and indirect (tangible and intangible) flood impacts on their agricultural production and livelihood, e.g., loss of cultivated products, clean up, water

pollution, business interruption etc. by choosing the certain damage level, either percentage or in monetary values.

As most of the local farmers are not familiar with such type of interview, the questions in Parts 3 and 4 were designed with 2 step answers:

– Step 1: the interviewees were asked to select the answer from 05 multiple choices of ranges of damages potentially incurred for selected flood scenarios.

– Step 2: from the range of possible damage, the interviewees were asked for more specification of how much the damage would be based on their experiences about the past flood events.

The survey consists of face-to-face interviews lasting about 30min and was conducted during the period of July-August 2014 and updated after flood seasons in 2016 by trained interviewers from Thuyloi University of Vietnam (Figure 2.22).

Figure 2.22. Social survey and interview local people

The flowchart in Figure 2.23 presents the entire approach adopted for this study from required data collection and processing, methods used and expected outputs.

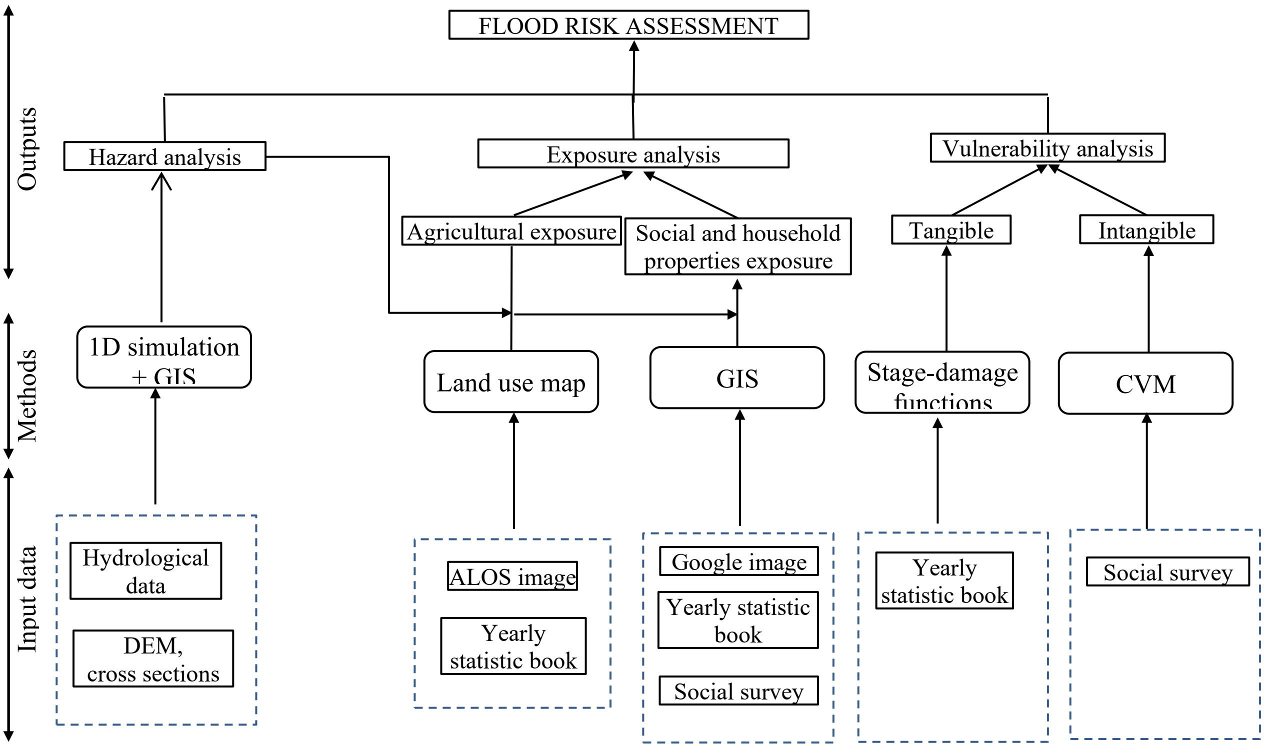


Figure 2.23 The adopted approach flowchart including: imput data, methods and outputs

Chapter 3 Flood hazard analysis

3.1 Introduction

Apparently, various inundation characteristics, like water depth, duration, velocity, rising rate, time of occurrence, etc. may influence the amount or degree of damage. Nevertheless, various past studies dealing emphasized that water depth is the main and representative factor for flood risk analysis (FLOODSite, 2007, Merz B., 2010, Schumann, 2011). Therefore, Chapter 3 is going to discuss the application of 1D modeling package named MIKE11 developed by DHI (Denmark) to simulate flow, water quality and sedimentation transport in river system from upstream down to estuary. As this is highly commercial and user friendly software, it is widely applied, including Vietnam, with good result. MIKE11 package consists of 4 modules as shown in Figure 3.xxx, of which two modules are used in this Study:

Rainfall-Runoff Module (RR) is a deterministic, lumped conceptual rainfall-runoff model which consists of four linear layers, including the snow storage layer, surface storage layer, lower zone storage layer and underground storage layer. In general, rainfall, evaporation and temperature are the input data needed for this model and the output of the model is the outflow over time (DHI, 2017). To estimate the final parameters, the model was calibrated with data series of selected flood events. The optimization of auto-calibration process is carried out by adjusting nine parameters of surface–root zone and groundwater storages until acceptable NASH index is achieved (Eq. 3-1). Then, river flow is simulated by using hydrodynamic module.

$$NASH = 1 - \frac{\sum(\text{Qo,i} - \text{Qs,i})^2}{\sum(\text{Qo,i} - \text{Qtbo})^2} \qquad (3\text{-}1)$$

in which: Qo,i : observed discharge; Qs,i : Simulated discharge and Qtbo : mean value of observed discharge series.

Hydrodynamic Module (HD) is the central one to solve the vertically integrated equation for the conservation of continuity and momentum based on Saint-Venant equation by means of a finite difference scheme. The input of this module includes river system network, cross sections, boundary conditions (DHI, 2017)

Also in this Chapter, for further assessment of flood consequences and future risk, the verified model is used to develop flooding scenarios in VG-TB basin with frequencies of 100-year, 50-year, 20-year and 10-year return periods selected based on design standard for flood protection works issued by Vietnam Government. These results were then analyzed and visualized in the form of flood hazard maps (i.e. river flood depth maps) by using ArcGIS software for flood return periods selected, i.e. 100-year, 50-year, 20-year and 10-year. Figure 3.1 is to present these steps of simulation process of this Chapter.

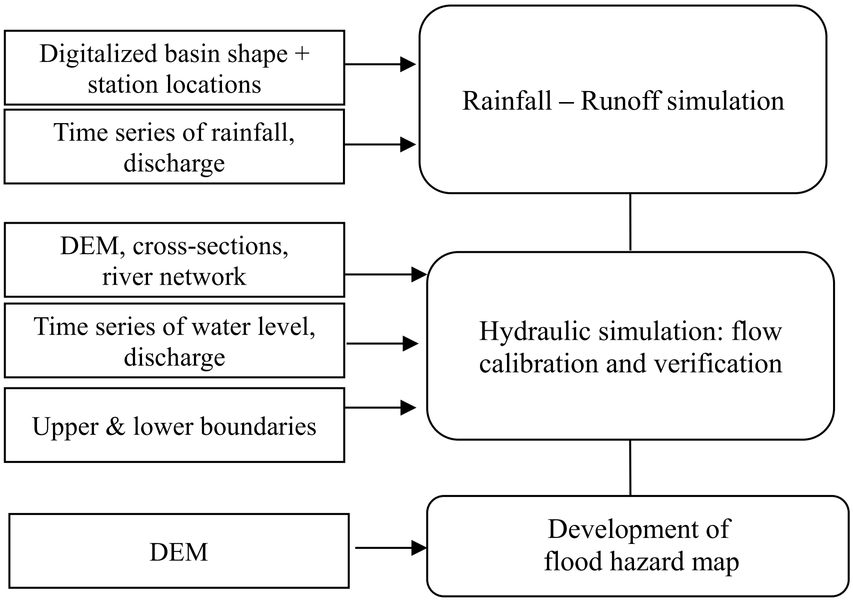


Figure 3.1. Steps of flood simulation for VGTB basin

3.2 One-dimensional flood simulation

3.2.1 Model set-up

Boundary conditions: (i) *Upper boundary*: Flow discharge series at Nong Son and Thanh My hydrological gauges; (ii) *Lower boundary:* water (tidal) level measured at Han, Lo and Dai inlets and (iii) Discharge flow of tributaries, namely Bau La, Tuy Loan, Vinh Trinh, Tra Kien, Ly, Bung, Kone, Trung Phuoc, Khe Da Mai, etc (Figure 3.2).

System network setting: VG-TB basin is highly dense and hydraulically complicated system, especially in the mid- and downstream area. The upper boundary of modeling network is set up with discharge time series at Thanh

My gauge (Vu Gia river) and Nong Son gauge (Thu Bon river). Meanwhile, the tidal level time series at three sea inlets named Han, Dai and Lo are used as lower boundary. For cross sections, the study was provided by Department of Water Resource, Ministry of Agriculture and Rural Development all measurements of 197 cross sections over the river course length of 336km of Vu Gia, Thu Bon and other main tributaries (Figure 3.3). Moreover, the network used in MIKE11 is also able to demonstrate the tributaries and hydraulic works of the system by using water balance equations for each corresponding point.

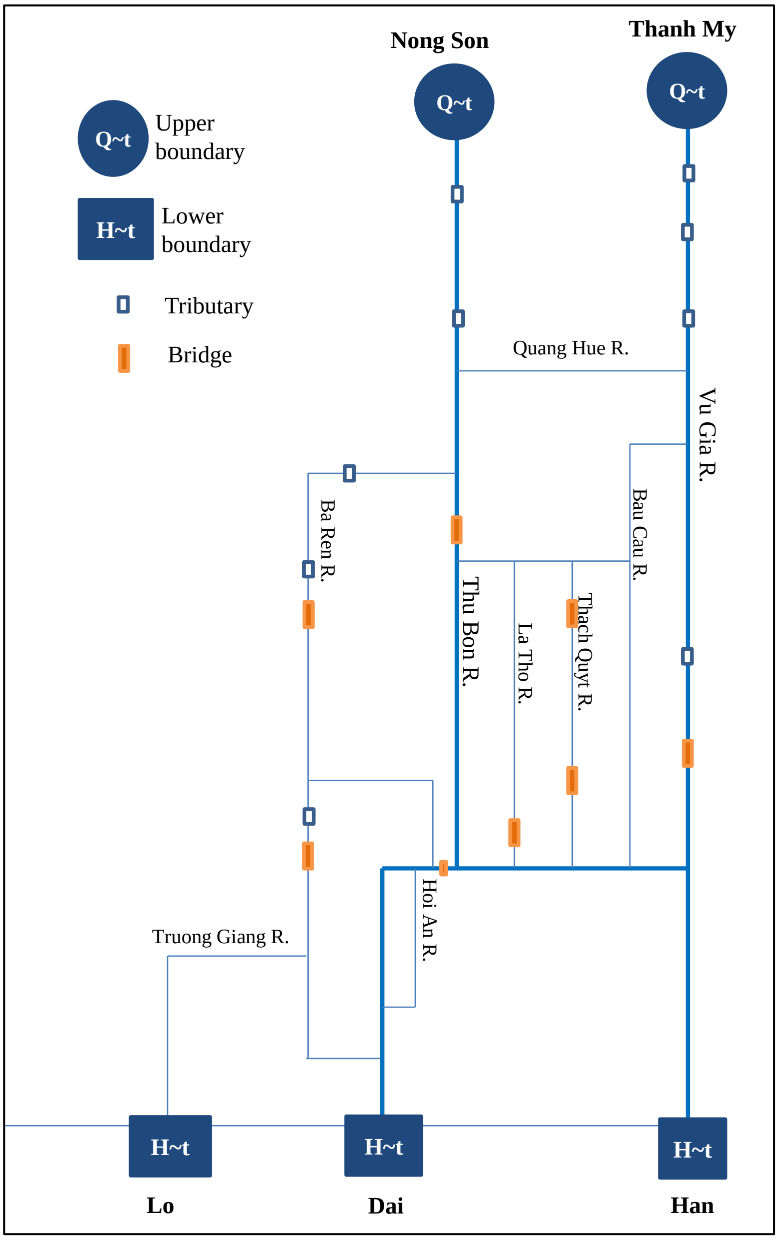


Figure 3.2. VG-TB river network

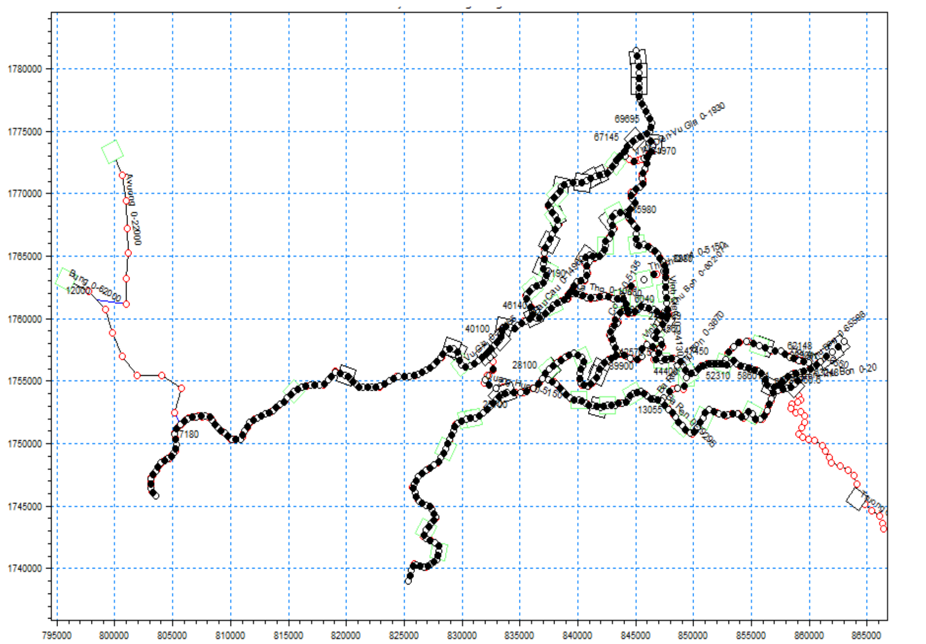


Figure 3.3 Digital river network used as an input for modeling

3.2.2 Flood runoff simulation

As reviewed in Chapter 2, VG-TB basin experienced serious flooding in the years of 1964, 1998, 1999, 2004, 2007, 2009 and 2013 (Son 2006; Quang Nam DONRE 2011; VAST 2012). For model calibration and verification, it is crucial to select events with complete measurement and can be representative for medium and serious flooding. Steps of calibration and verification process:

- Determination of time series of boundary conditions
- Assumsption of set of modelling parameters and running the model
- Evaluate and accuracy of the modelling results using NASH index:
- If the accuracy is insufficient, the roughness parameter is adjusted and the modelling running is repeated.

Details of this process applied for VGTB basin are described as following:

Steps 1: Hydrological simulation of rainfall-flow module: Two flood events were selected for calibration, including event 19 - 27/10/1994 representing medium flood with single peak and event 18 - 27/11/1998 representing devastating flood with multiple peaks. The verification is carried out using flood even 2007. The parameters of the model such as surface runoff, surface flows police, groundwater flow as well as threshold coefficients TOF, TIF... strongly depend on geophysical, cover layer conditions, the level of water storage at the starting time of calculation (first condition), and the distribution of rainfall in the basin, those factors need to be considered when applying the model. Table 3.1 presents NASH index for checking the accuracy of calibration and validation at both Nong Son and Thanh My gauge, which ranges between 0.73-0.94. Figure 3.4 presents a satisfactory correlation between observed and simulated rainfall-flow. These results show that the model can be applied for VGTB basin.

Table 3.1 NASH index of hydrological simulation

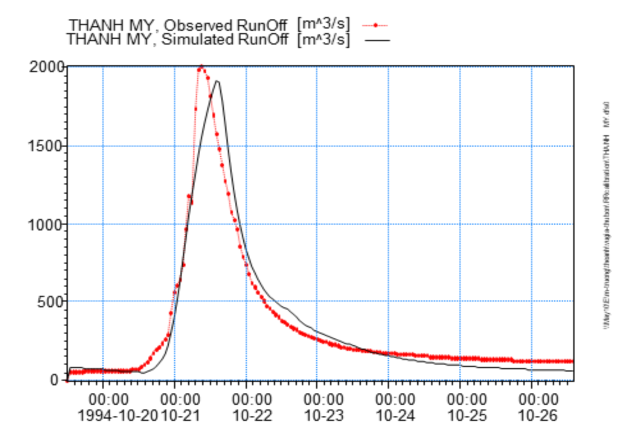
Gauge	1994	1998	2007
Nong Son	0.94	0.84	0.84
Thanh My	0.92	0.73	0.79

Step 2: Hydraulic simulation: the output of rainfall-runoff module is now used to simulate the river flow. To select typical and large flood event for simulation, this study used the time series of those in 1998 (Sep 1st – Dec 31st) and in 1999 (Sep1st - Dec31st) for model calibration and ones in 2002 (Sep 1st – Dec 31st) and 2004 (Sep 1st – Dec 31st) for verification. The analysis of calibrated and verified hydrographs as summarized in Table 3.2 and Figures 3.5, 3.6, 3.7 and 3.8 shows that the simulation is accurate regarding to peak water level as well as flood pattern (or volumes) deriving sufficient NASH index that can be used to develop future flood scenarios.

Table 3.2 NASH index of hydraulic simulation

	Observed peak		Simulated peak		NASH index
	$Hmax_{obs}$	Date	$Hmax_{sim}$	Date	
Calibration - Flood event 1998					
Ai Nghia st.	9.77	21/11/1998	9.87	21/11/1998	0.88
Giao Thuy st.	8.91	21/11/1998	9.22	22/11/1998	0.90
Calibration - Flood event 1999					
Ai Nghia st.	9.94	3/11/1999	9.96	3/11/1999	0.88
Giao Thuy st.	9.12	3/11/1999	9.96	3/11/1999	0.92
Verification - Flood event 2002					
Ai Nghia st.	6.40	25/09/2002	6.89	25/09/2002	0.98
Giao Thuy st.	5.52	26/10/2002	6.47	26/10/2002	0.99

Verification - Flood event 2004					
Ai Nghia st.	9.35	27/11/2004	9.45	28/11/2004	0.76
Giao Thuy st.	8.67	27/11/2004	9.33	27/11/2004	0.98

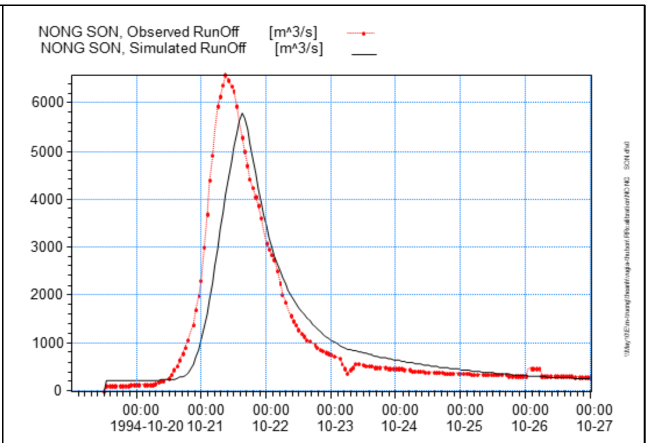


$R^2 = 0.964$

$\Delta Q_{peak} = Q_{sim} - Q_{obs} = -97.75 m^3/s$

$\Delta W = W_{sim} - W_{obs} = 9{,}694$ mil m^3

$T_{peak\ sim} - T_{peak\ obs} = -3$ hours

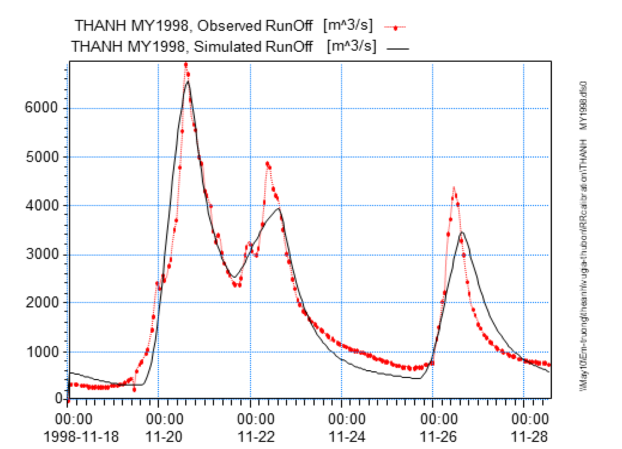


$R^2 = 0.96$

$\Delta Q_{peak} = Q_{sim} - Q_{obs} = -36 m^3/s$

$\Delta W = W_{sim} - W_{obs} = 12{,}540$ mil m^3

$T_{peak\ sim} - T_{peak\ obs} = -4$ hours

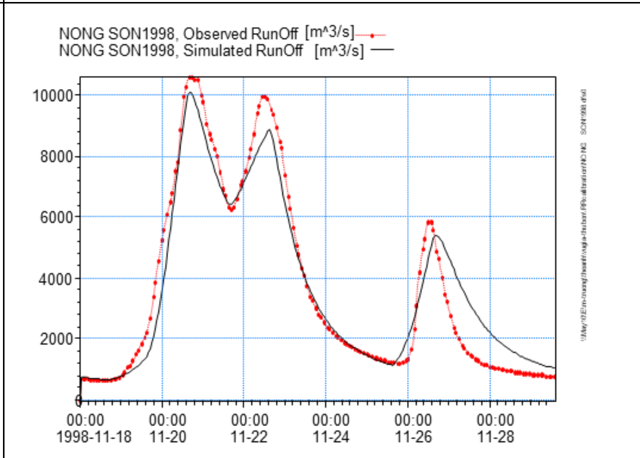


$R^2 = 0.91$

$\Delta Q_{peak} = Q_{sim} - Q_{obs} = -352 m^3/s$

$\Delta W = W_{sim} - W_{obs} = 1.15$ mil m^3

$T_{peak\ sim} - T_{peak\ obs} = -1$ hours



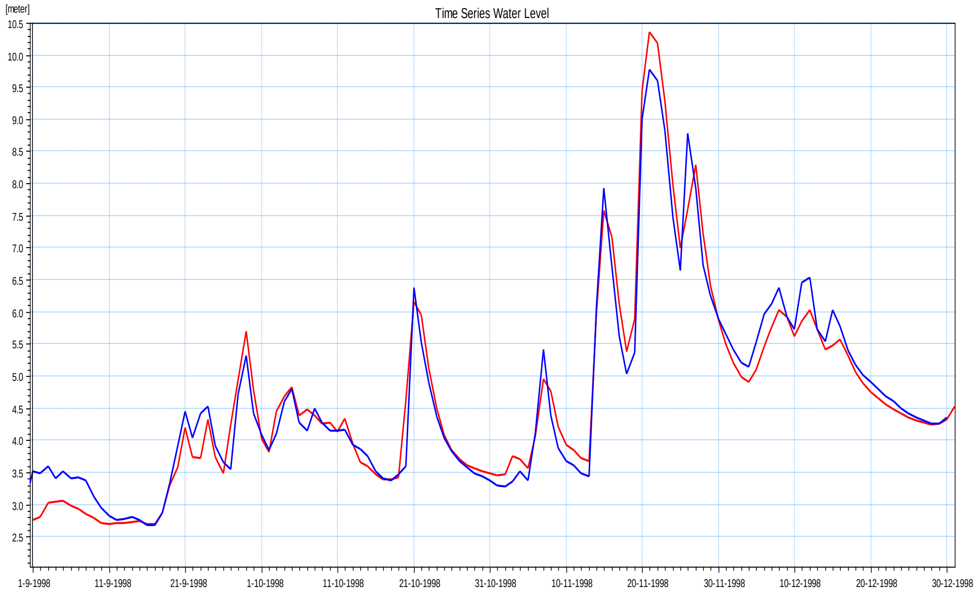
$R^2 = 0.94$

$\Delta Q_{peak} = Q_{sim} - Q_{obs} = -495 m^3/s$

$\Delta W = W_{sim} - W_{obs} = 81$ mil m^3

$T_{peak\ sim} - T_{peak\ obs} = 2$ hours

Figure 3.4 Result of hydrological simulation at Thanh My and Nong Son gauges



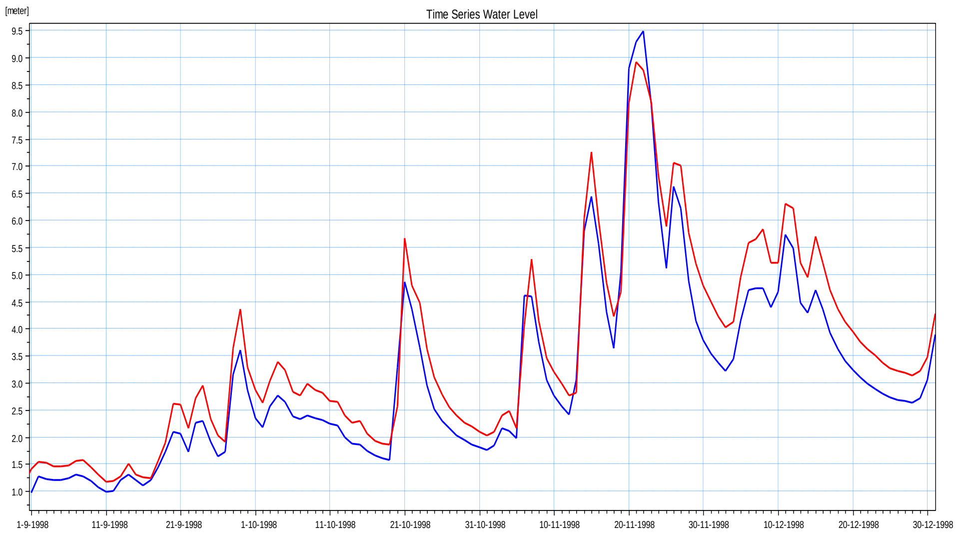
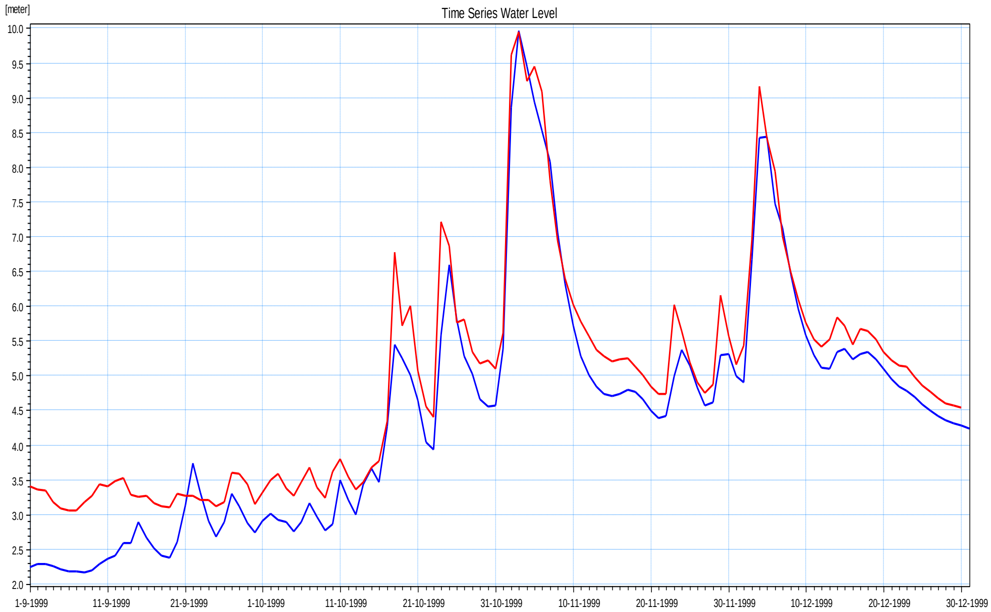


Figure 3.5 Result of hydraulic simulation for of flood event 1998
(upper: Ai Nghia station; lower: Giao Thuy station)



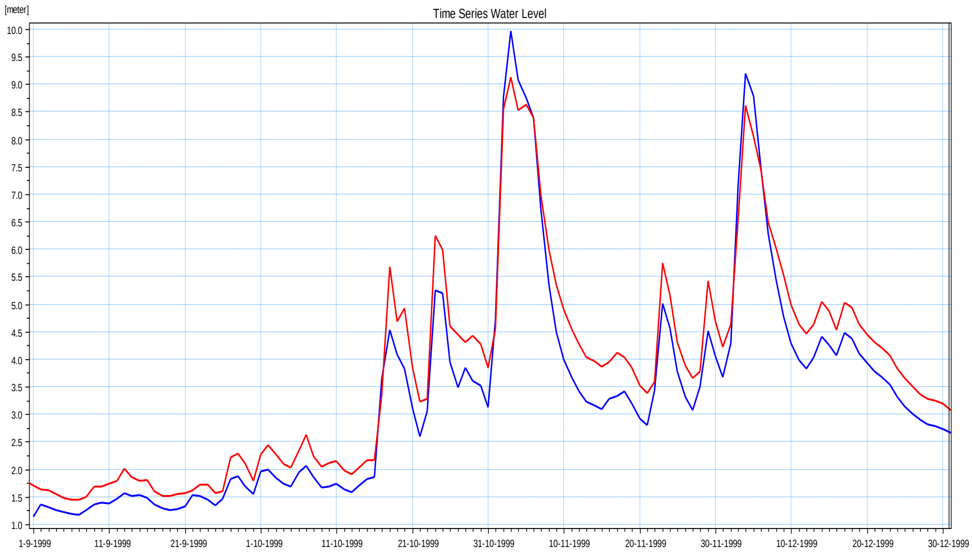
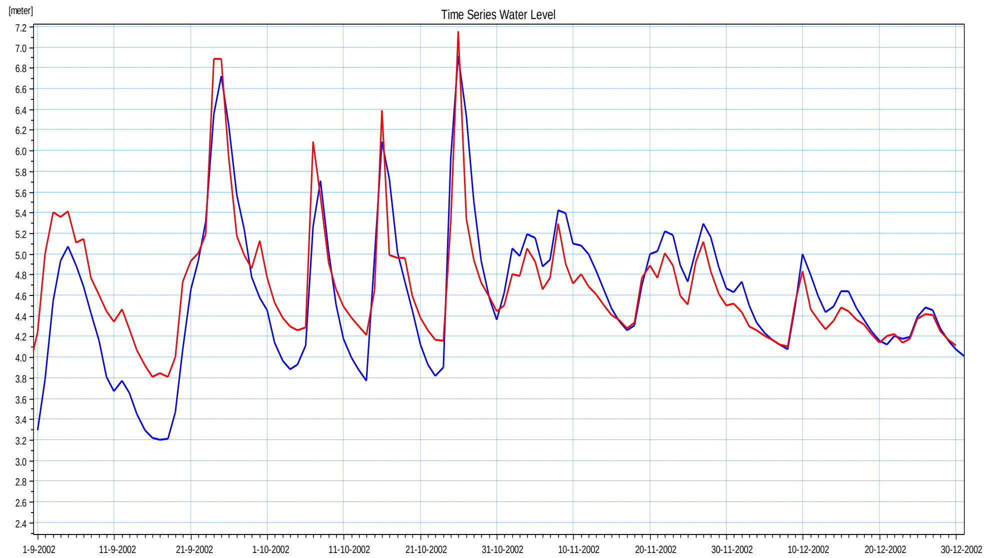


Figure 3.6 Result of hydraulic simulation for of flood event 1999
(upper: Ai Nghia station; lower: Giao Thuy station)



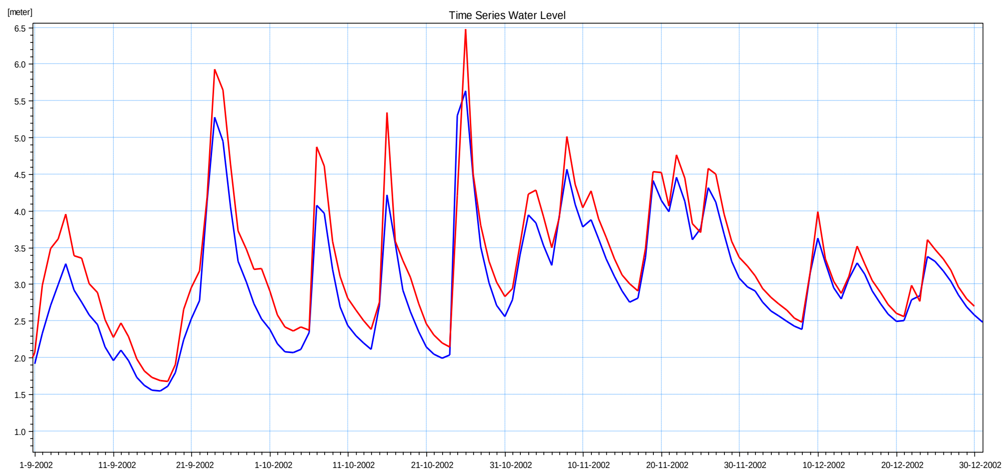
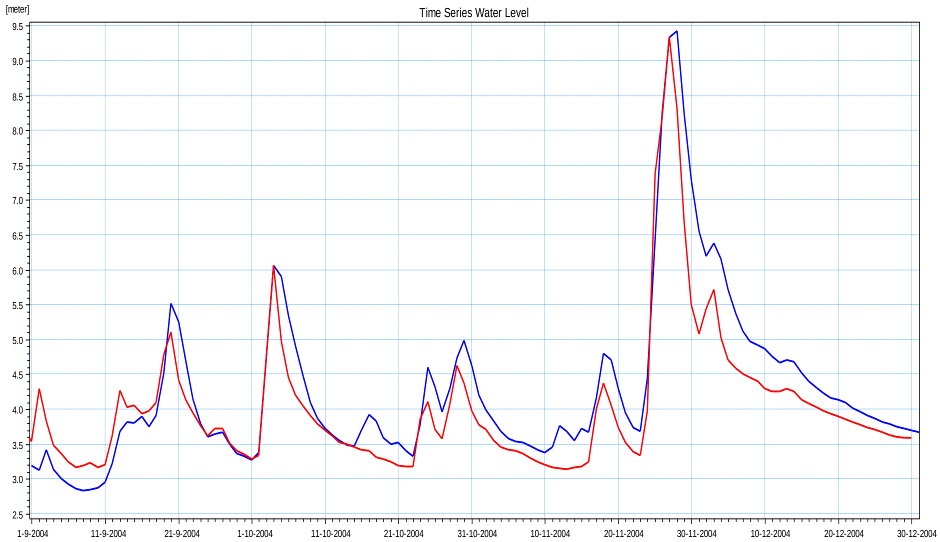


Figure 3.7 Result of hydraulic simulation (verification) of flood event 2002
(upper: Ai Nghia station; lower: Giao Thuy station)



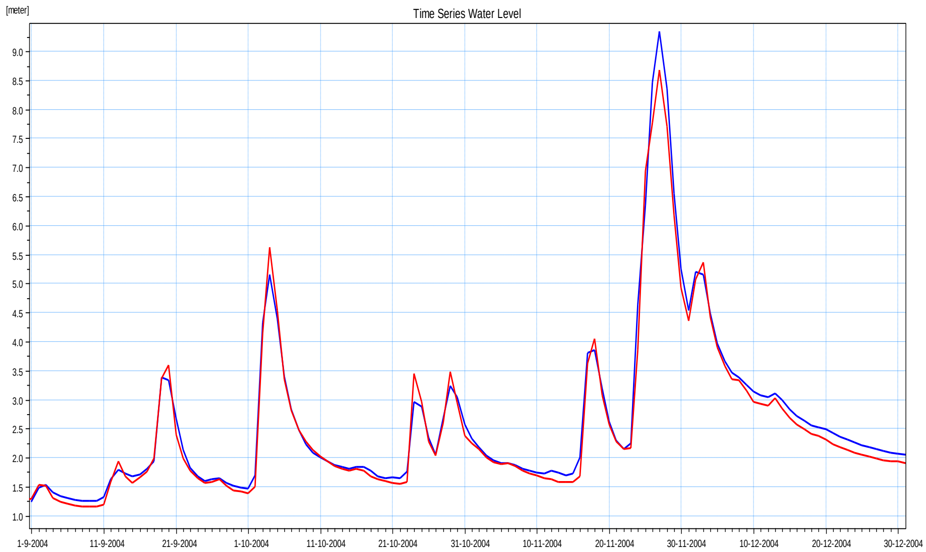


Figure 3.8 Result of hydraulic simulation (verification) for of flood event 2004 (upper: Ai Nghia station; lower: Giao Thuy station)

3.2.3 Development of flood scenarios with selected return periods

Based on the scope defined earlier in Chapters 1 and 2, this study selects 04 flood scenarios for further simulation and risk analysis, including those with return periods of 100 years, 50 years, 20 years and 10 years based on the recommendation from Ward et al. (2011). To do so, this section is going to describe the computation process of water level for these scenarios at two downstream stations named Ai Nghia on Vu Gia river and Giao Thuy on Thu Bon river. To prepare input for this computation, scaling method is used to simulate the discharge series at Nong Son and Thanh My stations and rainfall series at Tra My station for corresponding return periods. The detailed steps are described as below:

Scaling method:

This method is used to derive design hydrographs and design hyetographs of corresponding return periods from the hyetograph observed during a representative historical flood event based on Eq (3-2)

$$k = \frac{V_d}{V_a} \qquad (3\text{-}2)$$

Where: k - scaling ratio; V_a and V_d – actual representative and design values of total rainfall/maximum water level/discharge, respectively. By the other words, the design hyetograph or hydrograph V_d = Representative hyetograph or hydrograph V_a x Scaling ratio k.

From the available record, the flood in 1999 is selected as the representative event in order to simulate the flood hazard occurring in the Study area with selected return periods.

Rainfall frequency analysis:

- The frequency of hourly rainfall series at Tra My gauge during 1987-2013 is analyzed using Pearson Type III distribution as shown in Table 3.3 and Figure 3.9.
- Scaling method is then applied, i.e. using Eq. 3-2, for representative flood event in 1999 for the duration from 8:00am Oct 31st 1999 through 3:00pm Nov 06th 1999 Tra My station to derive scaling ratio k between the hyetographs of this representative year and selected return periods (Table 3.4)
- The hyetographs for selected return periods derived by scaling from representative year are shown in Figure 3.10.

Table 3.3 Statistical parameters of hourly rainfall series analysis

X_{ave} (mm)	Cv	Cs	Xp (mm)			
			100-year	50-year	20-year	10-year
4,095	0.29	0.07	7,453	6,953	6,250	5,671

Table 3.4 Calculation of rainfall scaling ratios

Gauge	Representative year	$k_{100\text{-}year}$	$k_{50\text{-}year}$	$k_{20\text{-}year}$	$k_{10\text{-}year}$
Tra My	1999	1.43	1.34	1.20	1.09

Runoff frequency analysis:

- Upper boundary gauges are Nong Son and Thanh My
- Flow frequency analysis based on peak discharge time series during 1987-2013 is carried out (Table 3.5 and Figures 3.11 and 3.12)
- The flood event during September 1st 1999 to December 31st 1999 is selected as the representative event. Then scaling method is again applied to calculate scaling ratios k to derive the design hydrographs with return period 100-year, 50-year, 20-year and 10-year at Nong Son and Thanh My gauges (Table 3.6 and Figures 3.13 and 3.14).

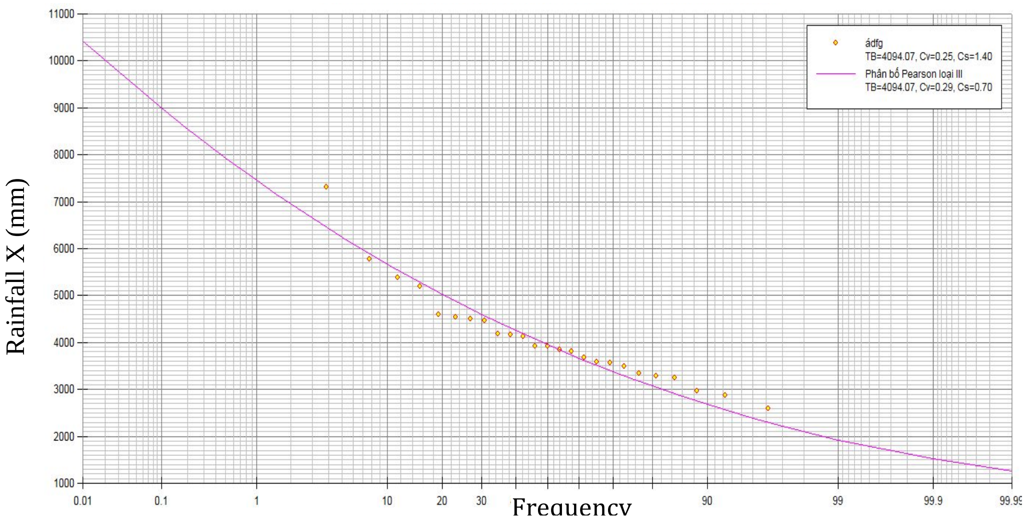


Figure 3.9 Frequency analysis of rainfall time series during 1987 – 2013 at Tra My gauge

3.3 Flood hazard mapping

In the following step of flood hazard analysis, the inundation maps are developed by visualizing the simulation results of MIKE11 in ArcGIS. These maps present the inundation extension and water depth created by exchanging files between MIKE11 and ArcGIS which can be done by using MKE11GIS extension.

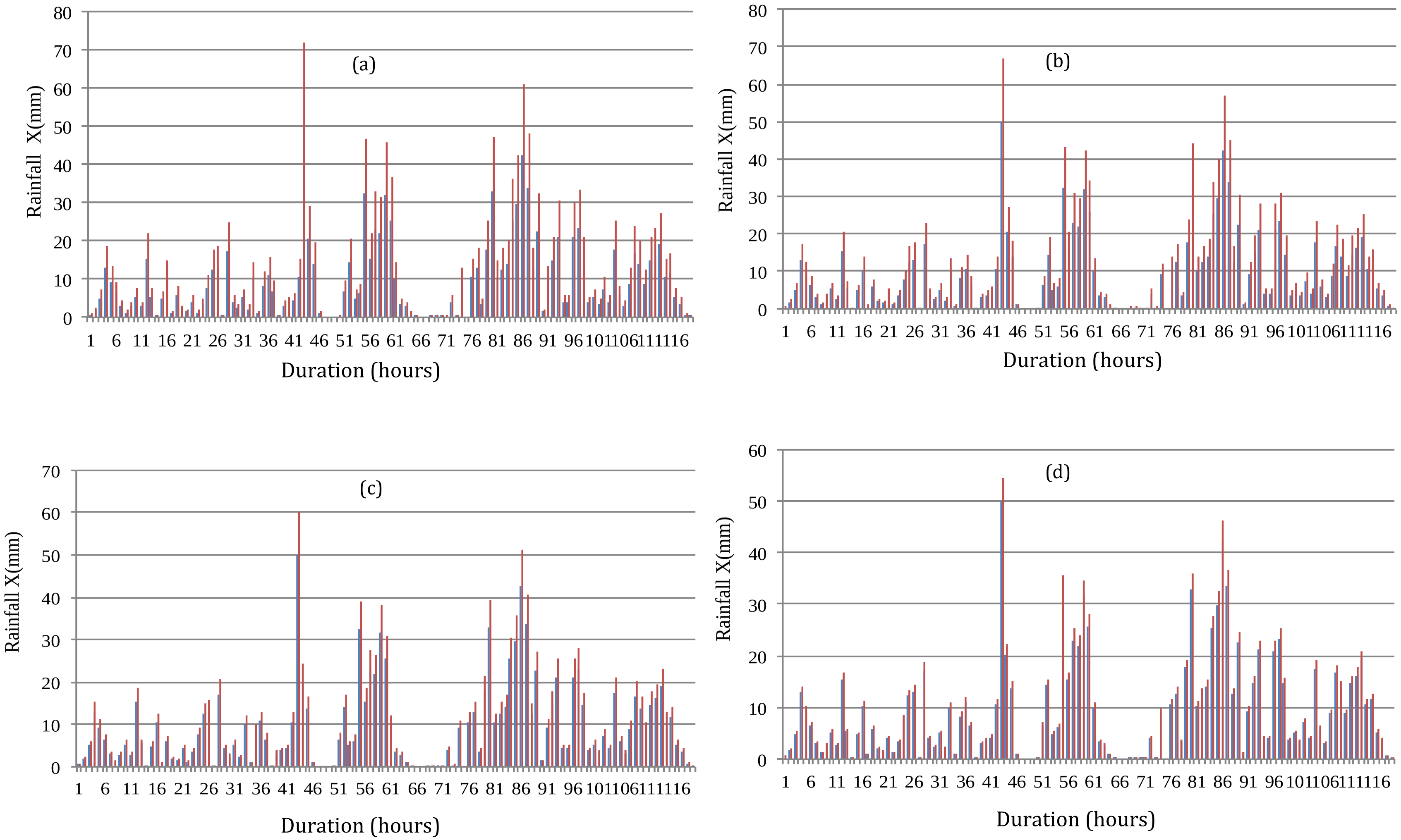


Figure 3.10 Rainfall hyetographs of selected return period scenarios
(a: 100-year; b: 50-year; c; 20-year and d: 10-year)

Rainfall of representative year
Design rainfall of certain return period scenarios

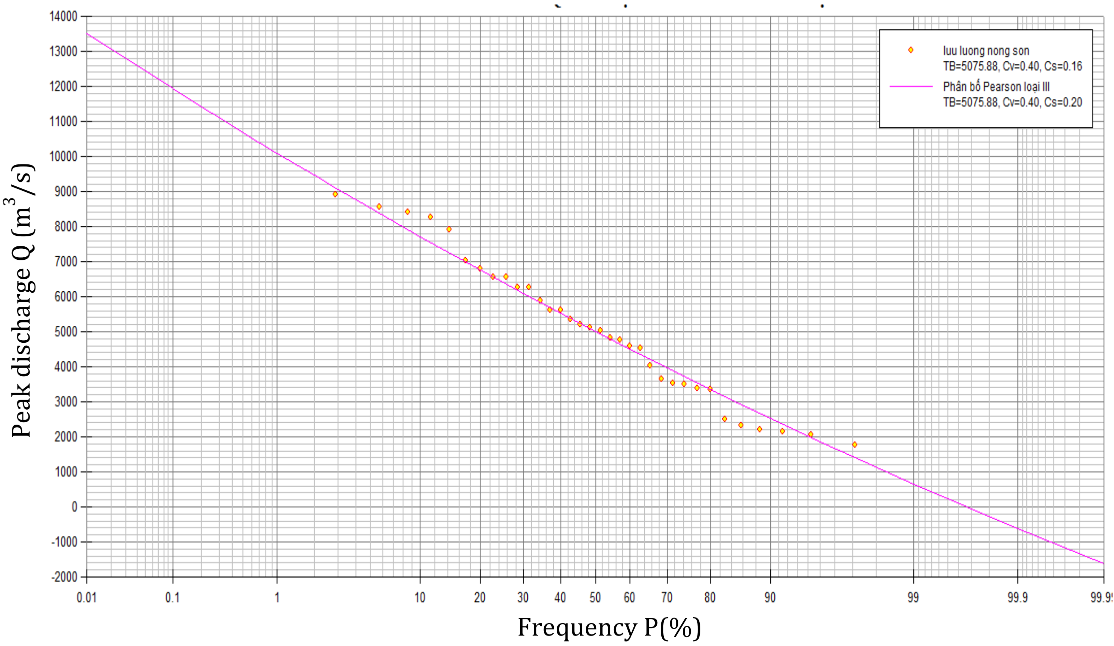


Figure 3.11 Frequency analysis of peak discharge time series during 1987 – 2013 at Nong Son gauge

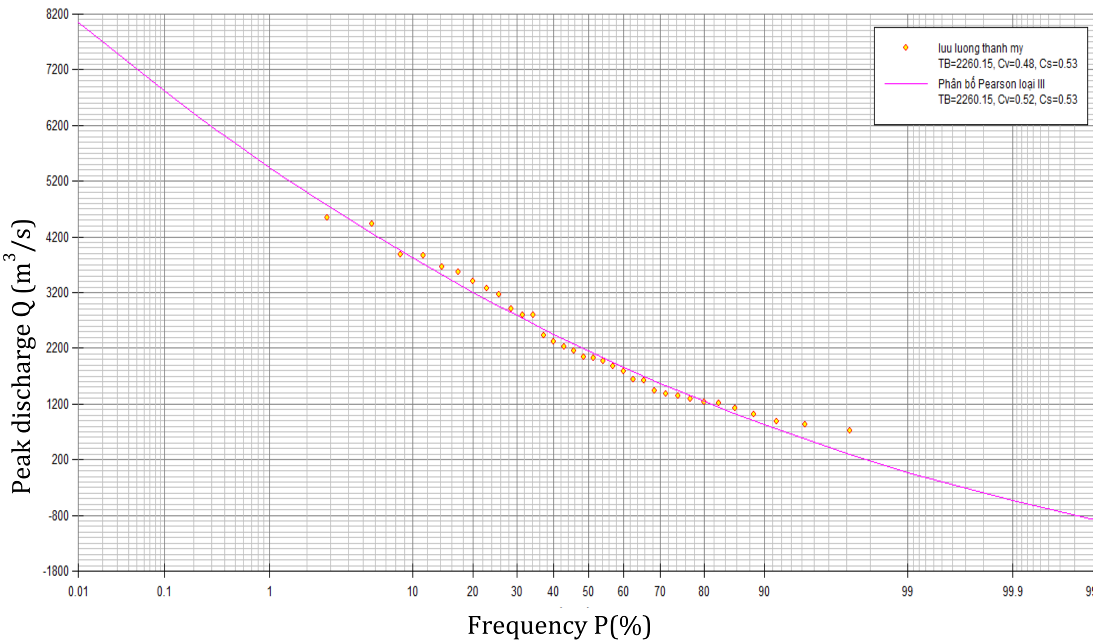


Figure 3.12 Frequency analysis of peak discharge time series during 1987 – 2013 at Thanh My gauge

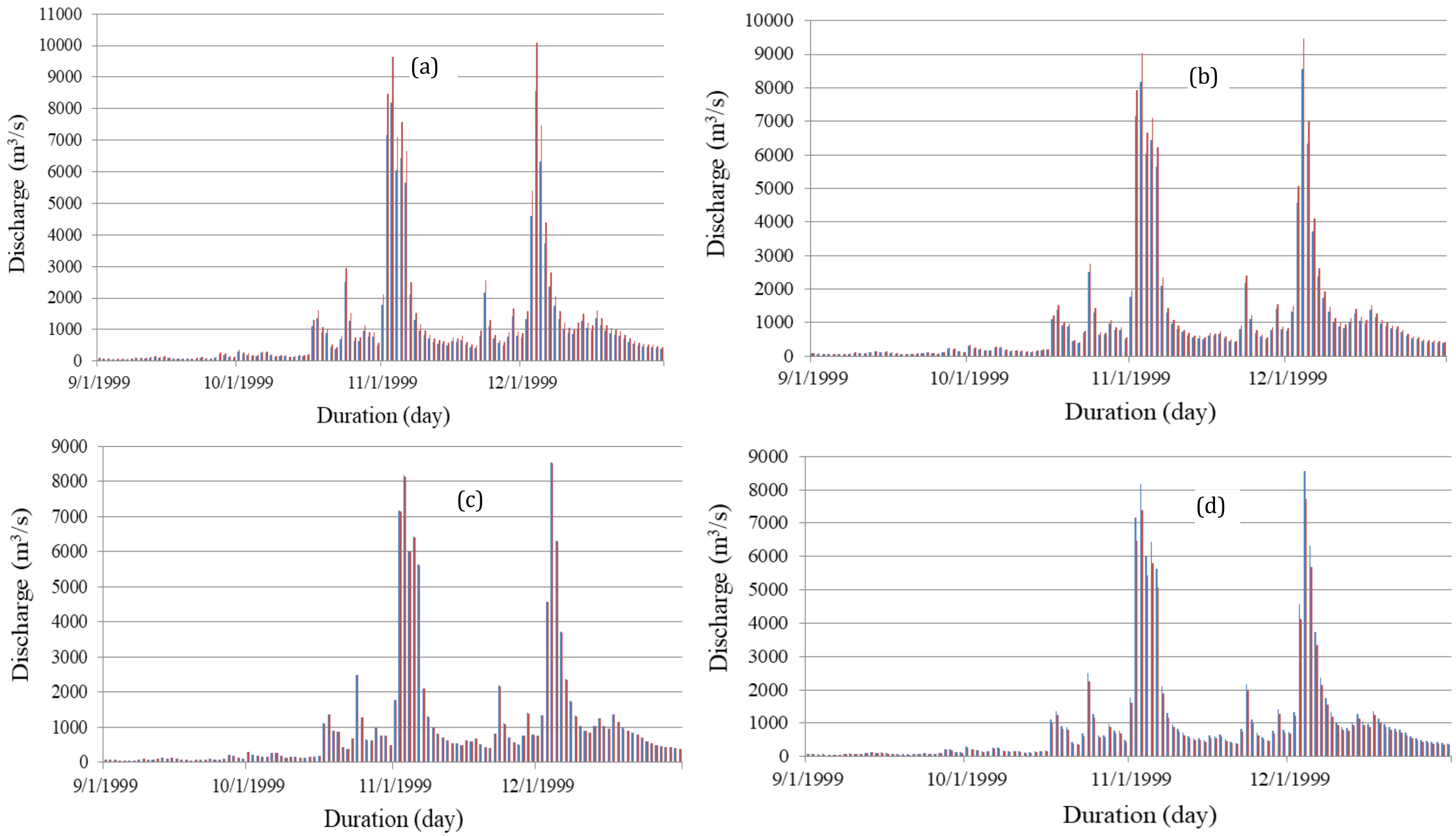


Figure 3.13 Scaled discharge distribution of selected return period scenarios at Nong Son gauge (a: 100-year; b: 50-year; c; 20-year and d: 10-year)

Observed discharge
Scaled discharge of certain return period scenarios

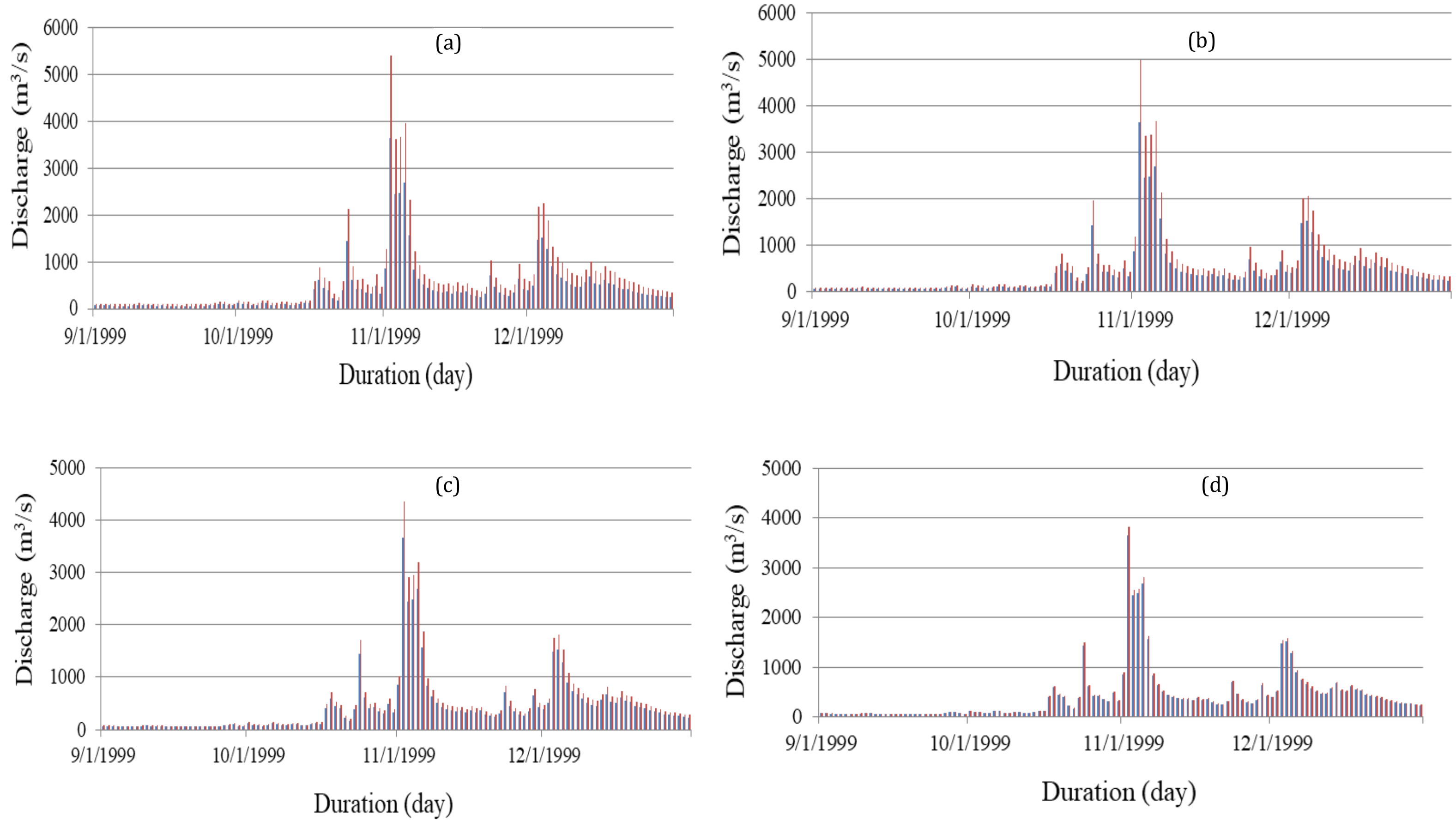


Figure 3.14 Scaled discharge distribution of selected return period scenarios at Nong Son gauge (a: 100-year; b: 50-year; c; 20-year and d: 10-year)

Observed discharge
Scaled discharge of certain return period scenarios

Table 3.5 Main statistic parameters of peak discharge time series

Gauge	Q_{ave}	C_V	C_S	Q_T (m3/s)			
				100-year	50-year	20-year	10-year
Nong Son	5,076	0.4	0.2	10,097	9,461	8,528	7,718
Thanh My	2,260	0.52	0.53	5,449	4,998	4,354	3,816

Table 3.6 Calculation of peak discharge scaling ratios

Gauge	Representative year	$k_{100\text{-}year}$	$k_{50\text{-}year}$	$k_{20\text{-}year}$	$k_{10\text{-}year}$
Nong Son	1999	1.18	1.11	1.00	0.90
Thanh My	1999	1.49	1.37	1.19	1.04

Usually, for flood hazard maps, inundation depth is classified more or less evenly (Alaghmand et al. 2012; Dawei 2011). Nevertheless, after field survey and consultation with local people about the past flood disasters, inundation classification applied in this study takes into account level of consequences for further vulnerability and risk analysis for property loss and casualties in next chapters that can classify into 5 levels: <0.5m (up to knee); 0.5m ÷ 1.0m (up to shoulder of an adult); 1.0m ÷ 2.0m (up to 1-story house roof); 2.0m ÷ 3.0m (up to 2-story house roof) and >3.0m (everything is submerged). Based on this classification, the modeling results is visualized in the form of inundation maps with selected return periods, i.e. 100-year, 50-year, 20-year and 20-year. These maps shown in Figures 3.15, 3.16, 3.17 and 3.18 indicate that the most serious inundation occurs from the junction of the two rivers, Vu Gia and Thu Bon, the Cua Dai estuary, especially in the communes namely Dai Minh, Dai Cuong, Dai Thang, Dai Hoa (Dai Loc district), Dien Quang, Dien Trung, Dien Phong (Dien Ban district), Duy Phuoc, Duy Thanh and Duy Vinh (Duy Xuyen disctrict). For detailed analysis, to focus only in Dien Ban District, the extension of inundation for each classification is calculated and presented in Table 3.7.

Table 3.7 Calculated inundation area (in hectare) for Dien Ban District

Water depth classification	100-yr		50-yr		20-yr		10-yr	
	Area (ha)	% over total area*	Area (ha)	% over total area*	Area (ha)	% over total area*	Area (ha)	% over total area*
<0.5m	1,556	7%	2,025	9%	2,518	12%	2,883	13%
0.5 -1.0m	2,347	11%	2,984	14%	3,497	16%	4,543	21%
1.0-2.0m	3,808	18%	4,159	19%	4,354	20%	4,540	21%
2.0-3.0m	5,044	23%	4,316	20%	3,444	16%	2,367	11%
>3.0m	5,332	25%	3,812	18%	1,508	7%	509	2%
Sum	18,087	84%	17,296	81%	15,321	71%	14,842	69%

*Total study area of Dien Ban District is 21,470ha

3.4 Summary

VG-TB river system in Quang Nam Province is strongly characterized by steep bed slope and complicated hydrological regime. These factors result in sudden and extreme flood hazard, which certainly the risk for human safety and environmental integration. Therefore, in order to be able to understand the flood pattern and its consequences, this study applied an integrated approach, including flood simulation by MIKE-NAM and MIKE11, GIS-based inundation extent visualization and statistical analysis of past flood record in the local area under climate change impact. The modeling calibration and validation come up with quite good result (NASH index at all the main gauges is higher than 0.7, even up to 0.95). Also, for peak discharge usually having large error, the difference between observed and simulated values is less than 10%. The model with such calibrated parameters was then used to simulate flood events of frequencies of 100-year, 50-year, 20-year and 20-year return periods.

For further analysis, the corresponding maps were developed to present the inundation extent and inundation depth, which indicate clearly that the study area of Dien Ban district is located in low-lying area and flooded seriously even in case of 10-year event.

In addition, the inundation maps also show that the flood with lower frequency causes substantial increase of total inundation area and more critically, mainly the increase of deep water. By the other words, the increase of total inundation is mainly due to the increase of deeply flooded area. This issue is an important concern as the statistical analysis and reviewing of international and national researches revealed the tendency of increased erratic weather phenomenon and consequently, extreme flow discharge threatening local community safety and sound environment. Within framework of this study, only qualitative assessment of flood consequences was carried out for different inundation level: <0.5m (up to knee), 0.5m-1.0m (up to shoulder of an adult), 1.0m-2.0m (up to 1-story house roof), 2.0m-3.0m (up to 2-story house roof), and >3.0m (everything is submerged).

Total inundation areas as much as of 18,087ha, 17,296ha, 15,321 and 14,822ha for the return periods of 100-yr, 50-yr, 20-yr and 10-year respectively. Nevertheless, when flooding occurs, the main issue of concern is not just total inundation area but also the area affected by deep water depth. As water depth from 1m and above is considered to cause significant impacts (Schumann, 2011), the areas is potentially inundated up to such level and more approximately account for 66%, 57%, 43% and 34% of total district area, meaning that extended cultivated land, aquaculture lots and residential area in the low lying is completely under deep water. Even in the scenario of 10-year return period, i.e. a disaster event can occur quite frequently, still very large area (32%) can be potentially inundated with water depth 1m-3m.

It is also noted that the increase in flood magnitude (with lower frequencies) results in the larger total inundation extension. However, as the VG-TB downstream is located in the valley surrounded by high mountain (Figure 3.19), rather than causing an even increase of all classes, the flood with higher magnitude (or lower frequency) results in substantial extension of deep inundated areas (with water depth of 1m and higher). For instance, while the inundation areas of water level less than 0.5m in all three scenarios are almost the same, the areas of water level of 1.0 - 3.0m for 100-year and 50-year return periods are much more compared to those in scenarios of 20-year and 10-year.

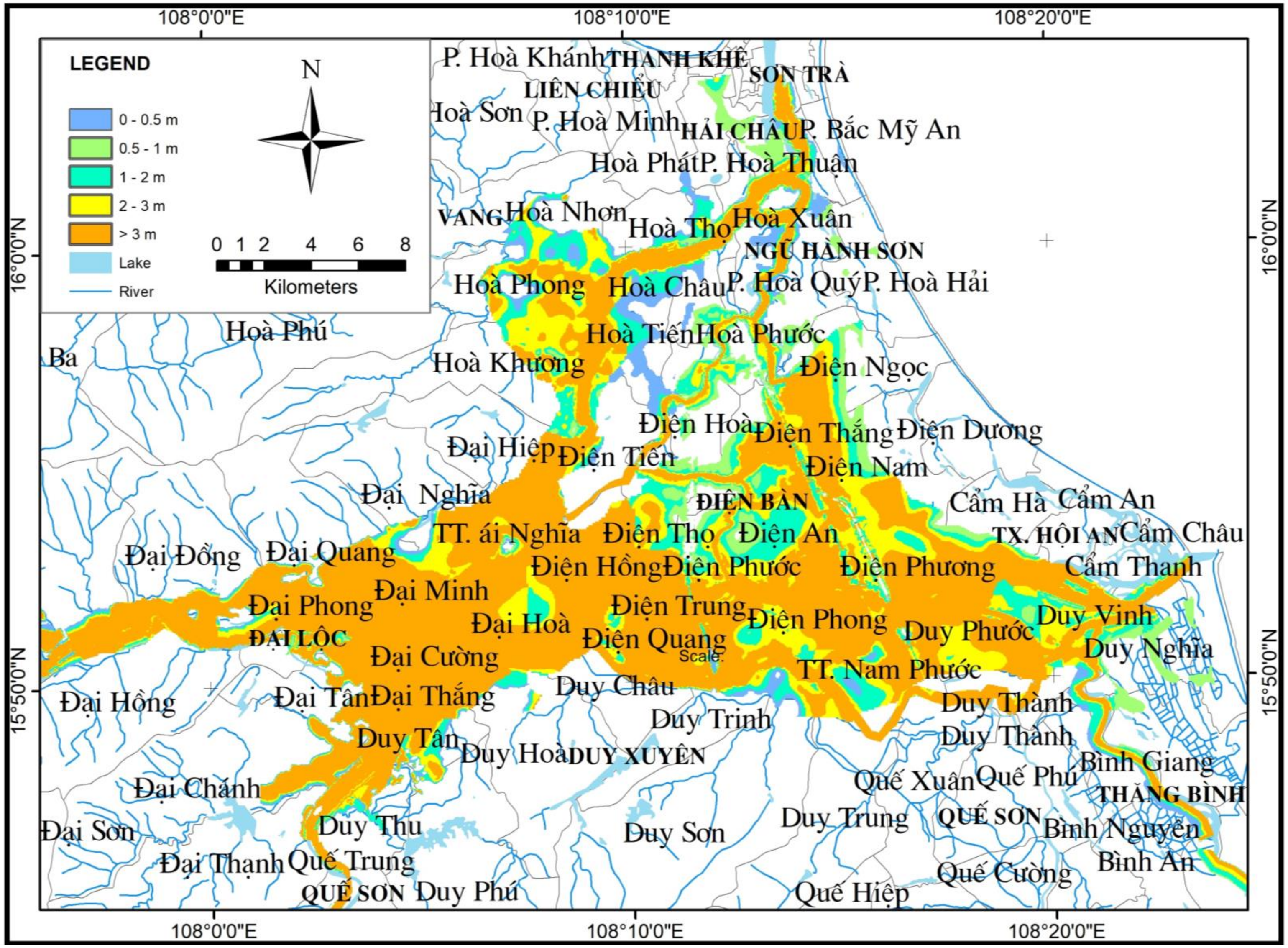


Figure 3.15 Inundation map with 100-year return period in VG-TB basin

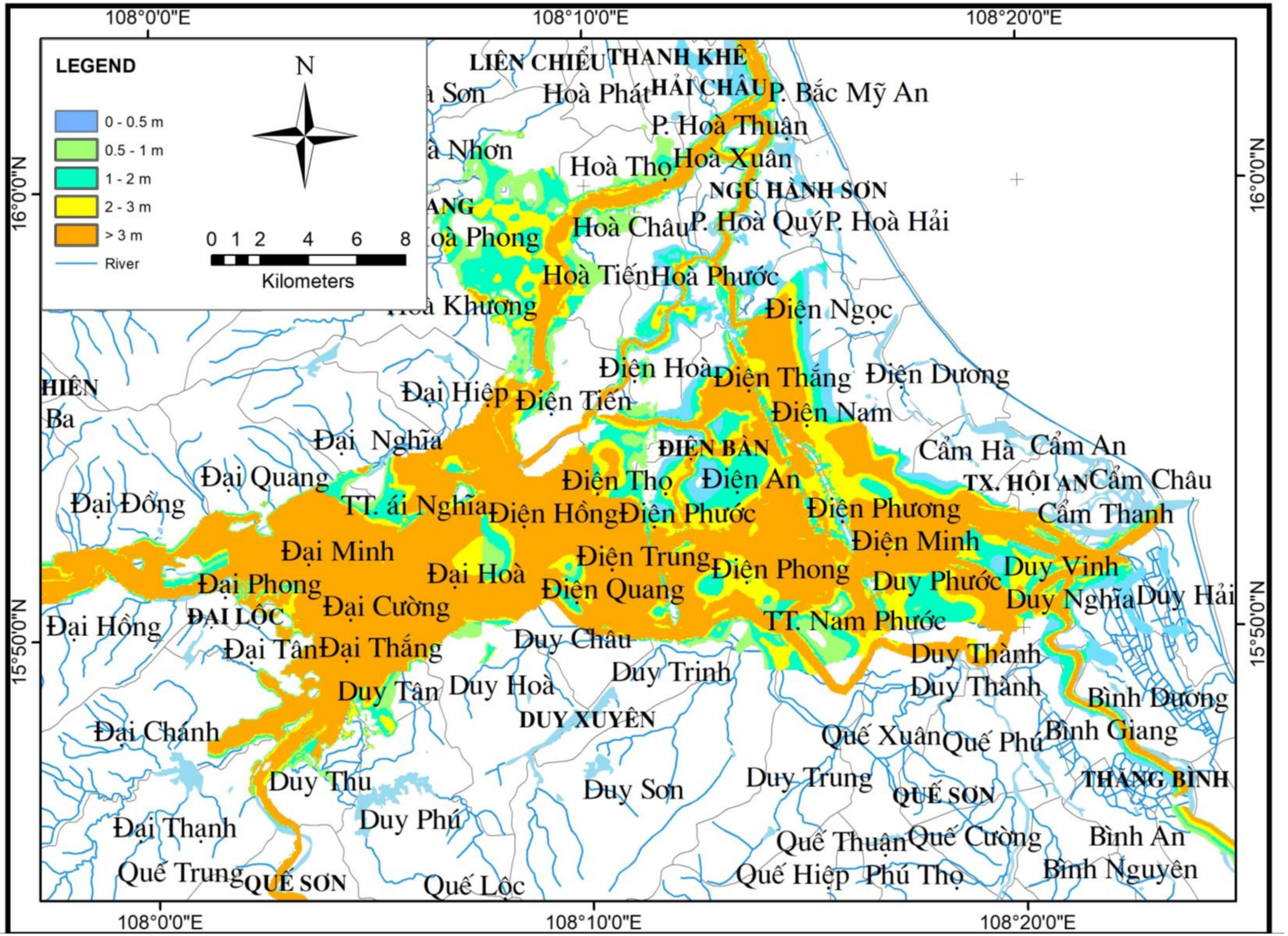


Figure 3.16 Inundation map with 50-year return period in VG-TB basin

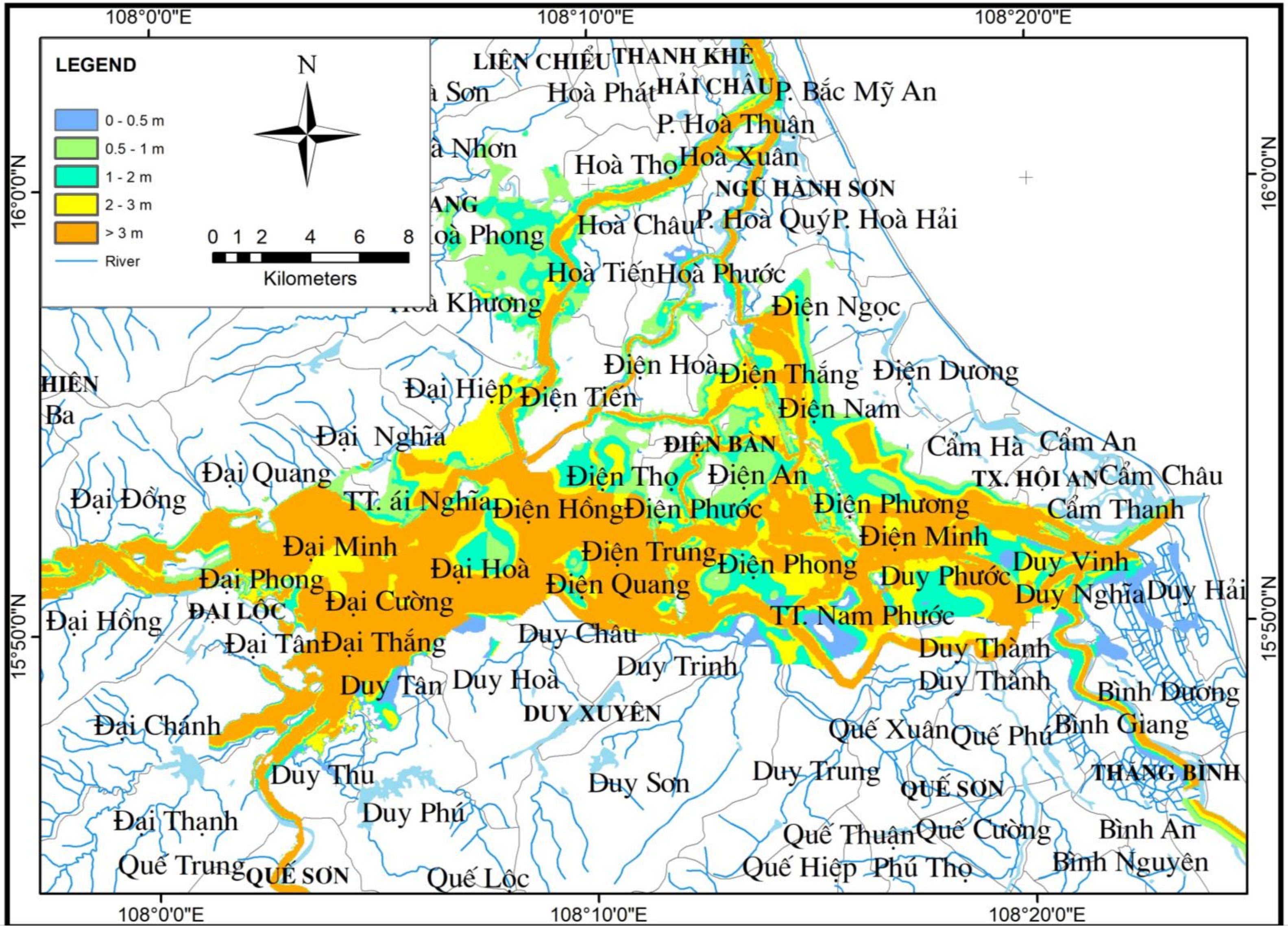


Figure 3.17 Inundation map with 20-year return period in VG-TB basin

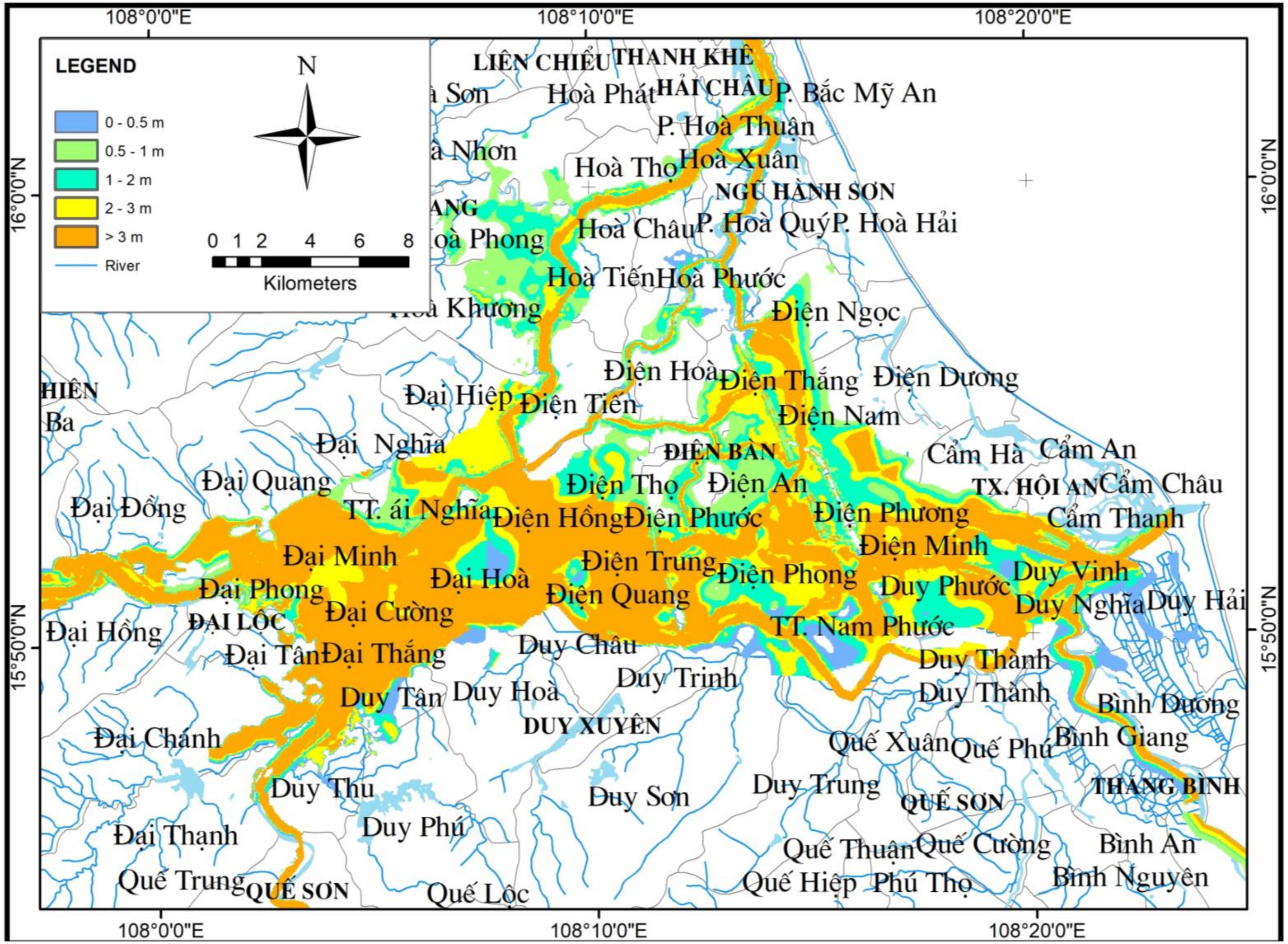


Figure 3.18 Inundation map with 10-year return period in VG-TB basin

Figure 3.19 A google image showing the study area located in the valley surrounded by high mountains

Chapter 4. Flood risk assessment for social safety

4.1 Introduction and identification of elements-at-risk

Being located in Central Vietnam, one of the most water related disaster prone region, Vu Gia-Thu Bon (VG-TB) suffers serious flooding almost every year. According to the available record, during past 15 years, flood disaster has caused approximately 750 fatalities in this basin (Quang Nam, 2015). The question how to quantify flood consequences, especially the occurrence of human loss, has been an increasing concern of flood managers. To date, various methodologies have been developed to estimate the consequences of coastal and river flooding in terms of numbers of fatalities and injuries with different level of input data requirement and technical complication. However, all these methods have been developed and validated with past disaster events in developed countries, especially in UK, Netherlands, Japan, New Zealand etc. (DEFRA, 2006; Zhai et al., 2006; Jonkman et al., 2008; NIWA, 2013). In developing countries, especially in rural floodplain areas, the perception of local authority and community about disaster risk is rather limited. Table 4.1 summarizes the advantages and disadvantages of most widely used methods developed in these past studies, which shows that the one developed by Penning-Rowsel et al. (DEFRA, 2006) is more flexible to modify for applying in the developing countries as it takes into account range of different social characteristics and thus, can be modified for applying in the developing countries. According to these studies and feedback from interviews with local authority and farmers, many accidents resulting in fatalities and injuries during flood disaster can be caused by the hazardous actions (deep water, high flow velocity, debris, chemical toxic etc.) but also by high vulnerability of local people, especially in rural areas due to their limited awareness and poverty. On the other hand, the local community living in river alluvial are familiar with annual flooding occurrence and thus, usually underestimate the disaster danger and consequential risk, e.g. people keep driving or fishing during flood or refuse to evacuate etc…

Therefore, the purpose of this Chapter is to develop an approach to flood vulnerability and risk analysis for human safety in Dien Ban District, one of the very low-lying area in VG-TB downstream and whereby, to produce flood risk curve (FRC) and annual social risk. It is important to emphasize that apart from negative consequences, from the history, it is well known that abundant water resource and annual flooding also bring rich rice field and many livelihood for local people. Even now, around 70-80% of population living in river delta and coastal zone of VG-TB basin earns their living by agriculture, aquaculture and exploiting natural resources. Therefore, building up the local resilience or so call "living with the flood proactively" strategy is vital for sustainable development. To achieve this goal, the approach used in Chapter 4 (see Figure 4.1) will integrate not only direct but also indirect and intangible issues of social vulnerability into the analysis and quantitative risk, e.g. potential rate of people exposed to flooding and consequential injuries and casualties. Based on the scope of research defined in Chapter 1, for category of Social Safety (SS), three elements-at-risk will be considered, namely:

1. Number of affected people (SS1)
2. Number of people exposed to the risk of injuries (SS2)
3. Number of people exposed to the risk of fatalities (SS3)

The results presented in this paper include the simulated inundation extension for events with return periods of 100 years, 50 years, 20 years and 10 years (equivalent to exceedance probabilities of 10%, 5%, 2% and 1%), and social risk for corresponding frequencies. Moreover, considering the fact that in Vietnam the data and information about flood consequences on human safety is very

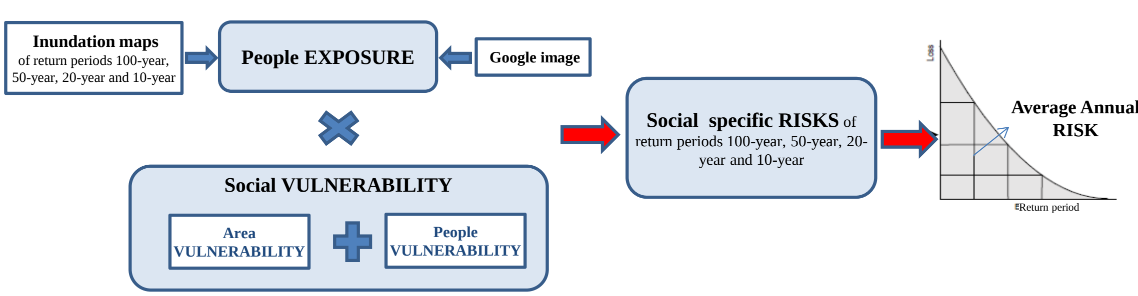


Figure 4.1. Flowchart of social vulnerability and risk analysis

limited and inaccurate, the approach and result of this study can be useful for disaster manage practice in the country as it can help to provide an quantitative information about the impacts on human safety caused by annual alluvial flooding.

Table 4.1 Comparison of application of some main methods for assessing loss of life caused by flooding

Waart's method (Jonkman et al., 2008)	
Simple hazard (input) data requirement	☑
Easy to use	☑
Producing only fraction of fatalities, but not injuries and other vulnerable groups	☒
Not yet applied in developing countries	☒
Jonkman's method (Jonkman et al., 2006)	
Producing people exposed to flood and possible fatalities	☑
Taking into account intangible indirect issues that can influence the rate of exposed people and number of fatalities	☑
Do not produce the number of injuries.	☒
Not yet applied in developing countries	☒
DEFRA method (2006)	
Moderate hazard (input) data requirement	☑
Easy to use	☑
Producing necessary outputs: people exposed to flood, potential injuries and fatalities	☑
Comprehensive as taking into account different factors that can influence the rate of injuries and fatalities.	☑
Some factors are qualitative being judged based on experience	☒
Not yet applied in developing countries	☒

estimation that every year how many people would expose to flood risk and among them, what is potential injuries and casualties, based on which, decision makers and local community can prepare sound disaster management strategy and annual action plan. Based on comparison in Table 4.1, the modified DEFRA's method is modified to apply taking into account both vulnerability characteristics of the local area and also vulnerability of people exposed to the hazard. In this method, it is suggested that the number of fatalities and injuries for a single flood event is a function of the population who potentially expose to flood, which is calculated based on hazard rating (magnitude) and vulnerability of area and people. This definition can be expressed by a series of following equations:

$$HR = (v + 0.5) * d + DF \quad (4.1)$$

$$SS2 = SS1 * HR * AV * Y \quad (4.2)$$

$$SS3 = SS2 * 2*HR \quad (4.3)$$

Where:

v - flood velocity (m/s)

d - water depth (m)

DF – debris factor (0-unlikely; 1-possible and 2-likely)

AV- Area vulnerability

Y-People vulnerability (% of vulnerable people compared to total population)

HR – Hazard rating (dimensionless)

SS1 – number of affected people, i.e. who expose to the flooding

SS2 – number of people exposed to medium risk of health effects (i.e. physical injuries, trauma and serious sickness)

SS3 – number of people exposed to high risk of health effects (i.e. fatalities)

Next sections are going to discuss the determination of these vulnerable factors and calculate the risks of the three elements at risk selected for social safety category.

4.2 Social safety exposure analysis

As overviewed in Figure 1.2 and 2.23 and then discussed in Chapter 2 and Chapter 3, Google image and inundation maps of 100-year, 50-year, 20-year and 10-year return periods are used to evaluate the exposure of houses and inhabitants in case of flood occurrence. From an image obtained from Google Earth, the number of houses is marked and counted, which is then converted to a GIS layer. By superimposing this layer with inundation maps developed in Chapter 3 with an example Figure 4.2 to derive the number of houses, i.e. households, of each inundation level. Then the number of people at risk (SS1) is equal to number of households multiplied by 4, the average persons of each household. The counting results are summarized in Table 4.3. Figure 4.3 presents the significance of households exposed to flooding, from which it is noted that the exposure to deep water in urban Vinh Dien town is more serious than in the rural area due to high population density.

4.3 Social intangible vulnerability analysis

4.3.1 Causes and circumstances of individual safety during flooding

When flood occurs, there are number of causes, in direct or indirect ways, to human health, i.e. physical injuries, sickness or even fatalities. The most popular ones are:

– Drowning: This is main cause of fatalities due to flooding (Jonkman et al., 2005). Such accident often occurs when people are trying to walk in floodwater, or driving in motorbikes and cars or boating. It also can happen when people stuck in the inundated houses.
– Physical trauma: The causes of physical trauma are similar to those causing drowning but at less serious level.
– Heart attack and other health emergency cases: this is indirect causes of fatalities. During flood disaster, all the medical services are suspended. Stressful psychology can result in heart attack or other medical emergency (e.g. birth delivery, high fever, sickness related to respiratory and diarrhea etc.).
– Contamination: Contamination of food and drink water and other sanitary issues can cause range of effects on local people's health. However, apart from direct health emergency and sickness, other long term health issues are often underestimated.
– Electrocution: this accident can occur inside the household or on the road when the electrical utilities and power cables are submerged

The significance of these accidents depends on the social vulnerability (DEFRA, 2006). Such vulnerability can be categorized into two groups: area vulnerability and people vulnerability with the description as following:

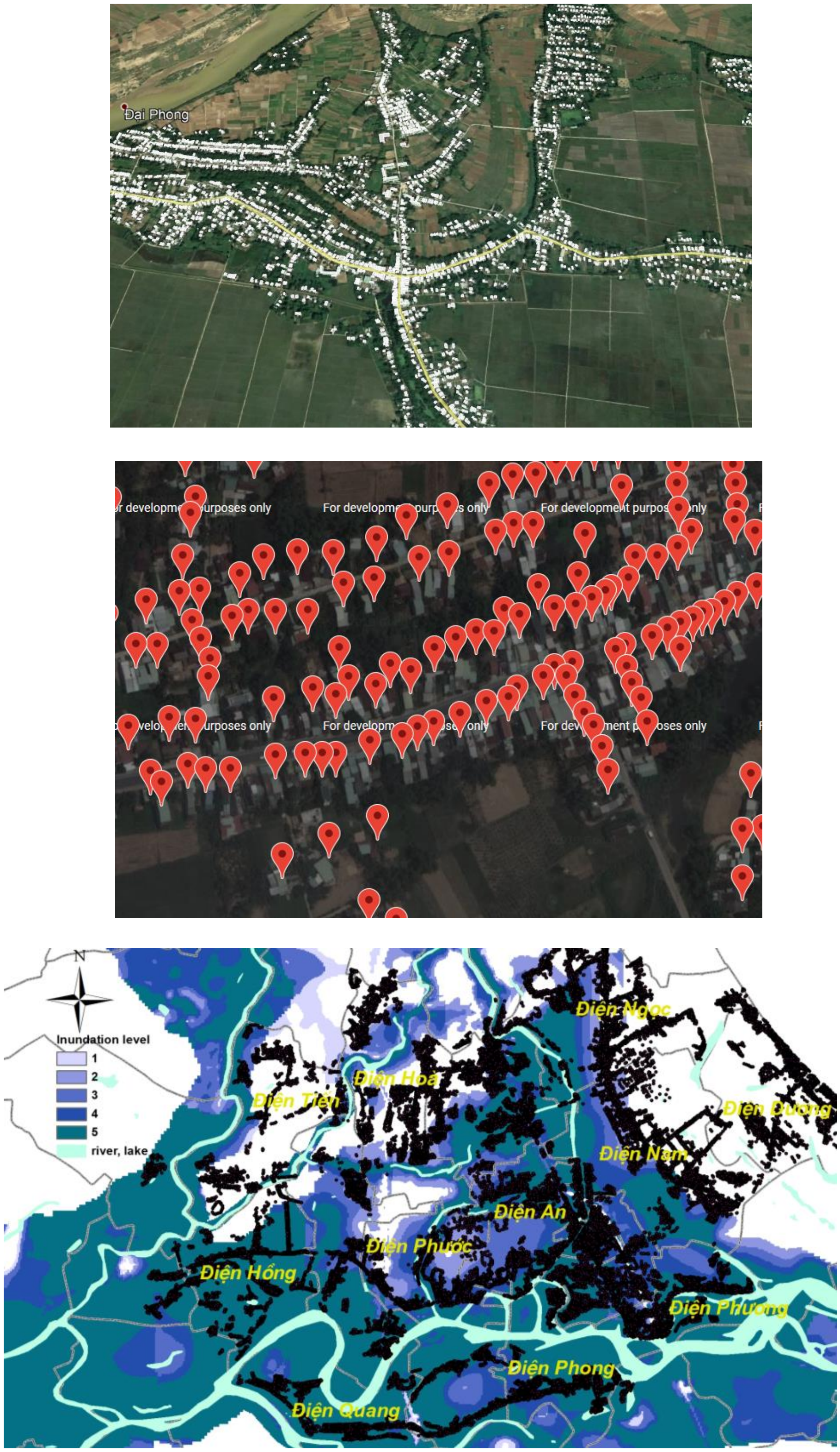


Figure 4.2 Demonstration of counting houses in considered flood area using Google image

Table 4.2 Result of people exposure analysis

Water depth	Flood scenarios: 100-year # of inundated houses	# of affected people (SS1)	%	50-year # of inundated houses	# of affected people (SS1)	%	20-year # of inundated houses	# of affected people (SS1)	%	10-year # of inundated houses	# of affected people (SS1)	%
Vinh Dien town												
<0.5m	295	1,180	14%	491	1,964	24%	527	2,108	26%	432	1,728	21%
0.5-1m	375	1,500	18%	405	1,620	20%	480	1,920	23%	328	1,312	16%
1-2m	410	1,640	20%	388	1,552	19%	165	660	8%	180	720	9%
2-3m	480	1,920	23%	295	1,180	14%	82	328	4%	-	-	0%
>3m	275	1,100	13%	115	460	6%	-	-	0%	-	-	0%
Rural area												
<0.5m	6,610	26,440	14%	7,574	30,296	16%	7,815	31,260	17%	6,561	26,244	14%
0.5-1m	9,081	36,324	20%	8,788	35,152	19%	6,602	26,408	14%	4,194	16,776	9%
1-2m	9,285	37,140	20%	7,164	28,656	16%	4,421	17,684	10%	2,203	8,812	5%
2-3m	7,157	28,628	16%	4,309	17,236	9%	1,655	6,620	4%	278	1,112	1%
>3m	3,262	13,048	7%	831	3,324	2%	45	180	0%	-	-	0%
% of affected people			17%			14%			11%			7%

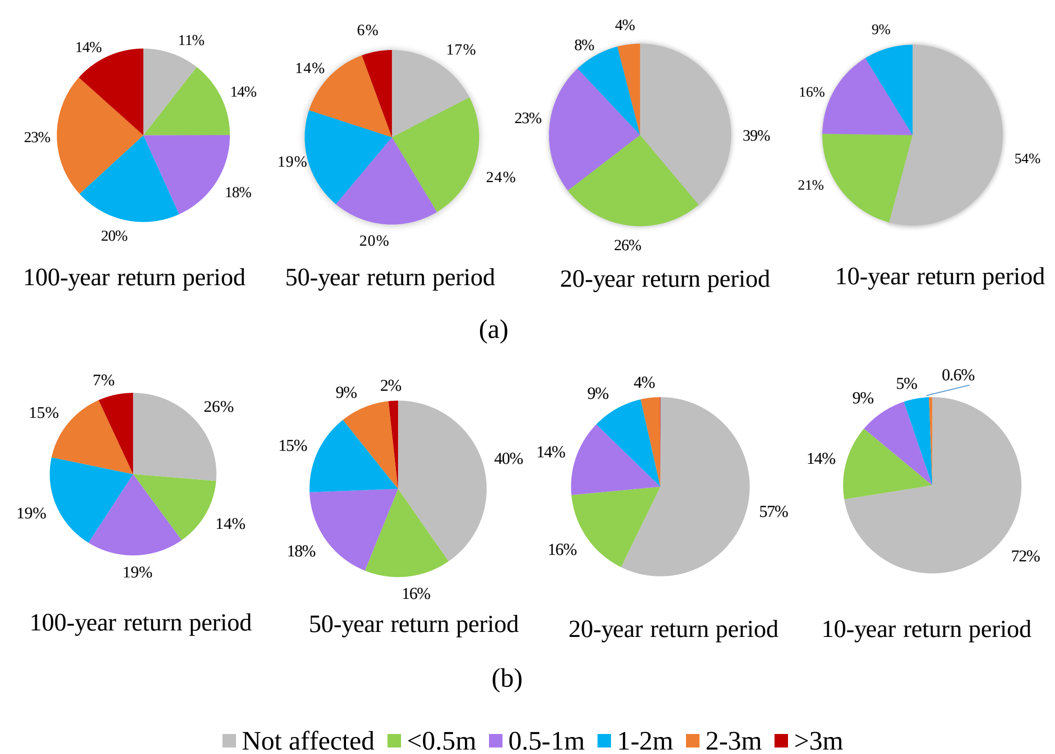


Figure 4.3 Distribution (in %) of houses in different inundation depth
(a) Vinh Dien town (b) Rural area

(1) Area vulnerability:

– Double disaster (typhoon + flooding): Very often that the torrential rainfall is formed by cyclone circulation causing double disaster. This factor is major concern of local people because people in Dien Ban has long experience of living with the flood, in many one storey houses they build elevated mezzanine to store their stuff when flood enters. The heavy property, mainly motorbike can be evacuated to high ground (e.g. bridge, main road, etc.) but if there is typhoon before the flood, it is impossible to do so. Therefore, with limited resources, it is very hard for local people to cope with and thus, their injuries and property damages would be significantly increased.
– Deep inundation: The study area is located in most low-lying area of VG-TB floodplain. As analyzed earlier in Chapter 3, due to the deep frying pan form of topography, the critical issue of concern is not total inundation extension but the deep flooding. The inundation in the paddy field is about 3-4m. In the houses, water depth varies depending on the height of ground floor, ranging from 0.5m up to 2m. Depending on the height and gender, in general, adult people are likely unable to stand in floodwater at 1m or higher. Water depth of around 0.5m – 1.0m already can be high risk for children and elderly people
– Flow velocity and speed of onset: The bed slope of VG-TB river system is rather steep causing quick rising of inundation in the downstream fluvial area
– Debris and mud flow: As the upstream is covered by forest with many timber logging activities, the flood flow often carry lots heavy wood which is highly dangerous for people and huge labour work to clean up the agricultural land area. The flood flow also carries lots debris and mud from gardens into houses which may cause injuries and more clean-up cost.
– Contamination: Water and environment becomes seriously contaminated due to flooding. Lack of safe drinking water can last for many days after the flooding and cause long term health problems for local people.

(2) People vulnerability

– Type of housing: People are more exposed to an accident during flood in these three types of houses: (1) houses are in not good condition and thus can be damaged partly or collapsed due to hazard; (2) houses has only one story and they cannot use their house as safe shelter; (3) houses are in remote areas and/or difficult to access the safe escape route. Unfortunately, these three types of houses are dominated in the study area.

– Flood warning: If people exposed to flooding receive warning sufficiently before the hazard really occurs their risk can be reduced. However, in the study area like elsewhere in Vietnam, weather forecast as well as communication for early warning and overall effective disaster preparedness plan is still limited. People often receive the warning late or inaccurate warning or no warning at all.
– Large group of vulnerable people: elderly people and children, disable people: In many households, there are only elderly and children are at home when flood occurs. Due to limited livelihood opportunity, many labours in Dien Ban district have to find permanent jobs far away from home, e.g. in the big cities. It means that, when the flood strikes, only elderly and children are at home. This factor results in higher risk for the safety of these people. On another
– social aspect, the disable people must be included in the vulnerable group that needs special assistance if evacuation is needed.

Table 4.3 Summary of intangible vulnerable issues learned from field survey

Issues of vulnerability	Level of vulnerability	Type of intangible vulnerability	
		Direct	Indirect
Area vulnerability			
Double disaster (typhoon + flooding)	High	x	
Deep inundation	High	x	
Flow velocity and speed of onset	Medium	x	
Debris and mud flow	Medium	x	
Contamination	Unknown	x	x
People vulnerability			
Type of housing	High	x	
Flood warning	Medium	x	
Large group of vulnerable people	High	x	x

– Awareness: The local people often underestimate the potential consequences of flood hazard due to partly lack of information and partly of low living standard. The later problems can be explained they intend to reluctant to evacuate and try to save their properties.

The vulnerability related to human safety is categorized as intangible and thus in this study, they can now be divided into direct or indirect. In Table 4.2 vulnerability issues listed above is summarized with classification into and qualitative evaluation of their significance for the study area. It is noted that the issues that contribute to high vulnerability relate to double disaster, deep inundation as well as type of housing and large group of vulnerable people. The issue of contamination is believed to be highly critical for people health even in the long term, not only during the flood event. However, there is very limited information on this issue and thus, its significance is temporarily evaluated as unknown. Also, Figure 4.4 presents some examples of vulnerability of local people during flooding.

4.3.2 Calculation of social vulnerability

Based on the overall analysis of vulnerable issues related to area and population characteristics, this section is going to describe calculation steps of social vulnerability factor. To do so, these variables are determined as following:

Hazard rating HR is function of average inundation depth, flood flow velocity and debris factor. The average inundation depth is derived from flood hazard maps developed in Chapter 3. For flow velocity, referred to Son (2006), it is in the range of 0.5–2m/s depending on level of flooding and thus in this case, it is approximately determined as 1.0m/s, 1.5m/s, 1.7m/s and 2.0m/s for water depths up to 1.0m, 2.0m, 3.0m and above, respectively. The debris factor is determined based the recommendations in DEFRA (2006), i.e. equal to 0.5 and 1.0 for water depths up to 2.0m and above, respectively. HR is then calculated using Eq (4.1) and shown in Table 4.4.

Area vulnerability AV: In the Guidance of DEFRA (2006), the contributing factors to the area vulnerability are proposed as below:

(1) Speed of onset: 1–low risk area (onset of flooding is very gradual, e.g. many hours); 2– medium risk area (onset of flooding is gradual, e.g. an hour or so) and 3– high risk area (rapid flooding)

(2) Nature of area: 1–low risk area (multi-storey housing); 2– medium risk area (conventional residential area combining 2-storey housing, commercial properties etc.) and 3– high risk area (bungalows, mobile single houses, campsite etc.)

(3) Flood warning: 1–low risk area (effective waring, reaching all target

Figure 4.4 Examples of social vulnerability during flood in rural area (provided by Quang Nam Storm and Flood Control and Rescue)

1. Children play with floodwater exposing to accident (drowning, trauma) and contamination
2. Involved officials are on duty during the disaster
3. Popular type of simple one storey houses can be seriously submerged
4. Highly vulnerable elderly people cannot be evacuated

people, sufficient in time and follow up evacuation action); 2– medium risk area (less effective warning) and 3– high risk area (no or insufficient warning).

These three contributing factors are estimated with the relevant scores and summed up to derive total area vulnerability. Dien Ban district is mainly rural area, except local administration central area named Vinh Dien town where has better housing, infrastructure and flood warning. Based on the analysis of site specific issues in earlier section in Table 4.2, the contributing factors and then AV area calculated separately for Vinh Dien town and the rural area, which is equal to 5 and 7.5, respectively (Table 4.4).

People vulnerability Y: DEFRA (2016) suggested that vulnerable people include residents aged 75 years or over and residents suffering from long term illness. In this study, as learned from the field trip and local statistics record (Quang Nam, 2015), highly vulnerable people must define to cover more target groups, including:

i. Elderly resident group: According to DEFRA, the elderly people who are considered to be vulnerable to flooding is those with age 75+. However, having considered poor living condition like in Dien Ban district, people become weak with age of about 70[1)]. According to past studies and field survey, 80% of interviewees release that age 70+ requires special assistance from other family members to cope with inundation situation. Additionally, in principle, the farmers in rural areas do not have pension but some provinces, including Quang Nam, have policy to provide special allowances and health insurance package for elderly of age 70 and over. Therefore, this study includes the group of aged 70+ elderly in highly vulnerable group which accounts for 8.0% of total population.

ii. Newborn babies and pregnant woman: pregnant women and mothers during maternity period as this group of people have to confront with high risk of inundated condition and also they cannot access to medical care during this period.

iii. Disable resident group includes permanent sick people and temporary patients who currently need medical treatment. This figure can be evaluated based on the number of patient beds in two hospitals and other six clinics in the survey[14)]. The consultation with the managers of these medical centers revealed that these centers are always full. When the flood occurs, most of these patients return home as the hospital and clinics may also be inundated. Therefore, it is really high risk for these patients to stay home in inundated condition and without necessary medical care.

In this case for Dien Ban District, people vulnerability component Y is proposed to include three main groups: elderly people with age 75+, children with age under 6 and disable people. Reffered to Statistical Year Book of Quang Nam (2015), Y is determined as 36.7% and 39.2% for Vinh Dien town and the rural area, respectively.

Substituting the vulnerable factors just identified into Eqs (4.1), (4.2) and (4.3) to derive the scores of social intangible vulnerability for selected element at risk for human safety (Table 4.6).

Table 4.4 Calculation of hazard rating (HR)

Inundation depth (m)	Average inundation depth (m)	Velocity (m/s)	Debris factor	Hazard rating HR
> 0.5	0.25	0	0	0.1
0.5 – 1.0	0.75	1.0	0.5	1.6
1.0 – 2.0	1.5	1.5	0.5	3.5
2.0 – 3.0	2.5	1.7	1	6.5
> 3.0	3.5	2	1	9.8

Table 4.5 Calculation of area vulnerability (AV)

Area	Flood warning	Speed onset	Nature of area	Area vulnerability AV
Vinh Dien town	2	1	2	5
Rest rural area	2.5	2	3	7.5

Table 4.6 Summary of calculated vulnerable factors

Inundation depth (m)	Average inundation depth (m)	HR	AV	Y (%)
Vinh Dien town				
> 0.5	0.25	0.1	5	36.7%
0.5 – 1.0	0.75	1.6	5	
1.0 – 2.0	1.5	3.5	5	
2.0 – 3.0	2.5	6.5	5	
> 3.0	3.5	9.8	5	
Rural area				
> 0.5	0.25	0.1	7.5	39.2%
0.5 – 1.0	0.75	1.6	7.5	
1.0 – 2.0	1.5	3.5	7.5	
2.0 – 3.0	2.5	6.5	7.5	
> 3.0	3.5	9.8	7.5	

4.4 Social safety risk analysis

4.4.1 Flood risk curves of social safety

In this section, the specific risks of selected element-at-risks for social safety SS1, SS2 and SS3 are calculated by substituting the values of exposure and vulnerability factors obtained from the analysis in previous sections into Eqs. 4.1, 4.2 and 4.3 (Table 4.6). Using another way to present specific risks, the values of specifc risks are plotted against corresponding return periods to derive FRCs of SS1, SS2 and SS3 (Figure 4.5, 4.6 and 4.7). From these figure it is noted that although SS1, i.e. the total extension of affected people increases proportionally with magnitude of flooding events there is significant rise of SS2 and SS3, i.e. the potential injuries as well as fatalities, between flood scenarios of 20-year and 50-year return periods. This can be explained by the fact that for the event with longer return period, i.e. more catastrophic one, the inundation in study area tends to increase in the water depth rather than in the total area as explained in Chapter 3.

4.4.2 Average Annual Risk (AAR) of social safety

Based on FRCs derived, the next step is to calculate AAR, which is another highly quantitative indicator for presenting risk. AAR is the area under the curves in Figures 4.5, 4.6 and 4.7 using the Eq.1-2:

$$\mathrm{AAR} = \sum_{i=1}^{n} \frac{1}{2}\left(\frac{1}{T_i} - \frac{1}{T_{i-1}}\right)(\mathrm{Risk}_i + \mathrm{Risk}_{i+1})$$

The result of AARs for SS1, SS2 and SS3 shown in Table 4.7 can be interpreted that in average, annually, the flood disaster in the study area is expected to result in 7.5% of total population, approximately 3,230 and 31 people exposed to risk of injuries and fatalities, respectively.

Table 4.7 Result of risk calculation for social safety

Flood scenario (Return period)	Affected people SS1 (%)	# of people exposed to risk of injuries SS2	# of people exposed to risk of fatalities SS3
Specific risk			
100-year	17%	12,440	163
50-year	14%	9,860	125
20-year	11%	3,900	31
10-year	7%	2,910	27
AAR	7.5%	3,230	31

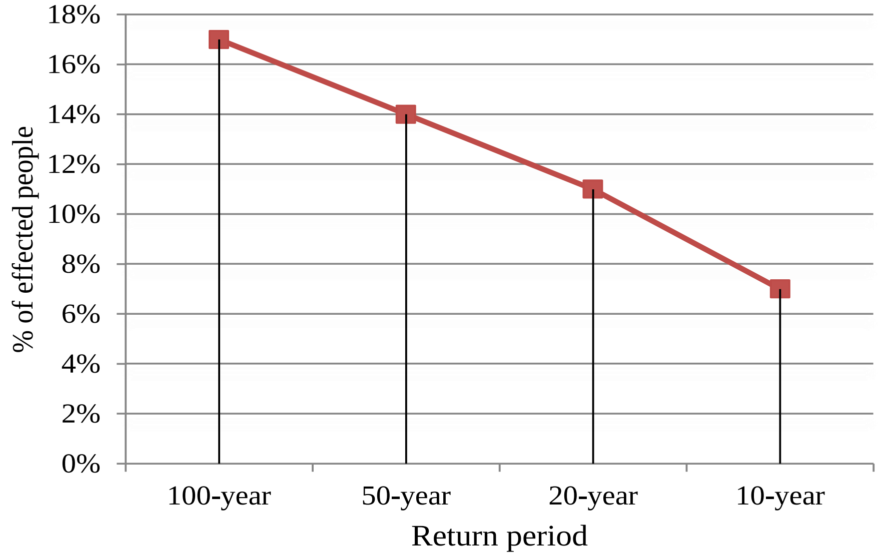


Figure 4.5 FRC of % affected people (SS1)

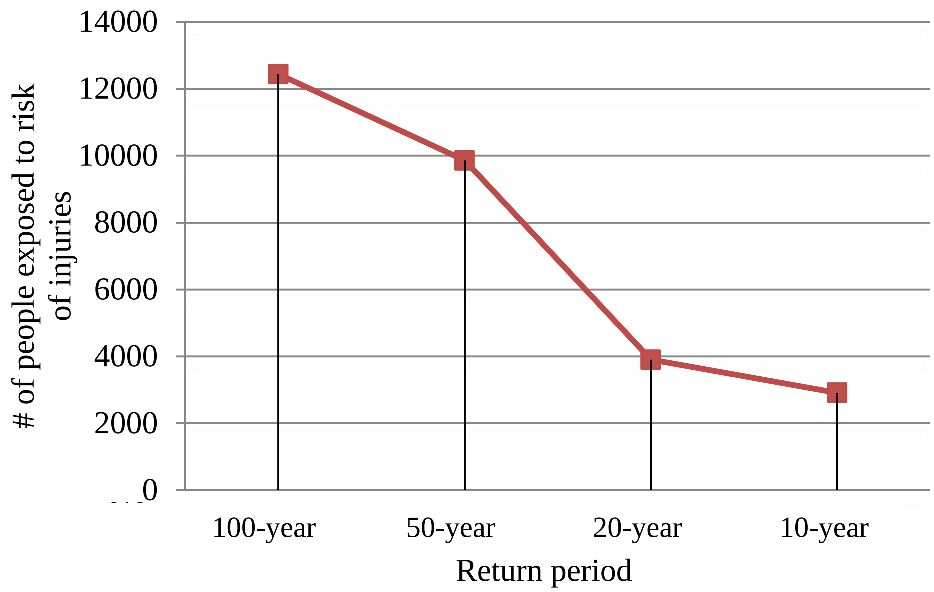


Figure 4.6 FRC of people exposed to risk of injuries (SS2)

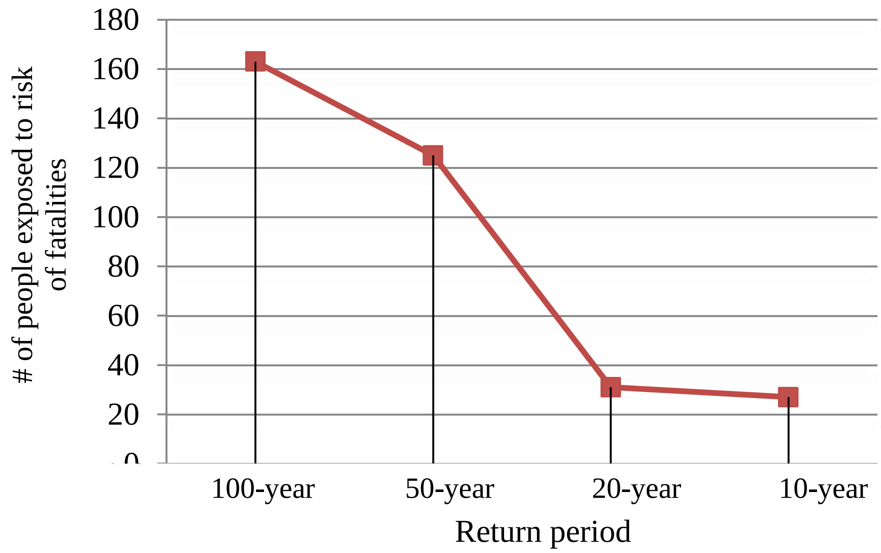


Figure 4.7 FRC of people exposed to risk of fatalities (SS3)

4.5 Summary

It is no doubtful that the social safety is most critical concern of any flood disaster management practice. However, in most cases, only the direct physical effects on human health are considered. The exposure and vulnerability analysis in Chapter 4 strongly indicates number of social and area characteristics potentially expose people to higher risk of direct and indirect health consequences.

Specifically, according to the finding from risk analysis and calculation, every year, in average, about 7.5% of population are affected flood disaster and more than 3,000 people exposed to high risk injuries and fatalities. In case of catastrophic event of 100-year return period occurred, these figures can rise up to 17% and more than 12,000 people.

Also, very importantly, the rate of risk of fatalities is as high as 27 cases and around 160 cases for frequent (i.e. 10-year return period) and catastrophic events i.e. 100-year return period) which requires strong measures to reduce risk and enhance resilience.

Chapter 5. Flood risk assessment for agriculture sector

5.1 Introduction and identification of agricultural elements-at-risk

Floodplains have traditionally supported dense population mainly engaged in intensive agriculture as a result of advantage of fertile soil and irrigation. However, the floodplains are extremely vulnerable to flooding. Deep inundation in such low-lying agricultural land can certainly cause sizable damages at local level affecting the sustainability of household livelihood. Particularly, in most rural areas of developing countries, due to poverty, flood events are dealt with in a reactive, rather than proactive, manner and little is done to be prepared for a catastrophic outcome of flood in the future and thus, the damage would be much accelerated (Lotsch et al., 2010; Sayers et al., 2013). As such agricultural production is highly vulnerable to climate related disasters, the data and information about its damages caused by flooding are far limited and scattered.

In the agricultural sector, the tangible losses usually consist of damage of cultivated products (rice, corn, annual and perennial trees, livestock) and irrigation infrastructure. Loss of business opportunity, environmental (soil and irrigated water) pollution, disaster compensation (loan interest exempted) that not traded directly in a market are far more difficult to assess in monetary terms and referred to as “intangible”. Due to its uncertainty and complication, intangible damage of agriculture is often neglected in flood damage assessment. However, several studies emphasize the significance of intangible damage and in some cases it is even much more serious than tangible ones, especially for agriculture in floodplain areas where the local farmers have been adapted to annual flooding so that the direct tangible damages can be quite reduced (Dasanayake et al., 2013). As a result, the risk of flood disaster is often underestimated, especially in the rural areas.

Using common approach for this study described in previous chapters, the task of Chapter 5 is to derive Flood Risk Curves (FRCs) and Average Annual Risk (AAR) in monetary values for agriculture sector of selected rural floodplain area of Dien Ban District, Quang Nam province in Central Vietnam based on hazard analysis of simulated flood scenarios of 100-year, 50-year. 20-year and 10-year return periods and exposure and vulnerability analysis of key agricultural elements-at-risk, including direct and indirect, tangible and intangible. Apart from quantitative AAR, the result also demonstrates the significance of indirect tangible and intangible (both direct and indirect) damages compared to the ones that are conventionally included in post disaster reports (see Figure 1.2).

To calculate tangible agricultural loss, damage curve methodology has been developed and applied in many countries (Dutta et al., 2003; Forster et al., 2008, Haskoning, 2009; Zhai and Ikeda, 2008; Nhu et al., 2017). However, much fewer works dealt with valuating intangible damages, especially in agricultural sectors. The methods for assessment of the intangible damages and the recommendation for their application were compiled and analyzed in Messner et al. (2007) and CONHAZ (2011). Later within XtremeRISK project, Dassanayake et al. (2013) carried out comprehensive summary on available approaches and methods used worldwide in evaluating the intangible losses due to coastal flooding and the integration methodologies for tangible and intangible losses in flood risk analysis. Specifically, the researchers of that project calculated the risk induced by the flood for two groups of intangible losses, including social (i.e. loss of life, injuries, mental health impacts and cultural losses) and environmental (i.e. damages to ecosystems) and the result was then presented in the relative values from 0 to 1, not in monetary term. On the other hand, the extensive review of past studies also find out that, apparently, Contingent Value Method (CVM), one of the social survey based methods, is highly applicable and flexible to deal with complexity and uncertainty of intangible issues caused by disaster events on socio-economy. Abbas et al. (2016) applied so called Willingness-to-Contribute (WTM), a similar approach to willingness-to-pay in CVM, in their study in Pakistan about the significance of willing in-kind contribution of local farmers in constructing structural measures to mitigate the flood risk. Particularly, in the context of increased frequency and uncertainty of extreme climatic events, it is believed that the disaster insurance is highly important to help with recovery and secure social stability and sustainability through mitigating financial risk. However, the implementation of this policy in most developing countries is very limited (Lotsch et al., 2010; Sayers et al., 2013). There have been several attempts were carried out by using social survey approach to seek public consent on willingness to pay for insurance. For example, Abbas et al. (2015) used CVM to collect primary data in five districts in Pakistan, the area of agricultural importance but highly affected by flooding, to evaluate the willingness to pay for flood insurance. The results showed that the driving factors of acceptability of this policy are age of household head, landownership, off-farm income sources and a perception about the effectiveness of flood insurance. In Vietnam, until now only one attempt was made to evaluate catastrophic flood risk insurance in the coastal zones using Choice Experiment Method, in which range of potential damages, including some indirect ones was covered (Brouwer et al., 2014).

Having considered the cultivation season characteristics and unit price, there are three key elements-at-risk of local agriculture sector selected, include: rice cultivation, other crop and fruit cultivation (e.g. corn, cassava, bean, chilli, water melon, vegetables etc.) and aquaculture, which are coded as RI, CR and AQ, respectively. In this area, the horticulture and perennial crop is also available but with rather small scale (only in private household gardens) and therefore, it is included in household property damage, not in agricultural damage. Nga et al. (2016) pointed out that in Dien Ban District, when flood occurs, the debris and mud flow seriously affects the environmental vulnerability. This is resulted by the fact that the upstream is covered by forest with many timber logging activities, the flood flow often carries lots heavy wood which is highly dangerous for people and requires huge clean-up cost of the agricultural area, especially aquacultural lots. Therefore, for each element, apart from direct loss of products, other damages can be incurred, such as clean-up cost, environmental remediation and business interruption. These damage categories are expressed by various indicators, which are also coded and classified into tangible and intangible, direct and indirect (Table 5.1).

Table 5.1 Identification of elements-at-risk

Elements at risk	Damage indicators	Type of damage: Direct		Indirect		Code
		Tangible	Intangible	Tangible	Intangible	
Rice cultivation (RI)	Loss of rice products	x				RI1
	Clean-up and recovery cost			x		RI2
	Soil and water remediation cost				x	RI3
	Business interruption		x		x	RI4
Other crop cultivation (CR)	Loss of crop products	x				CR1
	Clean-up and recovery cost			x		CR2
	Soil and water remediation cost				x	CR3
	Business interruption		x		x	CR4
Aquaculture production (AQ)	Loss of aquaculture products	x				AQ1
	Clean-up and recovery cost			x		AQ2
	Soil and water remediation cost				x	AQ3
	Business interruption		x		x	AQ4

5.2 Exposure analysis for agriculture

Exposure analysis refers to the evaluation of which elements or assets would be affected by a certain flooding scenario and how much they are affected in terms of inundation depth or other flood characteristics. As presented in Figure 2.23, to analyze the exposure of the agricultural elements-at-risk identified above, land use map is used, in which the agriculture area exposure to flooding can be calculated by superimposing the inundation maps obtained from hazard analysis in Chapter 3 over GIS based land use map, i.e. Figure 2.20 developed in Chapter 2. It means, for each flood scenario, the areas of defined elements at risk or land use types, are calculated for each flooding level. Table 5.2 is to summarize the result of exposure analysis for agriculture in Dien Ban District.

Table 5.2 Agricultural exposure to flooding (ha)

Inundation level	Inundation of rice field				Inundation of other crop field				Inundation of aquaculture			
	100-yr	50-yr	20-yr	10-yr	100-yr	50-yr	20-yr	10-yr	100-yr	50-yr	20-yr	10-yr
<0.5m	65	139	573	718	531	673	833	1,149	-	-	-	-
0.5 -1.0m	238	488	1,023	1,801	728	1,066	1,677	2,063	-	-	-	-
1.0-2.0m	832	1,252	1,739	1,854	1,542	1,810	2,131	2,187	-	-	-	110
2.0-3.0m	1,882	1,777	1,440	948	2,037	1,870	1,640	1,282	-	-	151	100
>3.0m	2,583	1,944	825	279	2,073	1,492	630	230	210	210	59	-
Sum	**5,600**	**5,600**	**5,600**	**5,600**	**6,911**	**6,911**	**6,911**	**6,911**	**210**	**210**	**210**	**210**

5.3. Vulnerability analysis for agriculture

5.3.1 Stage-damage functions of tangible vulnerability

After analyzing the exposure, the next step is to define the information about the susceptibility of selected elements at risk. As stated in Chapter 3, inundation depth is the main flood characteristic to have the most significant influence to be incorporated in flood risk analysis and thus s*tage-damage function* is used. This is a very popular method for evaluating damage rate of tangible direct elements-at-risk. In this study, this method is used to evaluate the damage rate of the elements at risk named RI1, CR1 and AQ1.

To derive the stage-damage functions, two main approaches can be distinguished: empirical approaches using damage data collected after flood events and synthetic approaches using damage data from collected by questionnaire with what-if questions, through the household survey (Bateman et al., 2006, Freeman et al., 2014). What-if analysis estimates the damage which is expected in case of a certain flood situation, e.g., “Which damage would you expect if the water depth 2m above the floor?”. The typical example for this approach is those developed for

United Kingdom (Penning-Rowsell et al., 2005).

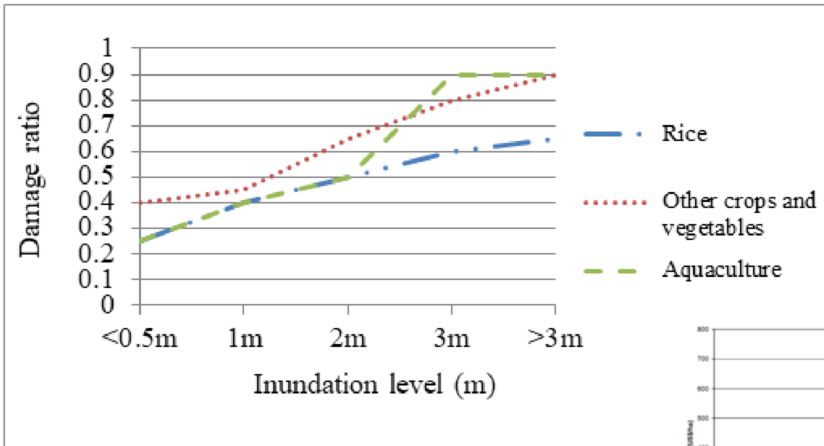
Regarding to the types of stage-damage function, another choice has to be made between relative or absolute functions, which present the relationship between flood level and the degree of damage in either monetary value or in damage ratios (Messner et al, 2007). Choosing any way to derive the stage-damage functions depend on the type and availability of data on the values of elements at risk.

a) Development of stage-damage functions of agriculture

For rice and crop cultivation: Nhu et al. (2017) proposed a method for establishing flood stage–damage functions of rice and several crops in data scarced regions, which were then tested by data from past flood events in several river basins in Central Vietnam and thus, they are adopted in this study to evaluate RI1 and CR1. These functions have similar form compared to those developed for Mekong Delta by Haskoning (2009) (Figure 5.2).

For aquaculture: As the impacts of flood inundation on aquaculture is not yet taken into account in any past studies, part of the household survey questionnaire was elaborated to investigate how the damage of fish and shrimp farming lots was related to the flood levels. Due to the fact that the farming lots are also aquatic body low damage occurs in case of small flooding. However, the damage significantly increases when the water depth is more than 2m. The direct damage of aquaculture can consist of washing away irrigation facility and farming products, bank collapse. Based on the information collected, the stage-damge function for aquaculture has been derived.

These stage-damage functions used in estimating direct damages of agriculture, i.e. elements at risk RI1, R1 and AQ1, are presented in relative damage as shown Figure 5.1



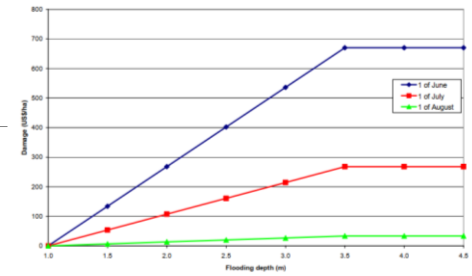


Figure 5.1 Stage-damage functions for agriculture compared to those produced for Mekong delta by Haskoning (lower)

FLOODSite (2007) and Rowsell (2013) pointed out that the “absolute” stage-damage function is quite advantageous as it does not require asset values and helps provide the result of estimated monetary damage due to a given flood scenario. Therefore, in this study, the absolute damage corresponding to certain inundation level is synthesized from the household survey. In the Questionaire used in the survey, “what-if” questions were designed to ask local residents to estimate the damage rates of certain inundation levels, e.g. “what is damage of your houses if the water level is above .... m from first floor” etc.

5.3.2 Unit value estimation of intangible vulnerability by CVM

- *For direct tangible elements at risk:* The unit values of RI1, CR1 and AQ1 are changeable depending on cultivation practice, e.g. types of land use as well as the time (or month during a year) when flood occurs. The study area is located in low lying floodplain and thus the cultivation practice has been well adapted to the flood season. The household survey revealed that from September through November no rice cultivation is taken place; the farmers still grow some crops and aquaculture, but the extension is reduced approximately 50%-80% compared to the rest of the year (Table 5.3). The unit values of land use of RI1, CR1 and AQ1 during this period are obtained from Quang Nam Year Book 2015 with the details in Table 5.4.

Table 5.3 Cycle of main crop cultivation in Dien Ban District

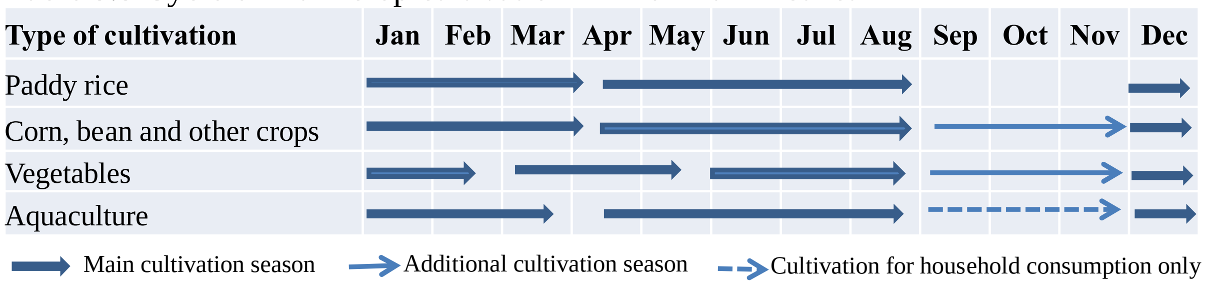


Table 5.4 Unit values of tangible elements at risk

Element-at-risk	Code	Unit values (Mil.VND/ha)	
		During Sep-Dec	Full unit value (before harvesting)**
Rice	RI1	0	91.5
Other crops	CR1	46	92.6
Aquaculture	AQ1	50	270

- *For direct intangible and indirect (tangible and intangible) elements-at-risk:* Data and information to determine these unit values were obtained by Contingent Value Method (CVM). From the review of the available methods used in disaster damage assessment in case of lacking or unavailability of data, CVM has been used widely because of strong advantage to be able to apply to almost all the intangible and indirect damage categories (Messner et al., 2007, Zhai et al., 2008, Meyer et al., 2013). In general, CVM is based on the household survey approach and in order to determine monetary values of non-market goods, especially environmental and social ones, people are asked in an interview about their willingness to pay to avoid a given decrement or damage of a particular non-market good or to accept the impacts by receiving a certain amount of compensation (Birol et al., 2006).

In this study, CVM is used to ask local authorities and farmers to estimate the damage rates and unit values of remaining elements including: RI2, RI3, RI4, CR2, CR3, CR4, AQ2, AQ3 and AQ4 as this information is not available in the official source of data. Because the farmers are not familiar with being interviewed, careful questionnaire design is vital by using dichotomous choices so that CVM can yield useful and accurate information. First, the finding obtained from in Part 1&2 of the Questionnaire helps provide overall assessment of indirect and intangible vulnerability of agriculture in the study area as summarized below:

i) Clean-up and recovery cost (RI2, CR2 and AQ2): this cost is common for all types of cultivation fields, including rice, corn and other crops and vegetables. The questionnaire respondents are relatively concentrated with the mean of VND5Mil and VND10Mil for inundation less than and more than 2m, respectively. For aquaculture, due to expensive investment, the clean-up cost of shrimp farming lots is quite high and increased significantly in case of serious inundation.

ii) Soil and water remediation cost: (RI3, CR3 and AQ3): Regarding to the pollution problem, the flood does bring fertile silt for soil but also many chemical substances from, for example, oil tanks, upstream mining… In addition, due to the fact that of intensive sand mining along the river course, the flood flow often brings lots sand onto the cultivated land. The recovery of aquaculture is even more difficult; the farmers have to dredge and remove the sedimentation in the farming lots; the water quality after severe flood events is often not appropriate causing yield reduction in the following farming season. Therefore, this issue is one of the most critical post disaster challenges because it is highly costly and takes quite long time to recover the quality of soil and water.

iii) Business interruption cost (RI4, CR4 and AQ4): In the study area, flood events can be multiple peaks lasting for couple of weeks, or even up a month (Figure 2.8). Due to such interruption, many farmers have difficulty to maintain their livelihood. In addition, they miss very good opportunity to sell products during Lunar New Year occasion in late January/early February, the most important holiday in Vietnam when the agricultural products, especially shrimp, fish and all types of vegetables can be traded with much higher prices compared to the rest of the year.

To determine the unit values of this group of elements-at-risk, the questions in Part 3 of Questionnaire were developed based on CVM to ask the interviewees to evaluate the cost they WOULD have to pay to repair and recover back to normal condition. These data and information is then analyzed to derive the mean values as summarized in Table 5.5

Table 5.5 Unit values of direct intangible and indirect elements at risk (mil VND)

<0.5m		0.5m - 1.0m		1.0m - 2.0m		2.0m - 3.0m		>3.0m	
Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Clean-up and recovery cost									
0.0	0.0	1.5	1.0-4.5	2.5	1.0 - 5.0	5.0	3.5-8.0	5.0	3.5-8.0
0.0	0.0	1.5	1.0-4.5	2.5	1.0 - 5.0	5.0	3.5-8.0	5.0	3.5-8.0
0.0	0.0	5.0	4.0-6.5	10.0	8.0-11.0	25.0	20.5-27.0	27.0	25.0-30.0
Soil and water remediation cost									
0.0	0.0	2.0	7.5-14.0	4.5	8.5-11.0	10.5	17.0-22.5	10.5	17.0-22.5
0.0	0.0	2.0	7.5-14.0	3.0	4.5-6.0	6.5	8.5-12.0	6.5	8.5-12.0
0.0	0.0	10.0	7.5-14.0	20.0	17.0-22.5	35.0	24.0-40.0	35.0	24.0-40.0
Business interruption cost									
0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
0.0	-	0.0	-	46.3	-	46.3	-	46.3	-
320	-	320	-	320	-	320	-	320	-

5.4 Risk analysis for agriculture

5.4.1 Specific risks of agriculture

After obtaining the values of exposure and vulnerabilities (i.e. inundated area, damage rate and unit value) of selected elements-at-risk of agricultural sector as presented in Tables 5.2, 5.4 and 5.5, Eq. (1.1) can be now interpreted to calculate the specific risk of each flood scenario by Eq. 5.2 (Messner et al., 2007; Zhai and Ikeda, 2008, Merz et al, 2010):

$$\text{Damage}_\text{T} = \sum_{\text{i}=1}^{\text{n}}(\text{Inundated area}_\text{i} \times \text{Damage rate}_\text{i} \times \text{Unit rate}_\text{i}) \qquad (5.\ 2)$$

Where: T- return period (*T*=100, 50, 20 or 10 years); i – element-at-risk; n - total elements-at-risk (in this study, n = 12); Damage rates and Unit values are obtained from vulnerability analysis as explained above.

The result of specific risks is summarized in Table 5.6. Figure 5.2 presents the contributions of specific risk of the selected elements-at-risk showing that rice cultivation, the direct loss of products and business interruption can be ignored; its loss is mainly due to clean up and environmental remediation cost. However, for other crop cultivation and aquaculture, intangible indirect loss of business interruption is dominated.

Table 5.6 Calculation of specific risk of each element-at-risk (Mil.VND)

Element-at-risk	1-100yr flood	1-50yr flood	1-20yr flood	1-10yr flood
RI1	-	-	-	-
RI2	24,762	22,467	15,673	10,770
RI3	51,103	45,681	33,654	24,829
RI4	-	-	-	-
CR1	231,730	219,153	200,192	185,937
CR2	36,873	21,874	16,678	13,028
CR3	47,539	28,143	21,148	16,389
CR4	366,694	219,879	203,766	171,264
AQ1	9,450	9,450	9,450	7,250
AQ2	5,670	5,670	5,341	3,605
AQ3	7,350	7,350	7,315	5,695
AQ4	67,200	67,200	66,880	66,880

5.4.2 Flood risk curves and average annual risk of agriculture

For each flood scenario, the direct tangible damage and indirect and intangible damage are derived separately as sum of corresponding elements-at-risk and the total risk is then produced by summing up these components. In the next step, FDCs are developed by plotting the damage values against the return period as illustrated in Figure 5.9. The average annual risks, including direct tangible, indirect and intangible and total, are then calculated as the areas under the corresponding curves using Eq. (5.3) (Table 5.7). To do this, having considered that the risk for frequent events, e.g. with return period less than 50 years, is rather stable, this study assumes that FDCs continue horizontally from the point of 10-

year return period.

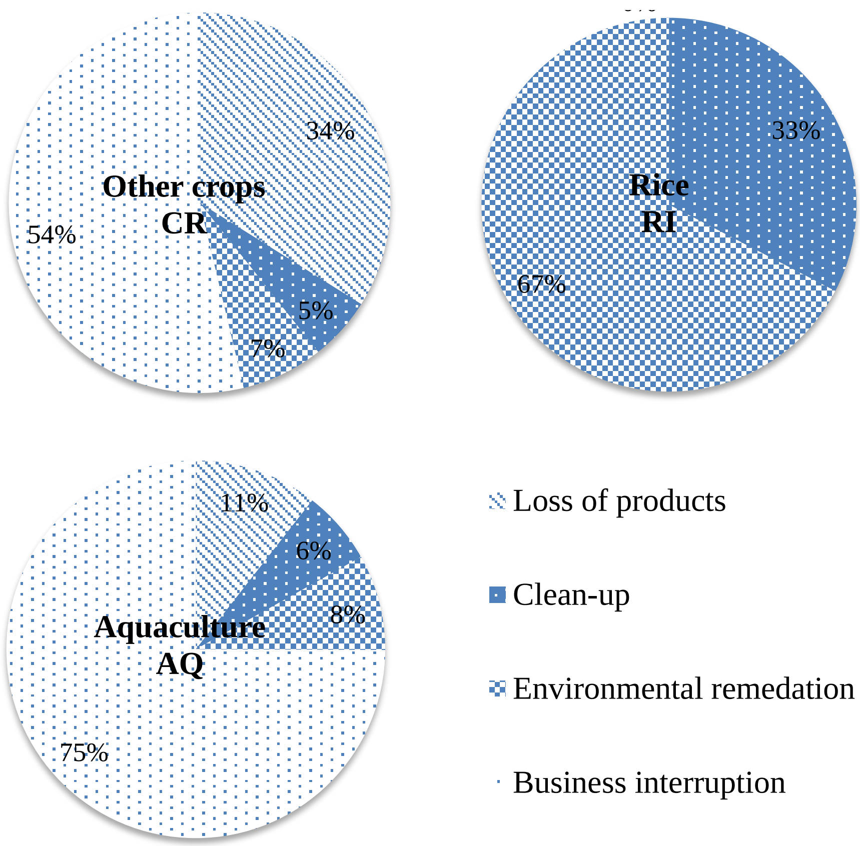


Table 5.7 Calculation of agricultural Average Annual Risk (AAR) (Mil VND)

	1-100yr flood	1-50yr flood	1-20yr flood	1-10yr flood	AAR
Direct tangible risk	241,180	228,603	209,642	193,187	**195,273**
Indirect & intangible risk	607,191	418,264	370,455	312,460	**321,317**
Total risk	843,371	646,867	580,097	505,647	**516,590**

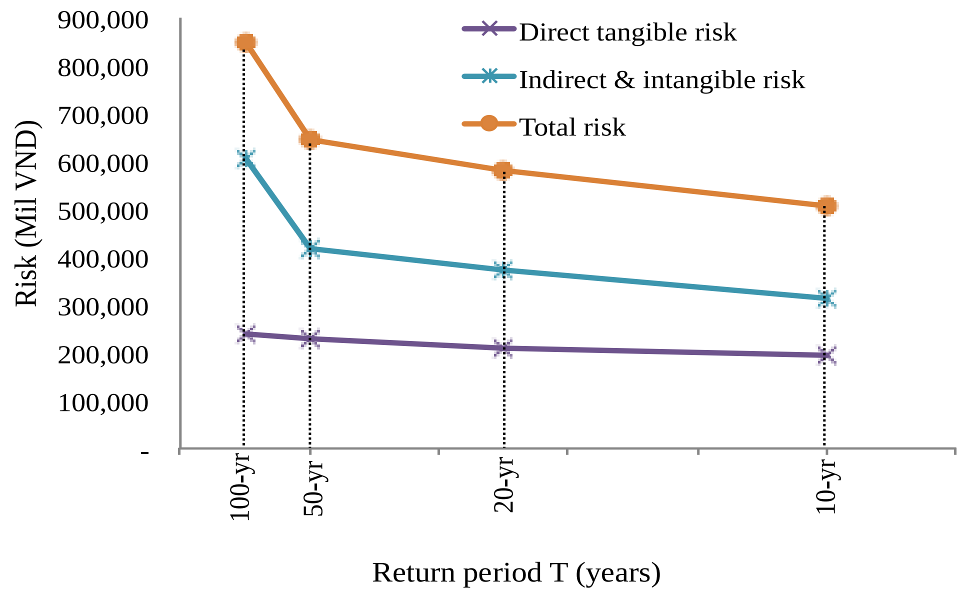


Figure 5.3 Flood Risk Curves of agriculture

5.5 Summary

In this study the estimation of annual flood risk for agricultural sector in VG-TB floodplain area of Dien Ban District, Central Vietnam is carried out consisting of three components: flood hazard simulation, vulnerability analysis for agricultural assets and then risk calculation by taking into account not only direct and tangible issues but also indirect and intangible ones. Several findings have been produced as follows:

- Although there is ongoing debate about the uncertainty and accuracy of CVM, the finding does show that this tool is very helpful collect indirect and intangible asset attributes of agriculture sector in rural floodplain area. As a result, more insight understanding about the total risk can be obtained that potential damage in fact would much higher than the direct damages evaluated after a flood event occurred.
- The flood hazard in this area is critical because due to topography like a rice bowl, the inundation is very deep and long. In case of extreme events (i.e. 100-year and 50-year return periods), about half of total area of 21,500 ha are inundated with water depth above 2.0 m.
- The local cultivation practice has been adapted to flooding season and thus,

most of rice and product is harvested and thus, the direct tangible damage only includes loss of other types of crops and aquaculture although the extension of these activities in the main rainy season is also reduced significantly.

- Regardless the deep inundated area is significantly reduced from rare to frequent events, the direct tangible risks are still quite similar. This factor can be misinterpreted by the local community about the risk as most of them believe that the flood loss may incur would be only about 2% of total agricultural production in the District.
- One of the key findings is the significance of direct intangible and indirect (tangible and intangible) risks, which are 1.5-2.5 times higher compared to direct tangible ones. These risks, including potentially losses of clean up and repair, environmental pollution and business interruption, increase substantially for the extreme flood events, i.e. the expected loss of the 100-yr event is almost double compared to 10-year event. In case of extreme flood events, e.g. 100-year return period, the loss of agricultural sector is expected to be very high, i.e. approximately 10% of its total annual production.
- To compare the result of this study (based on 2015 prices) with the actual reported losses to agricultural production in Dien Ban District, there are several constrains, including: (1) there has been no official criteria for natural disaster damage assessment in Vietnam; (2) the post disaster damage reports is far inaccurate; (3) no systematic database is available and thus, usually, only data and information on disaster damages during last two or three years can be available. Therefore, for validation, a post disaster report issued by local authority for the flood event in 2013 equivalent to event with 50-year return period is referred. In this report, the total losses to agriculture is VND250bil., including: corn and cassava, sweet potatoes: VND47bil; beans and chili: VND120bil, vegetables: VND73bil, no information about aquaculture damage.
- Every year, in the study area, the average risk of agricultural sectors due to seasonal flood is as high as VND516,590 mil, or equivalent to approximately US$22 mil, out of which, the annual intangible risk is highly significant as it accounts for approximately 62% mainly due to difficult recovery after several disaster occurred. This can be the reason for decrease of annual GDP rate for the year having damaging flooding as well as in the following years (Figure. 2.7)

To conclude, this Chapter is to derive the total risk of agricultural sector in a rural floodplain area and thereby, to highlight the significance of indirect and intangible damages compared to the tangible ones. To handle this task, an integrated approach was applied, in which apart from hydraulic modeling, spatial analysis and CVM through social survey was used to obtain intangible asset attributes. As the final result, the intangible, tangible and total risks were calculated and presented in the form of FRC and AAR which can be further used as relatively quantitative indicator to help the managers in policy development, e.g. disaster insurance initiative, and support local authority in preparing effective disaster management plans. Besides, the result of analysis of total risk for agricultural sector can be used as basis of cost-benefit analysis for structural investment where are lacks of sufficient financial availability. Particularly, the analysis of this Chapter reveals the applicability of CVM in developing policy non-structural measures to flooding in rural areas of the developing countries to enhance the adaptation and resilience of local community toward their long term well-being and sustainability

Chapter 6. Flood risk assessment for household properties

6.1 Introduction and identification of elements-at-risk

In practice, the damage to household properties in rural area is rarely counted sufficiently in the post disaster reports due to their uncertain and vague values (Bruun, 2013). Nevertheless, this damage is rather significant in all cases of flood disaster and thus should not deter the evaluation and subsequent implementation of flood risk management measures to mitigate the flood impacts on local community. Bearing this aim, Chapter 6 is dedicated to the working out an approach to evaluate the potential consequences of flood inundation on housing and household properties. As defined earlier about the scope of this research, the analysis will include not only direct tangible issues but highly importantly, the indirect and intangible ones. Penning-Rowsell et al. (2013) provided an overall summary of emerging issues the householders in flood affected area need to encounter (Table 6.1) which also emphasize the significance of indirect and intangible impacts induced by flooding and prolonged inundation.

Table 6.1 Overall flood impacts on household properties

Direct tangible losses for flooded households	Intangible losses for flooded households	Indirect losses for flooded households	Indirect losses for non-flooded households
Damage to building fabric	Worry about future flooding	Permanent evacuation from area	Increased travel costs
Damage to household inventory items	Loss of memorabilia and irreplaceable items and pets	Disruption to household due to flood damage	Loss of income/earnings
Cleanup cost	Damage to physical and/or mental health, death or injury	Temporary evacuation costs	Loss of utility services
	Loss of community	Disruption due to flood warning or alarms	Loss of other services
	Loss of confidence in authorities and services	Loss of utility services	Loss of leisure and recreational opportunities
		Loss of income/earnings	Increased cost of shopping and recreational opportunities
		Loss of leisure and recreational opportunities	
		Additional communication costs	
		Loss of services	
		Increased travel costs	
		Increased cost of shopping and recreational opportunities	

In Chapter 6, having considered practical conditions in the study area of Dien Ban district, the evaluation of flood consequences and risk of household properties is based on four elements at risk as following (Table 6.2).

Table 6.2 Identification of household properties elements-at-risk

Elements at risk	Type of damage				Code
	Direct		Indirect		
	Tangible	Intangible	Tangible	Intangible	
Damage to housing structure	x				HH1
Damage to content	x	x			HH2
Business interruption			x	x	HH3

Although flood disaster often causes significant consequences on local households, in practice, the complete evaluation of their damages remains a critical concern for flood risk management. This includes both direct damages and indirect losses, measured as tangible and intangibles impacts on the households. In this study, related to this category, as shown in Table 6.2, four two elements at risk are selected, which are:

- Physical damage to structure (HH1): this element is for tangible direct damages due to repair and/or replace cost of the doors, roof, plasterwork, garden after flooding. Damage to walls and floors can be considerable, expensive to repair and the structure may be uninhabitable while it is dried out and repair is undertaken. When serious structural damage occurs, partial or full collapse may occur, especially for simple and weak houses in rural areas
- Physical damage to content (HH2): This element includes both, direct tangible and intangible damages. The direct tangible damage can be damage of furniture, electrical appliances, vehicle, fabric items etc. partly or completely. Regarding to intangible damage, the flood every year lasting for a week or even longer results in severe consequences for households and local society, such as the loss of irreplaceable items (photographs, souvenirs, legal documents, books, notebooks and other school items, etc.).

- Business interruption, i.e. loss of earning from private business (HH3): during flood season, most cultivation is suspended and thus, the farmers often carry out private/seasonal business to earn their income, e.g. making handicraft and food processing products, part time service jobs, etc. Therefore, the interruption of such business due to flooding can cause their loss of this income.

An important element of physical damage is infrastructure. To answer the question whether it is worth to include road and railway in the risk assessment, the intensive literature review pointed out that the damage on road and railways very much depends on the types of flooding; they can be destroyed if high velocity and thus, it is worth being included in case of flash floods. FLOODSite (2007) emphasized that in case of plain flood areas, this kind of damage is more or less negligible.

In the study area, another major category of infrastructure is hydraulic structures, e.g. pumping stations, sluices and irrigation canals. It is very hard to derive accurate damage unit of these structures due to flooding and thus, their damage is considered as part of repair and recovery cost of agricultural production which was already discussed in Chapter 5.

6.2 Exposure analysis for household properties

Exposure analysis refers to the evaluation of which elements or assets would be affected by a certain flooding scenario and how much they are affected in terms of inundation depth or other flood characteristics. As presented in Figures 1.2 2.23, to analyze the exposure of the elements-at-risk of Household Properties identified above, following approach is used:

- Google Earth image analysis: in Chapter 4, while carrying out social safety exposure analysis, a GIS layer of the housing points was created and counted based on Google Earth image. Thereby, the exposure of houses to flooding is analyzed by superimposed this layer with inundation maps developed in Chapter 3 (Figure 4.2).

- Social survey to collect housing attibutes and based on that to classify type of houses: Having considered the characteristics learned from the survey and consultation with local officials, the houses in the study are can be divided into 03 classes with different level of flood vulnerability as following (also see Figure 6.1):

- Class 1: Temporary one story houses. About 15% and 5% of households in rural area and Vinh Dien town, respectively, still live in one storey simple houses which are made combinely from clay, straw and masonry. This type of houses is highly vulnerable to flooding as they can be damaged seriously. Their content can not be evacuated and thus also damaged significantly.

- Class 2: Masonry one storey houses. Out of all the houses surveyed, this type is most popular in Dien Ban rural area counting for about 50% while in Vinh Dien town this figure is about 35%. They are made from masonry with mezzanine and thus, they can stand small flood. Regarding the content, these households usually own some properties with higher values, such as furniture, motorbikes and electrical appliances. In case of low return period floods, these items can be seriously damaged as they can not be evacuated.

- Class 3: Masonry multi storey houses. Approximately 35% and 60% of households in rural area and Vinh Dien town are living in multi-storey houses newly built with good condition. As they are highly flood resistant, significant damage to

Figure 6.1 Typical types of housing in study area (upper: Class 1; middle: Class 2 and bottom: Class 3)

structure may not be occurred; part of valuable content, e.g. electrical appliances, etc., are evacuated to higher floor to avoid damages.

The numbers of each class of housing are then calculated for each inundation level of all 04 flood simulation scenarios (Table 6.3). To understand the level of exposure, Figure 6.2 illustrates the distribution (in percentages) of houses regarding to classes of inundation depth for urban area and rural area. It is realized that the exposure in Vinh Dien town is higher than in rural area. If comparing the 04 flood scenarios, one can see the sharp fall of exposure between 50-year and 20-year return periods, which is can be explained, similarly to the inundation map analysis in Chapter 3, by the influence of the "deep frying pan" topography in VGTB downstream (Figures 6.3 and 6.4).

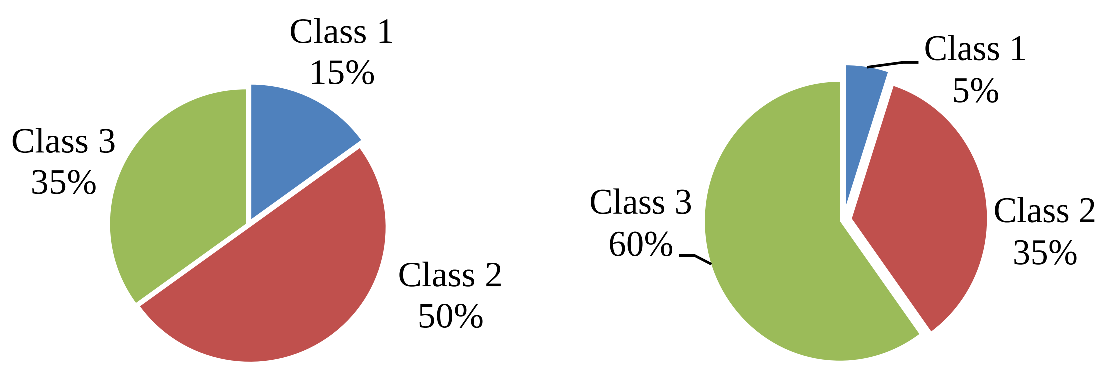


Figure 6.2 Housing classification in rural area (left) and in Vinh Dien town (right)

6.3 Vulnerability analysis for household properties

6.3.1 Housing attributes

As described earlier in Chapter 2, one of the objectives of the household survey was to collect empirical information on the attributes of housing in the study area for developing vulnerability analysis and thus, a broad range of housing types was investigated to focus in typical attributes as following:

Table 6.3 Analysis of housing exposure to flooding

Return period	Water depth	Vinh Dien Town: Total	Vinh Dien Town: Housing Class 1	Vinh Dien Town: Housing Class 2	Vinh Dien Town: Housing Class 3	Rural area: Total	Rural area: Housing Class 1	Rural area: Housing Class 2	Rural area: Housing Class 3
100-year	<0.5m	295	14	80	110	6,610	694	2,314	1,619
	0.5-1m	375	18	101	140	9,081	954	3,178	2,225
	1-2m	410	19	110	153	9,285	975	3,250	2,275
	2-3m	480	23	129	179	7,157	751	2,505	1,753
	>3m	275	13	74	102	3,262	343	1,142	799
50-year	<0.5m	491	23	132	183	7,574	795	2,651	1,856
	0.5-1m	405	19	109	151	8,788	923	3,076	2,153
	1-2m	388	18	105	144	7,164	752	2,507	1,755
	2-3m	295	14	80	110	4,309	452	1,508	1,056
	>3m	115	5	31	43	831	87	291	204
20-year	<0.5m	527	25	142	196	7,815	821	2,735	1,915
	0.5-1m	480	23	129	179	6,602	693	2,311	1,617
	1-2m	165	8	44	61	4,421	464	1,547	1,083
	2-3m	82	4	22	31	1,655	174	579	405
	>3m	0	0	0	0	45	5	16	11
10-year	<0.5m	432	21	116	161	6,561	689	2,296	1,607
	0.5-1m	328	16	88	122	4,194	440	1,468	1,028
	1-2m	180	9	49	67	2,203	231	771	540
	2-3m	0	0	0	0	278	29	97	68
	>3m	0	0	0	0	0	0	-	-

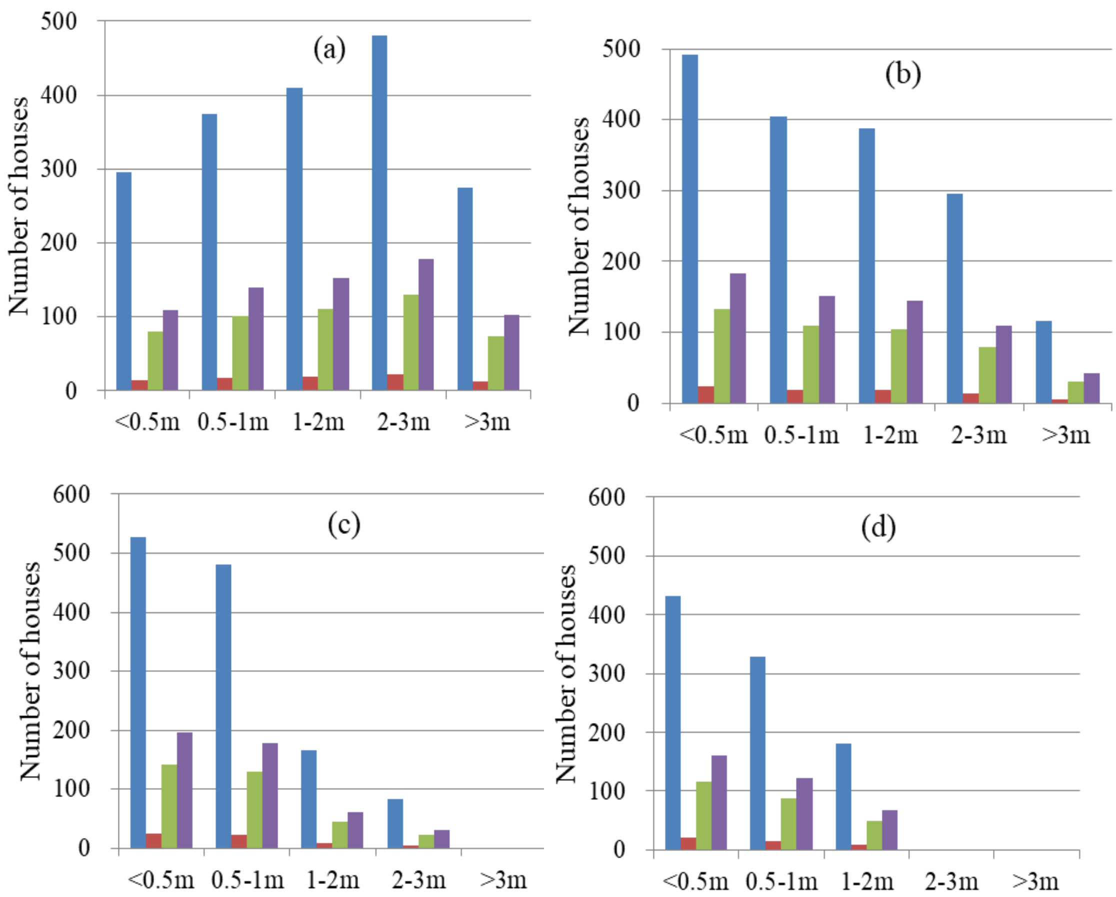


Figure 6.3 Number of houses exposed to certain water depth for selected return periods of 100-year (a), 50-year (b), 20-year (c) and 10-year (d) in Vinh Dien town

– Housing use: the use of the building will determine the number of people in the building in different periods of time and the value of the contents. Residential buildings, including those used partly for shop-retail or shop-servicing, were the most common building use, accounting for 90% and 70% in rural area and in Vinh Dien town, respectively. Therefore, due to limited resources, in this study, the use of buildings is homogenous.

– Housing materials (e.g. construction materials, structure etc.): This factor is highly important in determining the vulnerability (i.e.) damage rate caused by flooding, i.e. how much it can stand the inundation and flood speed. Out of almost 400 buildings surveyed, about ¾ have concrete or brick/stone supporting columns with external wall cladding comprised of similar material. Most of concrete frames observed were reinforced with steel although density of reinforcing was highly variable. Among the survey sample, wooden framed buildings were another type but much less common compared to concrete masonry ones. External walls were

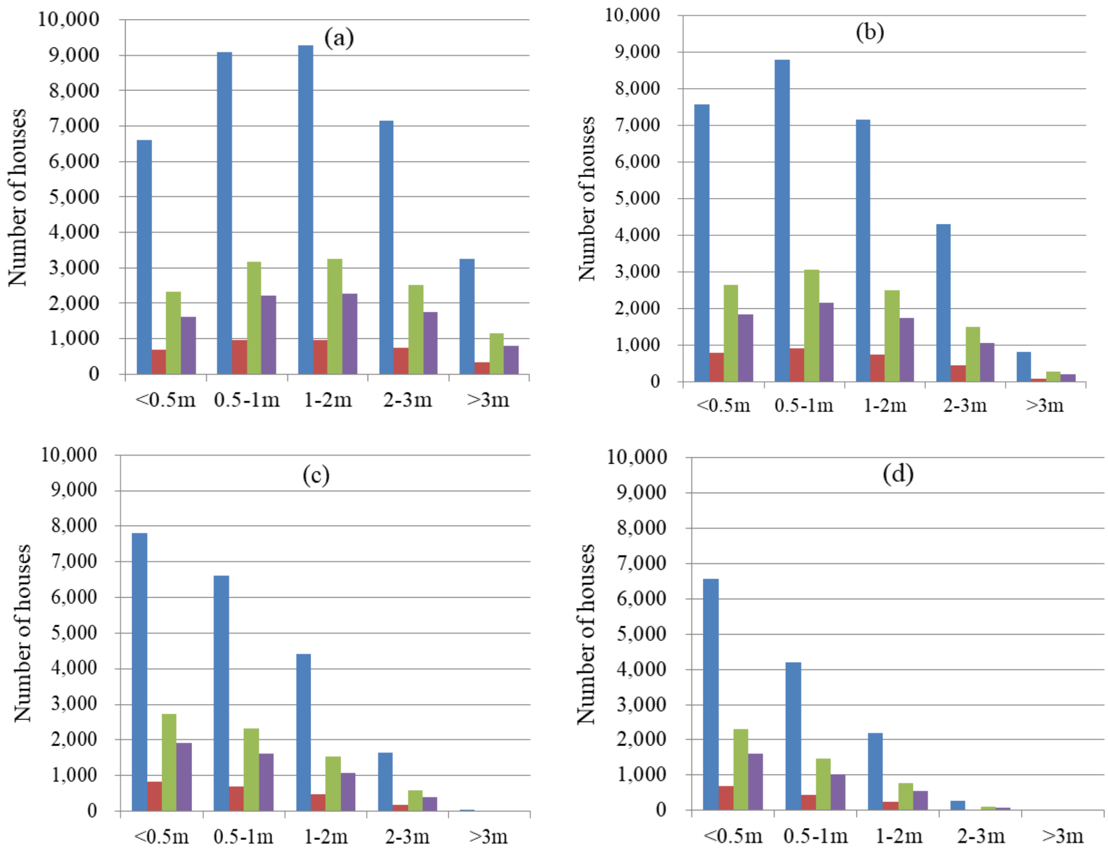


Figure 6.4 Number of houses exposed to certain water depth for selected return periods of 100-year (a), 50-year (b), 20-year (c) and 10-year (d) in rural area

cladded with either brick or stone masonry or wood, slabs or bamboo screen. Roofs are often cladded with tile (cement, terra cotta) or sheeting (fibrocement/metal) materials. A small number of buildings survey has roofs comprised of reinforced concrete slabs.

- Ground floor height: Such height can determine how high the house is inundated and if the building consists of more stories, the inhabitants will have distributed the content to higher floor, causing less damage when the lower floor is flooded. It also allows evacuation of people and valuable contents to higher floors. 'Concrete slab' ground floor was used for most of the building surveyed. A relatively small proportion of material used for ground floor was earthen. Having such ground floor material the floor height of most buildings is between 0.3-0.5m. Some of one floor houses are elevated higher than surrounding floor up to 1.0m in order to reduce vulnerability to flooding.

The survey was carried out intensively to investigate all these information about

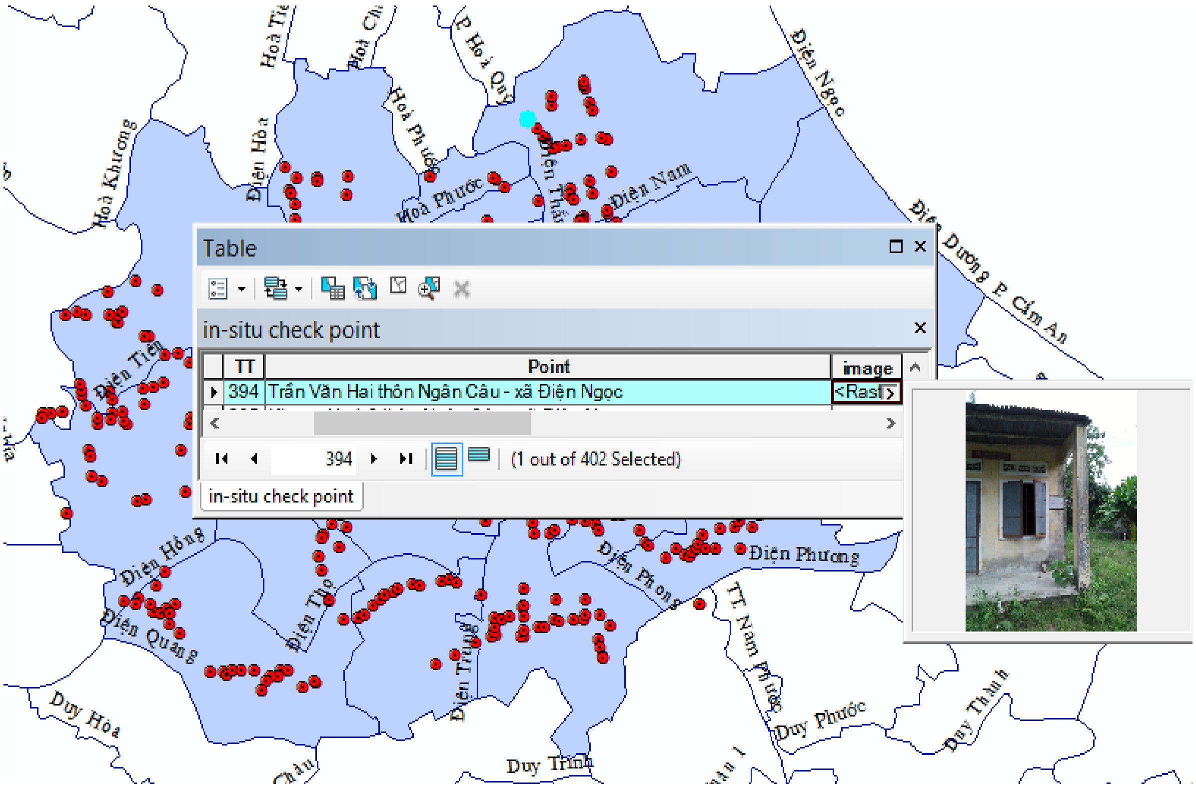


Figure 6.5 Distribution of sampling houses in social survey

these attributes of 400 houses, which were selected randomly over the entire study area as described in Chapter 2. Their locations are presented in Figure 6.5.

6.3.2 Stage damage functions of direct tangible vulnerability for household properties

As explain earlier in previous chapters, inundation depth is the key hazard parameter used in the analysis of damages and consequential risks. When flood occurs and a house is inundated, part (or entire) of its structure and content can be damaged. The significance of these damages totally depends on several factors, including: (1) the inundation level (i.e. water depth); (2) the vulnerability of the household, i.e. the value of content; the value of the house structure and (4) the housing attributes mentioned above. For example, if a household lives in a two or three story house, the valuable and moveable content can be evacuated to higher floors to reduce the losses and thus, reduce the vulnerability. The data and information on these damages in past disaster events are rather limited and bias and thus, the study attempted to derive the specific stage-damage functions based on synthetic data obtained from CVM through household survey (introduced earlier in Chapter 2).

In the questionnaire used in the survey, questions in Part 3 of the survey form directly address the physical damages of housing structure and content for different inundation water depths according to the flood hazard maps developed. To help local people get understood the technique and be oriented, in the survey questions, they are asked to evaluate the damage costs of individual items and components of their housing in terms of replacement or repair, including:

For physical damage to housing structure:

- Paths, paved areas and boundary fence: <0.5m: No significant damage; 0.5-1.0m: Some cracks on ground floor, displacement of fences; 1.0-2.0m: Significant damage to ground floor and fences; 2.0-3.0m and more: Serious damage to ground floor and fences
- Garden (e.g. fruit trees, vegetables, livestock): <0.5m: Some damages to vegetables; 0.5-1.0m: Most vegetables damaged due to waterlogging; other fruit trees with low water resistant ability also affected; 1.0-2.0m: Serious damages to vegetables perennial trees; significant cleanup work. Loss of livestock (chickens, ducks); 2.0-3.0m and more: Serious damages to vegetables and perennial trees; significant cleanup work. Loss of livestock (chickens, ducks, pigs, cows). Prolong inundation cause difficult recovery
- External structure: <0.5m: Minor cleanup required; 0.5-1.0m: Mortar, external wooden doors and architraves of 1st floor can be partly damaged; 1.0-2.0m: Mortar, external wooden doors and architraves of 1st floor are significantly damaged; 2.0-3.0m: Mortar, external wooden doors and architraves of 1st and 2nd floors are seriously damaged and >3.0m: Mortar, external wooden doors and architraves of entire houses/buildings are seriously damaged.
- Internal plasterwork and clean up: <0.5m: In most cases, it is not yet up to the 1st floor level, only minor cleanup required; 0.5-1.0m: The 1st floor starts to be inundated, cleanup and plasterwork repair are required; 1.0-2.0m: Plasterwork, internal doors and window, decoration of 1st floor are partly damaged; significant repair and clean up (mud, debris, contaminated water) are required;

2.0-3.0m: Plasterwork, internal doors and window, decoration of are damaged seriously in 1st floor and partly in 2nd floor; significant repair and clean up (mud, debris, contaminated water) are required and >3.0m: Plasterwork, internal doors and window, decoration of are seriously damaged in entire house; major repair and clean up (mud, debris, contaminated water) are required

For physical damage to household contents:

- Furniture: the level of damage to furniture depends on duration of inundation. Most of the furniture are moveable to higher floors (if there are) and thus, the damages would be significantly reduced for multistory houses.
- Vehicle: Most of households in the Study area own at least one motorbike. 15% of those living in Vinh Dien town has a car. When the inundation starts to rise, most of vehicle is moveable to higher ground. The damage can be occurred when the water level continues to raise and when it is >1.0m, damages are occurred.
- Electrical network and domestic appliances (refrigerator, rice cooker, pump etc.): Any electrical appliances in contact with water, no mater for how short a period is, immediately presents a health and safety hazard, especially the pumps, electrical plugs etc. Also, once in significant contact with water, they are very much likely to be written off.
- Pumping well: Most of households living in rural area use pumping wells to get clean water for daily use. When the flood occurs, the inundation starts to rise, one of the first impacts is that wells are out of work and contaminated right.
- Drink water tank: In urban Vinh Dien town, most of households use big tank to store drinking water from supply pipe network. The tank is not physically damaged but it can be contaminated. In case of serious inundation, it can be washed away causing dangers to people.
- Fabric items (clothes, blanket...) and other valuable goods: the extend of damages of these items increases with inundation depth and duration. The households living in multi storey houses can protect the valuable things in higher floors and thus, the loss is significantly mitigated.

During the survey and interviewing, using CVM, local people were asked to evaluate the damage of each item corresponding to certain inundation level based on their experience from past flooding events.

Table 6.4 shows the summary of the estimated ranges and mean values of these damage costs. Among all the items evaluated, the damage of external structure gets the widest range for group of class 1 housing due to the fact that some houses can totally collapse and the replacement cost is as high as rebuilding cost.

In the next step, stage – damage curves are constructed for two selected elements at risk of Household Properties, i.e. physical structure damage (HH1) and household content (HH2). The comparison of this result presented in Figure 6.6 with those developed in past studies by (Kok et al., 2005; Haskoning, 2009, NIWA, 2013) in Figure 6.7 shows the similar shape of the curves, i.e. the damage to household properties starts from inundation level of 0.5m and gradually increases until level of about 1.5m but after that, it substantially raises.

6.3.3 Stage damage functions for indirect and intangible cost of business interruption

The survey revealed that majority of residents aged from 20-50 involve in some business during flood season from June through November with the average rates of approximately 80% and 70% for Vinh Dien town and rural area, respectively. In Vinh Dien town, this figure is different for each class of housing, i.e 95%, 77% and 62% for class 1, 2 and 3, respectively. Regarding to the types of business, main activities that are popular in the study area include retailers, service providers, making handicraft and food product processing, gardening to grow bonsai/decoration trees. Figure 6.8 shows the distribution of all types of part time/seasonal earnings of local residents.

Table 6.4 Summary of the estimated household property damage costs

#	Damaged items	<0.5m		0.5-1.0m		1.0-2.0m		2.0-3.0m		>3.0m	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Housing class 1										
1.1	Physical damage to housing structure										
	Paths and paved areas, boundary fence	0	0	0.22	0-0.5	0.3	0-0.5	0.5	0.3-0.6	0.55	0.5-0.8
	Gardens	0.22	0.2-0.3	0.5	0.3-0.8	1.05	0.5-1.3	5.4	4.0-6.0	5.4	4.0-6.0
	External structure	0	0	0.57	0.0-0.7	1.2	1.0-1.5	1.45	1.0-2.0	1.45	1.0-2.0
	Internal plasterwork and clean up	0	0	0.57	0.3-0.7	1.2	1.0-1.5	1.45	1.0-2.0	1.45	1.0-2.0
1.2	Physical damage to household contents										
	Furniture	0	0	0.27	0-0.5	0.53	0.5-0.7	0.62	0.5-1.0	0.67	0.5-1.0
	Vehicle	0	0	0.31	0-1.0	1.42	0-2.0	1.65	0-2.0	1.65	0-2.0
	Electrical network and domestic appliances (refrigerator, rice cooker, pump etc.)	0.25	0-0.5	0.85	0.5-1.0	2.32	2.0-3.0	2.32	2.0-3.0	2.32	2.0-3.0
	Pumping well	0.25	0-0.5	0.41	0-1.0	0.41	0-1.0	0.41	0-1.0	0.41	0-1.0
	Drink water tank	0	0	0	0	0.72	0-1.0	2.55	0-3.0	2.55	0-3.0
	Fabric items	0	0	0.22	0-1.0	0.61	0-1.0	0.61	0-1.0	0.61	0-1.0
2	Housing class 2										
2.1	Physical damage to housing structure										
	Paths and paved areas, boundary fence	0	0	0.35	0-0.5	0.35	0-0.5	0.7	0.5-0.8	0.7	0.5-0.9
	Gardens	0.25	0.2-0.5	0.72	0.5-1.0	2.2	1.5-2.5	15.2	10.0-18.0	15.2	10.0-18.0
	External structure	0	0	1.56	1.0-2.0	2.53	2.0-3.0	3.77	3.0-4.0	3.77	3.0-4.0
	Internal plasterwork and clean up	0	0	1.56	1.0-2.0	2.53	2.0-3.0	3.77	3.0-5.0	3.77	3.0-5.0
2.2	Physical damage to household contents										
	Furniture	0	0	0.41	0-0.7	0.65	0.5-1.0	0.97	0.5-2.0	0.97	0.5-2.0
	Vehicle	0	0	0.35	0-1.0	2.84	1.0-3.0	3.3	2.0-5.0	3.3	2.0-7.0
	Electrical network and domestic appliances (refrigerator, rice cooker, pump etc.)	0.2	0-0.5	1.55	1.0-2.0	3.05	2.0-4.0	3.05	2.0-4.0	3.05	2.0-4.0
	Pumping well	0.4	0-0.5	0.88	0.5-1.0	0.88	0.5-1.0	0.88	0.5-1.0	0.88	0.5-1.0
	Drink water tank	0	0	0	0	0.35	0-1.0	2.74	1.0-3.0	2.74	1.0-3.0
	Fabric items	0	0	0	0	1.35	1.0-2.0	1.35	1.0-2.0	1.35	1.0-2.0
3	Housing class 3										
3.1	Physical damage to housing structure										
	Paths and paved areas, boundary fence	0	0	0.35	0-0.5	0.37	0-0.5	0.7	0.5-0.8	0.7	0.5-0.9
	Gardens	0.25	0.2-0.5	0.75	0.5-1.0	2.2	1.5-2.5	15.5	10.0-18.0	15.5	10.0-18.0
	External structure	0	0	2.05	2.5-3.0	2.9	2.5-3.0	5.5	4.0-6.0	5.5	5.0-6.0
	Internal plasterwork and clean up	0	0	2.05	1.5-2.5	2.9	2.5-3.5	5	4.0-7.0	5.5	4.0-7.0
3.2	Physical damage to household contents										
	Furniture	0	0	0.3	0-0.7	0.55	0.5-1.0	1.75	1.0-3.0	2.12	
	Vehicle	0	0	0.45	0-1.0	4.55	1.0-5.0	7.2	2.0-	8.5	2.0-

								10.0		10.0
Electrical network and domestic appliances (refrigerator, rice cooker, pump etc.)	0.2	0-0.5	1.02	1.0-2.0	3.46	2.0-4.0	4.05	3.0-5.0	4.55	3.0-5.0
Pumping well	0.4	0-0.5	0.88	0.5-1.0	0.88	0.5-1.0	0.88	0.5-1.0	0.88	0.5-1.0
Drink water tank	0	0	0	0	0.2	0-0.5	2.05	1.0-3.0	2.75	1.0-3.0
Fabric items	0	0	0	0	0.7	0-2.0	2.05	2.0-3.0	2.73	2.0-3.0

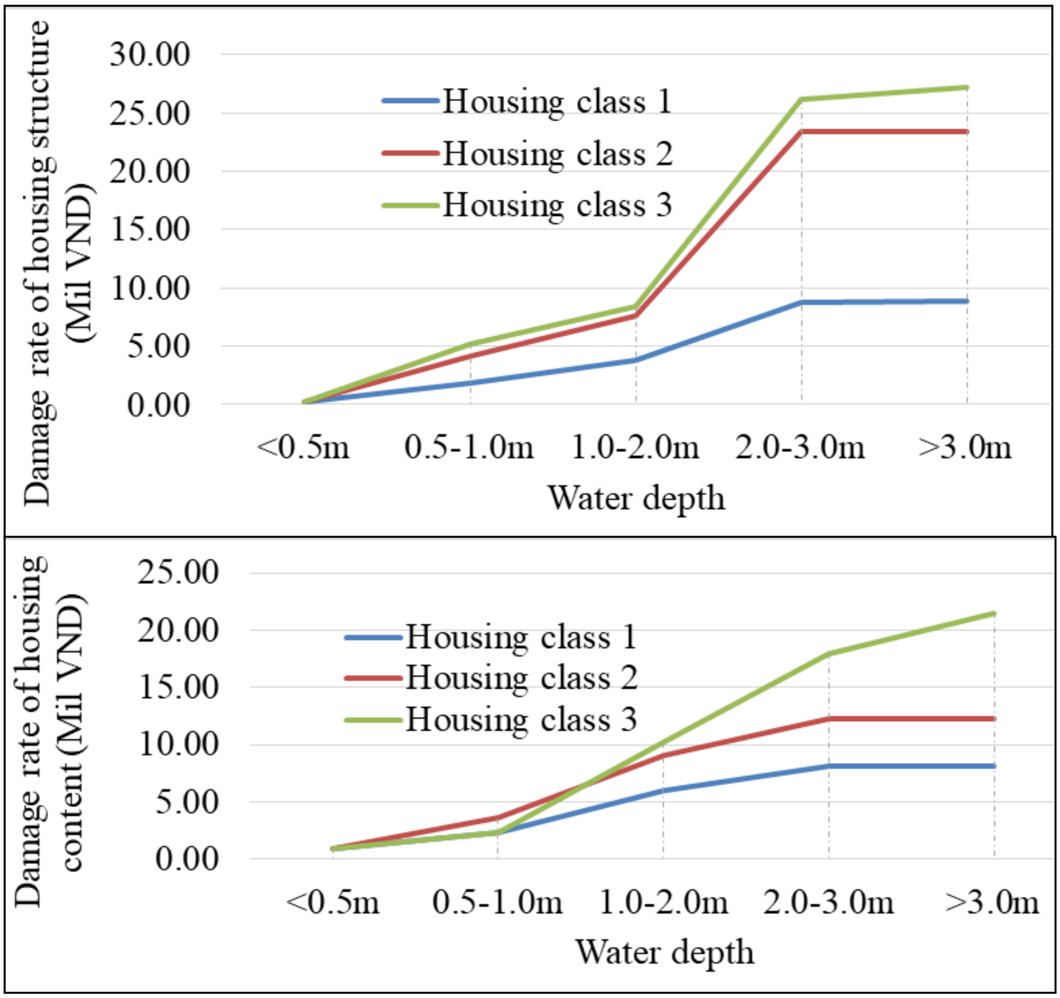


Figure 6.6 Stage-damage functions for household properties

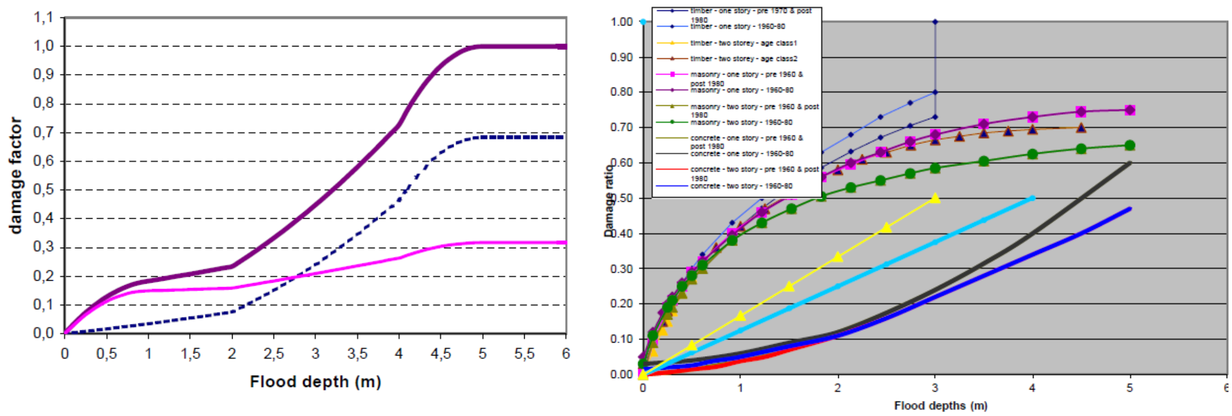


Figure 6.7 Examples of stage-damage functions from other studies

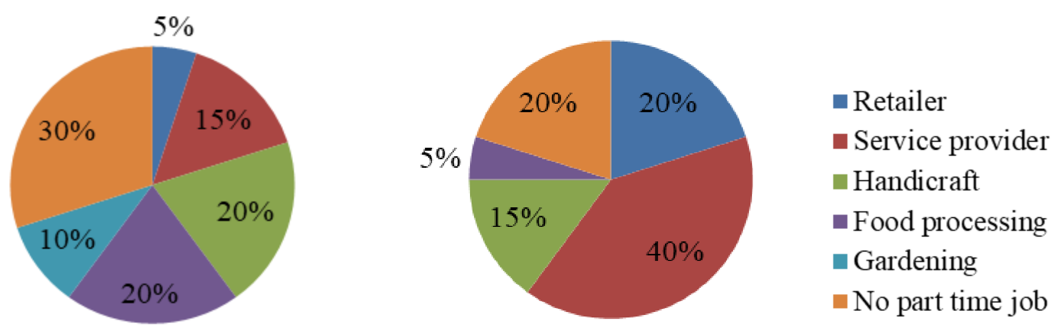


Figure 6.8 Percentages of households involved in extra business

The damage cost caused by business interruption is dependent on two vulnerable factors, such as duration of inundation and profit (or value) of certain business activities. The vulnerability of these factors is analyzed as following:

- Interruption duration: On the other hand, the survey also explored the duration of business interruption due to flooding. Local residents in Vinh Dien informed that their business is interrupted one or two more days after flood recedes. In the rural area, it takes longer for the farmers to resume their business. Table 6.5 presents the mean value of interruption days depending on the significance of inundation situation.

Table 6.5 Estimation of business interruption caused by flooding

Location	Interruption duration (days)				
	<0.5m	0.5-1.0m	1.0-2.0m	2.0-3.0m	>3m
Vinh Dien towm	2	3	4	5	6
Rural area	3	4	7	10	10

- Unit value: Similar to indirect and intangible values of agriculture in Chapter 5, the unit values of business interruption also obtained by CVM methods, in which the local residents were asked how much in average their household earn per day from additional business. In Table 6.6 the findings from the survey for damage costs due to business interruption is summarized showing that the ranges of these additional income increases from Class 1 through Class 3. This can be explain that the households with good income (i.e. owning good housing) can be either do not have any part time business activities or those with relatively high profit.

Table 6.6 Average income per day from part time business

Location	Class 1		Class 2		Class 2	
	Mean	Range	Mean	Range	Mean	Range
Vinh Dien town	250	100-300	360	200-400	580	300-700
Rural area	150	100-200	250	100-300	300	200-500

6.4 Risk analysis for household properties

6.4.1 Specific risks for household properties

The calculation and analysis of specific risks for Household Properties is carried out based on Eq. 1.2 and very much similar to the approach for agriculture, i.e. the specific risk of household properties is the function of hazard (inundation level), exposure (number of affected houses for each inundation level) and vulnerability (damage rate of various housing class at each inundation level) as presented below in Eq. 6.1.

$$\mathrm{Damage_T} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \sum_{j=1}^{m} \quad (\text{Number of affected households}_{ij} \times \text{Damage rate}_{\mathrm{ij}}) \tag{6. 1}$$

Where: T- return period (*T*=100, 50, 20 or 10 years); i – element-at-risk; n - total elements-at-risk (in this case, n = 3); j – sub element-at-risk (i.e. housing class), m - total sub elements-at-risk (in this part, m = 3). Damage rates are obtained from vulnerability analysis as explained above. The values of those variables are obtained from Figures 6.6 and Tables 6.5 and 6.6 to substitute into Eq. 6.1 The result of specific risks calculated for each element at risk of Household Properties category is presented in Table 6.7

6.4.2 Flood risk curves and average annual risk for household properties

Development of flood risk curves FRCs for each elements at risk of Household Properties is carried out by plotting the damages (in monetary values) against corresponding return periods (as described in Chapter 1 and used in Chapter 4 and 5). Figure 6.9 presents FRCs for selected three elements at risk for Household Properties category namely Household structure (HH1), Household content (HH2) and Business interruption (HH3)

In the following step, Average Annual Risk (AAR) is calculated by using Eq 1.2 as a single index of expected damage per year that can be helpful to prepare the disaster management in the local area in the long term.

$$\mathrm{AAR} = \sum_{i=1}^{n} \frac{1}{2}\left(\frac{1}{T_i} - \frac{1}{T_{i-1}}\right)(\mathrm{Risk}_{\,i} + \mathrm{Risk}_{i+1}) \qquad (1.2)$$

Where n is chosen so that all the relevant return periods are covered from negligible cost of quite frequent events to very rare events. However, as explained earlier, this study selected 04 flood scenarios (i.e. n=4) to be sufficient to develop FRC. The result of this calculation is shown in Table 6.8. Also, Figure 6.10 is to compare the significance of AAR of three elements at risk

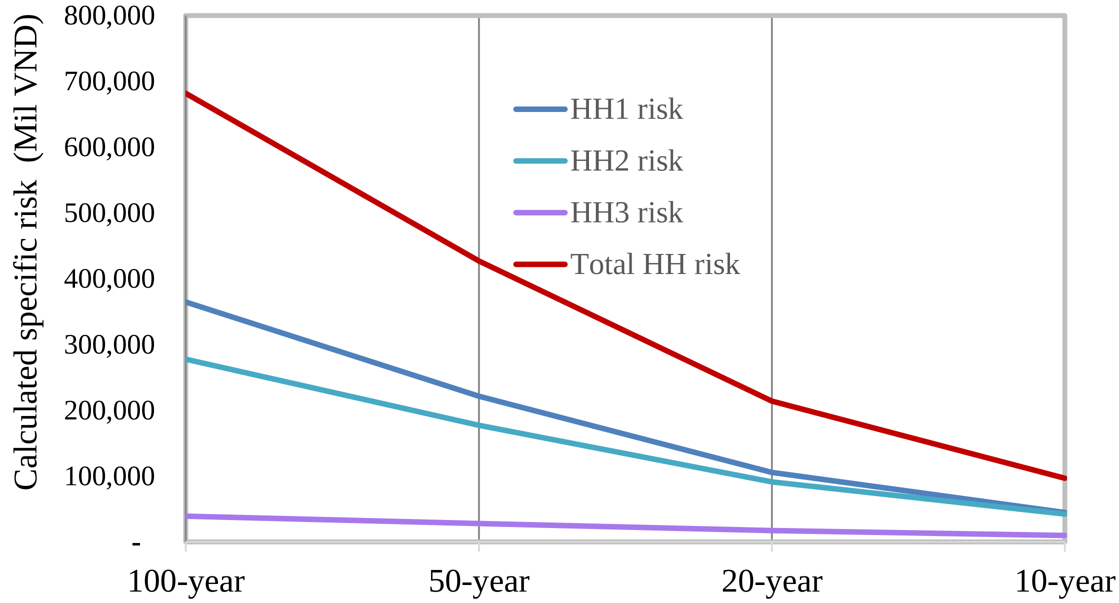


Figure 6.9 Flood risk curves for household properties

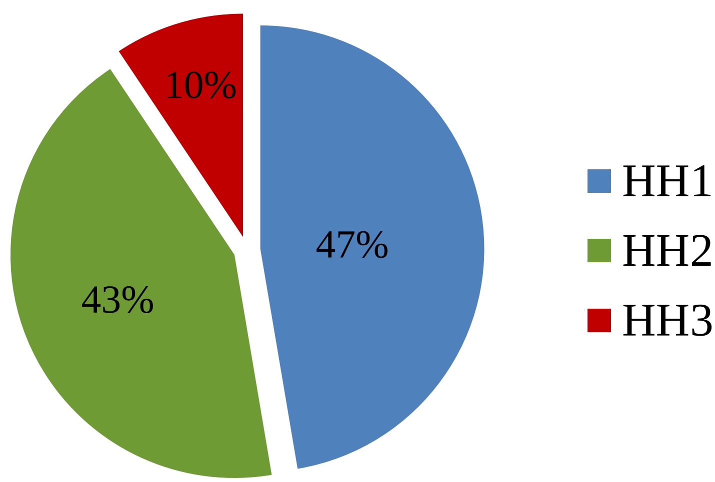


Figure 6.10 Contribution of each element-at-risks in AAR

6.5 Summary

In the Chapter 6, the estimation of annual flood risk for Household Properties of the community living in VG-TB floodplain area of Dien Ban District, Central Vietnam is based on three components similar to Chapter 5, including flood hazard simulation, exposure and household vulnerability analysis. In particular, risk is calculated by taking into account not only direct and tangible issues but also indirect and intangible ones. Several findings have been produced as follows:

- In order to obtain deep understanding of the potential damage that the local community would need to expose with in the future, the risk analysis of household property takes into account three elements-at-risk, which are classified as direct tangible (i.e. structure damage-HH1), direct tangible and intangible (i.e. content damage-HH2) and indirect tangible and intangible (business interruption).
- There is very much limited and unstandardized data and information on damages of past flood events related to household properties and thus CVM is again considered as an effective tool to collect attributes under this category.
- Having considered the main housing characteristics that can increase or reduce the vulnerability in case of flooding and thus, consequences are building material and number of stories, the housing in the study area are then divided into three classes, namely Class 1 – Temporary one-storey houses; Class 2 – Masonry one-storey houses and Class 3 – Masonry multi-storey houses. In Vinh Dien town, the majority is houses of Class 3 (60%) while in rural area this type of houses is only 35%. The housing Class 1 is 5% in Vinh Dien town and 15% in rural area. The rest is housing of Class 2, i.e. 35% and 50% for Vinh Dien town and rural area, respectively.
- The exposure analysis shows that large numbers of houses are deeply inundated (>1m) in case of 100-year flood event occurred, i.e. 57% in Vinh Dien town and 41% in rural area. For 50 year return period, these figures reduce to be 39% and 26%, which still potentially expose to significant consequences.
- The social survey was carried out using CVM method to collect primary information on flood damages of different housing. The questionnaire was developed in the way to help the householders, based on their experiences of past disaster events and current market prices, to judge and estimate approximately the costs they would need to pay for repair or replacement of damaged structural and content items once their houses are inundated to certain level. For example, "Which damage would you expect if inundation depth was up to 2m above the first floor". The collected information are then analyzed separately for Vinh Dien town and rural area.
- The result obtained from analysis of tangible vulnerability consists of two sets of stage damage curves developed for elements at risk HH1 (Household Structure) and HH2 (Household Content). Regarding to HH1 stage-damage

curves, for housing class 1, the damage rate gradually increases along with water level rising. For housing class 2 and 3, these curves make the high rise as soon as the water level gets up to 1m until 3m and after that remain more or less stable. Regarding the absolute values, for both HH1 and HH2, the damage rates are quite the same for all housing classes if inundation is less 1m but then they rise proportionally with the quality (or value) of the houses.

- Intangible vulnerability was analyzed based on element at risk of business interruption (HH3). Also by using CVM method, information on type of works, interruption duration and average income was collected and then synthesized separately. The result shows that majority, i.e. 70% ~ 80%, of households living in the study area engage in at least one type of work, excluding farming, that can be affected and interrupted by flooding situation with an average duration is 2~6days in Vinh Dien town and 3~10days in rural area due to the fact that in rural area, flooding often causes more damages to rural roads. The ranges of daily incomes are rather wide and much higher in Vinh Dien town compared to rural area.
- The specific risks were calculated for each element at risk showing that once the housing get inundated, its structure would expose to highest damage costs, closely followed by the those for content. Moreover, the potential direct damages of housing increase exponentially along with the raise of inundation depth.
- The intangible damage due to business interruption is much less than the direct damage cost. However, this should not be interpreted as insignificant consequence because the evaluation was not based on the same so called market price, i.e. the direct damage cost is based on "*what the householders have to pay/buy*" while the indirect one is "*what the householders earn*".
- Annual Average Risk (AAR) was calculated to show the contributions of three selected elements at risk HH1, HH2 and HH3 to the household property damage caused by flooding, say 47%, 43% and 10%, respectively. This figure can be considered as quantitative indicator in long term flood management in the local area.

Table 6.7 Specific risk calculation for Household Properties (in Mil VND)

Return period	Elements-at-risk	Calculated risk		
		Vinh Dien town	Rural area	Entire district
100-year	Household structure (HH1)			
	Housing class 1	448	21752	
	Housing class 2	7,851	177,083	
	Housing class 3	15,451	142,243	
	Specific risk for HH1	**23,750**	**341,078**	**364,828**
	Household content (HH2)			
	Housing class 1	478	24,450	
	Housing class 2	5,037	122,832	
	Housing class 3	11,977	113,033	
	Specific risk for HH2	**17,492**	**260,315**	**277,807**
	Business interruption (HH3)			
	Housing class 1	88	557	
	Housing class 2	718	19717	
	Housing class 3	1,598	16562	
	Specific risk for HH3	**2,404**	**36,837**	**39,241**
	Total			**681,876**
50-year	Household structure (HH1)			
	Housing class 1	297	13523	
	Housing class 2	5,028	106,755	
	Housing class 3	9,888	85,823	
	Specific risk for HH1	**15,213**	**206,101**	**221,314**
	Household content (HH2)			
	Housing class 1	338	16,039	
	Housing class 2	3,557	80,542	
	Housing class 3	7,896	69,046	
	Specific risk for HH2	**11,791**	**165,627**	**177,418**
	Business interruption (HH3)			
	Housing class 1	70	451	
	Housing class 2	574	13949	
	Housing class 3	1,276	11718	
	Specific risk for HH3	**1,920**	**26,118**	**28,038**
	Total			**426,770**
20-year	Household structure (HH1)			
	Housing class 1	117	6831	
	Housing class 2	1,861	51,520	
	Housing class 3	3,719	41,545	
	Specific risk for HH1	**5,697**	**99,896**	**105,593**
	Household content (HH2)			
	Housing class 1	146	8,693	

Return period	Elements-at-risk	Calculated risk		
		Vinh Dien town	Rural area	Entire district
	Housing class 2	1,526	43,481	
	Housing class 3	2,861	34,518	
	Specific risk for HH2	**4,533**	**86,692**	**91,225**
	Business interruption (HH3)			
	Housing class 1	42	323	
	Housing class 2	346	8,558	
	Housing class 3	769	7,188	
	Specific risk for HH3	**1,157**	**16,069**	**17,226**
	Total			**214,044**
10-year	Household structure (HH1)			
	Housing class 1	69	2993	
	Housing class 2	998	21,242	
	Housing class 3	1,992	17,259	
	Specific risk for HH1	**3,059**	**41,494**	**44,553**
	Household content (HH2)			
	Housing class 1	99	4,114	
	Housing class 2	1,031	20,412	
	Housing class 3	1,794	14,990	
	Specific risk for HH3	**2,924**	**39,516**	**42,440**
	Business interruption (HH3)			
	Housing class 1	30	208	
	Housing class 2	249	4783	
	Housing class 3	554	4018	
	Specific risk for HH3	**834**	**9,009**	**9,842**
	Total			**96,835**

Table 6.8 Result of Calculated Average Annual Risk AAR (in Mil VND)

Element at risks	100-year	50-year	20-year	10-year	AAR	%
HH1	364,828	221,314	105,593	44,553	55,334	47%
HH2	277,807	177,418	91,225	42,440	50,621	43%
HH3	39,241	28,038	17,226	9,842	10,943	10%
Total	681,876	426,770	214,044	96,835	116,898	

Chapter 7. Strengthening flood risk management in study area

7.1 Introduction

In the previous chapters, the study has carried out steps to derive quantitative risk in terms of specific risk of various flood scenarios and average annual risk (AAR). But once these results are generated, the question is: what for? How to use, to share among stakeholders this information? Which risk level is acceptable and What are the various risk reduction options? How much will they actually reduce the risk? As the risk is the function of hazard, exposure and vulnerability, to reduce the risk (i.e. potential damage and losses), we can reduce each or all these components (Figure 7.1). As a result, in general one single measure can be sufficient to control and mitigate but a combination of measures from structural engineering works to policies and self-adaptive capacities, from national level down to community/household levels etc., is vital. Although the scope of this study is carrying out flood risk assessment in a rural area with focus in intangible vulnerability, in order to complete the overall picture, Chapter 7 attempts to discuss briefly these questions and propose recommendation for the selected study area to reduce potential losses caused by future disaster events. In this Chapter, first part is to overview flood risk management in study area which is likely existing elsewhere in rural area of Vietnam. Then, based on practical condition and risk analysis result, several potential countermeasures, including structural and non-structural, will be recommended.

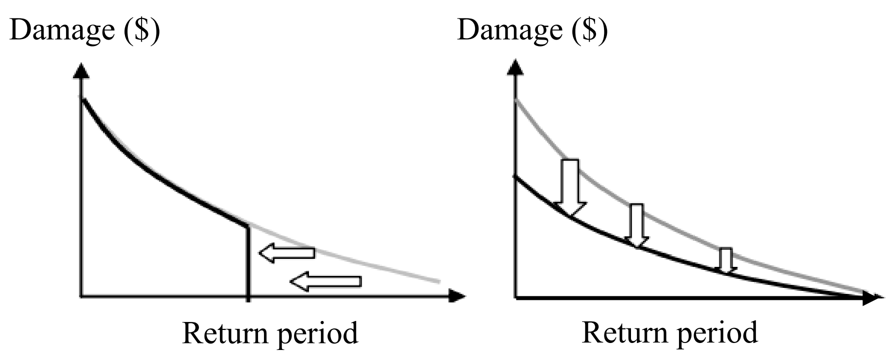


Figure 7.1 Measures to reduce flood risk

7.2 Overview of flood risk management practice in study area

7.2.1 Viet Nam disaster risk management framework

- Viet Nam enacted new legislation for Disaster Risk Management: the *Law on Natural Disaster Prevention and Control* (Law No. 33/2013/QH13). This legislation covers all natural hazards and provides a comprehensive framework for DRM planning. Until the passage of this legislation, meteorological and geophysical hazards were treated under separate ordinances and over 100 ordinances were relevant to DRM planning (Red Cross, 2014). The flood hazard management structure of Committees for Storm and Flood Control (CSFCs) at national, provincial, district and commune level was established prior to the legislation and continue under this legislation. The 2013 legislation includes provisions on early warning systems, risk mapping and community based disaster risk management (as well as elements of building codes and land use planning), providing a comprehensive framework for undertaking DRM activities and planning at all levels, including community based disaster risk management (CBDRM). For the safe operation of dams the relevant legislation is Decree No. 72/2007/ND-CP on Dam Safety Management (2007) and for the safety of large dams guidelines have been developed; the VNCOLD (2012) Dam Safety Manual.

- Disaster Risk Management Strategies and Plans: In Viet Nam, the document for guiding disaster risk management activities is the Strategy for National Disaster Prevention, Response and Mitigation to 2020 (CCFSC, 2009). The objectives of the strategy included moving away from the traditionally response-focused model to:
    - integrating risk management in national and provincial socio-economic development and management plans
    - establishing sustainable disaster recovery that integrates risk reduction
    - developing a regional disaster risk management strategy for each of Vietnam’s five regions
    - adopting combined structural and non-structural risk reduction measures, and
    - rationally allocating risk reduction responsibilities and targets across a defined set of ministries and departments

- Roles and responsibilities

The legislation and strategy identifies the cross-department Committee for Flood and Storm Control (CFSC) as the lead agency for managing flood preparedness and response at the provincial level. The Central Committee for Flood and Storm Control (CCFSC) is the National level standing committee made up of representatives from a wider number of government agencies (Figure 7.2) (CCFSC, 2009). The Central Committee for Flood and Storm Control provides a coordinating, multi-agency committee to develop plans, provide logistics training and support to the provinces. The organizational framework for the CCFSC is as follows:

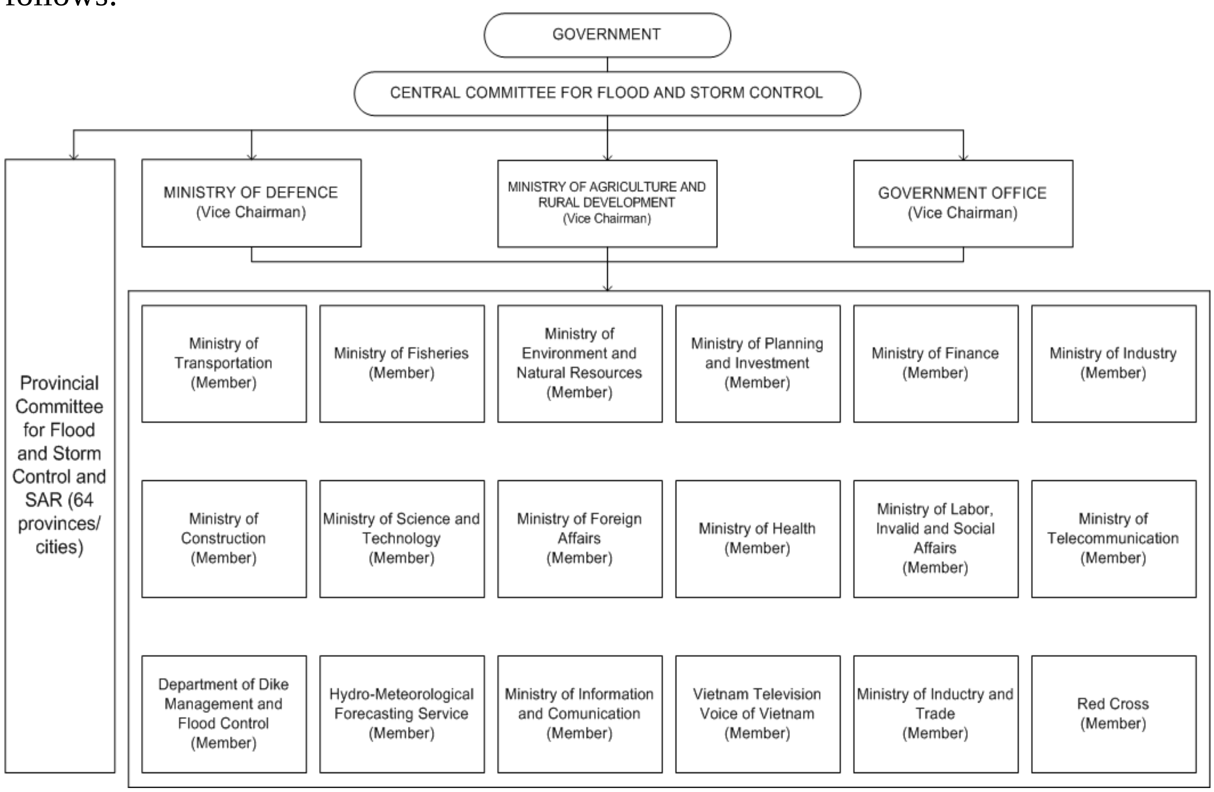


Figure 7.2 Organisational chart for the Central Committee for Flood and Storm Control

At the provincial level the CSFC is primarily comprised of representatives from the Department of Agriculture and rural Development (engineering, finance, irrigation etc.,) and local dam operators. The roles of the CCFSC and CFSC member organizations are to plan and implement flood management and DRM arrangements according to the 2013 legislation (Law No. 33/2013/QH13) and the national strategy (CCFSC, 2009).

7.2.2 Constrains of existing flood disaster management in rural area

- Inadequate hydraulic infrastructure to control the flood hazard: Most of river embankment system has been degraded and eroded and not sufficient to protect even early (small) flood that can occur before crop harvesting season causing serious impacts on agriculture. The river bed and canals are often silted up and blocked by plants and rubbish and thus, the drainage capacity is reduced resulting in larger and deeper inundation over the agricultural land and residential area.
- Ineffective communication, early warning and evacuation plan:

The following communication pathways are used for flood information exchange at commune level:

  - In the villages where houses are scattered from each other, public alerting by loudspeakers is popular way to convey the information on coming flood event. The loudspeakers have very wide coverage and good audibility in commercial and residential areas even along rural roads where houses are present. They are not always audible to agricultural workers as their effectiveness declines with distance. The loudspeakers are manually activated and warning messages read by a commune leader or delegated person. Provincial and commune level officials and dam operators reported that dam spillway releases should be notified at least 24 hours in advance to provincial officials at the CSFC so communes may be informed by letter and telephone, and have adequate time to activate the local loudspeaker warning system.
  - Door-to-door alerting by commune volunteers (on foot or travelling by scooter/ motorbike) is also undertaken in some communes.
  - Television and radio do provide warnings for large storm events. However, the information is very general as it comes from the National Center of Hydro-Meterological Forecast, which develops warnings and flood predictions at the provincial level. These warnings are not necessarily a

good indicator of how heavy rainfall will be managed in reservoirs by dam operators.

However, the flood emergency message from these communication pathways often does not provide sufficient time for evacuation. Moreover, most of the local road in poor condition are inundated or even damaged due to flooding and thus, cannot be used for evacuation, especially for disable people.

The preparation for evacuation center is done mainly based on the experience of local official rather than based on full understanding about the flood risk to people and economics.

- Lack of database on past flood events in the study area

When seeking information on the damages of the flood event in the past, it is very hard to collect full set of post disaster damages reports. Moreover, in country there has been not yet a guideline on this issue so that the local authority again carries out this task based on their experience. The information provided was summarized at the province and district level and was not collected by the government agencies with a focus on our study area, but as part of administrative reporting for larger areas. It was therefore difficult to isolate information specific to the study area for particular analysis.

Evacuation maps for flood hazard are currently not used at province, district or commune level. The communities and government officials in typically flood prone areas have knowledge from past flood events of areas at risk, and use their local understanding during response. Interviews with commune and district leaders, and local citizens indicated it was not very convenient assessable to the shelter areas or higher ground during most flood events, especially those combined with strong typhoons. Moving possessions and family members upstairs during flood events is also common practice where a mezzanine or second storey is available for vertical evacuation. Commune leaders informed us that army personnel could be requested at the commune level or the province level to assist with evacuation. Volunteer organizations within communes such as the Youth

Union provide assistance with evacuation (and rescue) support. Specific plans for those with disabilities are often available but unlikely updated annually.

- Poverty and lack of awareness

As described earlier in Chapter 2, the study area is n Quang Nam province, which is ranked from middle-to-poor provinces in Vietnam. Low income, limited education and public health care are the factors to accelerate the vulnerability or reduce their coping capacities. At district level, during survey, the local authority also share that they have very limited budget to either train their officials and volunteer disaster response team as well as or conduct evacuation drills.

7.3 Recommendations to improving flood risk management in study area

The gap in flood disaster management identified above in the study area, as well as elsewhere in the country, can be improved by using risk based approach. As shown in Figure 7.1, our ultimate target is to reduce the potential damage, i.e. the risk and thus, there are several ways as following:

- ✓ Risk avoidance, e.g. to control the hazard with very low return periods or avoid the hazard effected zone etc.
- ✓ Risk reduction: certain acceptable level of risk defined
- ✓ Risk transfer by financial insurance, outsources
- ✓ Risk retention by accepting the risk and reserve budget to compensate the expected damages.

Either way listed above, to reduce the risk, three questions must be answered: HOW? (By) WHO? and WHEN? (Figure 7.3) (Westen C.J.V., 2013)

Referred to the basic Eq. 1.1, the risk can be reduced by reducing its components, i.e. hazard, exposure (and number of elements-at-risk) and vulnerability (tangible and intangible) as following (UN IDSR, 2004):

- Awareness raising to change the behavior in increased vulnerability
- Knowledge development: information database, education and research;

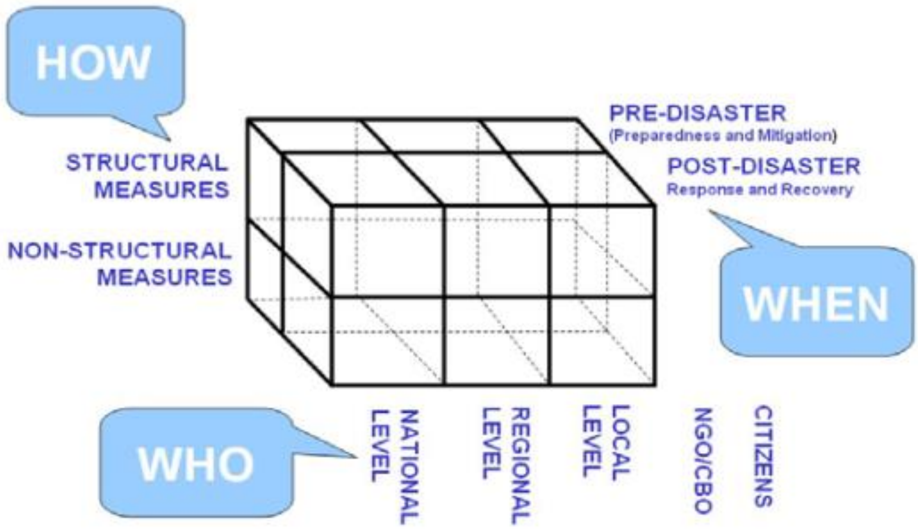


Figure 7.3 Important aspects of disaster risk reduction:
How, Who and When

itical commitment and institutional development

- Early warning: monitoring and forecast capability;
- Risk management application and instruments: environmental management, land-use and residential planning, financial instruments, physical and technical measures;
- Emergency management and recovery capacity.

The specific measures of these components that highly recommended for the study area are presented in Table 7.1. Moreover, it is also important to note that the disaster risk management is not just straightforward process but all its components are linked with each other in the loop requiring reviewing and updating regularly (Figure 7.4) (UN IDSR, 2004).

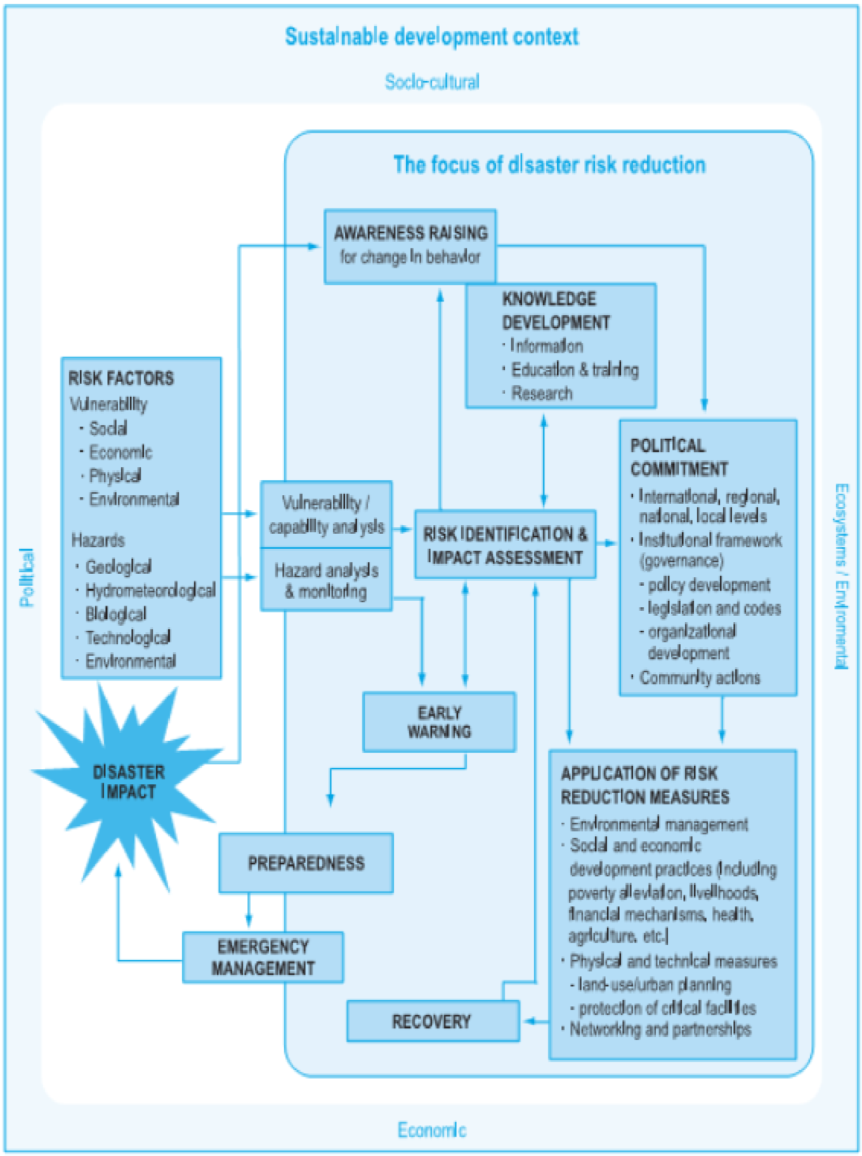


Figure 7.4 Framework for Disaster Risk Reduction from "Living with Risk"

Table 7.1 Recommended measures to reduce risk in the study area

Recommended measures	To reduce			
	hazard	exposure	vulnerability	
			tangible	intangible
Structural measures based on the analysis of cost vs. benefit and/or risk to be reduced				
Dam/reservoirs to retain the flood peak	x			
Flood retention basin and embankment to control early flood (before harvesting season) to avoid agricultural damage	x			
Flood proofing of houses			x	x
Non-structural measures				
Zoning and landuse planning: permanently evacuate households and agricultural land away from deeply inundated area		x		
Policy and institutional framework to reduce poverty, investment in research and education				x
Early warning capacity			x	x
Emergency planning based on total social risk calculated			x	x
Insurance and compensation			x	x
Environmental management and recovery			x	x
Community based disaster management, public awareness, evacuation drill			x	x

Chapter 8. Conclusion and future works

This study concerns the development of an integrated approach of hydraulic simulation, spatial analysis and social survey to quantify the flood risk focusing on intangible vulnerability for a pilot rural area located in the downstream of the large river system named Vu Gia Thu Bon (VG-TB), Central Vietnam. Based on the outcomes obtained from previous chapters, Chapter 8 is to provide the conclusions and propose further research issues.

8.1 Conclusion

VG-TB river system in Quang Nam Province is strongly characterized by steep bed slope and complicated hydrological regime. These factors result in sudden and extreme flood hazard, which is certainly the risk for social safety and economic integration.

To understand the flood pattern and its consequences, this study applied MIKE 11 package for flood simulation combined with GIS-based inundation extent visualization and statistical analysis of past flood record in the basin. Based on relatively sufficient hydrological and hydraulic data record, the modeling calibration and validation come up with quite good result (NASH index at all the main gauges is higher than 0.7, even up to 0.95). Also, for peak discharge usually having large error, the difference between observed and simulated values is less than 10%. The model with such calibrated parameters was then used to simulate flood events of 100-year, 50-year, 20-year and 10-year return periods. For further analysis, the corresponding maps were developed to present the inundation extent and inundation depth.

The inundation maps show that the flood with lower frequency causes substantial increase of total inundation area and more critically, mainly the increase of deep water. By the other words, the increase of total inundation is mainly due to the increase of deeply flooded area. This issue is an important concern as the statistical analysis and reviewing of international and national researches revealed the tendency of increased erratic weather phenomenon and consequently, extreme flow discharge threatening local community safety and sound environment. Within framework of this study, only qualitative assessment of flood consequences was carried out for different inundation level: <0.5m (up to knee), 0.5m-1.0m (up to shoulder of an adult), 1.0m-2.0m (up to 1-story house roof), 2.0m-3.0m (up to 2-story house roof), and >3.0m (everything is submerged). Dien Ban district is located the center of low lying floodplain and will be selected for further risk assessment.

The risk of social safety is defined as intangible with three elements-at-risk, including: (1) Percentage of affected people (SS1); (2) Number of people exposed to the risk of injuries (SS2) and (3) number of people exposed to the risk of fatalities (SS3). The risks were then calculated using modified DEFRA methods by taking into account not direct but also indirect area and people vulnerability issues. The finding does shows the high vulnerability and high risk for the safety of people living in Dien Ban District of VG-TB downstream. These finding in relatively quantitative manner can be of great help for local authority in preparing effective disaster management plan. For example, to implement emergency evacuation, the shelters must be sufficient to accommodate about 7.5% of district population; special assistance needs to be prepared for approximately 3,000 people exposed to high risk injuries and fatalities. In case of catastrophic event of 100-year return period occurred, these figures can rise up to 17% and more than 12,000 people. Also, based on rather high possible number of fatalities, i.e. 31 cases in average very year or even up to 160 cases in catastrophic events, the authority should consider appropriate strong measure to control the flood. The awareness about potential injuries due to accident and/or indirect illnesses and public health problems is expected to improve because currently, post disaster surveys include only direct physical accident.

Within the scope of economic risk analysis, this study selected two categories named agriculture (12 elements-at-risk, i.e. RI1, RI2, RI3, RI4, CR1, CR2, CR3, CR4, AQ1, AQ2, AQ3, Q4) and household properties (3 elements-at-risk, i.e. HH1, HH2 and HH3) to derive intangible, tangible and total risks in the form of specific risks corresponding to selected return periods (i.e. 100-year, 50-year, 20-year and 10-year), flood risk curves (FRC) and Average Annual Risk (AAR).

The analysis of direct tangible damages can be conducted using conventional method of stage-damage functions. Meanwhile, the tangible indirect and intangible (direct and indirect) damages were evaluated quantitatively by using Contingent Value Method (CVM). Among the stated preference methods, the CVM is the most commonly applied technique for the estimation of the intangible costs. It is preferred by the scientific community and few policy makers because it is more established and it is highly standardized. However, when estimating intangible impacts at larger scale areas and longer time frameworks, revealed preference (real market priced based methods) are more precise and effective.

The result of risk assessment of agriculture sector shows that regardless the deep inundated area is significantly reduced from rare to frequent events the direct tangible risks are still quite similar. This factor can be misinterpreted by the local community about the risk as most of them believe that the flood loss may incur would be only about 2% in average of total agricultural production in the District. Therefore, the key findings is the significance of direct intangible and indirect (tangible and intangible) risks, which are 1.5-2.5 times higher compared to direct tangible ones. These risks, including potentially losses of clean up and repair, environmental pollution and business interruption, increase substantially for the extreme flood events, i.e. the expected loss of the 100-year event is almost double compared to 10-year event. Every year, in the study area, the average risk of agricultural sectors due to seasonal flood is as high as VND516,590 mil, or equivalent to approximately US$22 mil, out of which, the annual intangible risk is highly significant as it accounts for approximately 62% mainly due to difficult recovery after several disaster occurred. This can be the reason for decrease of annual GDP rate for the year having damaging flooding as well as in the following years

To carry out risk assessment for household properties, type of housing (i.e. building material and number of stories) is highly important vulnerable factor, i.e.

increasing or reducing the consequences caused by flooding, and thus, in the study area all the houses are divided into three classes: Class 1 – Temporary one-storey houses; Class 2 – Masonry one-storey houses and Class 3 – Masonry multi-storey houses. The exposure analysis shows that large numbers of houses are deeply inundated (>1m) in case of 100-year flood event occurred, i.e. 57% in Vinh Dien town and 41% in rural area. For 50 year return period, these figures reduce to be 39% and 26%, which still potentially expose to significant consequences. The result obtained from analysis of tangible vulnerability consists of two sets of stage damage curves developed for elements at risk HH1 (Household Structure) and HH2 (Household Content). Regarding to HH1 stage-damage curves, for housing class 1, the damage rate gradually increases along with water level rising. For housing class 2 and 3, these curves make the high rise as soon as the water level gets up to 1m until 3m and after that remain more or less stable. Regarding the absolute values, for both HH1 and HH2, the damage rates are quite the same for all housing classes if inundation is less 1m but then they rise proportionally with the quality (or value) of the houses. Intangible vulnerability was analyzed based on element at risk of business interruption (HH3). Also by using CVM method, information on type of works, interruption duration and average income was collected and then synthesized separately. The result shows that majority, i.e. 70% ~ 80%, of households living in the study area engage in at least one type of work, excluding farming, that can be affected and interrupted by flooding situation with an average duration is 2~6days in Vinh Dien town and 3~10days in rural area due to the fact that in rural area, flooding often causes more damages to rural roads. The ranges of daily incomes are rather wide and much higher in Vinh Dien town compared to rural area. The specific risks were calculated for each element at risk showing that once the housing get inundated, its structure would expose to highest damage costs, closely followed by the those for content. Moreover, the potential direct damages of housing increase exponentially along with the raise of inundation depth. Annual Average Risk (AAR) was calculated to show the contributions of three selected elements at risk HH1, HH2 and HH3 to the household property damage caused by flooding, say 47%, 43% and 10%, respectively. This figure can be considered as quantitative indicator in long term flood management in the local area

It is important to note that unlike the risk of agricultural sector having significant contribution of intangible damages (1.5-2.5 times higher than tangible ones), the intangible damage due to business interruption in risk of household properties is much less than the direct damage cost. However, this should not be interpreted that the consequence of business interruption is an insignificant because the evaluation was not based on the same so called market price, i.e. the direct damage cost is based on "*how much the householders have to pay/buy*" while the indirect one is "*how much the householders earn*".

The integrated approach and results presented in this study can be used as quantitative input information in developing flood disaster management strategies. In particular, to propose and appraise which countermeasures are the most effective the decision makers should answer the question "how much risk need to be reduced", or "what is acceptable level of the risk for social safety and/or economic sector". Several recommendations on possible measures to reduce risk were proposed. Apparently, to reduce intangible damage and enhance resilience the soft measures are in preference.

8.2 Limitation and future works

To improve the result of this study, it is recommended to apply this approach in larger area. More resources should be utilized to develop more hazard scenarios and thereby, to increase the accuracy of risk calculation.

There is a need for a systematic definition and estimation of the physical impacts of flooding, as well as all other types of hazards, on human health and the environment. In this context, health societies and ecologists should cooperate closely. Hence, more effort and resources should be allocated for the cost assessment of the intangible effects caused by hazards.

Many uncertainties emerge in estimating the costs of the intangible effects due to their incomplete definition and absence of the market prices. A strong uncertainty factor is lack of knowledge on the physical impacts. More specific, only a few studies have been elaborated to define the ecological impacts of natural hazards.

Another uncertainty factor is the often low quality and quantity of the available data. CVM should be applied systematically in order to achieve more accurate results. In this context it is recommended that the surveys should be applied in repeated time periods and under similar context, eliminating this way the various biases.

Due to the complexity and uncertainty of the intangible effects, the combination of relevant methods would foster effectiveness and accuracy of the results. In this context, stated preferences and revealed preferences methods should be applied in parallel and complementary. However, such an option demands increased resources.

The complexity and uncertainty of valuating intangible effects fosters the integration of the cost assessment into policy making and management in order to provide a more comprehensive evaluation. Hence, the limits of valuing the intangible effects and bridging policy making with economics should be further investigated.

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