# Flood risk analysis and spatial flood risk assessment for Vietnam

by

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# List of related publications by author

**Refereed Journal Articles:**

**Luu, C.**, von Meding, J. & Kanjanabootra, S. 2018, Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam, Vietnam. *Natural Hazards*, Vol. 90 No. 3, pp. 1031-1050. https://doi.org/10.1007/s11069-017-3083-0

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**Luu, C.**, von Meding, J. & Mojtahedi, M. Evaluation of flood risk in Vietnam using multi-attribute decision-making analysis and national disaster database. *Journal of Flood Risk Management.* (Under review)

**Book chapter:**

**Luu, C.** & von Meding, J. 2018, Chapter 15: Analyzing Flood Fatalities in Vietnam Using Statistical Learning Approach and National Disaster Database. In: Asgary A. (eds) *Resettlement Challenges of Refugees and Disaster Displaced Populations*. Springer, Chennai

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# Abstract

Vietnam has been extensively impacted by flooding historically, sustaining heavy losses in human life, and damage to housing, agriculture, water resources, and transportation. Although the Vietnamese government has focussed on physical measures of flood defence such as dykes and early warning systems, the country still lacks flood risk assessment tools and methodologies developed at national and local levels, and holistic flood risk management (FRM) frameworks.

In this research, Vietnam's national disaster database was first sourced, and the data was collected and analysed to examine the flood risk of Vietnam's regions and provinces by using a new approach, multi-criteria decision techniques and statistical analysis. Second, the study investigated the flood fatalities in Vietnam by using statistical machine learning techniques and the national disaster database. Third, the study developed a novel flood risk assessment model that can rapidly create a flood risk map for a local scale by using spatial multi-criteria decision analysis and historical flood mark data. Fourth, FRM activities were investigated via in-depth interviews with decision makers FRM at the provincial, district, and commune levels in Quang Nam province, along with the legal and institutional frameworks.

The results have been published in several high ranking peer-reviewed journals. The key findings have led to recommendations for flood risk evaluation at the national level, flood fatality analysis, spatial multi-criteria decision analysis for flood hazard and flood risk assessments, and investigation of FRM approaches from legal and institutional frameworks to practice at local levels. This research project has broad implications for future efforts to mitigate flooding in Vietnam.

# Acknowledgement

I was interested in studying in the flood risk management field because I saw many poor people in Vietnam severely affected by floods. I believe that flood risk can be mitigated through comprehensive assessments and an effective management system. I think the research on flood risk reduction will allow me to make a meaningful contribution to society's well-being as a professional. I am so lucky to have an opportunity to do doctoral research on this field at the University of Newcastle. This is the most beautiful and meaningful journey in my life.

I would like to express my gratitude to many people for their help with this dissertation. First and foremost, I wish to thank my principal supervisor Dr Jason von Meding, and co-supervisor Dr Sittimont Kanjanabootra for their guidance and patience. They were consistently encouraging and supportive. I also would like to sincerely thank Dr Mohammad Mojtahedi, who provided me with suggestions on the model of multiple linear regression-TOPSIS for my data analysis. My special thanks go to Duc N. Tran for his kind support in the application of machine learning techniques in my thesis.

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I would like to thank my friends at the University of Newcastle for their support, friendship and kindness. To others not mentioned here, thank you very much for everything that you have done for me.

Finally, I would like to send my deepest gratitude and respect to my parents for their sentiments and faith in me; to my little family for their understanding, encouragement and sacrifice throughout my journey.

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# List of Abbreviations

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| CCFSC | Central Committee for Flood and Storm Control |
| CSCNDPC | Central Steering Committee for Natural Disaster Prevention and Control |
| CRED | Centre for Research on the Epidemiology of Disasters |
| CBDRM | Community Based Disaster Risk Management |
| DANA | Damage and Needs Assessment system |
| DEM | Digital Elevation Model |
| DM | Decision Maker |
| DSM | Damage Scanner Model |
| FRM | Flood Risk Management |
| GIS | Geographic Information System |
| IDW | Inverse Distance Weighting |
| MADM | Multi-Attribute Decision-Making |
| MCDM | Multi-Criteria Decision-Making |
| MODM | Multi-Objective Decision-Making |
| TOPSIS | Technique for the Order Preference by Similarity to Ideal Solution |
| VND | Vietnam Dong (Vietnamese currency) |
| WLC | Weighted Linear Combination |

# Chapter 1 Introduction

## 1.1 Background

A flood is a very complex phenomenon that links the natural environment, people and social systems (Slobodan 2012). Flood exposure and flood frequency are forecasted to increase, particularly in low latitudes in Asia and Africa (Hirabayashi et al. 2013). The intensity of tropical cyclones and rainfall will increase on average while its frequency is likely to decline or remain unchanged (Knutson et al. 2010).

Flood risk is a common threat to many populous cities, and riverine and coastal regions (Maaskant et al. 2009). The impacts of flood risk are expected to increase because of the population growth, economic improvement and climate change (Tanoue et al. 2016). Flood risk is defined by a combination of flood hazard, exposure and vulnerability (Kron 2005, Winsemius et al. 2013, WMO 2013b, Budiyono et al. 2014). The exposure is determined by the level of people, property and infrastructure exposed to this hazard. The vulnerability is defined as the people or assets affected by, or inability to cope with the impacts (Kron 2005, Lindley et al. 2007, Maaskant et al. 2009, Jongman et al. 2012b, Kobayashi and Porter 2012).

Flooding can have devastating impacts on lives, homes, livelihoods and infrastructures. A global disaster database has been being documented fro the period 1900-2016 (**Figure 1-1**). Asia has been reported to have the highest numbers of flood and storm events and the most significant impacts on human life. It is followed by the Americas, although the Americas have the highest economic loss. Within Asia, Vietnam is highly vulnerable to flood and storm events, being the eighth most affected country by extreme weather events 1996-2015 (Kreft et al. 2016) and the fourth most exposed to river flood risk by proportion of population (Luo et al. 2015).

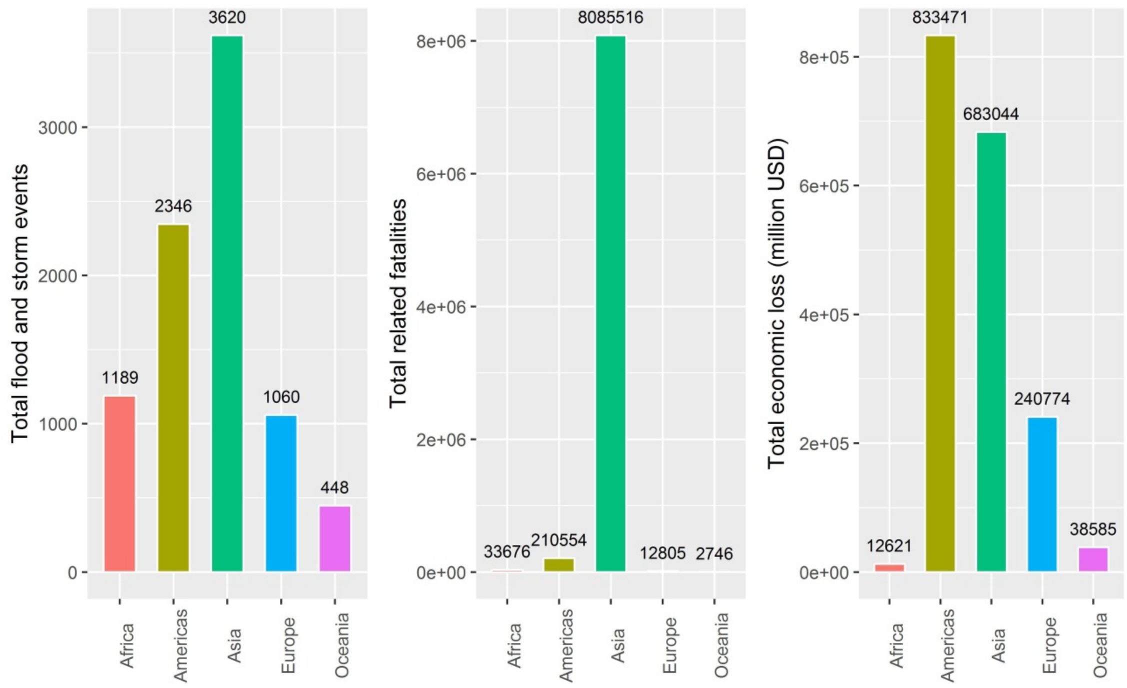


***Figure 1-1****: Flood events, related fatalities and economic loss for the period 1900-2016 at the global scale (compiled from EM-DAT database, http://emdat.be)*

FRM is gradually developing from a traditional approach based on design standards to a risk-based decision-making approach (Sayers et al. 2002a). A standards-based approach focusing on structural measures for flood defence is expected to withstand flood events. Further, the structural measures aim to reduce the hazard of these events (Harries and Penning-Rowsell 2011). Meanwhile, a risk-based approach enables informed choices and focuses on non-structural measures. These non-structural measures aim at reducing the vulnerability or susceptibility of people and their properties in flood-prone areas (WMO 2013a). The emerging perspective in FRM takes into account the changing hazards, exposure and vulnerability (Merz et al. 2014). Moreover, an integrated FRM concept has attracted considerable attention (Büchele et al. 2006) and well-defined extreme FRM is considered an important pillar of climate adaptation (Jongman et al. 2014).

The flood risk in Vietnam is a result of the tropical monsoon climate, dense river system, long coastline, and high population density in coastal and river areas (Razafindrabe et al. 2012). Developing countries are often more severely affected by disasters than developed ones (Hansson et al. 2008). The fatality rate and the economic loss per Gross Domestic Product (GDP) by disasters are higher in developing economies (Seneviratne et al. 2012). In Vietnam, floods caused substantial losses, including 14,927 fatalities, and economic loss equivalent to 1% of GDP between 1989 and 2015 (Luu et al. 2015a).

The archiving and analysis of disaster databases are critical for providing essential information for policy-setting and decision-making processes for disaster risk reduction (IRDR 2014, UNISDR 2015b). Disaster databases are available at global, regional and national scales (Grasso and Dilley 2013, Simpson et al. 2014). The Damage Assessment and Needs Analysis (DANA) system is Vietnam's national disaster database, which contains the data of direct damage caused by flood disasters since 1989 (Bollin and Khanna 2007, Hughey et al. 2011). DANA was developed by Central Committee for Flood and Storm Control (MARD 2006, Below et al. 2010). The exploration of these data could contribute to a better understanding of the disaster risk, which is one of the priorities of Sendai Framework for Disaster Risk Reduction (UNISDR 2015b).

Further, a flood hazard assessment map is recognised as the first stage in assessing flood risk (Directive 2007/60/EC). This map provides information about the extent of flood hazard areas to decision makers, planners and communities to take relevant response activities (WMO 2013b). This map is considered an essential instrument for developing strategies for flood risk mitigation and raising community awareness about flood risks (Vojinovic 2015).

Meanwhile, a flood risk assessment map incorporates flood hazard information together with the exposure data of population and assets, and their vulnerability to the hazard. Flood risk is assessed on the basis of three components, namely hazard, vulnerability and exposure. Spatial flood risk assessment is a useful tool for determining at-risk components and identifying at-risk locations, which is a primary foundation for setting appropriate mitigation and adaptation strategies and measures (Lindley et al. 2007, Foudi et al. 2015).

Flood damage statistics show that Vietnam is vulnerable to flood and storm events, which have had a severe human impact over the years. Although an increasing number of case studies have been conducted on flood risk analysis in Vietnam, there is still a lack of studies on detailed flood risk assessment tools developed at local and national levels. Therefore, this study aimed to investigate flood risk with detailed assessments at local and national levels, and FRM in practice. The study area description and the identified research problems are presented and highlighted in the following sections.

## 1.2 Study area description

Vietnam consists of three regions: the North, the Central and the South. The rainy season often lasts from May to December, occurring in the North from May to October, in the Central from June to December, and in the South from July to December (Vu et al. 2015). Vietnam experienced 295 significant storms (Category 6 to 12) between 1961 and 2014 as shown in **Figure 1-2**.

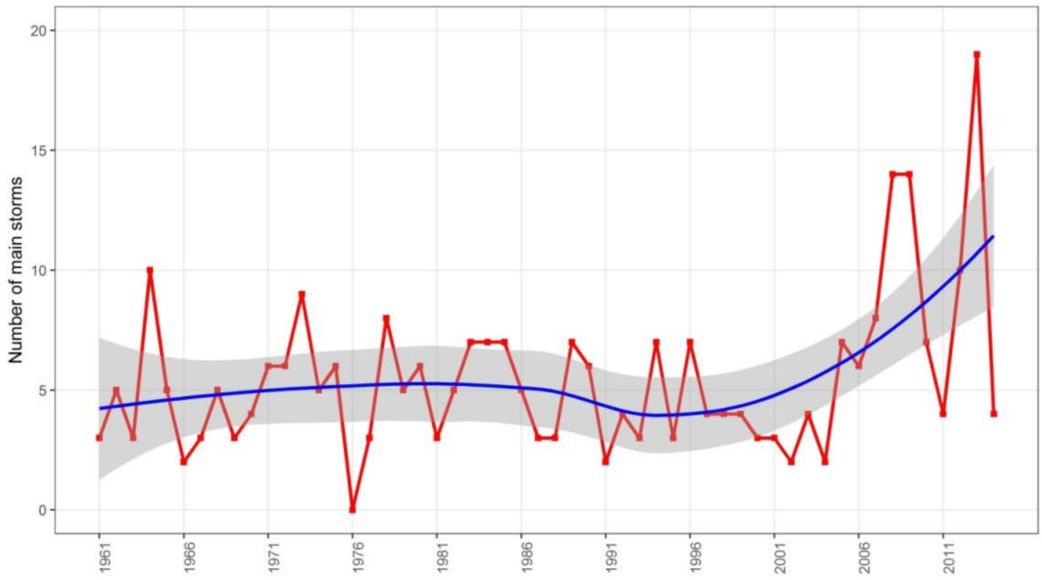


***Figure 1-2****: Total numbers of significant storms (Category 6 to 12) that struck Vietnam in 1961-2014 (source: compiled from NHMS (2015))*

Floods caused significant losses in Vietnam with more than 14,927 deaths, and economic damage equivalent to 1% of GDP between 1989 and 2015 (**Figure 1-3**). The flood risk results from tropical monsoon climate, dense river systems of more than 3,450 rivers and streams, a long coastline of 3,260 km, and densely populated coastal areas and river basins (Razafindrabe et al. 2012, Chau et al. 2014a). The three regions of Vietnam have different flood risks because of their geographical conditions. In the North, cascaded hydropower reservoirs in the Da river basin efficiently control floods. The flood control capacity of hydropower reservoirs on the Da river basin is approximately 7 $m^3$ of the 10.5 $m^3$ of the entire country (Vu 2010). This region has high landslide risk during the rainy season (Tien Bui et al. 2012). In the South, flooding is caused by storms, tide and sea level rise (Wassmann et al. 2004). The Central part is characterised by a sloping topography and narrow lowland plain less than 100 km in width (Yokoi and Matsumoto 2008). This region is often exposed to flood events that cause massive damage to human life and property (Shaw 2006, Tran et al. 2010, Chau et al. 2014a).

The Quang Nam province in Central Vietnam was selected as a case study in this research (**Figure 1-4**). The central part is the most flood-prone area in Vietnam. Over the years, floods have severely affected the communities' livelihood and socio-economic development (Luu et al. 2018a). The high flood risk in the Central region is determined by the frequent occurrence of severe floods (Razafindrabe et al. 2012) and human interference in the hydrological system such as deforestation (Meyfroidt et al. 2013). Agricultural expansion, industrial development, and population growth have increased flood vulnerability. The region is separated by rivers that originate from the Truong Son mountain range in the West.

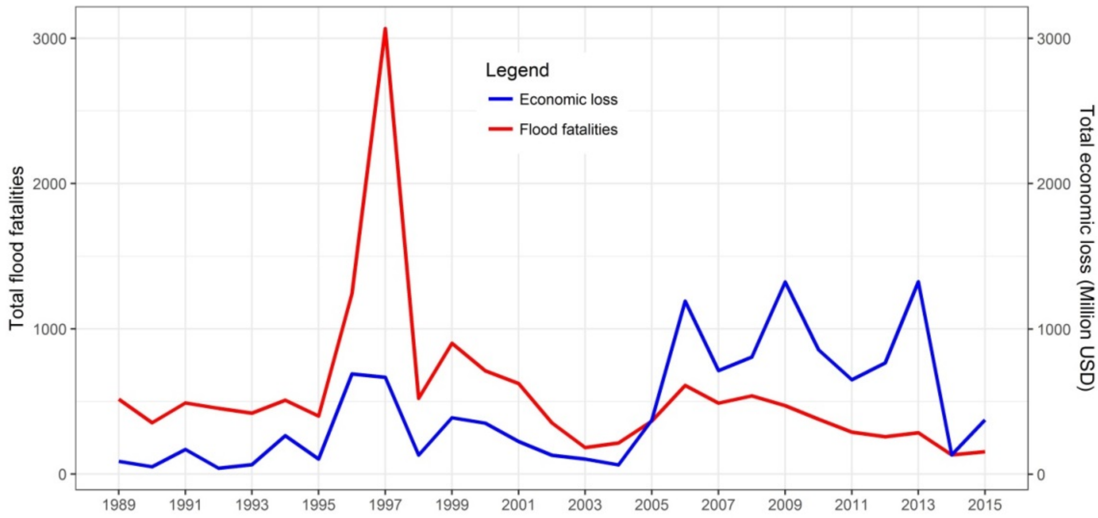


***Figure 1-3**: Death toll and total economic loss caused by floods and storms events between 1989 and 2015 in Vietnam (compiled from Vietnam's national disaster database, DANA)*

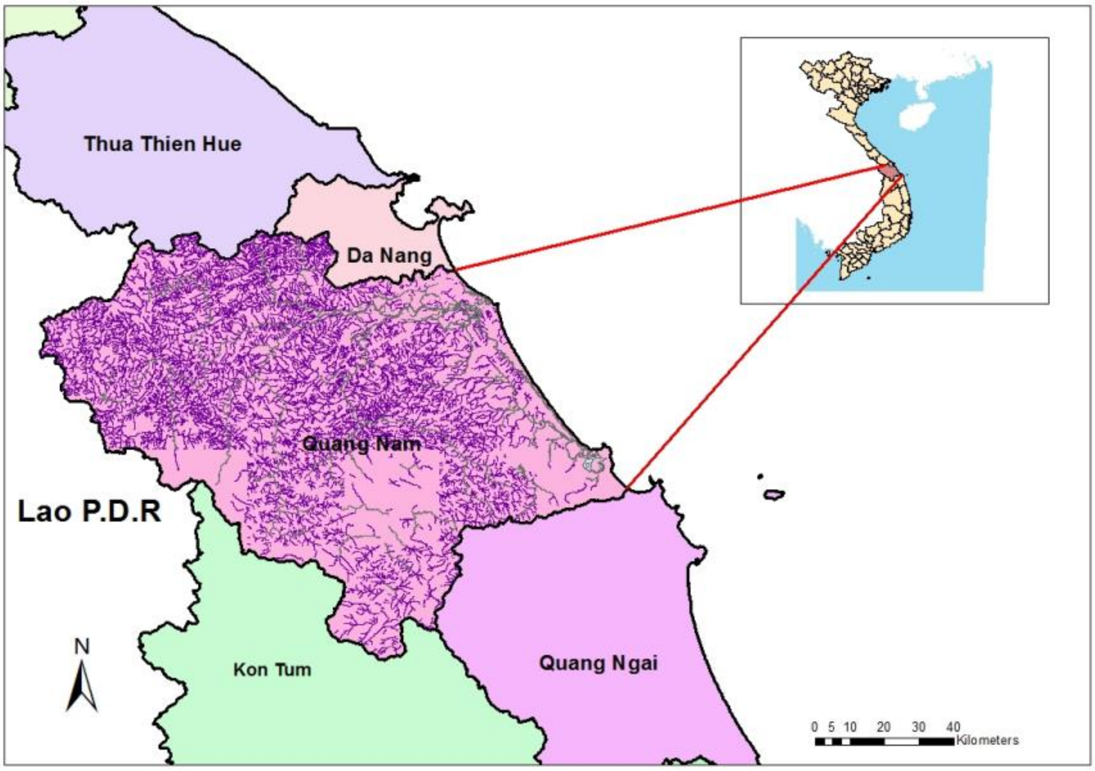


***Figure 1-4****: The study area, Quang Nam province, Central Vietnam*

Quang Nam has an area of 10,440 km$^2$ and had a population of more than 1.4 million in 2015. This province has a highly flood risk with a large river basin, Vu Gia-Thu Bon, and a long coastline. Populations live along river basins, and their livelihoods heavily depend on rivers for both agriculture and fishing. The rapid implementation of numerous hydropower plants in a short space of time has seriously affected the very existence of communities, along with the currently densely populated riverine regions (Luu et al. 2014).

There are nine large hydropower plants with an installed capacity of more than 60 MW and 33 small and medium hydropower plants with the capacity of less than 60 MW on the Vu Gia-Thu Bon river system in Quang Nam province (Lam et al. 2013). A region with densely cascaded dams can face a high flooding risk in a case of improperly following multi-reservoirs operation procedures (Ji et al. 2013). Many households have already been disrupted and often been relocated because of the construction of hydropower plants (Bui et al. 2013, Singer et al. 2014, Luu et al. 2015b). Vietnamese farmers have spent thousands of years cultivating the plains, so they have undergone annual devastating extreme weather events. However, when the multi-reservoirs procedures have not been followed appropriately (Le et al. 2014), densely hydropower reservoir cascades have forced downstream communities to adapt to their operating procedures, defined by an unnatural cycle of flooding. This defeats the flood mitigation mechanisms built up over generations.

The Quang Nam province often faces catastrophic flood events in the rainy season from September to December. Recent hazardous floods have been reported, including events in 1999, 2004, 2007, 2009, 2013, 2016 and 2017. Significant flooding occurrences have consistently caused a considerable loss of life and property damage in the Quang Nam province. The tributaries of the Vu Gia-Thu Bon river basin originate from high mountain ranges, then flow through narrow plains and empty into the sea (Nam et al. 2014). These very short and steep tributaries, together with rapid changes in the land use for agricultural expansion and hydropower development, have recently increased the flood risk in the province.

This case study was chosen for the following four reasons:

(a) Quang Nam is heavily affected by floods and storms in annual flood seasons.

(b) This area is at risk mainly from river flooding (mainly caused by long-lasting rainfall events), which is typical characteristic of many provinces in Central Vietnam.

(c) The Vu Gia-Thu Bon river basin on the boundary of Quang Nam province is one of the largest river basins in Vietnam with densely cascaded hydropower dams.

(d) The research approach can be applied to other provinces in Central Vietnam because they have the same characteristics of flood risk.

## 1.3 Research problem

Various structural and non-structural measures for flood control are being carried out in Vietnam, for example, dyke and embankment systems, reservoir dams, flood shelters, and upstream afforestation and forest protection (Garschagen 2011). In addition, the government has given priority to improve the early warning systems (e.g., hydro-meteorological observation stations in the entire country have been automated step by step while state-of-the-art technology for weather forecasting has been imported and applied in Vietnam). However, flood disasters have continued to severely affect Vietnam, particularly in relation to the high death toll (**Figure 1-3**). This has raised concerns about Vietnam's level of flood risk (Chau et al. 2014b).

Structural flood control works can modify flood hazards such as flood control reservoirs, detention basins, levees, dykes, diversion channels, and river channel improvements (Kobayashi and Porter 2012). In combination with structural measures, non-structural flood measures can provide a proactive approach for both managers and residents to better adapt to flood hazards. FRM focuses on non-structural measures and aims to mitigate the vulnerability and susceptibility of people and their properties in flood-prone areas (WMO 2013a).

The compilation and analysis of disaster databases present relevant information which can be used in the policy-setting and decision-making processes of disaster risk reduction. The national disaster database of Vietnam is built by the Central Committee for Flood and Storm Control (CCFSC) through the Damage and Needs Assessment system or DANA (MARD 2006). The disaster data from DANA was collected using a template and includes 12 damage categories with many indicators. Some studies have evaluated the quality of the DANA database. Nhu et al. (2011) provided a preliminary analysis of DANA and an overview of the impacts of floods and storms in Vietnam. Hughey et al. (2011) evaluated the completeness and accuracy of the DANA process. However, further studies are needed for a detailed analysis and exploration of this database for a better understanding of flood risk in Vietnam. Hence, the first research question considered in this study was as follows:

1. How can the national disaster damage database be utilised to evaluate and assess the flood risk for provinces and regions in Vietnam?

Human fatality is a critical criterion for evaluating flood risk (Maaskant et al. 2009). Although many studies on flood-related fatalities have been devoted to developed countries, less attention has been paid to developing ones. There are also no empirical studies on the application of statistical techniques to the analysis of the relationship between the flood damage attributes and the flood fatalities. Thus, the second research question considered in this study was as follows:

2. How do different aspects of flood hazards contribute to the loss of life in Vietnam?

Flood hazard assessment is a primary stage in assessing flood risk (Directive 2007/60/EC 2007), and a part of risk identification in a risk management process (NZS 9401:2008). The flood depth and duration affect the determined levels of flood damage (Lekuthai and Vongvisessomjai 2001). The flood depth of historical flood events is the most crucial factor for flood hazard assessments. The flood duration also severely affects the extent of damage in agricultural areas (Guo et al. 1998, Kent and Johnson 2001). However, most previous studies have not analysed the flood duration factor while assessing a flood hazard. Therefore, the third research question considered in this study was as follows:

3. How can historical flood marks be used to evaluate flood hazard (including flood depth and duration factors) for the Quang Nam province?

A flood risk assessment map is considered a fundamental tool for developing and establishing strategies for flood mitigation and raising public awareness on flood risk (Vojinovic 2015). A flood risk map aims to provide risk assessment information based on the past flooding events in combination with exposure and vulnerability information to support the decision-making process (WMO 2013b). Flood risk assessment maps and FRM action plans are the core tools in FRM (Directive 2007/60/EC). The incorporation of flood risk assessment into a Geographic Information System (GIS) environment provides a spatial flood risk assessment, which is a useful tool for underlining risks and identifying vulnerabilities (Mazzorana et al. 2012, Budiyono et al. 2014, Foudi et al. 2015). Therefore, the fourth research question considered in this study was as follows:

4. Is there a holistic way to assess the flood risk levels for the Quang Nam province?

Floods have seriously affected the Vietnamese people over the years, particularly with respect to life, housing, agriculture, water resources and transportation. Besides functional flood control measures such as dyke and early warning, FRM approaches need to be focused upon. Although there have been several studies on FRM at local scales, there is still a lack of studies on the practice of FRM activities under the legal and institutional frameworks in Vietnam, and how the legal framework of FRM delivers effective flood risk reduction and mitigation. An investigation of FRM activities at local scales could contribute to the development of an integrated FRM framework for Vietnam in the future. Thus, the fifth research question addressed in this study was as follows:

5. How are FRM activities implemented at local scales from policy to practice?

## 1.4 Research aims and objectives

On the basis of the research problems, this study aims to (1) assess flood risk by using spatial multi-criteria decision analysis, and (2) examine FRM activities at local levels along with the legal and institutional frameworks. To achieve these aims, the study focuses on several key objectives:

1. Evaluate flood risk at the national level using the national disaster database.
2. Analyse flood-related fatalities in Vietnam using the national disaster database.
3. Identify and assess the flood hazard for a case study in a flood-prone province using multi-criteria decision analysis and the GIS framework, and validate the result.
4. Assess flood risk for a case study in a flood-prone province by integrating flood hazard, exposure and vulnerability indicators using a spatial multi-criteria decision analysis.
5. Critique Vietnam's legal and institutional frameworks to provide an overview of the operation of FRM activities; and provide recommendations towards an integrated FRM framework for future flood mitigation efforts in Vietnam, based on rich local evidence from Quang Nam province.

The research results will (1) provide visualised flood risk assessments at both national and local levels, which may support decision makers in making appropriate flood mitigation measures and land use planning; and (2) present an investigation on FRM activities at local scales along with legal and institutional frameworks and discussions about gaps in practice and policy.

## 1.5 Types and sources of data

Information about historical events is a valuable input for assessing hazards and vulnerability in at-risk areas (WMO 2013b). The relevant information can be found in international and national databases or on a local level with local authorities, flood marks or newspaper archives. Flood mapping heavily depends on data, the analysis methods and techniques chosen.

Data is gathered from multi-stakeholders such as local authorities, interviews and surveys with experts and decision makers, and public sources (international and national databases, newspaper articles, reports, research projects and journal articles). The data types and sources used in this study include the following:

- Disaster damage data: death toll, economic loss and other damage attributes from the national disaster database of Vietnam.
- Topographic data: topographic maps with contours and river basin systems; and land use map. These data were obtained from Department of Survey and Mapping Vietnam and local authorities.
- Magnitude of hazard data: hydrologic data and flood mark data for past flood events. These data were obtained from rainfall stations and local authorities.
- Exposure and vulnerability data: population density and social-economic indicators. The rough data were obtained from local authorities.
- Local practices, strategies and capacities data: how do local communities and actors behave and cope. Data were obtained from multi-stakeholders at the local level.

## 1.6 Research significance

This thesis provides a spatial multi-criteria decision analysis of flood risk assessments for Vietnam at the local and national levels, and explores FRM activities at the local levels. It has five major components. The first is to evaluate the flood risk at the national scale for Vietnam by using Multi-Criteria Decision-Making (MCDM) method and national disaster database. The second one is to analyse the relative influence of the flood damage attributes on the flood fatalities in Vietnam by using statistical learning techniques and the national disaster database. The third is to assess the flood hazard at the local level, Quang Nam, Vietnam by using multi-criteria decision analysis and historical flood marks. The fourth is to provide a comprehensive flood risk assessment map for Quang Nam province, which incorporates flood hazard information with the exposure data of the population and the assets, and their vulnerability to the hazard. The fifth is to investigate the FRM activities at the local levels along with the legal and institutional frameworks and discuss the gaps in practice and policy. The outputs of this study may provide essential information for decision makers in FRM practice. The processes followed could be replicated in other locations in Vietnam.

## 1.7 Thesis by publication structure

This is a thesis by publication. It includes three parts and is structured into 11 chapters. The first part consists of **Chapters 1 to 4**, which present the background of this study, a literature review, a conceptual framework and the research methodology. The second part consists of **Chapters 5 to 9**, which are the published or submitted journal papers that have emerged from the research project. The third part consists of **Chapters 10 and 11**, which discusses the key themes emerging from the research, positions the results in the context of the wider body of knowledge, draws conclusions and makes recommendations.

**Chapter 1** provides an overview of the research project, research questions and thesis structure.

**Chapter 2** reviews the literature on flood risk analysis and assessment. It starts by reviewing the flood risk analysis approaches. This is followed by the applications of

MCDM techniques. The chapter then reviews the spatial multi-criteria decision analysis frameworks for flood hazard assessment and flood risk assessment maps. Next, the chapter presents a review of the research on flood fatalities. Finally, it reviews and discusses several typical frameworks for FRM.

**Chapter 3** starts by defining the factors of flood risk. A conceptual framework is proposed to incorporate these factors in the analysis and assessment of the flood risk. In the framework, the flood risk assessment and analysis processes aim to provide an essential background for FRM, flood risk adaptation and mitigation actions, and governance. This is followed by the use of the framework for addressing the research questions. Finally, it presents a research flowchart.

**Chapter 4** presents the research design and the data analysis methods used in this study. This is followed by the justification for selecting the relevant research approaches. This chapter describes in detail on MCDM methods including TOPSIS and AHP, and the integration of these methods into a GIS framework. It also introduces the statistical learning techniques and qualitative research approach adopted in this study.

**Chapter 5** is a journal article titled "Flood risk assessment using multi-criteria decision-making method and national disaster database", and is under review in *Journal of Flood Risk Management*. This chapter introduces an approach to rank the flood risk for 63 provinces and 8 regions of Vietnam by using a combination of multiple linear regression technique and a multi-attribute decision-making method. Vietnam's national disaster database is sourced, collected and analysed to examine the flood risk of the regions and provinces in Vietnam. The result is then integrated into a GIS environment to develop a flood risk map for Vietnam. The output from this assessment tool has implications for FRM at the national and local levels.

**Chapter 6**[1] has been accepted for publication and is forthcoming in a book chapter entitled "Exploring the relative influence of flood damage attributes on flood fatality attribute in Vietnam's national disaster loss database". This chapter presents an analysis of the relative influence of the flood damage attributes on the flood fatalities in Vietnam during the period 1989-2015. This longitudinal investigation is necessary to understand the flood damage attributes influencing on the fatalities in Vietnam for the development of risk reduction strategies. More specifically, statistical learning techniques and the national disaster database are used to explore the relative variable importance measures of the flood damage attributes with respect to the fatalities. The result shows that the flood housing damage attribute has the most significant impact on mortality in Vietnam; the other flood damage attributes play a smaller role. This finding has implications for Vietnam's government policies on disaster risk reduction with priorities given to housing improvements and flood shelter development in flood-prone areas for flood risk adaptation.

**Chapter 7**[2] was published in *Natural Hazards*, as a paper entitled "Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam". This chapter presents an approach to analyse flood hazard by using flood mark data and a digital elevation model. The flood mark data includes flood depth and flood duration. The analytic hierarchy process is used to assess the criteria and the sub-criteria of the flood hazard. The weights of the criteria and the sub-criteria are generated based on the judgements of decision makers by using this

[1] Luu, C. & von Meding, J. 2018, Chapter 15: Analyzing Flood Fatalities in Vietnam Using Statistical Learning Approach and National Disaster Database. In: Asgary A. (eds) Resettlement Challenges of Refugees and Disaster Displaced Populations. Springer, Chennai

[2] Luu, C.; Von Meding, J.; Kanjanabootra, S. Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam, Vietnam. Natural Hazards 2018, 90, 1031-1050, https://doi.org/10.1007/s11069-017-3083-0

method. This assessment is integrated into a GIS environment via spatial analytic techniques to produce a flood hazard map.

**Chapter 8**[3] was published in *Water*, as a paper entitled “A Flood Risk Assessment of Quang Nam, Vietnam Using Spatial Multicriteria Decision Analysis”. This chapter presents the application of spatial multi-criteria decision analysis for assessing the flood risk in Quang Nam, Vietnam. The flood hazard map in Chapter 8 is integrated with flood exposure and vulnerability indicators by using a hierarchy model to create a flood risk map. The local flood risk assessment map is essential for assisting the decision-making process of FRM in a local area.

**Chapter 9**[4] was published in *International Journal of Disaster Risk Reduction*, as a paper entitled “Flood risk management activities in Vietnam: A study of local practice in Quang Nam province”. This chapter demonstrates an application of qualitative research to understand FRM activities at the local levels in the Quang Nam province of Vietnam, along with the legal and institutional frameworks that are intended to focus, but often restrict the policies and practices. Vietnam’s legal and institutional frameworks are analysed to provide an overview of the scope of the existing FRM activities in Vietnam. The extent to which FRM in Vietnam is examined following a theoretical framework, and then it is pinpointed where practice might be strengthened. Based on this positioning, 27 individual interviews with decision makers in FRM at the provincial, district and commune levels in Quang Nam province were conducted. Finally, the gaps in policy and practice in FRM activities at the local levels are discussed.

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[3] Luu, C.; von Meding, J. A Flood Risk Assessment of Quang Nam, Vietnam Using Spatial Multicriteria Decision Analysis. Water 2018, 10, https://doi.org/10.3390/w10040461

[4] Luu, C.; Von Meding, J.; Kanjanabootra, S. Flood risk management activities in Vietnam: A study of local practice in Quang Nam province. International Journal of Disaster Risk Reduction 2018, 28, 776-787, https://doi.org/10.1016/j.ijdrr.2018.02.006

**Chapter 10** is a thematic discussion of the key issues that have been encountered in this research. It positions the results in the context of the body of knowledge on flood risk analysis and assessment and articulates the practical implications of this research.

**Chapter 11** presents a summary of findings, how the objectives have been met, research limitations and recommendations.

# Chapter 2 Flood risk analysis: Spatial multi-criteria decision analysis and risk management

## 2.1 Introduction

First, this chapter provides an overview of the advances in flood risk analysis approaches in Section 2.2. Second, the applications of GIS (Section 2.3) and MCDM techniques (Section 2.4) to FRM are reviewed. Third, a flood risk analysis using the MCDM methods is presented in Section 2.5 and the spatial multi-criteria decision analysis frameworks are discussed in Section 2.6, focusing on flood hazard assessment and flood risk assessment maps. Next, the flood fatality analysis is presented in Section 2.7. Finally, several standard FRM frameworks are reviewed in Section 2.7.

## 2.2 Flood risk analysis

Floods affect more people than other natural hazards (UNISDR 2015a). A flood is a very complex phenomenon that links the natural environment, people and social systems (Slobodan 2012). Flood exposure and flood frequency are forecasted to intensify, particularly at the low latitudes of Africa and Asia (Hirabayashi et al. 2013). The intensity of tropical cyclones and rainfall increases on average while their frequency is likely to decreased or remained unchanged (Knutson et al. 2010).

Flood risk is a common threat to many populous cities, and riverine and coastal regions (Maaskant et al. 2009). The impacts of flood risk are projected to increase because of population growth, economic increase and climate change (Tanoue et al. 2016). Flood risk is defined by a combination of flood hazard, exposure and vulnerability (Kron 2005, Giupponi et al. 2013, WMO 2013b, Budiyono et al. 2014, Zhou et al. 2017). The exposure is determined by the level of people, property and infrastructure exposed to the hazard. The vulnerability is described by the predisposition of exposed factors such as people, livelihoods and properties impacted by a hazard event (Kron 2005, Lindley et al. 2007, Maaskant et al. 2009, Cardona et al. 2012, Jongman et al. 2012b, Kobayashi and Porter 2012).

FRM is gradually developing from a traditional approach based on design standards to a risk-based decision-making approach (Sayers et al. 2002a). The risk-based approach has been increasingly operationalised in FRM in recent decades (Martin et al. 2017). A standards-based approach focusing on structural measures for flood defence is expected to withstand. Structural measures aim to reduce the hazard of flood events (Harries and Penning-Rowsell 2011). Meanwhile, a risk-based approach enables informed choices and focuses on non-structural measures (WMO 2013a). The emerging perspective in FRM is taking into account the changing hazards, exposure and vulnerability (Merz et al. 2014).

Studies on flood risk assessments can be classified into and summarised as five popular approaches. The first is hydraulic/hydrological models, e.g., de Moel et al. (2009), Tsakiris (2014), Apel et al. (2016) and Hlavčová et al. (2016). The second is the measurement of vulnerability and exposure indicators, e.g., Cutter et al. (2000), Scheuer et al. (2011) and Mahmood et al. (2017). The third is a spatial multi-criteria decision analysis, e.g., Kienberger et al. (2009), Kappes et al. (2012), Dewan (2013a), Xiao et al. (2017), and de Brito et al. (2018). The fourth is machine learning predictive models, e.g., Tehrany et al. (2014), Tien Bui et al. (2016), Kourgialas and Karatzas (2017), Tien Bui and Hoang (2017), Terti et al. (2017) and Razavi Termeh et al. (2018)). The fifth is the combination of hydraulic models and other approaches, e.g., Winsemius et al. (2013), Ronco et al. (2015) and Vu and Ranzi (2017). These approaches are often combined with a GIS environment to visualise flood risk assessment in risk maps. Flood risk maps have several primary purposes such as supporting the implementation of community emergency plans, regional land use planning (Fernández-Lavado et al. 2007), and FRM plans (Albano et al. 2017).

The first approach, hydraulic/hydrological models, has been applied in the regions that have time series of streamflow and meteorological data at gauging stations (de Moel et al. 2009). Tsakiris (2014) used two-dimensional fully dynamic flood modelling to simulate flood risk maps for the Rapentoza watershed in Greece. Apel et al. (2016) combined fluvial and pluvial hazard analyses to assess the flood hazard for Can Tho city, Vietnam. Hlavčová et al. (2016) used hydraulic modelling to estimate the flash flood hazard. Hydraulic models have uncertainties due to incomplete input data and non-linear relationship between precipitation, run-off and catchment characteristics (Neuhold et al. 2009, Hlavčová et al. 2016). This approach provides accurate and reliable assessment models; however, it depends on the details of the input data and requires many input parameters such as updated river cross-sections, series meteorological and streamflow data.

The second approach, the measurement of vulnerability and exposure indicators, is used to analyse the vulnerability or/and exposure associated with flood risk. Cutter et al. (2000) presented a method for spatial flood vulnerability assessment using biophysical and social indicators. Scheuer et al. (2011) modelled flood vulnerability via a combination of economic, social and ecological indicators and coping capacity. Mahmood et al. (2017) combined rainfall data with the calculation of the vulnerability index to assess the flood risk in Khartoum State, Sudan. The main limitation of this approach is that the indicators are often equally weighted.

The third approach, spatial multi-criteria decision analysis, has been widely applied in recent studies because of its advantages such as simple GIS integration and decision makers' involvement. Kienberger et al. (2009) used AHP and Delphi techniques to model the socio-economic flood vulnerability in Salzach catchment, Austria. Xiao et al. (2017) used fuzzy AHP and order weighted averaging techniques to build a flood risk assessment map for the lower Han River region, China. Further, de Brito et al. (2018) employed the AHP and ANP methods via experts' judgements to assess flood vulnerability for Lajeado and Estrela, Brazil. Beyond the limitation of the second approach, this approach assigns weights to the criteria based on the judgements of experts or decision makers. However, this approach has several drawbacks such as subjective judgments in weighting indicators (Schmoldt et al. 2001) and subjective model validation. This approach can be potentially applied in data-scarce areas that lack time series meteorological and streamflow data for hydraulic modelling.

The fourth approach, machine learning predictive models, is a very novel approach that applies mathematical algorithms to build predictive risk models. Tehrany et al. (2014) incorporated the weights-of-evidence model and the support vector machine model to provide a flood susceptibility map for Kuala Terengganu, Malaysia. Tien Bui et al. (2016) used neural fuzzy inference and metaheuristic optimisation to map flood susceptibility for the Tuong Duong district, Hoa Binh province, Vietnam. Kourgialas and Karatzas (2017) used the artificial neural network technique to assess flood hazard and then integrate the assessments into the GIS environment to provide a flood hazard map. Similar to the multi-criteria decision analysis approach, this approach can be potentially applied in the data-scarce areas (Wagenaar et al. 2017). In addition, the strong point of this approach is that the model performance can be evaluated and validated via mathematical algorithms. However, this approach has limited the application in the analysis of flash flood and landslide events. The rationale for this is that the machine learning approach requires the existence of the known outcome variables. The flash flood event database can be set for binary classification, therefore, the outcome variables in these studies are binary variables (e.g. flood and non-flood points).

The fifth approach, the combination of hydraulic models and other approaches, utilises mixed approaches to provide assessments on various aspects. Winsemius et al. (2013) used the hydrological model, and the exposure and vulnerability indicators to assess the river flood risk on a global scale. Ronco et al. (2015) combined the hydraulic model with the multi-criteria decision analysis for assessing the flood risk for Sihl River, Switzerland. Vu and Ranzi (2017) integrated an FLO-2D hydraulic model with several indicators (residential area and road network) to assess the annual flood damage for Quang Ngai province, Vietnam.

The fourth approach, spatial multi-criteria decision analysis, was selected for the present study. This approach is suitable for the available data in Vietnam, and it has advantages over the other approaches. Flood risk assessments are used to analyse flood risks (Apel et al. 2008, Jeffers 2013). Flood risk assessments and flood risk analyses lead to the final aim of FRM or flood risk mitigation (Büchele et al. 2006, Dráb and Říha 2010, de Moel et al. 2011). This is the background for developing a conceptual framework for this study, which is presented in detail in Chapter 3 .

## 2.3 Geographic information system

GIS is designed to collect, update, store, process, integrate, search, analyse and display all geographic data forms. Most human activities are associated with a particular location, meaning that with defined geographic coordinates. GIS has become a useful technological platform to integrate the analysis and management of multi-disciplinary information, and to support accurately and timely decision-making process.

GIS can integrate spatial data (maps) with the associated attributes (non-spatial data) along with the tools for data connection, combination analysis and data overlaying (Wieczorek and Delmerico 2009). Therefore, GIS allows policy and decision makers to analyse and assess the current situation, forecast the future, and combine socio-economic development conditions and environmental issues in sustainable development planning. Moreover, when a comprehensive GIS database is created, it can be exploited for managing, planning and selecting priorities for development and environmental improvement. GIS also supports information dissemination through maps and strengthens the public participation in planning, implementing and monitoring processes.

## 2.4 Multi-criteria decision-making methods

MCDM is the most popular decision-making branches (Triantaphyllou et al. 1998, Triantaphyllou 2000). MCDM aims to select the best from a set of alternatives on the basic of the evaluation of multiple criteria. MCDM is classified into Multi-Objective Decision-Making (MODM) and Multi-Attribute Decision-Making (MADM) (Hwang and Yoon 1981). However, the terms MADM and MCDM are commonly used to refer to the same class of models (Triantaphyllou 2000).

MCDM methods are used to deal with quantitative variables and to support decision makers (DMs) in addressing flood management issues such as formulating their alternatives or quantifying these priorities (Levy 2005). Many MCDM techniques are widely applied to FRM such as AHP, ANP, TOPSIS, CP, ELECTREE, MAUT, PROMETHEE, VIKOR and SAW (de Brito and Evers 2016). Among these, two methods were used in this study: AHP and TOPSIS.

TOPSIS was developed by Hwang and Yoon (1981). The application of TOPSIS method is gaining increasing attention in FRM (de Brito and Evers 2016). The main advantages of TOPSIS are its simple process and algorithm; and its ease to use and calculation (Velasquez and Hester 2013). However, this method is based on the metric distance measure, and therefore non-linear preferences cannot be simulated (Mojtahedi and Oo 2016). Another disadvantage is that the judgments' consistency checking is difficult because of the Euclidean distance in this method (Velasquez and Hester 2013).

AHP was proposed by Saaty (1988). AHP fundamentally operates in the decision-making process by quantifying the priorities for multi-criteria using the judgements of one or more DMs or experts (Harker 1987, Millet and Harker 1990). AHP relies upon the judgements of experts, so this method focuses on the quality of experts instead of the number of experts. This method is widely used in making decisions in economics, education, transportation, planning, resources allocation and integrated management (Ramanathan 2001, Vaidya and Kumar 2006).

Several advantages of AHP include the direct DMs opinion involvement, simple GIS integration (Malczewski 1999), criteria and sub-criteria systematisation (Ishizaka and Labib 2009), and consistency in judgement (Koczkodaj et al. 2017). Besides these advantages, this approach has three main limitations. The first one is that the evaluation and ranking of indicators are based on the personal choice and knowledge of DMs or experts, which results in subjective preference in the evaluation (Schmoldt et al. 2001). The second weakness is that this approach requires a large number of pairwise comparisons and the large number of alternatives or criteria make it overwhelming (Harker 1987, Millet and Harker 1990, Carmone Jr et al. 1997). The third drawback is that this method has pair-wise comparisons, which are based on very general and vague criteria (Velasquez and Hester 2013). However, these shortcomings remain in almost MCDM methods (Ishizaka and Labib 2009, Velasquez and Hester 2013).

The assignment of weights has a fundamental role in the risk decision-making process. Weighting articulates the importance or preference of the criteria and is often a subjective process (Chen et al. 2001). The weights of the criteria can be determined by the direct judgements of an expert group (Kienberger et al. 2009, Kokangül et al. 2017) or by statistical methods such as linear regression (Olson 2004), non-parametric resampling (Mojtahedi and Oo 2016), and principal component analysis.

## 2.5 Flood risk analysis using MCDM methods

Flood risk threatens many low-lying, riverine and coastal areas throughout the world, where are usually densely populated (Maaskant et al. 2009, Winsemius et al. 2013). The riverine and coastal flood risks are forecasted to globally increase because of the sea level rise, and the incresees in the cyclone magnitude and rainfall (Bosher et al. 2009b). Recently, there has been a shift of flood policies from the traditional flood protection approach to the FRM approach (Schanze 2006). Following the risk-based approach is the broad application of flood risk analysis and GIS at the local levels (Meyer et al. 2009, Fernández and Lutz 2010, Budiyono et al. 2014, Dahri and Abida 2017), and the global level (Jongman et al. 2012b, Winsemius et al. 2013, Tanoue et al. 2016).

Kappes et al. (2012) proposed an indicator-based methodology for assessing and mapping vulnerability to multiple natural hazards. In this methodology, MCDM methods are applied to assign the weights to the vulnerability indicators, and spatial analytical techniques are used for incorporating the indicators into an assessment map. Papathoma-Köhle (2016) used this approach to assess the debris-flow hazards for South Tyrol.

Furthermore, de Brito and Evers (2016) implemented a systematic literature review of MCDM applications in flood risk analysis via 128 peer-reviewed papers published between 1995 and 2015. The result illustrated that the number of MCDM publications is increasing rapidly, and AHP and TOPSIS are the most applied methods. Besides many advantages, MCDM methods often depend on the personal choice and knowledge of DMs or experts, which lead to subjective judgements in defining the criteria weights (Schmoldt et al. 2001).

The applications of TOPSIS method has been increasing in FRMwith various applications in the recent times. Ghanbarpour et al. (2013) employed TOPSIS to find the best flood control measure by comparing the flood hazard mitigation measures. Mojtahedi and Oo (2016) used a combination of non-parameter resampling bootstrap technique and TOPSIS to rank the flood risk of the states and territories in Australia. Jun et al. (2011) used TOPSIS to assess the four hydrologic vulnerability indices towards sustainable water resources management. The TOPSIS method was used to calculate the scores of alternatives for FRM by Evers et al. (2012). The fuzzy TOPSIS technique has been also applied in many studies on flood risk assessment (Jun et al. 2013, Lee et al. 2013, Lee et al. 2014). However, no application of TOPSIS has been undertaken for the flood risk assessment in Vietnam.

AHP is the most widely used MCDM method for assessing flood risk. Gao et al. (2007) used AHP to assess the flood vulnerability of Dongting lake region in China. Jiang et al. (2009) applied AHP to assess the flood risk for seven counties in Malaysia. Kienberger et al. (2009) used AHP with four expert-derived weights for the flood vulnerability assessment in Salzach catchment, Austria. Fernández and Lutz (2010) incorporated AHP in GIS to provide flood hazard map for Tucuman province in Argentina. Ozturk and Batuk (2011) combined AHP in a GIS framework for determining the flood vulnerability of South Marmara Basin, Turkey. Thanh and De Smedt (2011) used AHP-WLC to map the landslide susceptible zones in A Luoi district, Thua Thien Hue province, Vietnam. Le Cozannet et al. (2013) used AHP to derive the weights for a physical flood vulnerability map. Ouma and Tateishi (2014) built a flood vulnerability assessment map by using integrated AHP-GIS. Chen et al. (2015) provided a spatial AHP-derived evaluation framework for regional flood risk analysis with a case study in central Queensland, Australia. Dahri and Abida (2017) applied Monte Carlo AHP and GIS techniques to delineate a flood susceptibility map in Gabes river basin, Tunisia. de Brito et al. (2018) presented a participatory AHP and ANP approaches for assessing the flood vulnerability in Lajeado and Estrela, Brazil. However, it still lacks the applications of AHP, especially the potential application of AHP-GIS in mapping flood risk assessment in Vietnam.

## 2.6 Spatial multi-criteria decision analysis for assessing flood risks

### *2.6.1 MDCM-GIS integration*

GIS allows the collection, storage, analysis and management of geographic information, and is a vital element in risk assessments. The GIS software can be used for topographic or hydrological models, maps, and spatial assessment. GIS is a core tool for spatial analysis and is appropriate to handle the spatial flood risk data (Meyer et al. 2009). GIS analytical techniques have been widely applied for flood risk assessments (Finn and Thunen 2014). Following the risk-based approach for flood problems, there is an emerging trend of the integration of MCDM methods and GIS analytical techniques for assessing risk (de Moel et al. 2009, Meyer et al. 2009). GIS-based MCDM can be considered a process that combines spatial data and the DMs' judgments to gather information for the decision-making process (Malczewski 1999, Malczewski 2006).

Spatial flood risk assessment can determine at-risk elements and specify at-risk locations, thereby providing reliable information for FRM activities (Lindley et al. 2007). The incorporation of flood risk assessment into a GIS framework has been applied in many recent studies (de Moel et al. 2009, Meyer et al. 2009, Karmakar 2010, Ward et al. 2010, Jongman et al. 2012b, Winsemius et al. 2013, Budiyono et al. 2014, Foudi et al. 2015, Koks et al. 2015, Tang et al. 2018). Meyer et al. (2009) combined MCDA with GIS for assessing the flood risk of River Mulde in Saxony, Germany. Furthermore, de Moel et al. (2009) developed a framework for mapping the flood hazard and risk assessments. Koks et al. (2015) proposed a methodology to assess the flood hazard, exposure and vulnerability jointly. Tang et al. (2018) used the Monte Carlo AHP and GIS approach for delineating flood susceptible maps for Gucheng County, China.

The MCDM-GIS models are used for spatial analysis of various assessments and decision problems (Malczewski and Rinner 2015b). Weighted Linear Combination (WLC) technique is widely applied to integrate MCDM methods into a GIS framework (Malczewski 2000). AHP can be used to determine weights for the indicators, and then WLC is used to integrate the weighted factor layers into a GIS framework (Dewan 2013c).

### *2.6.2 Flood hazard assessment map*

A flood hazard assessment map is an essential tool for formulating mitigation strategies and raising public awareness about flood risk (Vojinovic 2015). The flood assessment hazard map is aimed to inform decision makers, planners and communities of the extent of flood hazard areas to take suitable flood risk mitigation measures (WMO 2013b).

Flood hazard maps together with FRM action plans are the primary control instruments for managing flood risk (Directive 2007/60/EC).

Flood hazard maps can be developed by using hydrological and hydraulic models, which produce inundation maps for several periods (Apel et al. 2008, Winsemius et al. 2013). The hydrological and hydraulic models require observed and simulated input parameters (e.g. updated river cross-sections, time series meteorological data and observed discharge data) (de Moel et al. 2009). Many regions lack these data because of the lack of hydro-meteorological observation stations with longitudinal data. In contrast, flood hazard maps can be generated using a Digital Elevation Model (DEM) and historical flood depth data (Hagemeier-Klose and Wagner 2009, Bhuiyan and Baky 2014, Chau et al. 2014b). The flood depth data of historical flood events are the most crucial indicator for assessing flood hazard. Besides, the flood duration factor has severe impacts, particularly in agricultural areas. Farm produce such as paddy fields (Kent and Johnson 2001) and orchards (Guo et al. 1998).can be destroyed in cases of a long duration of water logging.

Several researchers have developed flood hazard maps for the Quang Nam province, e.g. Chau et al. (2013) and Ho and Umitsu (2011). Chau et al. (2013) used a DEM with the grid of 30 m x 30 m, land use map, and flood depth markers to predict inundation of Quang Nam. Ho and Umitsu (2011) used a DEM, LANDSAT image, and flood depths of the 1999 historical flood event to construct a flood hazard map for the Vu Gia-Thu Bon river basin. Only the flood depth data was considered to create the flood hazard maps for Quang Nam province; and the flood duration indicator was not integrated into these maps.

The socio-economic data and geospatial data in Chau et al. (2013) were used with the assumption that land use and topography data have remained unchanged since the data were collected. However, flood risk analysis and management requires accurate and up-to-date data for at-risk areas (Ward et al. 2010). This drawback can be solved by future studies with updated input data.

### *2.6.3 Flood risk assessment map*

Flood risk can be considered to be a combination of flood hazard, exposure and vulnerability (Merz et al. 2014, UNISDR 2015a) to deal with FRM problems. Flood risk assessment incorporates flood hazard information with the exposure data of populations and assets, and their vulnerability to the hazard (Jha et al. 2012). This assessment can explicate the recognition of flood characteristics. Dráb and Říha (2010) adopted the European Directive (Directive 2007/60/EC) for analysing the implementation of FRM in the Czech Republic. Spatial flood risk assessment is a useful tool to underline risks and identify vulnerabilities that help to prepare appropriate adaptation and mitigation measures (Büchele et al. 2006, Lindley et al. 2007).

The incorporation of flood risk assessment into a GIS framework has been applied in many recent studies (Karmakar 2010, Ward et al. 2010, Jongman et al. 2012b, Winsemius et al. 2013, Budiyono et al. 2014, Foudi et al. 2015). To summarise literature reviews, there are three popular frameworks in this field, namely KULTURisk of Giupponi et al. (2013), Damage Scanner Model of Klijn et al. (2007), and integrated AHP-WLC of Dewan (2013c).

The approach of flood risk assessment in the KULTURisk framework (Giupponi et al. 2013) is a combination of hazard, vulnerability and exposure as shown in **Figure 2-1**. This framework was developed by Giupponi et al. (2013) and is available at http://www.kulturisk.eu/. This framework has been applied in several recent studies

(Ronco et al. 2014, Gain et al. 2015, Giupponi et al. 2015, Mukolwe et al. 2015, Ronco et al. 2015).

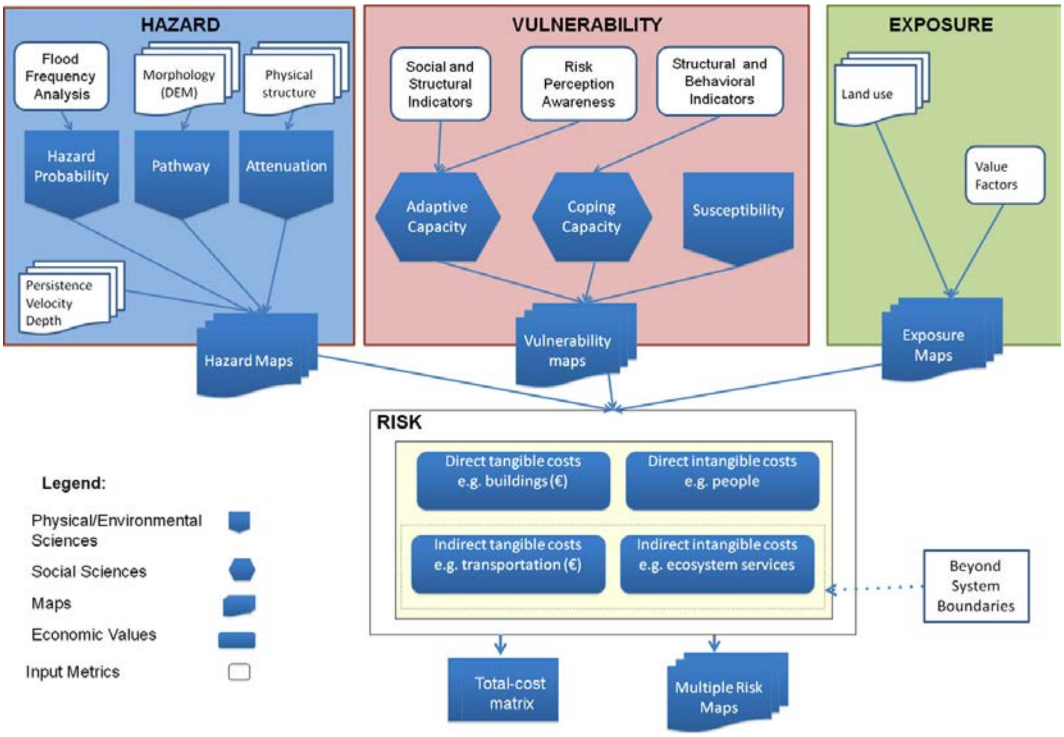


***Figure 2-1**: KULTURisk framework for assessing flood risk (Gain et al. 2015)*

Damage Scanner Model (DSM) is used to assess flood risk by overlaying maps. DSM was developed by Klijn et al. (2007). This model has then been applied to many case studies in European basins (Bouwer et al. 2009, Bouwer et al. 2010, Aerts and Botzen 2011, de Moel and Aerts 2011, te Linde et al. 2011, Ward et al. 2011, Jongman et al. 2012a), and in Jakarta, Indonesia (Ward et al. 2010, Budiyono et al. 2014). Bouwer et al. (2010) used three land-use scenarios as input for DSM to analyse the future flood risk in the Dutch polder area. Budiyono et al. (2014) used DSM to assess the flood risk in Jakarta, Indonesia by combining three flood risk components (hazard, exposure and vulnerability) in a flood risk map (**Figure 2-2**).

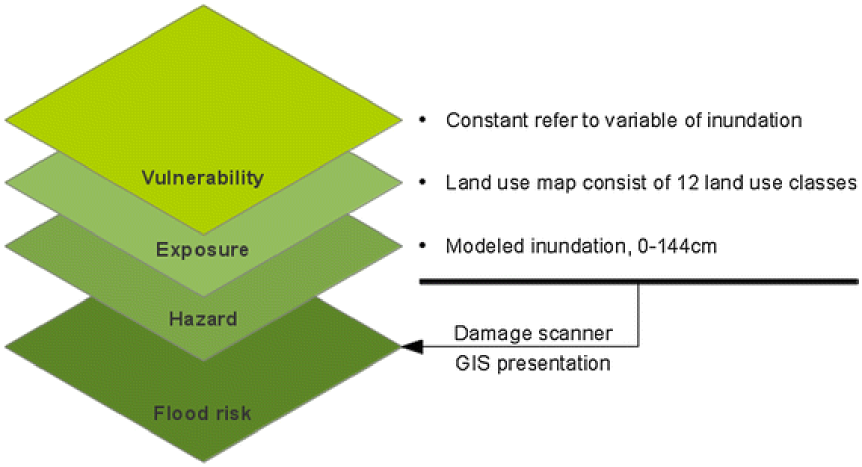


***Figure 2-2***: *Flood risk assessment model of Budiyono et al. (2014)*

The spatial multi-criteria decision analysis framework shown in **Figure 2-3** is the combination of AWH and WLC in a GIS environment. First, AHP  is used to define weights for flood risk indicators, and then WLC is used to integrate the weighted factor layers into a GIS map (Dewan 2013c). In this research, flood risk is assessed by a composite vulnerability index, which is a combination of physical vulnerability, social vulnerability and coping capacity.

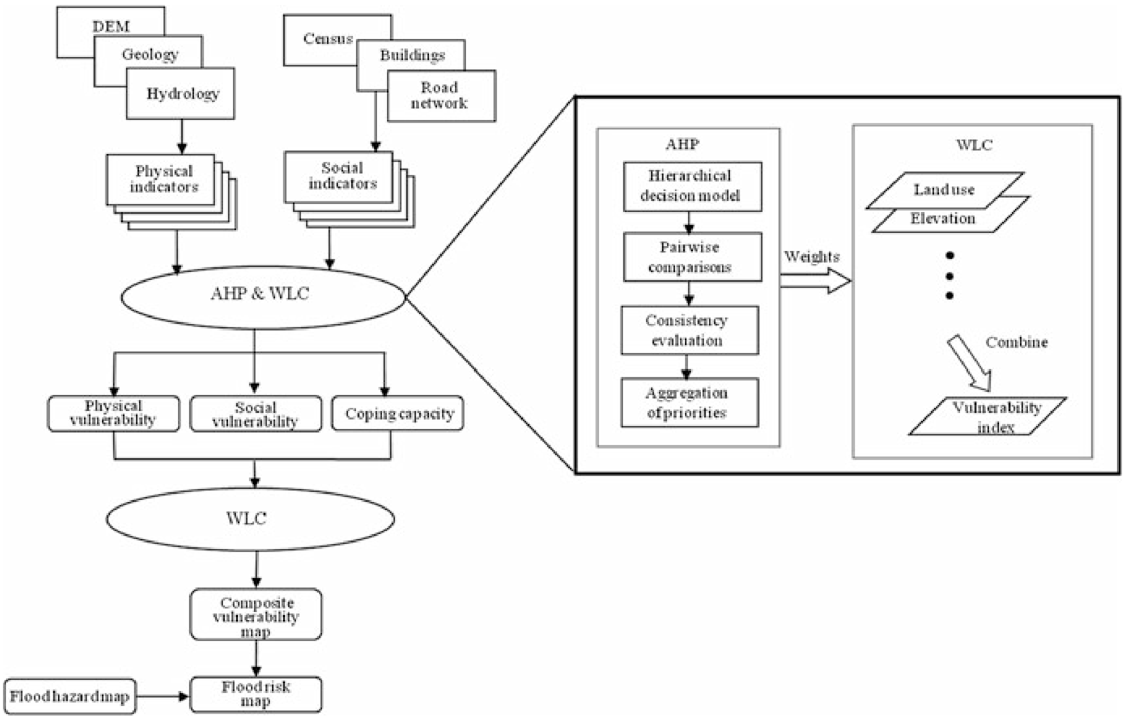

***Figure 2-3**: Spatial multi-criteria decision analysis for assessing flood risk in an integrated AHP-WLC framework (Dewan 2013c)*

Research on flood risk analysis has been increasing with case studies in Vietnam. Several hydraulic models were built for mapping flood risks in Mekong Delta of Vietnam (Apel et al. 2016, Triet et al. 2017). Chau et al. (2013) applied GIS analytical techniques to map the impacts on the agriculture sector of extreme floods for Quang Nam province. In another research, Chau et al. (2014a) used a cost-benefit analysis tool to assess the flood impacts on agricultural production in Quang Nam province. The risk management framework in standard AS/NZS 4360:1999 was adapted for analysing FRM in the case studies of Thua Thien Hue province (Tran et al. 2009) and Da Nang city (Razafindrabe et al. 2012). Several geospatial assessment tools have been used for flood risk assessments (Tran et al. 2009, Ho and Umitsu 2011, Chau et al. 2013). Some statistical machine learning models have recently been developed for flash flood susceptibility maps (Tien Bui et al. 2016, Tien Bui and Hoang 2017). However, there has been little research on specific flood risk assessments with the combination of MCDM and GIS in Vietnam. Against this backdrop, this study uses a spatial multi-criteria decision analysis to generate a flood risk assessment map for Quang Nam, Vietnam.

## 2.7 Flood fatality analysis

The Global Disaster Database identifies Asia as the most vulnerable continent to flood and storm events, with approximately 3,620 floods and storms resulting in at least 8,085,516 fatalities between 1900 and 2016 (**Figure 1-1**). Laurens and Bas (2017) explored the EM-DAT database over the period 1900-2015 and found that the trend of flood fatality is decreasing for all global regions, except South East Asia. Within this region, Vietnam is among the most vulnerable countries being the eighth most intensely affected by extreme weather events (1996-2015) (Kreft et al. 2016) and the fourth most exposed to river flood risk by the proportion of population (Luo et al. 2015).

The loss of life is a critical indicator in flood risk evaluation and is frequently used to assess the severity of a flood event (Maaskant et al. 2009, Boudou et al. 2016). Some frameworks have been proposed to estimate flood fatalities. Penning-Rowsell et al. (2005) proposed a method to predict injuries and deaths in floods on the basic of flood characteristics. Jonkman and Vrijling (2008) developed an approach to estimate flood fatalities using the following three steps: analysis of specific flood characteristics, estimation of the total number of exposed people, and assessment of the fatality rate among the exposed population.

Flood-related fatality has been extensively studied in developed countries, e.g. Coates (1999), Ashley and Ashley (2008), FitzGerald et al. (2010), Diakakis and Deligiannakis (2013), and Sharif et al. (2015), while there has been little research on the flood fatalities reported in the developing countries, e.g., Paul and Mahmood (2016) despite their higher fatality rates.

In the research on flood fatalities, the two common approaches are (1) building predictive flood fatality models (Jonkman et al. 2002, Zhai et al. 2006, Jonkman and Vrijling 2008, Di Mauro et al. 2012), and (2) analysing the circumstances and causes of flood fatality (Jonkman and Kelman 2005, Jonkman et al. 2009, Paul and Mahmood 2016). The predictive models are often combined with hydraulic models and contain a large amount of detailed meteorological data and specific flood characteristics (Jonkman and Vrijling 2008). The approach of analysing causes and circumstances is applied to specific events or regions with detailed information about the demographic characteristics and behaviours of flood victims.

Vietnam is facing a higher frequency and intensity of floods and storms. Floods have caused havoc in poor communities in Vietnam with around 80% of the population living in the rural areas. Floods and storms have led to loss of crops and houses and have trapped many Vietnamese farmers in a vicious cycle of poverty. Flood fatalities are unacceptably high, with at least 14,927 dead and missing people between 1989 and 2015. However, there have been no studies on flood-related fatalities in Vietnam.

## 2.8 Flood risk management

### *2.8.1 Four-stage disaster management cycle*

Peek and Mileti (2002) reviewed the history of disaster research and summarised a four-stage cycle of mitigation, preparedness, response and recovery as indicated in **Figure 2-4**. A disaster management strategy is developed with the objective of reducing risk-related losses such as life, injury, money, and economic disruption. Many studies on disaster management have been organised around the four stages of mitigation, preparedness, response and recovery (Altay and Green 2006, Moe and Pathranarakul 2006, Khan et al. 2008, Bosher et al. 2009a, Slobodan 2011).

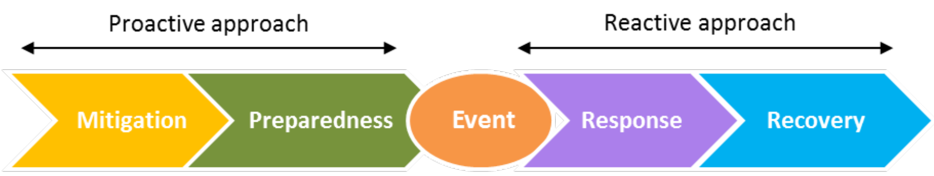


***Figure 2-4****: Disaster management approaches*

Disaster management aims to reduce the impact of disasters through interconnected mitigation, preparedness, response and recovery activities (Peek and Mileti 2002, Moe and Pathranarakul 2006, Slobodan 2011). Similar to disaster management, FRM includes mitigation, preparedness, response, and recovery activities (Moe and Pathranarakul 2006, Mojtahedi and Oo 2017). FRM activities can help to reduce the adverse impacts of floods and improve flood resilience (Bosher et al. 2009a), in particular, a proactive approach (mitigation and preparedness) can significantly minimise deaths and damages (Moe and Pathranarakul 2006). The details of FRM activities are listed in **Table 2-1**.

***Table 2-1*** *FRM activities adapted from ADRC (2005) and Altay and Green (2006)*

| FRM stage | Detailed activity item |
|---|---|
| **Mitigation** | Zoning and land use controls to prevent construction in flood-prone areas |
| | Developing flood risk management plan |
| | Training and education on flood risk management |
| | Developing information systems for flood risk management |
| | Providing timely and efficient information related to flood risk |
| | Constructing and consolidating the dyke/tide wall, embankment and drainage systems |
| | Focusing on forest management such as forestation and forest protection |
| | Analysing risks to measure the flood-prone areas |
| | Focusing on water resource management such as river basin management |
| | Constructing and consolidating the dyke/tide wall, embankment and drainage systems |
| **Preparedness** | Constructing and consolidating meteorological observation systems |
| | Preparing hazard maps |
| | Constructing early warning communication systems |
| | Stockpiling food and material |
| | Evacuating people and properties from threatened locations |
| | Constructing shelters |
| | Developing community's awareness of flood risk management |
| | Preparing emergency kits (vehicles and equipment) |
| | Developing coordination and collaboration procedures among stakeholders |
| | Conducting emergency drills to train personnel and test capabilities |
| | Recruiting personnel for flood emergency services |
| **Response** | Activating the flood emergency operation plans |
| | Providing information on flooded areas to the public |
| | Implementing effective mobilisation of resources |
| | Evacuating threatened populations |
| | Rescuing populations in flooded areas |
| | Constructing temporary housing (tents) |
| | Providing first aid treatment |

| | |
|---|---|
| | Operating shelters and supply of mass care |
| | Monitoring secondary disasters |
| | Recording detail impacts |
| | Estimating economic damages |
| **Recovery** | Cleaning flood debris |
| | Reconstructing infrastructures (water supply, electricity supply, schools, roads, bridges, dykes, embankment and so on) |
| | Controlling and monitoring diseases after the floods |
| | Providing aid for residents in the flooded areas |
| | Supporting the affected residents to restore livelihood |
| | Developing appropriate land use planning |
| | Documenting lessons learned and best practices in the recovery phase |

### *2.8.2 Flood risk management frameworks*

Many frameworks are available in the field of disaster risk management. One of the typical frameworks is the disaster risk reduction model of Davidson (1997), shown in **Figure 2-5**. This model has been adopted in many studies (Chen et al. 2001, Bjarnadottir et al. 2011, Cardona et al. 2012, Dewan 2013b). The four factors have been identified as contributing to disaster risk: hazard, exposure, vulnerability, capacity and measures (Davidson 1997).

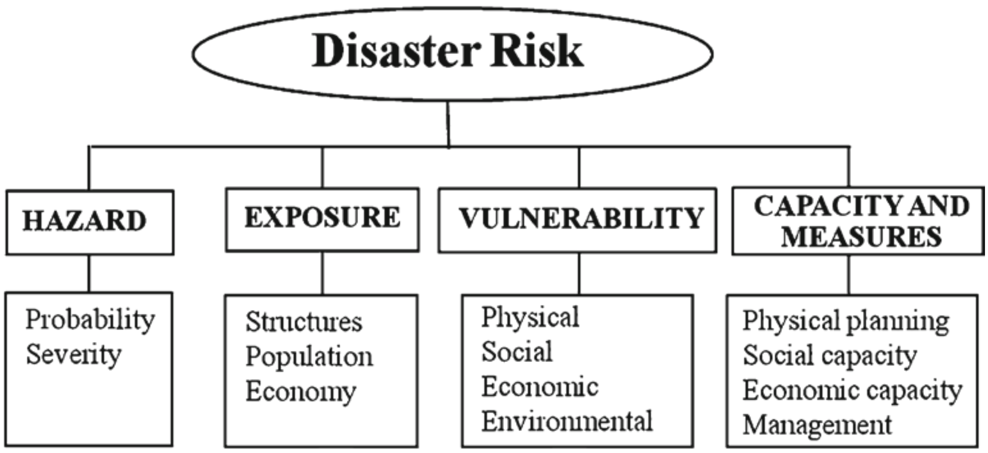


***Figure 2-5**: Conceptual framework to identify disaster risk (Davidson 1997, Bollin and Hidajat 2006, Dewan 2013b)*

A proper risk management framework could allow and ensure effective risk management activities; therefore, three risk management frameworks of international standards were reviewed. The first framework is a risk management process framework provided in the AS/NZS ISO 31000:2009 risk management standard of Australia and New Zealand (**Figure 2-6**). Tran et al. (2008) and Razafindrabe et al. (2012) adapted this standard for analysing FRM in Thua Thien Hue province and Danang city. The second framework is the Flood Risk Directive of Europe (Directive 2007/60/EC). This directive emphasises the establishment of a framework for flood risk assessment and risk mapping. Dráb and Říha (2010) adopted the European Directive for investigating the implementation of FRM in the Czech Republic. The third framework is the New Zealand Standard for managing flood risk (NZS 9401:2008). This standard provides a FRM framework for New Zealand as shown in **Figure 2-7**. Kobayashi and Porter (2012) adapted this framework to develop a strategic flood management framework for China.

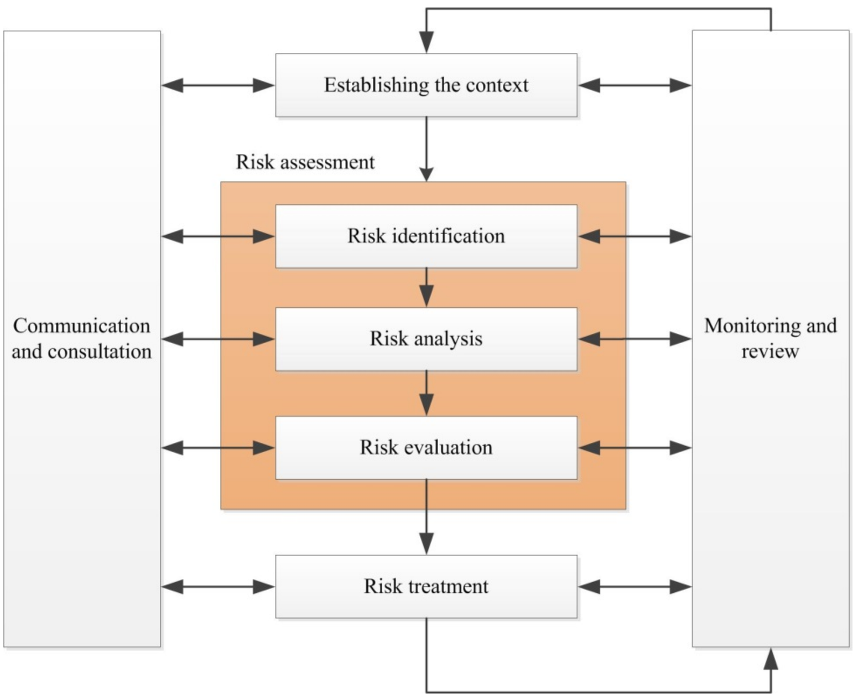


***Figure 2-6**: A risk management framework (source: (AS/NZS ISO 31000:2009))*

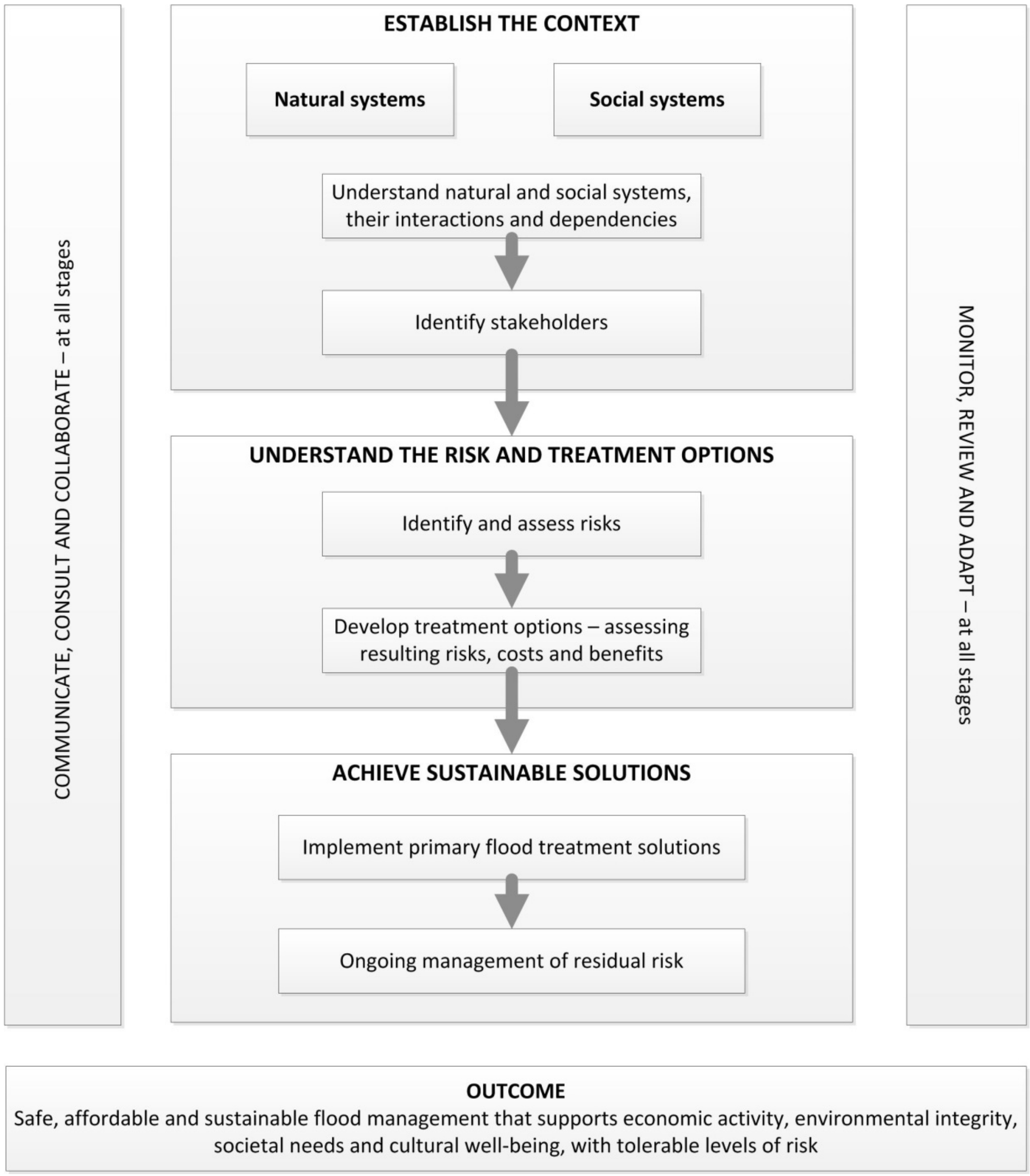


***Figure 2-7****: Flood risk management process (source: (NZS 9401:2008))*

Based on the above standards (AS/NZS ISO 31000:2009 and NZS 9401:2008), the risk management process can be summarised in the following stages:

- Assessment: identify and analyse hazards, vulnerability and risk in a particular location and develop the respective maps.
- Evaluation: weight and consider people's perception of risks and the communities' willingness to reduce risks to invest for increased safety.

- Management: develop overall concepts and particular risk reduction projects by using preventive and preparedness measures.
- Measuring: establish monitoring systems and measure the effectiveness of risk reduction.

Moe and Pathranarakul (2006) first developed an integrated framework for disaster management on the basic of the conceptual public project management as shown in **Figure 2-8**. This framework was then applied to analyse the stakeholders' engagement in FRM in Mojtahedi and Oo (2014) and Mojtahedi and Oo (2017).

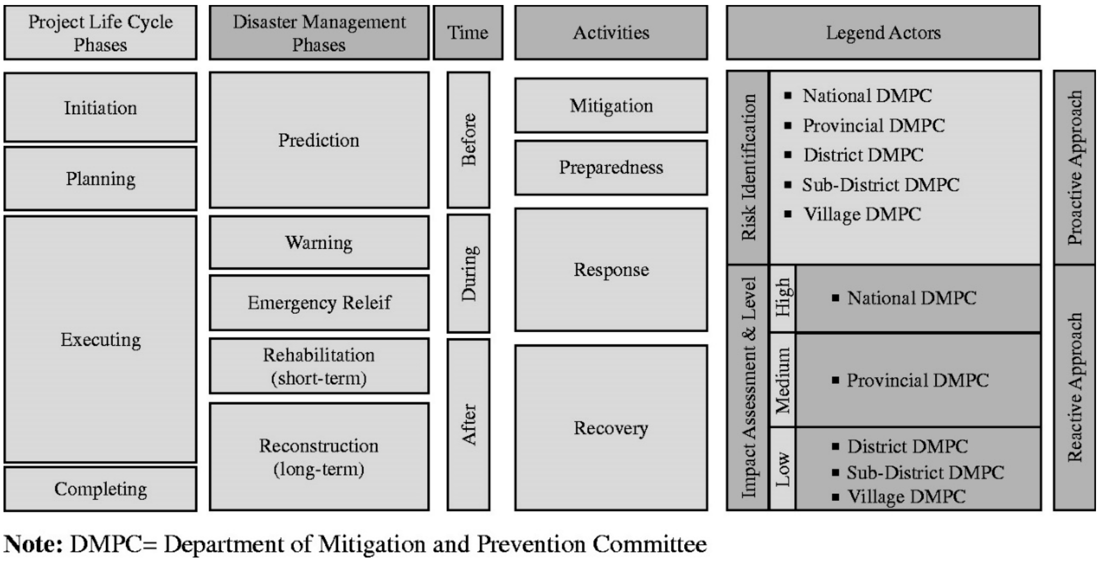


***Figure 2-8****: Integrated disaster management framework (Moe and Pathranarakul 2006)*

## 2.9 Summary

This chapter presented literature reviews on flood risk analysis and its application in a GIS environment, MCDM methods and their application of MCDM methods in flood risk analysis, spatial multi-criteria decision analysis in flood risk assessment, flood fatality analysis, and flood risk management frameworks. The review showed that the application of the MCDM methods and the spatial multi-criteria decision analysis have attracted increasing attention in FRM; however, this approach is lacking in Vietnam.

The chapter also reviewsd standard risk management frameworks, which can be referenced to develop a FRM framework for Vietnam.

# Chapter 3 Conceptual framework

## 3.1 Introduction

This chapter begins with the factors of flood risk discussed in Section 3.2. A conceptual framework is proposed in the following section (Section 3.3). The conceptual framework is operated to address the research questions presented in Section 1.3 and the research objectives discribed in Section 1.4. The operationalisation of the conceptual framework is presented in Section 3.4, including five components of the thesis. The last section (Section 3.5) summarises the five components in a research flowchart.

## 3.2 Factors of flood risk

Flooding is the natural method for river systems to discharge the water resulting from massive rainfall events (WMO 2006a). Flood risk is a common threat to many populous and low-lying areas (Maaskant et al. 2009). A risk-based approach for flood hazards has gained increasing attention alongside the increase in severe flood events in the recent decades (de Moel et al. 2012). Following this approach, flood risk is determined as a product of the probability and consequences of a flood event (Ward et al. 2011).

Risk assessments are made to measure the social, economic and infrastructural effects that may result from a particular hazard. Flood risk is assessed by the likelihood or probability of a flood event and its impacts or consequences (Sayers et al. 2002a, WMO 2013b). Alternatively, flood risk is the probability of losses and includes the three components of hazard, exposure and vulnerability (Winsemius et al. 2013, Glosińska 2014, UNISDR 2015a). The changes in flood risk are linked to the changes in flood hazards, exposure and vulnerability as indicated in **Figure 3-1**.

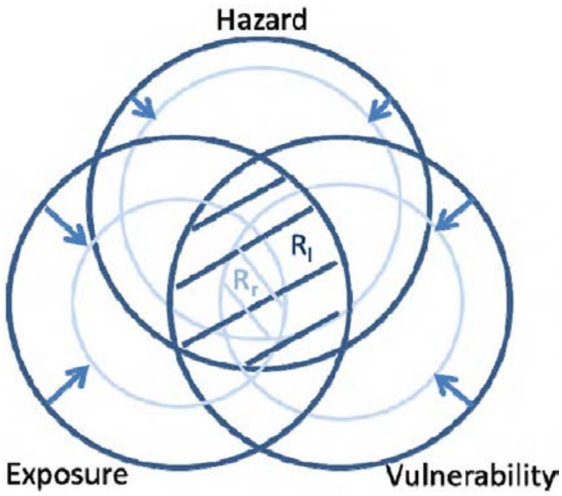


***Figure 3-1****: Flood risk illustrated as a combination of flood hazard, vulnerability and exposure (WMO 2013b)*

The relationship between risk factors and flood risk reduction is illustrated in **Figure 3-1**. Flood risk reduction measures aim to reduce or modify the three components of flood risk. The risk of floodings can be managed by reducing the possible consequences (de Moel et al. 2015). The consequences are determined by the exposure and vulnerability to a hazard event (Kron 2005, Lindley et al. 2007, Maaskant et al. 2009, Jongman et al. 2012b, Kobayashi and Porter 2012). These three components are often taken into account when evaluating potential risks.

Flood hazard can be determined as the probability of a certain level of danger occuring at one location and as natural and man-made triggers (Kron 2005, Field 2012). Flood hazard is driven by flood depth, velocity and duration (Boudou et al. 2016).

Exposure represents people, property, livelihoods, environmental resources and infrastructure exposed to a hazard event (Field 2012). The exposure to flooding is estimated through the population in potential inundation areas and acts as a proxy for assessing flood risk (Peduzzi et al. 2009, Jongman et al. 2012b). Maaskant et al. (2009) defined exposure as the number of people and the value of assets subject to flooding.

Exposure is related to the inventory of population and economic resources in hazard-prone areas (Cardona et al. 2012).

Vulnerability is defined by the propensity to be adversely affected by a hazard event (Kron 2005, Field 2012, Jongman et al. 2012b). Cardona et al. (2012) determined vulnerability as the predisposition of exposed factors such as people, livelihoods and properties affected by a hazard event. Vulnerability can be identified on the basic of social, economic, cultural and ecological characteristics of affected areas (Krishnamurthy et al. 2011). Kubal et al. (2009) devised the criteria for three dimensions of vulnerability including economic, social and ecological indicators to assess the flood risk vulnerability.

## 3.3 Conceptual framework

This study focused on the flood risk analysis or flood risk assessment and management for Vietnam, whose context is presented in the previous chapter including Sections 2.5, 2.7, 2.6 and 2.7. **Figure 3-2** depicts the proposed conceptual framework that demonstrates the inter-relationships between flood risk components, flood risk assessment and FRM.

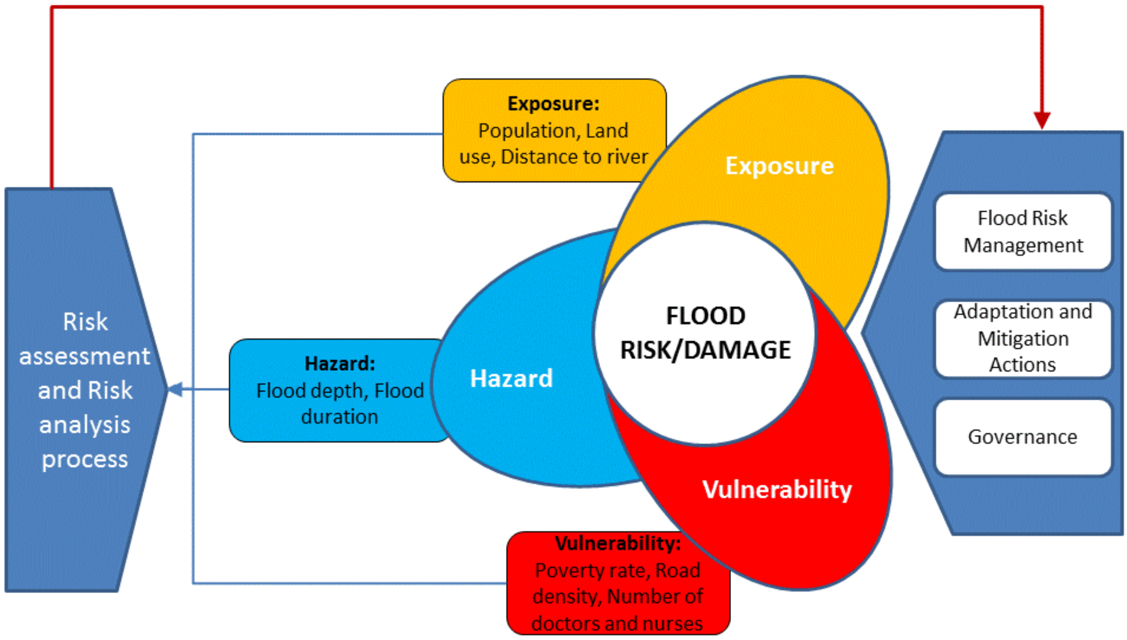


***Figure 3-2****: Conceptual research framework proposed for this study*

This study aimed to incorporate the flood hazard information within the context of the data on flood exposure and vulnerability to a hazard event. Flood risk is assessed on the basic of three components of hazard, vulnerability and exposure. The indicators of flood risk components are adapted from various studies and based on a critical analysis of the available data in Vietnam. They are listed in **Table 3-1**.

***Table 3-1*** *Measurement indicators for flood risk components*

| Components | Indicator | Data source | Reference |
|---|---|---|---|
| Flood hazard | Depth | Flood mark data | Zou et al. (2012), Dewan (2013c), Foudi et al. (2015), Gain et al. (2015), Ronco et al. (2015) |
| | Duration | | Boudou et al. (2016), Chinh et al. (2017), Vu and Ranzi (2017) |
| Flood exposure | Land-use | Land-use map | te Linde et al. (2011),, Zou et al. (2012), Dewan (2013c), Ouma and Tateishi (2014), Gain et al. (2015), Ronco et al. (2015) |
| | Distance to rivers | River network map | Dewan (2013c), Terti et al. (2017) |
| | Population density | Statistical yearbooks | Wang et al. (2011), Peduzzi et al. (2009), Zou et al. (2012), Dewan (2013c), Gain et |

| | | | |
|---|---|---|---|
| | | | al. (2015), Ronco et al. (2015), |
| Flood vulnerability | Poverty rate | Statistical yearbooks | Tran et al. (2008), Dewan (2013c), Winsemius et al. (2015) |
| | Road density | Road network map | Scheuer et al. (2011), Dewan (2013c), Ronco et al. (2015) |
| | Number of doctors and nurses | Statistical yearbooks | Scheuer et al. (2011), Dewan (2013c) |

The flood depth and duration were used to analyse the flood hazard in this study. The flood mark data were collected after disastrous flooding events occurred in 1999, 2004, 2007, 2009 and 2013 by Quang Nam Provincial Steering Committee of Natural Disaster Prevention and Control. The flood marks of the years 2007 and 2009 only contained flood depth data. The flood marks of the year 2013 included both flood depth and flood duration data.

Three criteria, namely land-use categories, distance to rivers, and population density - were considered in this study to estimate the flood exposure. Land-use categories are often used to calculate the losses in flood risk assessment models (Bouwer et al. 2010). The distance to rivers criteria were derived from the river network data. It was assumed that people living close to river systems are at a higher risk than those who did not (Dewan 2013a). Further, population density is the most critical criterion in assessing flood risk as it is defined by human settlements. More densely populated areas are at a higher risk when floods occur (Peduzzi et al. 2009).

Three other criteria, namely poverty rate, road density, and the number of doctors and nurses, are also used in this study to estimate vulnerability. The poor are more likely to be affected by disasters (Winsemius et al. 2015), and poverty is often seen as a structural cause of vulnerability. The poverty rate criterion is therefore critical to this study. Infrastructure, such as roads, plays a significant role in response (e.g., evacuation) and recovery activities (Dewan 2013a), and locations without infrastructure suffer. Meanwhile, understanding the number of healthcare facilities in flood-prone areas is critical to our knowledge of the level of preparedness in an area (Dewan 2013a). The Quang Nam province lacks data on the number of hospitals but has data on the number of doctors and nurses in each commune, so this criterion is considered in analysing flood vulnerability. More criteria, such as gender, age and persons with disabilities, could be added to analyse flood vulnerability; however, such data are lacking in the research area.

Risk assessment maps include hazard characteristics (e.g., location, frequency, probability and intensity), exposure and vulnerability indicators (e.g., physical, health, social, environmental and economic dimensions), and coping capacity in risk scenarios. The risk assessments are sometimes considered a risk analysis process.

There always remains a residual flood risk after the implementation of structural FRM. The trend is to incorporate non-structural measures into FRM strategies. Flood insurance is one of the solutions for managing residual flood risk (Crichton 2008). It supports and complements non-structural approach in developed countries such as Germany (Surminski and Thieken 2017), the United Kingdom (Botzen and van den Bergh 2008) and Australia (Lamond and Penning-Rowsell 2014). In Vietnam, there is a lack of access to public resources such as insurance and emergency relief during flood events (Chau et al. 2014b). Those most affected by disasters are the most marginalised, discriminated against, dispossessed and displaced in Vietnam. They face relatively grave difficulties as the affected households often receive extremely limited financial support from local governments according to Decree 67/2007/ND-CP. The poverty rate, as is common on a global scale, is invariably linked to the disaster impact.

Disaster impact data collection and analysis (UNISDR 2015b) can support fundamental information for policy-setting and decision-making in disaster risk reduction (IRDR 2014). Many available disaster databases at the national, regional and global scales are itemised and compiled in the reports of Grasso and Dilley (2013) and Simpson et al. (2014). It is necessary to translate disaster loss data into meaningful information (Gaillard and Mercer 2013).

Vietnam is highly vulnerable to flood and storm events, with severe impacts on human life over the years. However the country lacks studies on detailed flood risk assessment tools developed at the local and national levels. Following the conceptual framework, this study aims to investigate flood risk with detailed assessments at the local and national levels, and FRM in practice.

Flood risk assessments at the local levels are crucial as they can support the decision-making process in FRM. Considering the population increase and urban development, I believe it is essential to understand the spatial flood risk assessment, which could allow effective flood mitigation measures in the future.

In Vietnam, the official national Damage Assessment and Needs Analysis (DANA) database is developed by the Central Government of Vietnam through the Central Committee for Flood and Storm Control. This database stores information regarding the direct damages of flood disasters in Vietnam since 1989 (Below et al. 2010, Hughey et al. 2011). Some researcher, such as Hughey et al. (2011) and Nhu et al. (2011), have evaluated the quality of the DANA database. However, further analysis and assessment of the flood risk from this database have not been undertaken.

This study first evaluated and analysed the flood risk at the national level through Vietnam's national disaster database. Second, a case study for a typical province was investigated for a comprehensive flood risk assessment using the MCDM-GIS framework. Third, FRM activities at local scales were examined along with the legal and institutional frameworks that are supposed to focus but often restrict, policy and practice.

Quang Nam was selected for conducting a case study in this thesis. Successive flood events have significantly impacted residents’ livelihood and the socio-economic development in Quang Nam province. Risk management approaches can help to reduce the adverse impacts of flood risk in this area. Before a disaster ever materialises, FRM activities should be implemented to mitigate risk and discuss the avoidance of activities that actually create risk. Land use management is considered an effective measure in managing flood risk (Jha et al. 2012). Flood risk assessment maps are essential tools for developing risk reduction strategies and raising risk awareness in communities (Vojinovic 2015).

A case study was designed in which data was collected, and included secondary data sources, and in-depth interviews and AHP questionnaires as the primary data. Fieldwork was conducted in Quang Nam province with three main objectives: (1) collecting the secondary data including flood marks, flood damage data and GIS data, (2) conducting AHP questionnaire survey with the local staff for collecting their judgements on the flood risk factors, and (3) condcuting interviews with the local staff working in the committees at the commune, district and provincial levels to investigate FRM activities at their localities.

## 3.4 Operationalisation of the conceptual framework

This study was based on detailed flood risk assessments at the local and national levels, and FRM in practice. The conceptual framework (Section 3.3) was implemented to address the research questions presented in Section 1.3. In this study, each research question was addressed via a research approach. Five research approaches are presented in the following subsections and summarised in a flowchart in the next section.

### *3.4.1 Flood risk evaluation*

Flood risk threatens many low-lying, riverine and coastal areas throughout the world, which are usually densely populated (Maaskant et al. 2009, Winsemius et al. 2013). The riverine and coastal flooding risks are forecasted to increase because of the sea level rise, and the growth of the tropical cyclone magnitude and rainfall globally (Bosher et al. 2009b). Recently, there has been a change of flood policies from traditional flood protection to FRM pattern (Schanze 2006). Following the risk-based approach, GIS techniques are broadly used in flood risk assessments at the local scales (Meyer et al. 2009, Fernández and Lutz 2010, Budiyono et al. 2014, Foudi et al. 2015, Nguyen and Woodroffe 2015) and the global scale (Jongman et al. 2012b, Hirabayashi et al. 2013, Winsemius et al. 2013, Muis et al. 2016, Tanoue et al. 2016). The spatial flood risk assessments are beneficial tools for identifying at-risk locations with different risk levels (Büchele et al. 2006, Mazzorana et al. 2012). They serve to set appropriate flood mitigation and adaptation actions.

The TOPSIS method has been applied in many recent studies in FRM (de Brito and Evers 2016). Jun et al. (2011) used TOPSIS to assess the four hydrologic vulnerability indices towards sustainable water resources management. The TOPSIS method was applied to calculate the scores of alternatives for managing the flood risk by Evers et al. (2012). Ghanbarpour et al. (2013) employed TOPSIS to find the best flood control measure by comparing the flood hazard mitigation measures. Mojtahedi and Oo (2016) used a combination of non-parameter resampling bootstrap technique and TOPSIS to rank the flood risk of the states and territories of Australia. The fuzzy TOPSIS technique has been also applied in many studies on flood risk assessment (Jun et al. 2013, Lee et al. 2013, Lee et al. 2014).

This study proposed a combination of the multiple linear regression technique and TOPSIS to investigate Vietnam's national disaster database. The multiple linear regression technique was used to generate the weights for flood damage attributes. The goal is to score and rank the flood risk for 8 regions and 63 provinces in Vietnam. Then, the flood risk evaluation was integrated into a GIS environment to create a flood risk map. The results could enhance the capacity to assess disaster risks by using the national disaster database and provide better information for decision-making process regarding FRM.

### *3.4.2 Flood fatality analysis*

The Global Disaster Database identifies Asia as the most vulnerable continent to floods and storms, with more than 3,620 floods and storms resulting in over 8,085,516 fatalities between 1900 and 2016 (**Figure 1-1**). People in developing countries might be more vulnerable to flood hazards than the inhabitants of developed countries (Kahn 2005, Hansson et al. 2008, Jongman et al. 2015).

Loss of human life is a critical criterion for evaluating flood risk (Maaskant et al. 2009). The analyses of flood fatalities could support the identification of vulnerability indicators for flood hazards. Loss of life associated with flood events has been extensively studied in developed countries (e.g. Coates (1999), Ashley and Ashley (2008), FitzGerald et al. (2010), Sharif et al. (2015), Haynes et al. (2017), and Terti et al. (2017)), while few studies have been conducted in dthe eveloping countries (e.g. Paul and Mahmood (2016)). Studies on flood-related fatality in developing countries are few despite the higher fatality rates of these countries (Jonkman 2005).

Because of the lack of studies on flood-related fatality in Vietnam, this study aimed to analyse the national disaster database to better understand the flood risk associated fatalities. A statistical machine learning approach was used to evaluate the relative importance of the flood damage attributes on fatalities. The relative influence measures of the flood damage attributes to the flood fatality attribute might provide useful information for the FRM policies and appropriate interventions to mitigate mortalities in flood events in the future.

### *3.4.3 Flood hazard assessment*

Flood hazard assessment is a primary stage in assessing flood risk (Directive 2007/60/EC 2007). Flood hazard assessment maps aim to provide decision-makers and communities information about the hazard levels in flood-prone areas (WMO 2013b). They are the foundation to establish appropriate response activities and raise community awareness about flood risk (Vojinovic 2015).

Flood hazard maps can be developed from hydrological and hydraulic models, which display inundation maps for several return periods (Dewan et al. 2007, Merz et al. 2007, de Moel et al. 2009, Budiyono et al. 2014). The hydrological and hydraulic models contain a high level of detailed data such as longitudinal observed discharge and meteorological data, and updated river cross-sections (Büchele et al. 2006, de Moel et al. 2009, Apel et al. 2016). This approach is hardly applied to data-scarce areas, particularly in developing countries with a lack of gauging stations. In contrast, flood hazard maps can be generated using historical flood markers and a DEM (Hagemeier-Klose and Wagner 2009, Bhuiyan and Baky 2014, Shen et al. 2015).

This research approach aims to develop a method to assess flood hazard by using historical flood mark data and a DEM with the case study of Quang Nam province. The

AHP method was used to assign weights to the flood hazard's criteria and sub-criteria on the basis of the decision-makers' evaluation. The flood hazard assessment was then integrated into a GIS framework by using spatial analysis techniques to create a flood hazard assessment map for Quang Nam, Vietnam. The output map classified the flood hazard locations according to the hazard levels. Therefore, it was necessary for the FRM activities.

### *3.4.4 Flood risk assessment*

Flood risk assessment maps aim to provide information on flood hazards combined with other relevant information that can support the decision-making process in FRM (WMO 2013b). The incorporation of flood risk assessment into a GIS framework has been applied at the global, regional and local scales in many recent studies.

At the global scale, Jongman et al. (2012b) used two approaches, namely the population method and the land-use method, to estimate the global flooding exposure, and Winsemius et al. (2013) proposed a river flood risk assessment framework at a global level. At the regional level, de Moel et al. (2009) developed a flood risk assessing and mapping framework for Europe. At the local level, Ward et al. (2010) established a GIS-based flood model for simulating the flooded areas and the exposed assets, and for evaluating the current and future coastal flood hazard of northern Jakarta. Budiyono et al. (2014) conducted the flood risk assessment in Jakarta by using the Damagescanner model, which combined three flood risk components in a flood risk map.

The applications of the spatial multicriteria decision analysis are increasing in the field of flood risk assessment. Meyer et al. (2009) used the analysis for assessing the flood risk for River Mulde in Saxony, Germany. Kubal et al. (2009) devised the criteria for three dimensions of economic, social and ecological indicators to assess the urban flood risk of Leipzig, Germany. Scheuer et al. (2011) measured the flood risk by integrating the multicriteria of flood vulnerability. Dewan (2013c) utilised AHP and WLC to assess flood vulnerability by combining physical vulnerability, social vulnerability and coping capacity.

This study aimed to identify and quantify the flood risk components in Quang Nam province through a spatial multicriteria decision analysis. It first identified and measuresd the components of flood risk including the hazard, exposure and vulnerability indicators by using an analytic hierarchy model. Then, the spatial MCDM techniques are applied to analyse the data and to combine it into a GIS environment to create a flood risk assessment map. The study develop a new model, spatial multicriteria decision analysis and flood mark data, to assess flood risk for a case study of Quang Nam province with the 2013 flood event. The flood risk map output, which adequately considered the flood risk factors of hazard, exposure and vulnerability, can assist and empower the decision-making process of FRM activities in the region.

### *3.4.5 Flood risk management activities*

Flood damage data suggest that floods have had severe impacts, particularly the loss of life, on the communities in Vietnam (**Figure 1-3**). Population growth, agricultural expansion, and industrial development have increased the flood vulnerability, particularly in the river basins and coastal areas of Vietnam (Tran et al. 2008). Floods tend to affect low-income communities in coastal and rural areas as they all have sources of income dependent on the natural environment. Socio-economically marginalised groups face grave difficulties in disaster resilience when they lack public hazard protection such as emergency relief and insurance (Garschagen et al. 2014).

An effective FRM approach can help to reduce the adverse impacts of floods and improve flood resilience (Bosher et al. 2009a). The FRM decision-making processes in Vietnam use a top-down approach, which often has insufficient involvement of the stakeholders (Almoradie et al. 2015). Vietnam's top-down approach to FRM is based on centralised government roles at the national and provincial levels (Chau et al. 2014b). Although there have been an increasing number of case studies on FRM in Vietnam, few studies have been conducted on the practice of FRM activities under the legal and institutional frameworks, and how the legal framework of FRM delivers effective flood risk reduction and mitigation.

This study aimed to understand the FRM activities at the local levels in the Quang Nam province, along with the legal and institutional frameworks that are intended to focus, but often restrict, policy and practice. First, Vietnam's legal and institutional frameworks were analysed to provide an overview of the operation of FRM activities and a proposed conceptual FRM framework for Vietnam. Second, the study introduced a case study in Quang Nam province and investigated the FRM activities at the local levels via interviews with decision-makers in FRM at provincial, district and commune levels. Finally, following the empirical evidence, gaps in policy and practice of FRM activities at the local levels were discussed.

## 3.5 Research flowchart

This section summarises the five components used to investigate the research questions presented in Section 1.3. The conceptual framework was used to address the five research questions systematically. **Figure 3-3** depicts the five research components of the thesis in the form of a research flowchart.

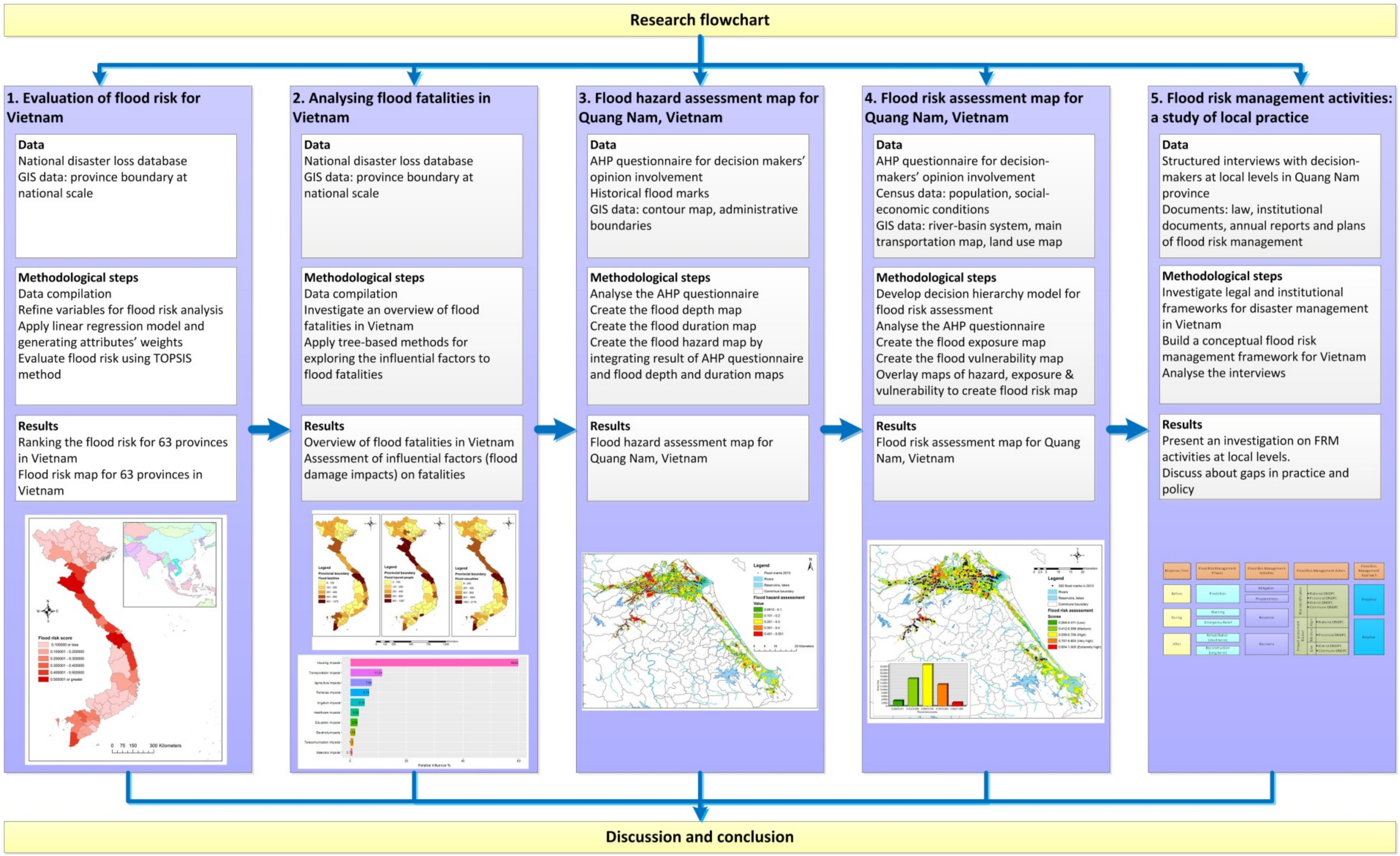


***Figure 3-3**: Five research components applied in this study*

# Chapter 4 Methodology

## 4.1 Introduction

This chapter explores the methodology used in the research. Section 4.2 looks at the overall research strategy and design, while the subsequent sections explain some of the specific methods and tools used in chapters 5-9 (the research papers). The details of MCDM methods are prsented in Section 4.3 including TOPSIS (Subsection 4.3.1) and AHP (Subsection 4.3.2). The comprehensive integration of the MCDM methods and GIS is described in Section 4.4. Section 4.5 presents the specific aspects of the statistical analysis methods and the disaster data used in the research. A qualitative analysis of the interview data is presented in Section 4.6. The ethical considerations and locations of fieldwork are described in Sections 4.6 and 4.7 respectively. The rationalisation for selecting the methods is based on the research questions presented in Section 1.3, the research objectives presented in Section 1.4 and the literature review presented in Chapter 2. It is also emphasised in each of the papers (Chapters 5-9).

## 4.2 Research design

The research methodology is considered an overall strategy to achieve the research aims and objectives (Sutrisna 2009). Sutrisna (2009) provided a continuum depicting the quantitative and qualitative methods at the data level, as shown in **Figure 4-1**. An overview of the research philosophies and approaches shown in **Figure 4-2** was given by Saunders et al. (2009). An adopted research philosophy often consists of important assumptions to underpin the research strategies and the selected methods as part of these strategies.


***Figure 4-1***: *Complete "continuum" in research methodology (Sutrisna 2009)*

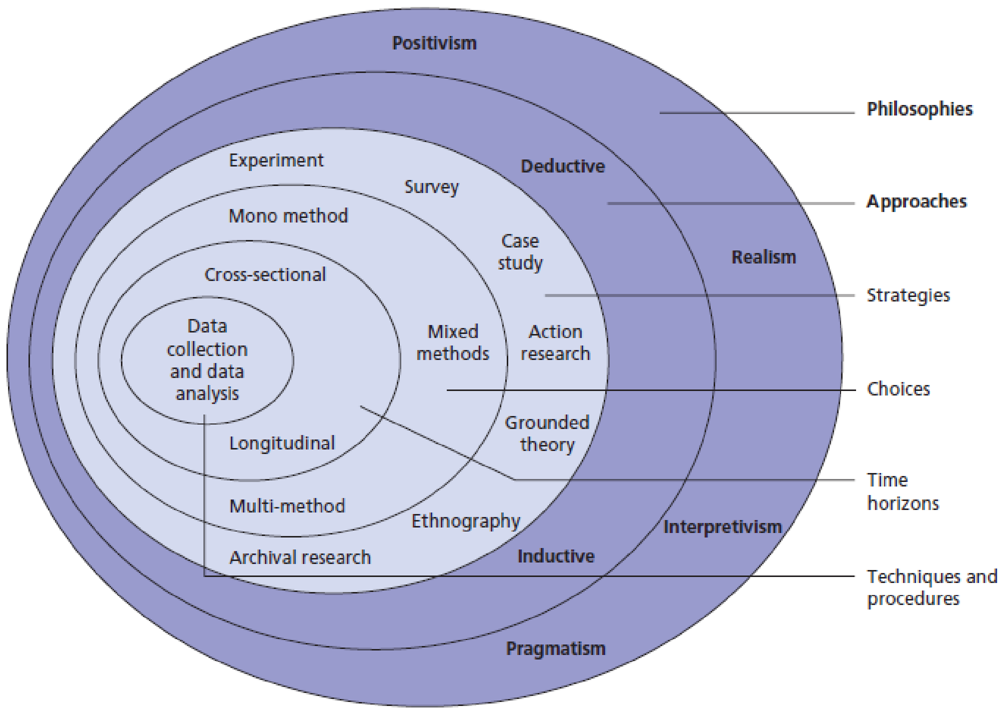


***Figure 4-2***: *Research philosophy (Saunders et al. 2009)*

Because this research was focused on how the flood risk is experienced at the local level in Vietnam, it aligned with a "constructivist paradigm" which holds that humans construct knowledge and meaning from their experiences.

Creswell (2014) provided a framework for research design as shown in **Figure 4-3**. He defined three research approaches, namely qualitative, quantitative and mixed methods. Qualitative research is used to explore and understand individuals or groups relating to human or social problems by collecting data on the participants' views. The data is inductively analysed by coding for description and themes. The researcher can then interprete these data in a variety of way. Meanwhile, quantitative research is applied to test theories by investigating the relationship between variables via models or functions. The variables can be analysed and measured using statistical methods or techniques. Finally, the mixed methods research is an investigation approach combining both qualitative and quantitative research methods. Research approaches aim to answer particular research questions (Hesse-Biber 2010).

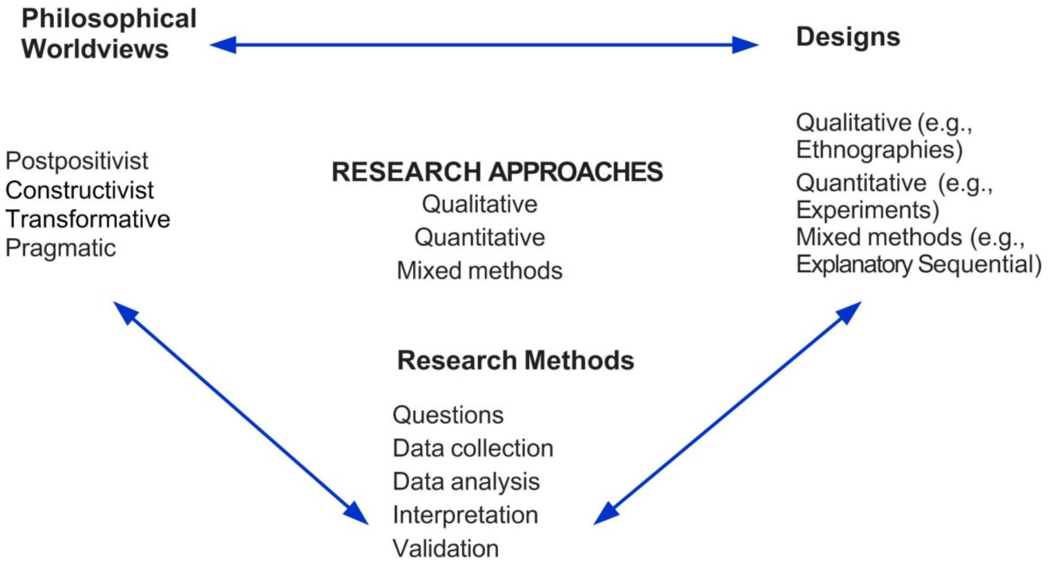


***Figure 4-3**: Interconnection of worldviews, design, and research methods as a research framework (Creswell 2014)*

Both qualitative and quantitative data are essential to contribute to a full understanding of the issue in Quang Nam province. Based on the research questions and the contemporary events relevant to the study, a case study research method was selected as described in Yin (2014). A case study can integrate both qualitative and quantitative research. The overall process for conducting case study research is shown in **Figure 4-4**. Case study research execution involves design, data collection and analysis. When the research question is addressed, and the parameters of a case study are determined; a pilot case study is conducted to validate the methodology. Yin (2014) suggests four principles for the data collection procedure. They include: working with multiple sources of evidence, developing a case study database, sustaining a chain of evidence, and utilising data from electronic sources carefully. The suggestion aims to secure the validity, reliability, and transparency of the collected data. He proposed the following five techniques for efficient data analysis: pattern matching, explanation building, time-series analysis, logic models, and cross-case synthesis.

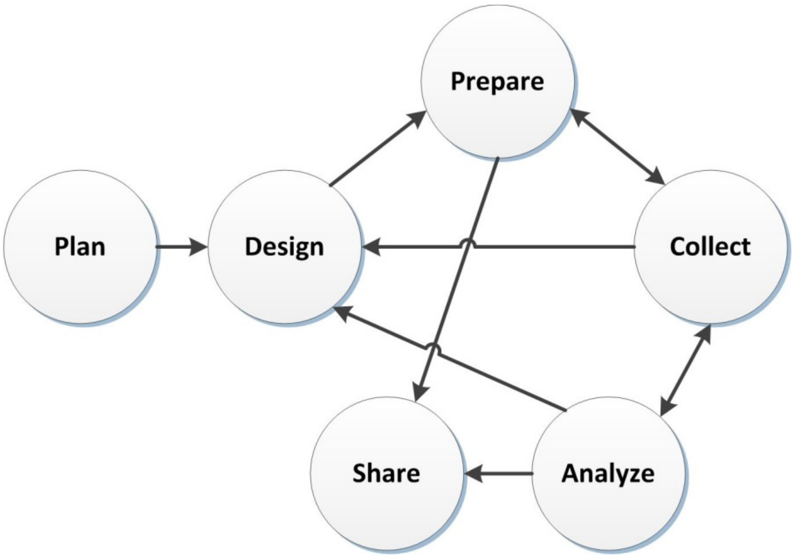


***Figure 4-4**: Interactive process of case study research designed by Yin (2014)*

The research design of this study is built on the basic of above viewpoints with both quantitative and qualitative research methods alongside a case study. Quantitative and qualitative studies collect evidence to assess flood risk, explore flood risk management and make recommendations for flood mitigation measures, using a local data set in a local context.

First, statistical analysis is utilised to establish the context for the study, looking at the flood hazard datasets and local studies on flood risk and mitigation. After the context was established, a case study is adopted. The study area encompasses the entire Quang Nam province. Second, multiple sources of evidence are considered, including a collection of topography maps and related databases, document review, observation data, and interviews with local authorities. Third, these data are analysed through MCDM methods, statistical learning techniques and geospatial analyst techniques. This study adopts a risk-based approach for evaluating and assessing flood risk at the local and national levels. The core of this approach is to integrate MCDM methods with GIS mapping to create flood risk maps. Three components of flood risk including hazard, exposure and vulnerability are incorporated in the MDCM techniques for flood risk assessments. Finally, risk assessment maps are generated from the integration of multi-criteria decision analysis and GIS.

In this study, qualitative research aims to collect evidence to both analyse the existing policy and make recommendations for positive change, using a local data set in a local context. The first stage will analyse legal and institutional frameworks in FRM to establish the context for the study. When the context is established, a case study research will be adopted, within which multiple sources of evidence are considered. These sources of evidence will include exploratory of in-depth interviews with DMs and document review. Data will be analysed through a combination of systems mapping of the disaster context, a cognitive mapping of interviews and coding of documents.

## 4.3 Multi-criteria decision-making methods

The fourth approach, MCDM methods allow working with quantitative variables so that they can be applied to decision-making processes. These methods have potential applications in solving flood risk management issues, e.g. formulating their preferences and measuring these priorities. As discussed in Section 2.2, the spatial multi-criteria decision analysis approach is selected for the present study as this approach is suitable for the available data in Vietnam, and it has advantages over the other approaches. Two MCDM methods were used in this thesis, namely TOPSIS and AHP.

### *4.3.1 TOPSIS*

TOPSIS selects the alternative, which is the closest to the ideal solution and farthest from the negative ideal solution. Two artificial alternatives are hypothesised in the method: (1) ideal alternative, which has the best attributes values, and (2) negative ideal alternative, which has the worst attributes values.

The TOPSIS method is presented as a series of successive steps (Hwang and Yoon 1981, Yoon and Hwang 1995):

Step 1: construct decision matrix D = ($d_{ij}$).

Step 2: standardise the decision matrix. The vector normalisation is used for computing $r_{ij}$.

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}} \quad , \qquad i = 1, \dots, m;\ j = 1, \dots, n \tag{4-1}$$

Step 3: construct a weighted standardised decision matrix by multiplying attribute weights with each rating.

$$v_{ij} = w_j \times r_{ij} \quad , \qquad i = 1, \dots, m;\ j = 1, \dots, n \tag{4-2}$$

where $w_j$ is the weight of the j$^{th}$ attribute

Step 4: determine Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The PIS ($A^*$) and NIS ($A^-$) are defined regarding the weighted normalised values:

$$A^* = \{v_1^*, v_2^*, \dots, v_j^*, \dots , v_n^*\}$$

$$A^* = \left\{\left(\max_i v_{ij} \middle| j \in\right), \left(\min_i v_{ij} \middle| j \in J_2\right) \middle| i = 1, \dots, m\right\} \tag{4-3}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\}$$

$$A^- = \left\{ \left( \min_i v_{ij} \,\middle|\, j \in J_1 \right), \left( \max_i v_{ij} \,\middle|\, j \in J_2 \right) \middle|\, i = 1, \ldots, m \right\} \quad (4\text{-}4)$$

Where $J_1$is a set of benefit attributes and $J_2$is a set of cost attributes.

Step 5: determine separation from PIS ($S_i^*$) and separation from NIS ($S_i^-$). The distance between alternatives is measured by the n-dimensional Euclidean distance. $S_i^*$ and $S_i^-$ are then given by Eqs (4-5) and (4-6).

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left( v_{ij} - v_j^* \right)^2}, \qquad i = 1, \ldots, m \quad (4\text{-}5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left( v_{ij} - v_j^- \right)^2}, \qquad i = 1, \ldots, m \quad (4\text{-}6)$$

Step 6: determine relative closeness to ideal solution $C_{i*}$.

$$C_{i*} = \frac{S_i^-}{S_i^* + S_i^-}, \qquad 0 < C_{i*} < 1, \qquad i = 1, \ldots, m \quad (4\text{-}7)$$

Step 7: rank ordinal priority: a group of alternatives is ranked by sorting $C_{i*}$ in the descending order.

### *4.3.2 AHP*

AHP was originally developed by Thomas L. Saaty (Saaty 1977). AHP is a robust decision analysis tool used to support the decision-making process. This method has been broadly applied in many fields, and recently, in FRM (de Brito and Evers 2016). The method procedure can be summarised in the following four main steps (Tzeng and Huang 2011):

- Step 1: Constructing a hierarchical decision model;

- Step 2: Developing a pairwise comparison matrix $A = [a_{ij}], ij = 1,2, \dots, n.$ as in Eq (4-8) for the criteria or sub-criteria.on the basic of DMs' judgment and reciprocal judgement axiom;
- Step 3: Obtaining the weights of the criteria and sub-criteria.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (4\text{-}8)$$

where $a_{ij}$ is based on the DMs' evaluation, and reciprocal judgement rule, and if $a_{ij} = a$, then $a_{ji} = 1/a\,, a > 0$.

***Table 4-1*** *The scale of absolute value number in AHP method (Saaty 2005)*

| **Intensity of importance** | **Definition** | **Explanation** |
|---|---|---|
| 1 | Equal importance | Two criteria/sub-criteria are equal important |
| 2 | Weak | |
| 3 | Moderate importance | One criterion/sub-criterion is slightly favoured over another |
| 4 | Moderate plus | |
| 5 | Strong importance | One criterion/sub-criterion is strongly favoured over another |
| 6 | Strong plus | |
| 7 | Demonstrated importance | One criterion/subcriterion is very strongly favoured over another |
| 8 | Very, very strong | |
| 9 | Extreme importance | Evidence favouring one criterion/sub-criterion over the other is the highest possible order of affirmation |
| Reciprocals | If $A_i$ is the judgment value when *i* is compared with *j*, then $A_j$ has the reciprocal value when compared to $A_i$ | A reasonable assumption |

Pairwise judgment scoring follows the rule of Saaty (1977) with a nine-point scale as indicated, where $a_{ij}$ is based on DMs' evaluation, and reciprocal judgement rule, if $a_{ij} = a$, then $a_{ji} = 1/a, a > 0$.

**Table 4-1**. Judgments' consistency is examined using consistency ratio (C.R.) in Eq. (4-9). Saaty (1977) recommended that the consistency ratio should be less than 0.1, although he suggested that higher consistency does not mean higher accuracy.

$$C.R. = C.I./R.I. \tag{4-9}$$

Random Index (R.I.) mentions a randomly created reciprocal matrix from the nine-point scale, and is obtained via **Table 4-2** depending on the number of criteria *n*.

***Table 4-2** Random Index (R.I.)by Saaty (1988)*

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| R.I | 0.0 | 0.0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

Consistency Index (C.I.) is determined via Eq. (4-10).

$$C.I. = (\lambda_{max} - n)/(n - 1) \tag{4-10}$$

where

$\lambda_{max}$ is the largest eigenvalue obtained from pairwise comparison matrix, and

*n* is the number of criteria.

AHP can work with one or more DMs' evaluation. If there is more than one DM, all the individual judgments can be combined for the final evaluation result on the basic of the geometric mean rule via Eq. (4-11) of Saaty (1989). Before combining the judgments of the group of DMs or experts, the pairwise comparison judgments of each DM must satisfy the consistency checking (C.R. < 0.1).

$$a_{12} = [a_{12}^{1} \times a_{12}^{2} \times \ldots \times a_{12}^{N}]^{1/N} \quad (4\text{-}11)$$

where

1 … $N$ are DMs, and

$a_{12}^{1}$ … $a_{12}^{N}$ are the judgements of DMs from 1 to N.

## 4.4 Combination of MCDM and GIS

GIS techniques are widely applied in the flood risk analysis. There are several theoretical methods for integrated GIS-MCDM, e.g. WLC, outranking methods and ideal point methods (Malczewski and Rinner 2015a).

AHP develops priorities for multi-criteria to derive the best decision on the basic of the judgements of different groups (DMs, stakeholders or experts) involved in the decision-making process (Saaty 1989, Saaty 1990). AHP is the most implemented MCDM methods in flood risk analysis. In this method, DMs provide the weights of the criteria and sub-criteria by comparing the relative importance between the pair of criteria and subcriteria. The AHP assessments depend on the subjective judgment of the experts or DMs; therefore, this method focuses on the quality instead of the number of experts.

WLC is the most commonly used techniques for handling spatial multi-criteria decision problems (Malczewski and Rinner 2015a). The combination of MCDM and WLC can be potentially applied in the spatial analysis of the assessment situations (Malczewski and Rinner 2015b). The combination aims to incorporate MCDM assessments into a GIS framework. The MCDM methods are used to generate the weights for indicators and WLC is used to integrate the weighted factor layers into an assessment map (Dewan 2013c). The application has been presented in many recent studies on flood risk analysis (Rahman et al. 2012, Nguyen and Woodroffe 2015, Dahri and Abida 2017, de Brito et al. 2018).

The WLC methodology is based on a weighted average concept (Malczewski 1999, Malczewski 2006). Each criterion is handled as a data layer in the GIS environment. WLC is used to aggregate all the weighted layers by the corresponding criteria and sub-criteria weights (Dewan 2013c). The integrated AHP-WLC approach is used for creating flood risk assessment maps in this study. The following equation interprets the AHP-WLC method:

$$FRA = \sum_{i=1}^{i} \sum_{j=1}^{j} w_i w_{ij} x \qquad (4\text{-}12)$$

where

FRA is flood risk assessment index,

$w_i$ and $w_{ij}$ are the weights of the *i*th and *j*th criteria respectively, and

*x* represents the value of a criterion.

## 4.5 Statistical machine learning analysis

Machine learning or statistical machine learning is the combination of classical statistics and computer science. Prediction is a significant endeavour of machine learning, to answer questions about how to select relevant factors and how to build good predictive models. Machine learning can be divided into supervised and unsupervised machine learning (James et al. 2013a). Supervised machine learning has a target variable or an outcome, while unsupervised machine learning does not. Supervised learning consists of such techniques as regression, decision tree, neural networks, k-nearest neighbours (k-NN), support vector machines, Bayesian learning and random forests. Unsupervised learning includes such techniques, cluster analysis, principal component models and hidden Markov models. The applications of machine learning are increasingly popular in genetics, medical science, business and flood risk studies (Tehrany et al. 2014).

The basic idea of a machine learning framework is described in Eq. (4-13) with the following two main steps:

$$Y = f(X) \tag{4-13}$$

- Training/development: a training data set of labelled examples is $\{(X_1, Y_1), \cdots, (X_N, Y_N)\}$, and the prediction function $f$ is estimated by minimising the prediction error on the training data set.
- Testing/validation: apply $f$ to a testing example $X$ and the predicted value $Y = f(X)$ is outputted.

Algorithms are used to check the accuracy of machine learning models including bootstrap, data splitting, k-fold cross-validation and leave-one-out cross-validation. The indices of mean square error, R-squared or AUC of the ROC curve are used to examine the model performance (or measure the model accuracy). In this study, the machine learning framework is implemented in five main steps. First, the sample data is collected. Second, the original sample data is randomly split into training and testing data sets with a ratio of 70/30. Third, a model is developed by using the training data set. Fourth, cross-validation techniques are performed to validate the model using the testing data set. Finally, the mean squared error index is used for the model performance evaluation.

### *4.5.1 Disaster data*

Disaster impact data collection and analysis can support the policy-setting and decision-making processes (Thieken et al. 2005, UNISDR 2015b). Databases itemising disaster loss and damage at the national, regional and global levels are compiled in Simpson et al. (2014) and Grasso and Dilley (2013). For instance, the Global Disaster Database can be accessed via the EM-DAT system (www.em-dat.be), and many national disaster databases can be accessed via the DesInventar system (www.desinventar.net/DesInventar/index.jsp).

Vietnam's national disaster database is collected and stored through the Damage and Needs Assessment system or DANA (Hughey et al. 2011). The Central Committee for Flood and Storm Control (CCFSC) is the official organisation that collects, stores and reports DANA (MARD 2006). The DANA database provides hydro-meteorological disaster damage information at the national level. The DANA data only includes the direct loss of recovery and the reconstruction of damaged property and infrastructure, and does not cover the secondary loss of business interruption (Wang et al. 2010).

The CCFSC has documented the damage data of more than 200 storms from 1989 to 2015. The data contains an extensive range of flood impacts data with 12 categories, namely economic loss, human impacts, housing impacts, education impacts, healthcare impacts, agriculture impacts, irrigation impacts, transportation impacts, fisheries impacts, telecommunication impacts, electricity impact, and material impacts. The DANA database can contribute essential information for FRM activities when the detailed analyses are conducted.

This study used supervised machine learning methods for analysing DANA data, including multiple linear regression and tree-based techniques. The approach aims to address the first and second research questions presented in Section 1.3.

### *4.5.2 Multiple linear regression model*

Regression analysis, which was developed by Sir Francis Galton in 1886, is a principal analysis method and the most widely used statistical technique in many areas of academic and applied sciences (Eye and Schuster 1998, Bi 2012). The multiple linear regression model is highly flexible for examining the relationship between a group of independent or predictive variables and a dependent variable or response variable (Aiken et al. 2003). The purpose of linear regression analysis is to find an equation to describe the relationship between X (independent variables) and Y (dependent variable). A multiple regression model (population) with $p$ independent variables ($x_i$) and one dependent ($Y$) is described as follows:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_p x_{pi} + \varepsilon \qquad (4\text{-}14)$$

where

$\beta_0$ denotes the intercept

$\beta_1, \beta_2, \ldots, \beta_p$ represents the regression coefficients

$Y$ indicates the dependent variable or response variable

$x_{pi}$ are the regressors or independent variables

$\varepsilon$ denotes the residual or random error

The estimated multiple regression model with $p$ independent variables is shown in the Eqs. (4-15) and (4-16).

$$\widehat{Y_i} = b_0 + b_1 x_{1i} + b_2 x_{2i} + \cdots + b_p x_{pi} \qquad (4\text{-}15)$$

$$\varepsilon = \widehat{Y_i} - Y_i \qquad (4\text{-}16)$$

where

$\widehat{Y_i}$ denotes the estimated value of Y;

$b_0$ represents the estimated intercept; and

$b_1, b_2, \ldots, b_p$ indicate theestimated regression coefficients

### 4.5.3 Tree-based methods

Tree-based methods consist of decision trees, bagging, random forest and boosting techniques. The detailed underpinning methodology of these techniques is presented in the subsections below.

#### 4.5.3.1 Decision trees

Decision trees include regression and classification trees. A regression tree is applied for a continuous outcome, while a classification tree is used for a categorical outcome. The decision is based one or four indices: Gini index, Chi-square statistic, information gain and variance reduction. The tree pruning technique is often applied to fit decision trees (James et al. 2013c).

#### 4.5.3.2 Bagging and Random forest

The bagging technique (bootstrap aggregating) is applied to solve the high variance problem of decision trees (James et al. 2013c). Bagging is a particular case of random forest where the number of terminal nodes is equal to the number of predictors (Breiman 1996). Random forest algorithm, for both regression and classification, is a panacea for all data science problems. This method constructs a multitude of decision trees and selects the best as the final result which can be used to build predictive models. The random forest algorithm can be presented in the following steps (Liaw and Wiener 2002):

1. Draw $n_{tree}$ bootstrap sample from the original dataset. A sample of these $n_{tree}$ is taken at random with replacement;

2. For each of these samples, develop an unpruned regression tree: randomly sample $m_{try}$ of predictors and select the best split from these variables at each node;

3. Predict the new dataset by aggregating the predictions of trees.

Random forest for regression is constructed by growing trees depending on a random vector such that the predicted tree takes numerical values as opposed to class labels. Strobl et al. (2008) suggested that the conditional importance for random forest should be applied for the highly correlated predictor variables when this tool reflects the actual impact of each variable. Cross-validation techniques are applied for the model performance evaluation including Leave-One-Out Cross-Validation (LOOCV) and Out-of-Bag (OOB) error (Liaw and Wiener 2002).

*4.5.3.3 Boosting*

Similar to the random forest, the boosting technique can be used for regression and classification models. We ran the '*gbm*' package (Ridgeway 2015) in the R software to fit the boosted regression model for the training data set in this study. Boosting also give prediction models that are averages of the trees, but it is a sequential method in which each of the trees is added to improve the performance of the previous collection of trees. The sequential algorithm of the boosting technique is as followed James et al. (2013c):

1. Setting $\hat{f}(x) = 0$ and $r_i = y_i$ for all $i$ in the training data set.

2. For $b = 1,2, \ldots, B$, repeating:

(a) Fitting a tree $\hat{f}^b$ with a number of splits d ($d + 1$ terminal nodes) to training data set $(X, r)$.

(b) Updating $\hat{f}$ by adding in a shrunken version of the new tree:

$$\hat{f}(x) \leftarrow \hat{f}(x) + \lambda \hat{f}^{b} \tag{4-17}$$

(c) Updating residuals:

$$r_i \leftarrow r_i + \lambda \hat{f}^{b} \tag{4-18}$$

3. Outputting a boosted model:

$$\hat{f}(x) = \sum_{b=1}^{B} \lambda \hat{f}^{b} \tag{4-19}$$

## 4.6 Qualitative analysis

A qualitative study follows the inductive logic of research as indicated in **Figure 4-5**. The qualitative research questions focus the study's purpose, including a central or broad question and its associated sub-questions (Creswell 2014). The sub-questions narrow the focus of the study.

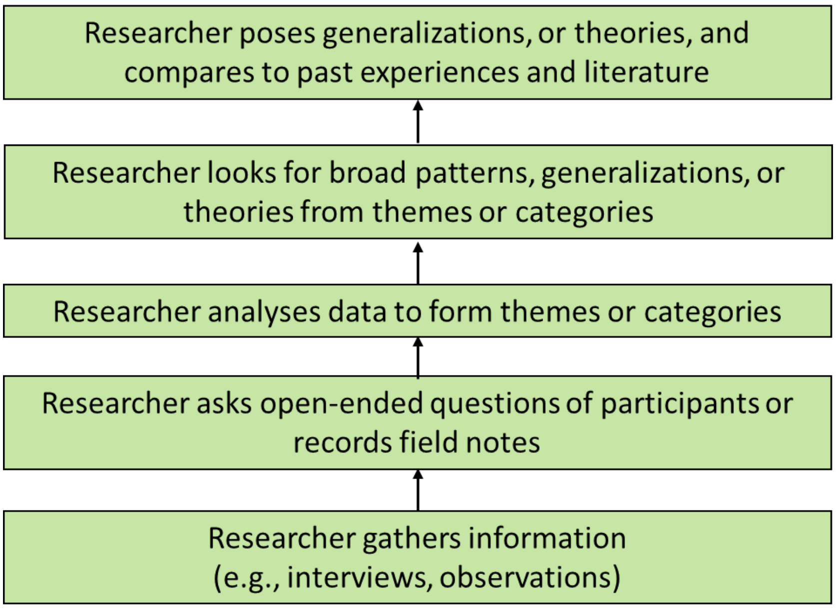


***Figure 4-5**: Qualitative research inductive logic (Creswell 2014)*

This study collected interview data, and the qualitative analysis focuses on this data. There are four interview techniques: face-to-face, telephone, e-mail, and MSN messenger interviews (Opdenakker 2006). The face-to-face and e-mail interview techniques were selected for this study on the basic of their advantages and disadvantages listed in Opdenakker (2006) and their local appropriateness.

The qualitative analysis procedure was presented in detail in Creswell (2014). **Figure 4-6** shows the six detailed steps for analysing qualitative data: (1) collecting raw data, (2) organising and preparing the collected data for analysis, (3) reading through all the collected data, (4) coding the data into themes via a codebook, (5) interrelating these themes, and (6) interpreting the meaning of these themes.

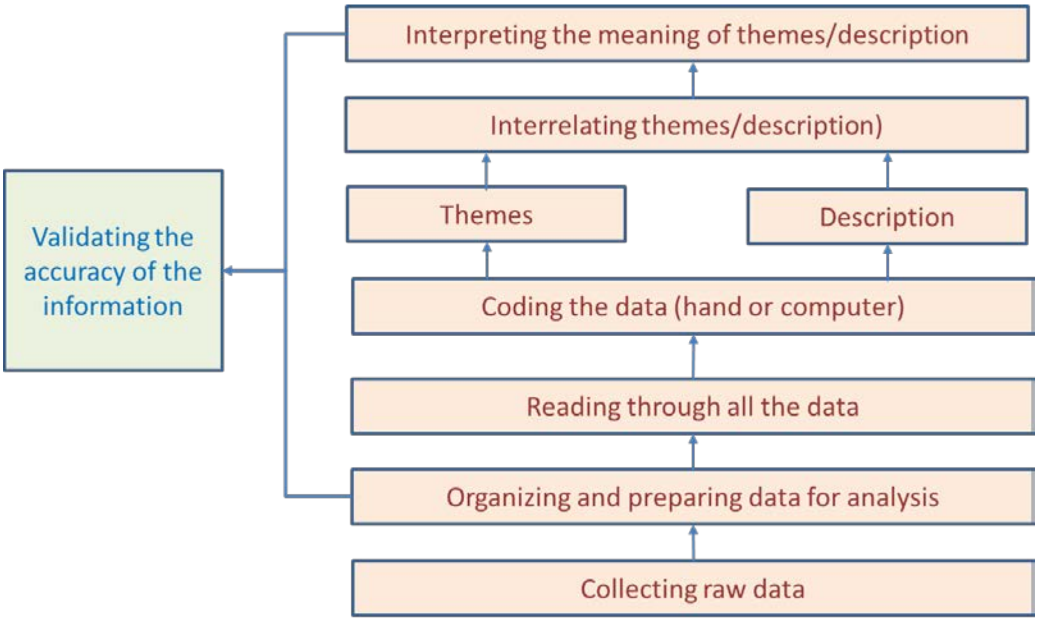


***Figure 4-6**: Steps for qualitative data analysis (Creswell 2014)*

Baxter and Eyles (1997) provided a set of criteria for establishing rigour qualitative research: credibility, transferability, dependability and confirmability (**Table 4-3**). They reviewed the methodology of 31 interview analysis papers and suggested strategies to satisfy these four criteria. They also produced a checklist for evaluating qualitative research. This process was followed when dealing with the Quang Nam case study data.

***Table 4-3** Criteria and strategies for a rigour qualitative study (Baxter and Eyles 1997)*

| Criteria | Definition | Assumptions | Strategies to satisfy criteria |
|---|---|---|---|
| **Credibility** | Authentic representations of experience | Multiple realities<br>Causes not distinguishable from effects<br>Empathetic researcher<br>Researcher as instrument<br>Emphasis of the research endeavour | Purposeful sampling<br>Disciplined subjectivity/bracketing<br>Prolonged engagement<br>Persistent observation Triangulation<br>Peer debriefing<br>Negative case analysis<br>Referential adequacy<br>Member checking |
| **Transferability** | Fit within contexts outside the study situation | Time and context-bound experiences<br>Not responsibility of 'sending' researcher<br>Provision of information for 'receiving' researcher | Purposeful sampling<br>Thick description |
| **Dependability** | Minimisation of idiosyncrasies in interpretation Variability tracked to identifiable sources | Researcher as instrument<br>Consistency in interpretation (same phenomena always matched with the same constructs)<br>Multiple realities<br>Idiosyncrasy of behaviour and context | Low-inference descriptors, mechanically recorded data<br>Multiple researchers<br>Participant researchers<br>Peer examination<br>Triangulation, inquiry audit |
| **Confirmability** | Extent to which biases, motivations, interests or perspectives of the inquirer influence interpretations | Biases, motivations, interests or perspectives of the inquirer can influence interpretation Focus on investigator and interpretations | Audit trail products<br>Thick description of the audit process<br>Autobiography<br>Journal/notebook |

***Table 4-4*** *Checklist for qualitative research evaluation (Baxter and Eyles 1997)*

| Question | Elaboration/examples |
|---|---|
| 1. What was the natural history of the research? | Original purpose(s) of the research Rationale for methodology<br>How research developed over time<br>Fieldwork relations |
| 2. What data were collected and by what methods? | Method of note-keeping<br>Method of tape-recording |
| 3. How was the sampling done? | Explicit delineation of sample frame (working universe)<br>Random or purposeful?<br>Rationale for type of sampling used |
| 4. How was the data analysis done? | Procedures for summarising and presenting data<br>How data was selected for presentation |
| 5 What results are presented? | Description of researcher's objective for results presentation (e.g. theory-building or description<br>Differentiation of data-derived as opposed to pre-existing constructs<br>Differentiation of participant concepts as opposed to theoretical (researcher-derived) constructs |
| 6. How credible and dependable are the data-construct links? | Details of the relationship(s) between the data and constructs/concepts derived from data (e.g. member checking) |
| 7. How credible is the theory/hypothesis? | Specification of the relationship between constructs/concepts and theory/hypotheses |
| 8. How transferable are the findings? | Recognition of the limits imposed by the sampling strategy |

An important step in qualitative data analysis is data coding. Coding is the assigning of codes to raw data, which allows for data expansion, transformation and reconceptualisation. DeCuir-Gunby et al. (2011) provided specific steps to produce a codebook for coding the collected interview data. The circular process of coding is presented in **Figure 4-7**. Codes are developed from three major areas: theory, data and research goals, and the detailed steps are shown in **Figure 4-8**. The interview data from Quang Nam was coded and analysed following this guidance and the results are presented in Chapter 9 (Luu et al. 2018b).

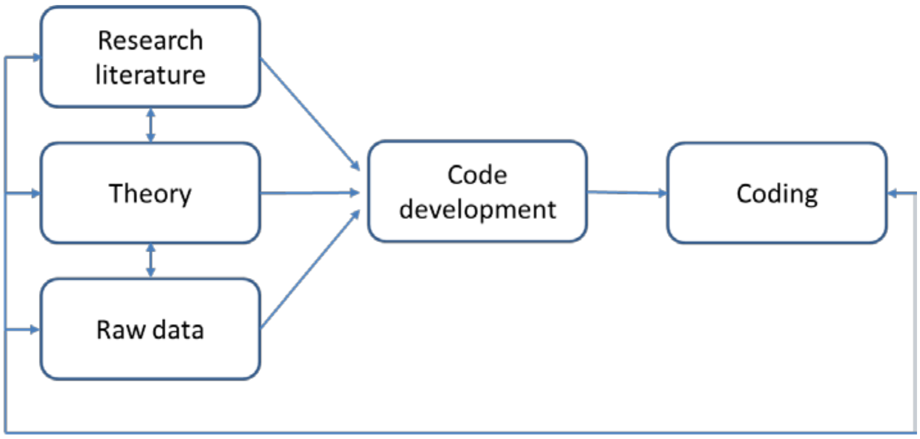


***Figure 4-7****: Circular coding process (DeCuir-Gunby et al. 2011)*

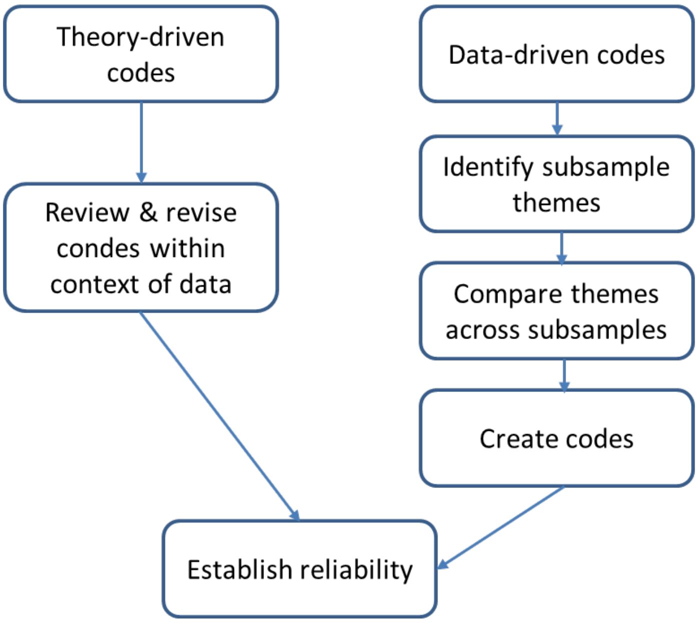


***Figure 4-8****: Steps for creating a codebook (DeCuir-Gunby et al. 2011)*

## 4.7 Ethical considerations

The first consideration for a research proposal is to anticipate the ethical issues in the data collection process (Creswell 2014). This study was conducted at the University of Newcastle, so it abided by the rule and regulations of the University Human Research

Ethics Committee (HREC). A human ethics application was submitted to HREC, which was subsequently approved in June 2016, approval No. H-2016-0125.

All interviewees received an information statement sheet, which explains the research objectives, the content of questions and their participant choice as per the procedure of the University HREC. They agreed to participate in this study and gave their consent freely.

## 4.8 Locations of fieldwork

Quang Nam is exposed to riverine and coastal flood risk during the weather extremes of storms, floods, flash floods, and typhoons (Chau et al. 2013). The Vu Gia-Thu Bon river basin, in the western part of Quang Nam, has a total area of 5.290 $km^2$ and is one of the largest river basins in Vietnam. Over the years, flood and storm events have had severe impacts on the communities' livelihoods and socio-economic development (Chau et al. 2014a). FRM is under increasing pressure due to population and economic growth, human interference leading to environmental damage, and the influence of climate change.

This province was selected for the case study. The research was designed to invite DMs from the hierarchical levels of institutional structures, including provincial, district and commune levels, to take part in the interviews. The interviewees were representatives of Steering Committees for Natural Disaster Prevention and Control at the provincial, district, and commune levels in Quang Nam province.

The four selected districts mentioned in **Table 4-5** are located along the Vu Gia-Thu Bon river basin. They are frequently subjected to flooding in rainy seasons. The communes listed in **Table 4-5** are identified by their districts. These communes are the most vulnerable to flood risk in the four districts.

***Table 4-5*** *Communes and districts in Quang Nam province for fieldwork*

| Districts | Dai Loc | Dien Ban | Duy Xuyen | Hoi An |
|---|---|---|---|---|
| Communes | Ai Nghia | Dien Phuoc | Duy Thanh | Cua Dại |
| | Dai An | Dien Tho | Duy Trinh | Cam Kim |
| | Dai Hoa | Dien Trung | Duy Vinh | Cam Nam |
| | Dai Cuong | Dien Quang | Duy Chau | Thanh Ha |
| | Dai Minh | Dien Hong | Duy Nghia | |
| | Dai Chanh | | Duy Hai | |
| | Dai Tan | | | |

## 4.9 Summary

Data analysis methods were subsequently applied in the five research approaches discussed in Section 3.5 following the research questions presented in Section 1.3 and the research objectives given in Section 1.4.

TOPSIS and multiple linear regression techniques were used to rank the flood risk of 63 provinces and municipalities of Vietnam. The result was then integrated into a GIS environment to create a flood risk map for Vietnam (Chapter 5 ).

The spatial multi-criteria decision analysis was applied for flood risk assessment in Quang Nam province. This method was used in the third and the fourth research approaches (Section 3.5): flood hazard assessment map (in a published journal article (Luu et al. 2018a)) and flood risk map for Quang Nam province (in Chapter 8 ). The flood risk components of the hazard, exposure and vulnerability indicators were assessed by using the AHP method. The assessment was then integrated into a GIS framework to create a flood risk map (Chapter 8 ).

Qualitative research was used to explore the extent to which FRM in Vietnam follows the recognised theoretical frameworks, and pinpoint where practice might be strengthened. Qualitative analysis was applied to the interview data collected from the

DMs in the FRM at the provincial, district, and commune levels in Quang Nam province. The detailed research approach and results are presented in Chapter 9.

# Chapter 5 Evaluation of flood risk using multi-criteria decision-making analysis

## 5.1 Introduction

Data analysis of disaster losses is acquiring more and more attention (UNISDR 2015b, Thieken et al. 2016). The analysis can have implications for policy-setting and decision-making in disaster risk reduction (UNISDR 2015b). Disaster databases are available at global, regional and national scales (Grasso and Dilley 2013, Simpson et al. 2014). For example, global disaster database is available at EMDAT system (www.emdat.be); and many national disaster databases can be accessed via Desinvestar system (www.desinventar.net/DesInventar/index.jsp).

Damage Assessment and Needs Analysis or DANA database is Vietnam's national disaster database. The DANA database has been documented direct flood damages since 1989 (Below et al. 2010, Hughey et al. 2011). Central Committee for Flood and Storm Control (CCFSC) of Vietnam has developed the DANA database (MARD 2006, Bollin and Khanna 2007, Hughey et al. 2011) (CCFSC was renamed to Central Steering Committee for Natural Disaster Prevention and Control since 2017). Flood impacts in the DANA database are collected through one template of 12 categories with many indicators (Hughey et al. 2011).

The DANA database was explored in studies of Hughey et al. (2011) and Nhu et al. (2011). Hughey et al. (2011) discovered the completeness and accuracy of DANA process. Nhu et al. (2011) provided a preliminary analysis of DANA. However, it still lacks detailed explorations of DANA database for evaluation and assessment of flood risk for provinces and regions in Vietnam.

Flood risk threatens many low-lying, riverine and coastal areas throughout the world, where are usually densely populated (Maaskant et al. 2009, Winsemius et al. 2013). The riverine and coastal flooding risks are forecasted to increase due to sea level rise, and the growth of tropical cyclone magnitude and rainfall globally (Bosher et al. 2009b). Recently, there has been a change of flood policies from traditional flood protection to flood risk management pattern (Schanze 2006). Following the risk-based approach, spatial flood risk assessments have been increasingly implemented at both local levels (Meyer et al. 2009, Ward et al. 2010, Müller et al. 2011, Papaioannou et al. 2014, Chen et al. 2015, Nguyen and Woodroffe 2015, Dahri and Abida 2017) and a global level (Jongman et al. 2012b, Hirabayashi et al. 2013, Winsemius et al. 2013, Tanoue et al. 2016). The spatial flood risk assessments are beneficial tools for identifying at-risk locations with different levels which are the basis for setting proper adaptation and mitigation actions (Mazzorana et al. 2012, Koks et al. 2015, de Almeida et al. 2016, Thieken et al. 2016).

Multi-Criteria Decision-Making (MCDM) aims to select the best from a group of alternatives based on the evaluation against multiple attributes. MCDM can be devided into Multi-Attribute Decision-Making (MADM) and Multi-Objective Decision-Making (MODM) (Hwang and Yoon 1981). MADM methods allows to handle quantitative variables and support DMs in solving management issues, e.g. formulating preferences and measuring priorities for decision-making process (Levy 2005). Many MADM methods are widely used in flood risk assessment such as AHP, ANP, TOPSIS, CP, ELECTREE, MAUT, PROMETHEE, VIKOR and SAW (de Brito and Evers 2016).

TOPSIS or Technique for Order Preference by Similarity to Ideal Solution introduced by Hwang and Yoon (1981) has been increasingly implemented in flood risk management field (de Brito and Evers 2016) with various applications in recent time.

Jun et al. (2011) used TOPSIS to assess the four hydrologic vulnerability indices towards sustainable water resources management. TOPSIS method was applied to calculate scores of alternatives for flood risk management in the study of Evers et al. (2012). Ghanbarpour et al. (2013) employed TOPSIS to find the best flood control measure by comparing flood hazard mitigation measures. Mojtahedi and Oo (2016) used a combination of non-parameter resampling bootstrap technique and TOPSIS to rank the flood risk of states and territories for Australia. Fuzzy TOPSIS technique is also applied in many studies in flood risk assessment (Jun et al. 2013, Lee et al. 2013, Lee et al. 2014). However, there has not been any application of TOPSIS undertaken for flood risk assessment in Vietnam.

The main advantages of TOPSIS are simple process and algorithm, and easy to use and calculate (Velasquez and Hester 2013). However, non-linear preferences cannot be modelled by this method due to the use of metric distance (Mojtahedi and Oo 2016). Another shortcoming is that it is difficult for judgement consistency checking due to the use of Euclidean distance in this method (Velasquez and Hester 2013).

The assignment of weights has a fundamental role in the TOPSIS process and may vary from DM to DM. The weights should reflect the purpose of evaluation. There are 8 techniques to generate weights for attributes: (a) equal weights for all attributes, (b) weights from ranks (Yu et al. 2011), (c) ratio weighting, (d) quantification of qualitative ratings (Likert-type scale and fuzzy logic) (Liang and Ding 2003), (e) weights generated by regression (Olson 2004), (f) simulation (Monte Carlo), (g) non-parametric resampling (Mojtahedi and Oo 2016), and (h) linear programming technique for multi-dimensional analysis of preference (LINMAP) (Li 2008).

This study proposes a combination of multiple linear regression technique and TOPSIS to investigate Vietnam's national disaster database (DANA). The analysis aims to score and rank flood risk for eight regions and 63 provinces in Vietnam. After that, the flood risk evaluation is integrated into a GIS environment to create a flood risk map. The results can enhance capacity to assess disaster risks using national disaster databases and contribute better information for decision-making process regarding flood risk management.

## 5.2 National disaster database of Vietnam

The CCFSC has developed a national system for natural disasters' damage and loss assessment since 1989 (Hughey et al. 2011). The data is stored in Damage and Needs Assessment system or DANA database. The database provides information on damages caused by hydro-meteorological disasters at the national level. The DANA records direct financial losses for the recovery of damaged properties and infrastructures (Wang et al. 2010).

The flood damage data has been documented over 200 storms from 1989 to 2015 across the country. The data contains an extensive range of direct flood damage data with 12 categories, including economic loss, human impact, housing impact, education impact, health-care impact, agriculture impact, irrigation impact, transportation impact, fisheries impact, telecommunication impact, electricity impact and material impact (Hughey et al. 2011). The DANA has provided a primary database for Vietnam's flood risk analysis. This study aims to investigate the DANA for a detailed analysis of flood risk for Vietnam.

## 5.3 Proposed multiple linear regression-TOPSIS method for flood risk analysis

Based on the available data of flood impacts of Vietnam, this study employed multiple linear regression technique to generate weights for attributes and then used TOPSIS method to rank flood risk of 63 provinces and eight regions of Vietnam. The multiple linear regression technique was used to produce weights for TOPSIS in a study of Olson (2004).

## *5.3.1 Multiple linear regression analysis*

### *5.3.1.1 Multiple linear regression model*

Regression analysis, which is developed by Sir Francis Galton in 1886, is one of the most widely used statistical techniques in many areas of academic and applied sciences (Eye and Schuster 1998, Bi 2012). Multiple regression analysis is highly flexible to explore the relationship between a group of predictive variables and a response variable (Aiken et al. 2003). The purpose of linear regression analysis is to find an equation to describe the relationship between X (independent variables) and Y (dependent variable). Multiple regression model with *p* independent variables in Eq. (5-1) is to describe the linear relationship between one dependent ($Y$) and dependent variables ($x_i$).

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_p x_{pi} + \varepsilon \qquad (5\text{-}1)$$

where

$\beta_0$ : intercept

$\beta_1, \beta_2, \ldots, \beta_p$ : regression coefficients

$Y$: dependent variable or response variable

$x_{pi}$: regressors or independent variables

$\varepsilon$: residuals or random error

The regression coefficients are calculated using sample data. The estimated multiple regression model with *p* independent variables is shown in Eqs. (5-2) and (5-3).

$$\widehat{Y_i} = b_0 + b_1 x_{1i} + b_2 x_{2i} + \cdots + b_p x_{pi} \tag{5-2}$$

$$\varepsilon = \widehat{Y_i} - Y_i \tag{5-3}$$

where

$\widehat{Y_i}$ : estimated value of Y

$b_0$ : estimated intercept

$b_1, b_2, \ldots, b_p$ : estimated regression coefficients

#### 5.3.1.2 Variable importance measures

The most directive interpretation of regression models is to measure the relative importance of each predictive variable (Hair Jr. et al. 2014). The weights of attributes or independent variables are derived from the relative importance of variables (Grömping 2015). Bi (2012) reviewed contemporary methods for generating relative importance of correlated variables. They recommended the LMG method for raw data, which determines variable importance by variance decomposition of regressors. Grömping (2015) also suggested LMG method after reviewing and taking an example analysis of several methods. LMG indicator, which is proposed by Lindeman, Merend and Gold in 1980 (Lindeman et al. 1980), is employed to calculate the variable importance of the regression model in this study. The explanation of LMG (Lindeman et al. 1980, Bi 2012, Grömping 2015) is as follows:

$$LMG(x_k) = \frac{1}{p!} \sum_{rpermutation} seqR^2(\{x_k\}|r) \tag{5-4}$$

where $r$ = 1, 2,…, p! and $seqR^2(\{x_k\}|r)$ denotes the sequential sum of squares for the predictors $x_k$ in the ordering of the predictors in the $r$-th permutation.

### 5.3.2 TOPSIS

The TOPSIS method is demonstrated in seven steps (Hwang and Yoon 1981, Yoon and Hwang 1995) as the following:

Step 1: set up a decision matrix D = ($d_{ij}$).

Step 2: standardise the decision matrix. The vector normalisation is used for calculating $r_{ij}$.

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}} \quad , \qquad i = 1, \ldots, m;\ j = 1, \ldots, n \tag{5-5}$$

Step 3: create weighted standardised decision matrix by multiplying attributes' weight to each category.

$$v_{ij} = w_j \times r_{ij} \quad , \qquad i = 1, \ldots, m;\ j = 1, \ldots, n \tag{5-6}$$

where $w_j$ is the weight of the j[th] attribute.

Step 4: ascertain Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The PIS ($A^*$) and NIS ($A^-$) are determined based on the weighted normalised values:

$$A^* = \{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\}$$

$$A^* = \left\{\left(\max_i v_{ij} \middle| j \in\right), \left(\min_i v_{ij} \middle| j \in J_2\right) \middle| i = 1, \ldots, m\right\} \tag{5-7}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\}$$

$$A^- = \left\{\left(\min_i v_{ij} \middle| j \in J_1\right), \left(\max_i v_{ij} \middle| j \in J_2\right) \middle| i = 1, \ldots, m\right\} \tag{5-8}$$

Where $J_1$is a group of benefit attributes and $J_2$is a group of cost attributes.

Step 5: determine separation from PIS ($S_i^*$) and separation from NIS ($S_i^-$). The distance between alternatives is calculated by the n-dimensional Euclidean distance. $S_i^*$ and $S_i^-$ are then given by Equations (5) and (6).

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2}, \qquad i = 1, \dots, m \tag{5-9}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \qquad i = 1, \dots, m \tag{5-10}$$

Step 6: determine relative closeness to ideal solution $C_{i*}$.

$$C_{i*} = \frac{S_i^-}{S_i^* + S_i^-}, \qquad 0 < C_{i*} < 1, \quad i = 1, \dots, m \tag{5-11}$$

Step 7: rank ordinal priority: a group of alternatives is ranked by descending orderly sorting of $C_{i*}$.

## 5.4 An application to flood risk analysis for Vietnam

**Figure 5-1** shows five analysing stages with applications of techniques mentioned in the previous section using flood damage data obtained via DANA database.

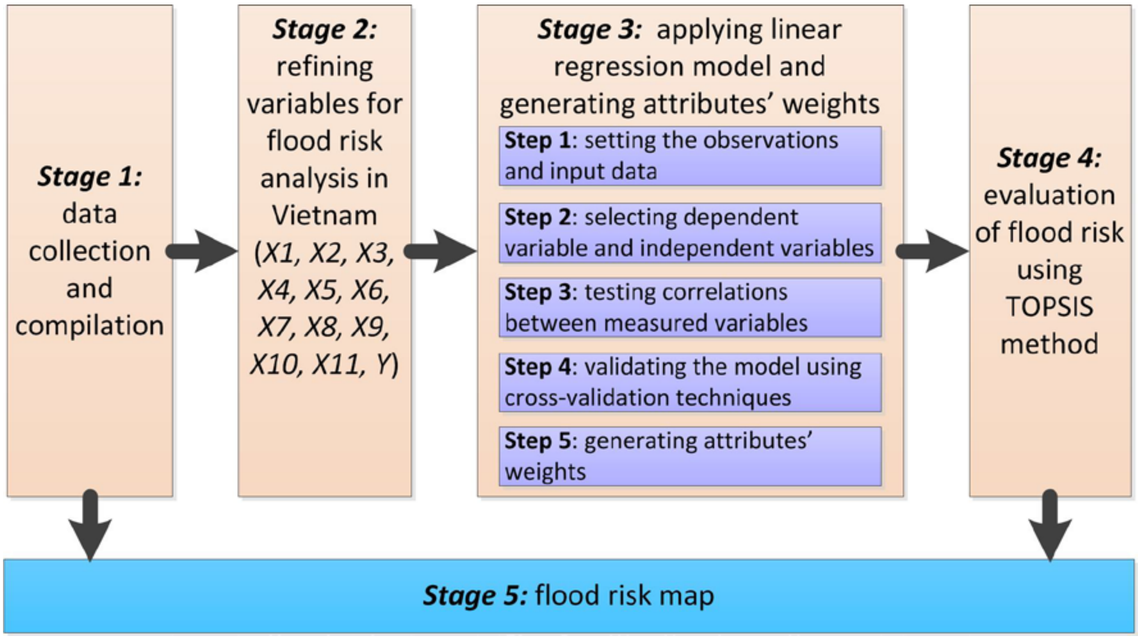


***Figure 5-1***: *Activities, phases and approach in this study*

### 5.4.1 *Stage 1: data collection and compilation*

The flood damage data from DANA database included over 200 data cards of over 200 storms from 1989 to 2015. First, the damage data cards were transferred to an excel file. Then the data were separated into 63 provinces and eight regions of Vietnam (**Table 5-1**) to analyse impacts of flood hazards.

***Table 5-1*** *Regions and provinces in Vietnam*

| Main regions | Regions | Provinces |
|---|---|---|
| **North** | Northwest (NW) | Ha Giang, Phu Tho, Tuyen Quang, Bac Kan, Cao Bang, Bac Giang, Lang Son, Thai Nguyen, Quang Ninh |
| | Northeast (NE) | Hoa Binh, Dien Bien, Son La, Yen Bai, Lai Chau, Lao Cai |
| | Red River Delta (RRD) | Vinh Phuc, Bac Ninh, Ha Noi, Ha Nam, Hai Duong, Hai Phong, Nam Dinh, Thai Binh, Hung Yen, Ninh Binh |
| **Central** | North Central Coast (NCC) | Thanh Hoa, Nghe An, Quang Binh, Ha Tinh, Thua Thien Hue, Quang Tri |
| | South Central Coast (SCC) | Quang Nam, Da Nang, Quang Ngai, Phu Yen, Binh Dinh, Binh Thuan, Khanh Hoa, Ninh Thuan |

| | | |
|---|---|---|
| | Central Highlands (CH) | Kon Tum, Dak Lak, Dak Nong, Gia Lai, Lam Dong |
| **South** | Southeast (SE) | TP Ho Chi Minh, Binh Phuoc, Binh Duong, Ba Ria Vung Tau, Tay Ninh, Dong Nai |
| | Mekong Delta (MK) | Bac Lieu, An Giang, Can Tho, Dong Thap, Ben Tre, Long An, Hau Giang, Kien Giang, Tien Giang, Ca Mau, Vinh Long, Soc Trang, Tra Vinh |

### *5.4.2 Stage 2: refining variables for flood risk analysis in Vietnam*

The damage categories from the DANA database were refined in variables as in **Table 5-2**.

***Table 5-2*** *Refining variables for flood risk analysis in Vietnam categories collected from 1989 to 2015*

| **Damage category** | **Variable** | **Item** | **Unit** |
|---|---|---|---|
| Human | $X_1$ | Deaths | No. |
| | | Missing | No. |
| Housing | $X_2$ | Houses collapse, washed away | No. |
| | | Houses submerged, damaged | No. |
| Education | $X_3$ | Classrooms collapsed, washed away | Room |
| | | Classrooms damaged | Room |
| Health-care | $X_4$ | Clinics collapsed, washed away | No. |
| | | Clinics submerged, damaged | No. |
| Agriculture | $X_5$ | Paddy inundated | Hectare |
| | | Farm produce submerged, damaged | Hectare |
| | | Seeding submerged | Hectare |
| | | Industrial tree lost | Hectare |
| | | Industrial tree damaged | Hectare |
| | | Sugar-cane damaged | Hectare |
| | | Planted forest damaged | Hectare |
| | | Orchard damaged | Hectare |
| Irrigation | $X_6$ | Earth eroded, washed away, redeposited | Cubic meter |
| | | Rock eroded, washed away, redeposited | Cubic meter |
| Transportation | $X_7$ | Earth eroded, washed away, redeposited | Cubic meter |

| | | | |
|---|---|---|---|
| | | Rock eroded, washed away, redeposited | Cubic meter |
| Fisheries | $X_8$ | Fish and shrimp feeding area destroyed | Hectare |
| Telecommunication | $X_9$ | Telephone poles collapsed | No. |
| Electricity | $X_{10}$ | High-voltage electric towers broken | No. |
| | | Electric distribution poles broken | No. |
| Materials | $X_{11}$ | Cement damaged by water | Ton |
| | | Salt wetted, lost | Ton |
| | | Clinker wetted | Ton |
| | | Coal drifted | Ton |
| | | Rush damaged | Ton |
| | | Fertiliser damaged by water | Ton |
| Economic loss | $Y$ | Total estimated economic loss | Million VND |

### 5.4.3 Stage 3: applying multiple linear regression analysis and weighting for flood damage attributes

The regression model was run with flood damage dataset between 1989 and 2015. The data included 27 years or 27 samples for 63 provinces. Therefore, the dataset included 1701 observations. The observed data was shown in **Table 5-3**. $Y$ was set as a response variable. $X_1$ to $X_{11}$ were set as predictor variables.

***Table 5-3*** *Input data set*

| Year | $X_1$ | $X_2$ | $X_3$ | $X_4$ | ... | … | … | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | $Y$ | Province | Region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1989 | 5 | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 | 0 | Phu Tho | NE |
| 1990 | 0 | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 | 0 | Phu Tho | NE |
| 1991 | 0 | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 | 0 | Phu Tho | NE |
| 1992 | 0 | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 | 0 | Phu Tho | NE |
| 1993 | 4 | 1355 | 50 | 0 | | | | 0 | 0 | 0 | 0 | 4650 | Phu Tho | NE |
| 1994 | 2 | 1118 | 47 | 0 | | | | 0 | 0 | 0 | 0 | 4500 | Phu Tho | NE |
| 1995 | 2 | 923 | 29 | 0 | | | | 0 | 0 | 0 | 10 | 15800 | Phu Tho | NE |
| … | … | … | … | … | | | | … | … | … | … | … | … | … |

Flood damage data (observed data) has zero value if no storms. Some observations have zero values for variable Y (total economic loss) but have values for other damages if these damages are small or no compensation for those years in those local areas. Due to the large variation in the flood damage data, log transformation is used for both response and predictive variables for better fitting the normal distribution (Zhou et al. 2017).

Cross-validation methods were used to validate the multiple linear regression model. The cross-validation methods evaluate the performance of a model by assessing the good predictive ability for a new dataset. Leave-one-out cross-validation (LOOCV) and k-fold cross-validation techniques can provide the best cross-validation estimate (James et al. 2013b).

Mojtahedi and Mousavi (2011) also showed that LOOCV technique is reliable for model validation. The LOOCV technique first leaves the first part out of a training dataset and then rebuilds the model using a new smaller training sample. We used the statistical R software with '*boot'* package (Canty and Ripley 2016) to analyse the k-fold cross-validation and LOOCV.

The k-fold cross-validation technique first randomly divides the set of observation into k equal-sized groups or folds. The first part or group is a validation dataset, and the model is fit for the resting k-1 groups. Mean Squared Error (MSE) index was applied to check the model performance. The MSE produces an estimation of the test error rate to assess the resulting validation (James et al. 2013b).

The cross-validation results (**Figure 5-2**) showed that the MSEs of both LOOCV and k-fold CV models with degree of polynomial from 2 to 10 are approximately the same and better than the first model. Therefore, the model was validated.

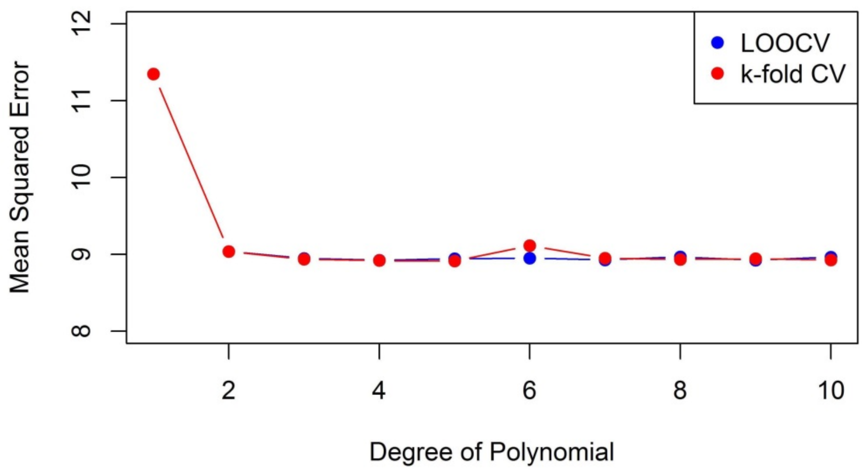


***Figure 5-2**: Error curves of 10-fold cross-validation and LOOCV with different random splits and ten times repeated of the two cross-validation methods*

The multiple regression model for transformed data was computed using the statistical R software. The model had adjusted R-squared of 0.6976 and residual standard error of 2.921. After that, the weights of attributes or independent variables was generated based on LMG indicator using '*relaimpo*' package (Grömping 2006) in the statistical R software (R Core Team 2016). The weights of attributes after normalisation are shown in **Table 5-4**.

***Table 5-4** Flood damage attributes weights based on regression model and LMG indicator after normalisation*

| Attributes | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|
| Weights | 0.0812 | 0.1653 | 0.0528 | 0.0222 | 0.1244 | 0.0456 |
| *p*-value | <0.0001 | <0.0001 | 0.2788 | <0.0001 | <0.0001 | 0.6615 |
| Attributes | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | |
| Weights | 0.0621 | 0.0877 | 0.0108 | 0.0403 | 0.0071 | |
| *p*-value | <0.0001 | <0.0001 | 0.8581 | 0.0102 | <0.0001 | |

The weights of attributes in **Table 5-4** indicate the relative importance of flood risk criteria in Vietnam. The high importance attributes include housing impact ($X_2$), agriculture impact ($X_5$), humanitarian impact ($X_1$), fisheries impact ($X_8$), transportation impact ($X_7$), education impact ($X_3$) and irrigation impact ($X_6$). The low importance attributes are electricity impact ($X_{10}$), telecommunication impact ($X_9$), health-care impact ($X_4$) and material impact ($X_{11}$).

### *5.4.4 Stage 4: evaluation of flood risk*

Vietnam includes eight regions: Northwest (NW), Red River Delta (RRD), Northeast (NE), North Central Coast (NCC), Central Highlands (CH), South Central Coast (SCC), Mekong Delta (MD) and Southeast (SE) as in **Table 5-1**. Each region contains many provinces. This study was designed to evaluate and rank the flood risk for provinces and regions in Vietnam.

TOPSIS algorithm was calculated using statistical R software with '*topsis*' package (Yazdi 2013). The attributes weights were taken from the analysing result of multiple linear regression model using LMG indicator. The attributes are the flood damage data. Final score (RC) and final ranking for regions and provinces from TOPSIS are shown in **Table 5-5** and **Table 5-6** respectively.

***Table 5-5*** *Regression analysis and TOPSIS outcomes for flood damages attributes of regions in Vietnam*

| **Regions** | **PIS** | **NIS** | **RC** | **Rank** |
|---|---|---|---|---|
| Northeast (NE) | 0.15748 | 0.02122 | 0.11875 | 5 |
| Northwest (NW) | 0.16439 | 0.01982 | 0.10760 | 6 |
| Red River Delta (RRD) | 0.12963 | 0.06909 | 0.34767 | 4 |
| North Central Coast (NCC) | 0.05008 | 0.15160 | 0.75170 | 1 |
| South Central Coast (SCC) | 0.06764 | 0.11997 | 0.63947 | 3 |
| Central Highlands (CH) | 0.16750 | 0.01368 | 0.07549 | 7 |
| Southeast (SE) | 0.17421 | 0.00126 | 0.00719 | 8 |
| Mekong Delta (MD) | 0.06296 | 0.14253 | 0.69360 | 2 |

NIS: negative ideal solution; PIS: positive ideal solution; RC: relative closeness.

***Table 5-6*** *Regression analysis and TOPSIS results for flood damages attributes of provinces in Vietnam*

| Province | RC | Rank | Region | Province | RC | Rank | Region |
|---|---|---|---|---|---|---|---|
| Phu Tho | 0.0995 | 32 | NE | Quang Nam | 0.56453 | 2 | SCC |
| Ha Giang | 0.06227 | 45 | NE | Quang Ngai | 0.41211 | 9 | SCC |
| Tuyen Quang | 0.04722 | 49 | NE | Phu Yen | 0.24476 | 15 | SCC |
| Cao Bang | 0.05095 | 48 | NE | Binh Dinh | 0.42523 | 6 | SCC |
| Bac Kan | 0.04449 | 51 | NE | Khanh Hoa | 0.11488 | 28 | SCC |
| Thai Nguyen | 0.03248 | 55 | NE | Ninh Thuan | 0.06829 | 42 | SCC |
| Lang Son | 0.02793 | 56 | NE | Binh Thuan | 0.09057 | 35 | SCC |
| Bac Giang | 0.04337 | 52 | NE | Kon Tum | 0.06052 | 46 | CH |
| Quang Ninh | 0.09703 | 34 | NE | Gia Lai | 0.0378 | 53 | CH |
| Hoa Binh | 0.03725 | 54 | NW | Dak Lak | 0.11313 | 29 | CH |
| Son La | 0.12923 | 25 | NW | Lam Dong | 0.08578 | 37 | CH |
| Dien Bien | 0.04556 | 50 | NW | Dak Nong | 0.02153 | 58 | CH |
| Lao Cai | 0.08163 | 40 | NW | TP HCM | 0.00752 | 62 | SE |
| Lai Chau | 0.07593 | 41 | NW | BR VT | 0.06707 | 44 | SE |
| Yen Bai | 0.05589 | 47 | NW | Binh Duong | 0.00752 | 63 | SE |
| Vinh Phuc | 0.08188 | 39 | RRD | Dong Nai | 0.01009 | 59 | SE |
| Ha Noi | 0.13169 | 24 | RRD | Binh Phuoc | 0.00862 | 61 | SE |
| Bac Ninh | 0.02726 | 57 | RRD | Tay Ninh | 0.00936 | 60 | SE |
| Hung Yen | 0.06709 | 43 | RRD | An Giang | 0.26409 | 12 | MD |
| Ha Nam | 0.11818 | 27 | RRD | Bac Lieu | 0.13551 | 23 | MD |
| Hai Duong | 0.08876 | 36 | RRD | Ben Tre | 0.12769 | 26 | MD |
| Hai Phong | 0.09914 | 33 | RRD | Can Tho | 0.20734 | 19 | MD |
| Thai Binh | 0.27265 | 11 | RRD | Ca Mau | 0.42132 | 7 | MD |
| Nam Dinh | 0.21624 | 17 | RRD | Dong Thap | 0.38753 | 10 | MD |
| Ninh Binh | 0.13907 | 22 | RRD | Hau Giang | 0.11156 | 30 | MD |
| Thanh Hoa | 0.46532 | 4 | NCC | Kien Giang | 0.25599 | 13 | MD |
| Nghe An | 0.59446 | 1 | NCC | Long An | 0.24821 | 14 | MD |
| Ha Tinh | 0.48765 | 3 | NCC | Soc Trang | 0.10166 | 31 | MD |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Quang Tri | 0.21861 | 16 | NCC | Tien Giang | 0.2065 | 20 | MD |
| Quang Binh | 0.43966 | 5 | NCC | Tra Vinh | 0.08345 | 38 | MD |
| T.T.Hue | 0.41507 | 8 | NCC | Vinh Long | 0.15791 | 21 | MD |
| Da Nang | 0.21453 | 18 | SCC | | | | |

The ordinal ranking of flood risk for regions in **Table 5-5** indicates that the NCC region has the highest flood risk score of 0.7517, followed by the MD and SCC regions with the scores of 0.6936 and 0.63947 respectively. The SE and CH regions have the lowest flood risk scores of 0.00719 and 0.07549 respectively. Flood risk is higher in the coastal and delta areas, and lower in the highland and non-coastal areas.

The result in **Table 5-6** shows that Nghe An province in the NCC region has the highest flood risk with the score of 0.59446, following by Quang Nam province in the SCC region with the score of 0.56453. Five provinces including Binh Duong, Ho Chi Minh city, Binh Phuoc, Tay Ninh and Dong Nai in the SE region have the lowest flood risk scores.

### *5.4.5 Stage 5: flood risk map*

The result of evaluation of flood risk using regression model and TOPSIS methods was combined with a GIS environment to build a flood risk map. The flood risk map for 63 provinces in Vietnam using final score (RC) in **Table 5-6** was established using ArcGIS® software by Esri. The result is displayed in **Figure 5-3**. The flood risk map output can be a good reference for DMs and planners to identify the level of flood risk areas, develop flood risk management strategies and have appropriate flood risk mitigation measures.

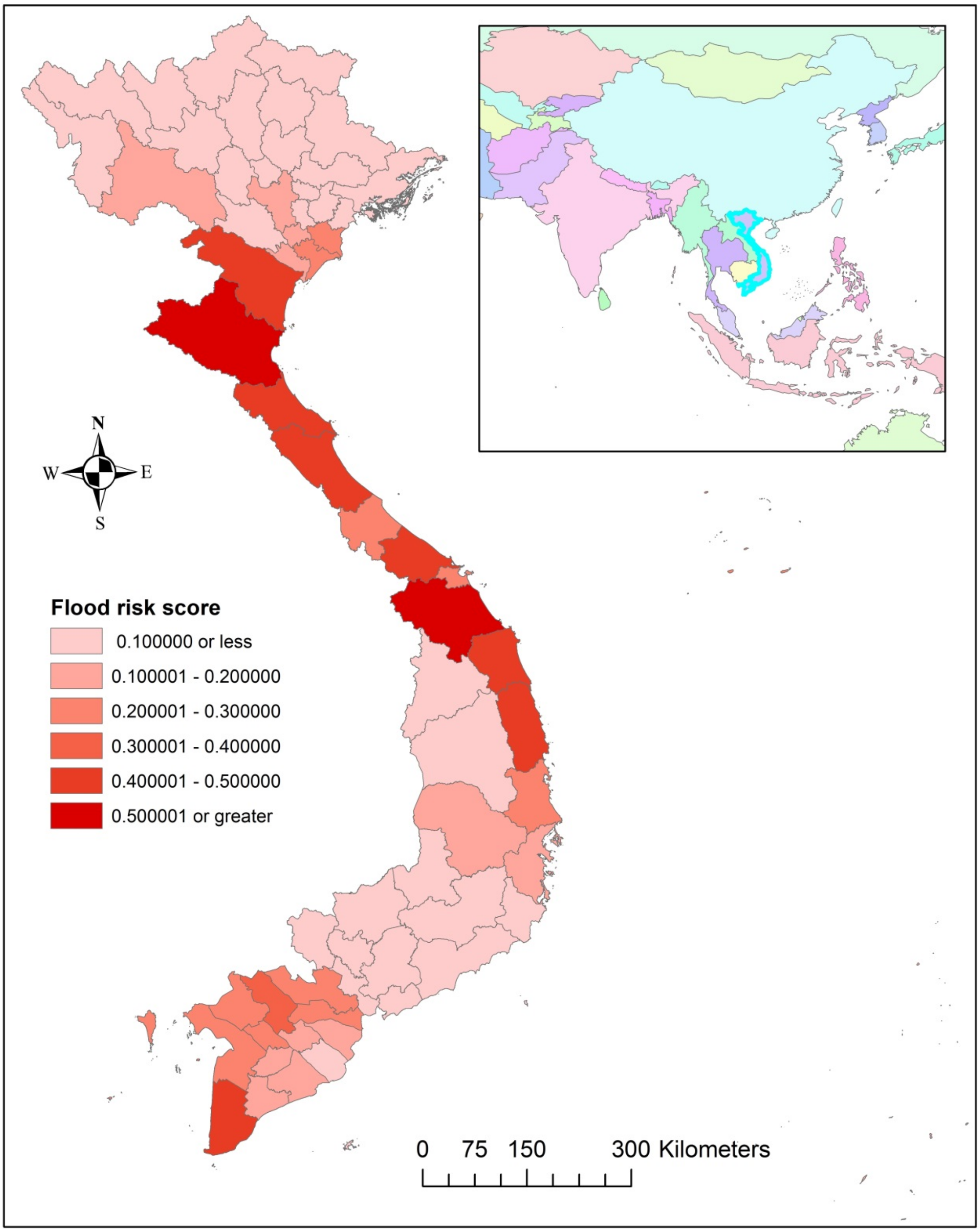


***Figure 5-3****: Spatial patterns of the flood risk map by provinces in Vietnam using regression analysis and TOPSIS outcomes for flood damage attributes*

The provinces in the NCC, MD and SCC regions have the highest flood risk scores. The provinces in the SE and CH regions have the lowest flood risk scores. Nghe An has the highest flood risk score in the NCC region and ranks the first in the country. Quang

Nam has the highest flood risk in the SCC region score and ranks the second in the country. Ca Mau has the highest flood risk score in the MD region and ranks the seventh in the country. Binh Duong province in the SE region has the lowest score and ranks the last in the country. Dak Nong province in the CH region ranks the fifty-eighth in the country.

## 5.5 Discussion and conclusion

This study presented a novel approach to investigate Vietnam's national disaster database. The multiple linear regression-TOPSIS method employed to examine and rank the flood risk for 8 regions and 63 provinces in Vietnam. A flood risk map was created based on the TOPSIS ranking results. The results provided a detailed flood risk assessment on a national scale, which provides accessible risk information for DMs and planners to classify the most at-risk areas, and has implications for flood risk management in Vietnam.

TOPSIS has been increasingly applied in flood risk management due to their ability to deal with multiple attributes (de Brito and Evers 2016). TOPSIS was used to calculate hydrologic vulnerability indices (Jun et al. 2011) or to prioritise flood mitigation alternatives (Ghanbarpour et al. 2013). TOPSIS was also applied to rank states and territories of flood risk for Australia (Mojtahedi and Oo 2016). The application of multiple linear regression-TOPSIS approach in this study could consolidate the approach of MADM in flood risk management.

The ranking of eight regions in **Table 5-5** reflects the reality of flood risk in Vietnam. The NCC and SCC regions are sloping and narrow with a long coastal line. The topography of this area is fragmented by rivers that originate from mountain ranges in the west, flow through narrow plains before emptying into the sea. Due to these conditions, the NCC and SCC regions are frequently subjected to floods causing huge loss of life and property (Tran et al. 2008, Ho and Umitsu 2011, Bubeck et al. 2012). The northern part of Vietnam including NE, NW and RRD has five largest cascade hydropower reservoirs on Da river basin, which have effectively controlled flood risk. The capacity of reservoir system on Da river basin is 7 billion cubic meter, accounting for 70% of the whole national hydropower system of 10.5 billion cubic meters. Flooding in the MD and SE regions is mainly caused by heavy rainfall, tide and sea level rise (Wassmann et al. 2004). The SE and CH regions have higher terrain than the other regions, so they are at lower flood risk.

**Table 5-6** provides the ordinal ranking of flood risk for provinces in Vietnam. Nghe An and Quang Nam provinces rank the first and second for flood risk respectively. Nghe An province was selected for a case study on legal frameworks supporting disaster risk reduction, which was conducted by International Federation of Red Cross and Red Crescent Societies (Tukker and Ngo 2014). Quang Nam has a long coastal line and Vu Gia - Thu Bon river basin, one of the largest river basins in Vietnam. This province has low-land areas along Vu Gia river and Thu Bon river, which are frequently subjected to flooding. Binh Duong, Tay Ninh, Binh Phuoc and Dong Nai provinces in the SE region have higher land areas and no coastal line, so they have the lowest flood risk scores. The flooding in Ho Chi Minh city is affected by the urban drainage system and tide. The flooding problem in this city is increasing when the rapid development of the city is out of the capacity of the drainage system (Storch and Downes 2011).

Vietnam is often in the path of tropical depressions and storms forming in the East Sea. Severe storms are accompanied by strong wind, high waves, tide and heavy rainfall. High waves and tide threaten coastal areas, while prolonged torrential rainfall often causes severe flooding. Population growth, agricultural expansion and industrial development have increased flood risk, particularly in river basins and coastal areas in Vietnam (Shaw 2006). The MADM-GIS approach in this study can support flood risk management activities by providing flood risk assessment results and a visualised map. The results can provide a reference for planners, policy-makers and researchers to build a holistic flood risk management framework for Vietnam. In addition, the approach of multiple linear regression-TOPSIS and a GIS framework can be potentially applied to analyse disaster databases in other countries or regions, which are categorised in attributes and recorded over an extended period.

The main limitation of our flood damage modelling is that the modelling depends on the relevance of flood damages and the available national disaster database. Any errors in this natural hazards damage data can relate to many factors such as measurement methodologies, loss indicators and procedure of data documenting. Therefore, to improve the quality of flood risk assessment, it is called for studies on a standard for flood damage data collection, which will consider both direct and indirect damages, and tangible and intangible costs.

In conclusion, the present approach proposed a combination of regression analysis and TOPSIS method for analysing Vietnam’s national disaster database, DANA, and then integrated the result into a GIS environment to provide a flood risk map for Vietnam. The results included the rank of flood risk for regions and provinces and a flood risk map for Vietnam. The output provided a spatial flood risk assessment at the national scale, which can assist DMs in Vietnam to make informed decisions about flood risk management activities.

# Chapter 6 Exploring the relative influence of flood damage attributes to fatality attribute and policy implications[5]

## 6.1 Introduction

The Global Disaster Database identifies Asia as the most vulnerable continent to floods and storms, with about 3,620 floods and storms resulting in over 8,085,516 fatalities between 1900 and 2016 (**Figure 1-1**). Developing economies are often more severely affected than developed ones in natural hazards (Kahn 2005, Hansson et al. 2008, Jongman et al. 2015). Within Asia, Vietnam is severely affected by floods and storms, being the eighth most intensely affected by extreme weather events 1996-2015 (Kreft et al. 2016) and the fourth most exposed to river flood risk by population proportion (Luo et al. 2015).

Loss of human life is a critical criterion for evaluating flood risk (Maaskant et al. 2009). Flood-related deaths have been extensively studied in developed countries (e.g. Coates (1999), Ashley and Ashley (2008), FitzGerald et al. (2010), Sharif et al. (2015), and Terti et al. (2017)), while few studies have been done in developing ones (e.g., Paul and Mahmood (2016)). A few studies on flood-related fatalities in developing countries have been taken despite their higher fatality rates (Jonkman 2005).

Research on flood fatalities has several approaches. Penning-Rowsell et al. (2005) propose a methodology to predict fatalities and injuries in flood events using flood hazard and exposure characteristics. Jonkman and Vrijling (2008) provide a method to

[5] Luu, C. & von Meding, J. 2018, Chapter 15: Analyzing Flood Fatalities in Vietnam Using Statistical Learning Approach and National Disaster Database. In: Asgary A. (eds) Resettlement Challenges of Refugees and Disaster Displaced Populations. Springer, Chennai

estimate death toll in flood events in three-step sequence: analysis of flood hazard characteristics, estimation of total exposed population, and assessment of fatality rate among those exposed. Many studies focus on analysing the circumstances and causes of flood fatalities (Jonkman and Kelman 2005, Jonkman et al. 2009, Haynes et al. 2017). The analysis requires details such as the cause of death, gender, age, evacuation condition, time of day, and coping capacity, and is undertaken for specific regions or events. Another research approach to study on flood fatalities is to build predictive models (Zhai et al. 2006, Di Mauro and De Bruijn 2012, Di Mauro et al. 2012). These models are often combined with hydraulic models and require very detailed input parameters, which are difficult to apply to data-scarce areas. One of the reasons for the minimal number of studies on flood-related deaths in developing countries is the lack of available detailed data for analysis.

Recently, there has been a significant increase of studies on flood risk analysis in Vietnam. Tran et al. (2008) explored the coping mechanisms to flood risk of rural communities in Thua Thien Hue province. Chau et al. (2013) used GIS techniques to map flood impacts on agriculture in Quang Nam province. Chinh et al. (2016) investigated flood risk management on preparedness, response and recovery of the private small businesses and households in Can Tho city. Tien Bui et al. (2016) used machine learning approach for modelling flood susceptibility in Tuong Duong district. Luu et al. (2018a) assessed flood hazard for Quang Nam province using spatial multi-criteria decision analysis approach. However, there have been no studies on flood-related fatalities in Vietnam.

Disaster impact data collection and analysis (UNISDR 2015b) can support fundamental information for policy-setting and decision-making in disaster risk reduction (IRDR 2014). Many available disaster databases are itemised and compiled in the reports of Grasso and Dilley (2013) and Simpson et al. (2014). For example, the Global Disaster Database can be accessed at the Emergency Events Database (www.emdat.be), and many national disaster databases can be accessed at DesInventar (www.desinventar.net/DesInventar/index.jsp). Besides improving the quality of disaster loss databases and completing standards of data recording and attributing, it is also necessary to promote the use of databases, especially policy applications (Grasso and Dilley 2013). In Vietnam, the official national Damage Assessment and Needs Analysis (DANA) database is developed by the Central Government of Vietnam through the Central Committee for Flood and Storm Control. This database has stored direct damages of flood disasters in Vietnam since 1989 (Below et al. 2010, Hughey et al. 2011).

Some studies evaluated the quality of the DANA database such as Hughey et al. (2011) and Nhu et al. (2011). However, further analysis and assessment of flood risk from this database have not been undertaken. Due to the lack of studies using DANA and also highly limited studies on flood-related fatalities in Vietnam, the present research aims to analyse flood risk associated with loss of life through using the DANA database. We employ machine learning approach with multiple linear regression model, random forest for regression and boosting techniques to evaluate the relative importance of flood damage attributes to flood fatality attribute using Vietnam's national disaster database documented between 1989 and 2015. The relative influence measures of flood damage attributes to fatalities may provide useful information for flood risk management policies and appropriate interventions to mitigate mortalities in flood events in the future.

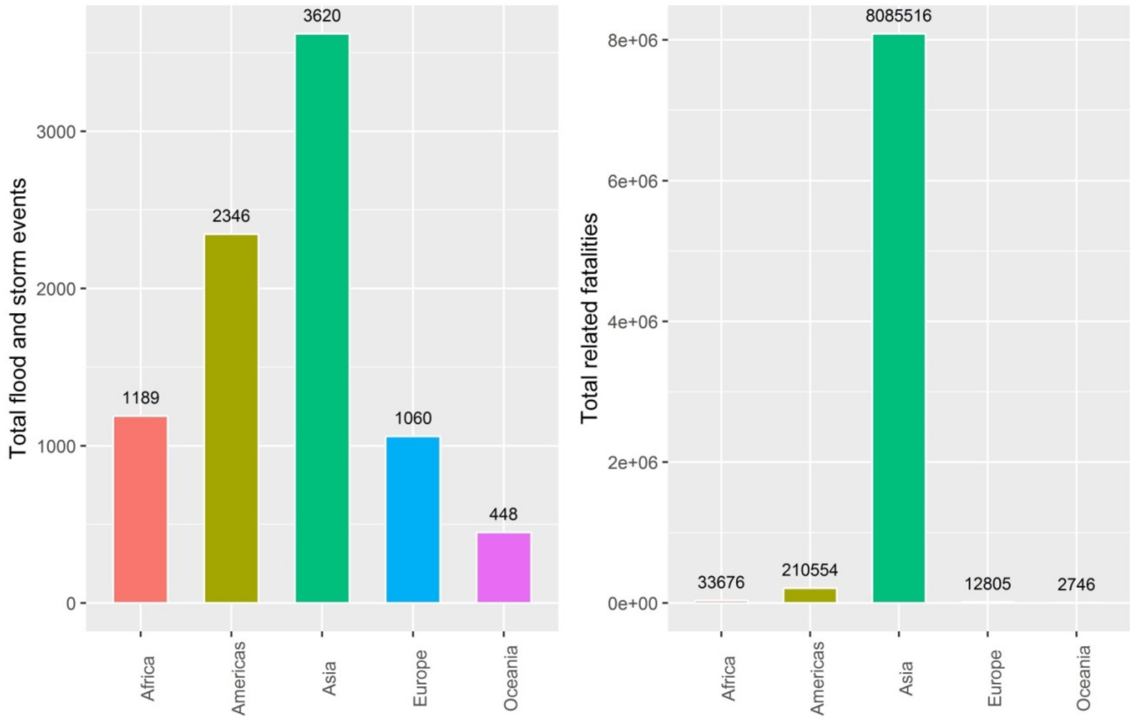


***Figure 6-1***: *Total number of floods and storms, and death toll 1900 and 2016 at the global scale (data source: http://emdat.be accessed 20 April 2017)*

## 6.2 Flood damage data

Flood damage data is collected after storm and flood events via DANA system by the Central Committee for Flood and Storm Control (MARD 2006, Bollin and Khanna 2007, Below et al. 2010). DANA lacks information on physical exposure of buildings and infrastructure that is similar to the limitation of many global, regional and national disaster databases (Simpson et al. 2014). The data is gathered by categories with various damage indicators such as fatalities, injuries, number of houses damaged, area of paddy and farm produce damaged, volume of earth eroded and washed away, and area of fish and shrimp feeding destroyed (Hughey et al. 2011). However, the DANA database only reports the direct losses of recovery and reconstruction of damaged properties and infrastructure and does not record the values lost from business interruption or service disruption (Wang et al. 2010).

This study sources and collects the flood damage data from DANA database, which includes more than 200 data cards of over 200 flood and storm events between 1989 and 2015. Vietnam encompasses 58 provinces and 5 main municipalities, or 63 provinces, which are grouped into 8 regions according to the similarities in topography, flora, fauna, climate and socio-economic characteristics. Therefore, the data are then compiled for 63 provinces (**Figure 6-2**) and 8 regions (**Figure 6-4**) of Vietnam.

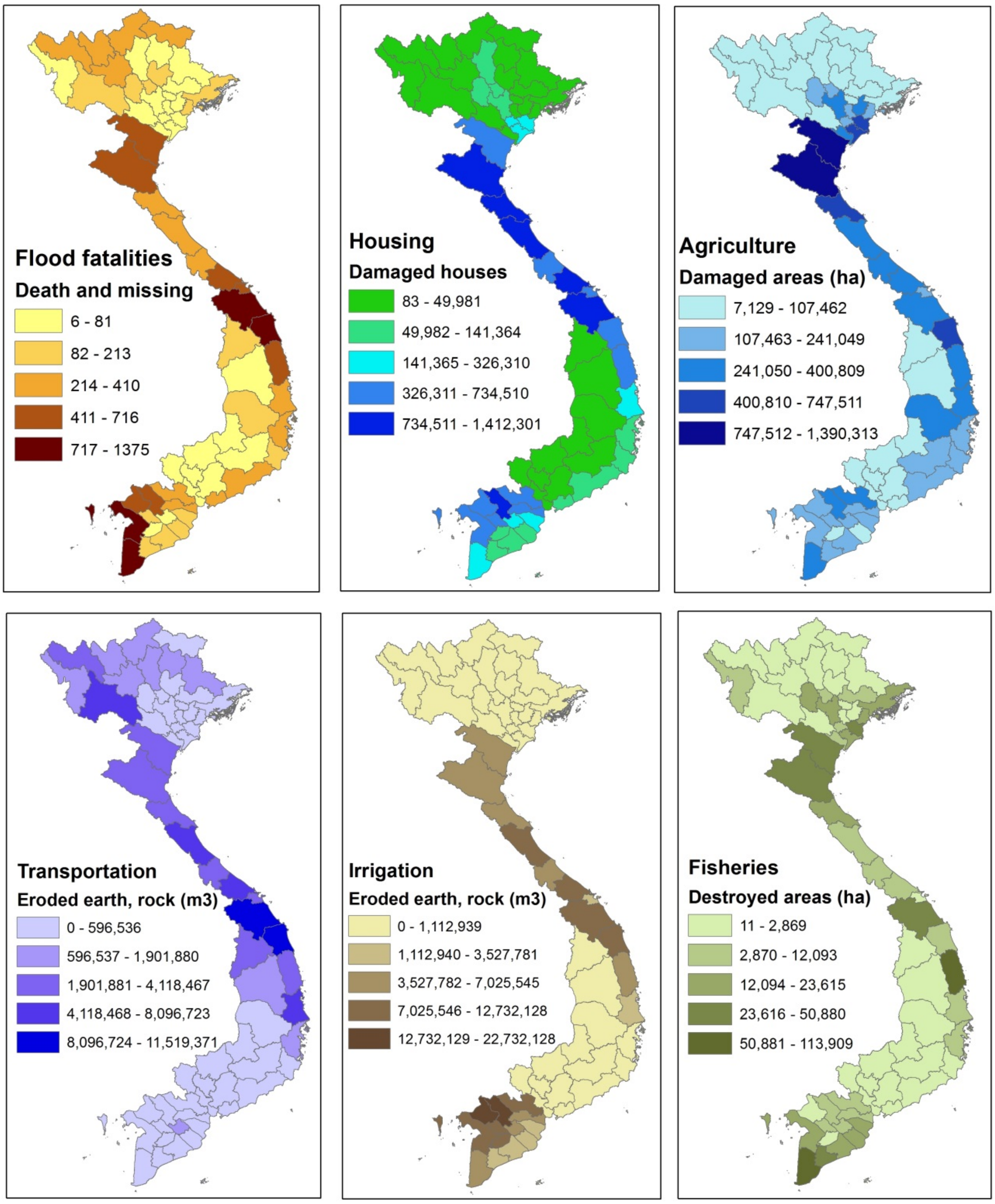

***Figure 6-2**: Spatial distribution of provincial level flood impacts*

*(Note: Flood fatalities are number of dead and missing people; housing impact is number of houses; agriculture impact is area of paddy and farm produce damaged; transportation impact is volume of earth, rock eroded of roads; irrigation impact is volume of earth, rock eroded of dykes, canals and embankments; and fisheries impact is area of fish and shrimp feeding destroyed)*

Flood fatality is a critical indicator in risk assessment. Flood fatality or death toll is defined as people affirmed as dead and missing people assumed dead (Below et al. 2010). Flood and storm events have posed a severe impact on the Vietnamese people, especially the loss of life, with over 14,927 flood fatalities reported between 1989 and 2015 (**Figure 6-3**).

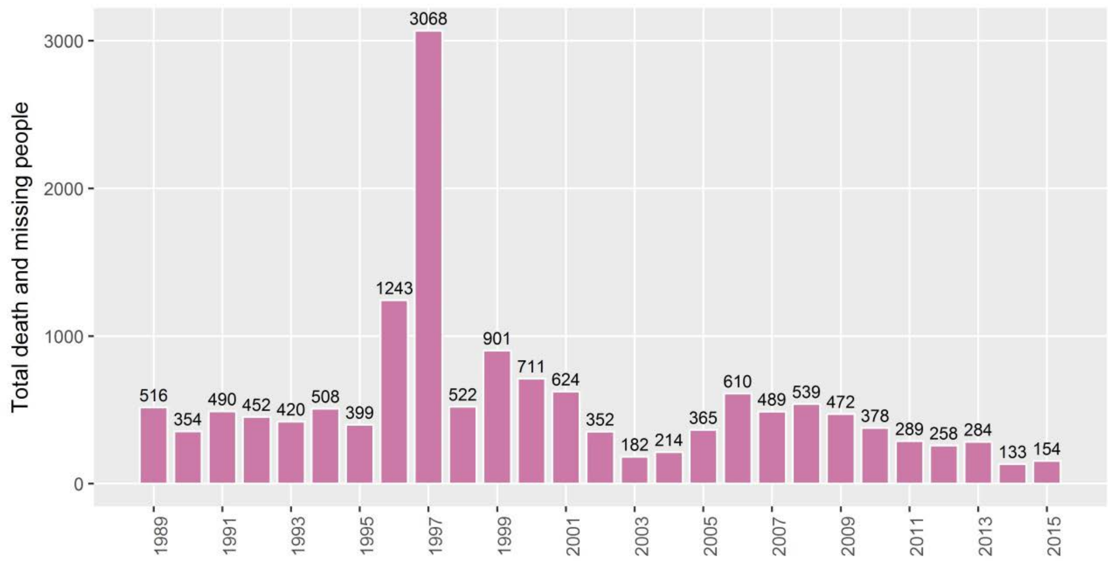


***Figure 6-3**: Flood fatalities in Vietnam, 1989-2015*

The number of deaths due to floods varies in different regions of Vietnam during the observation period as shown in **Figure 6-4**. The highest numbers occurred in Mekong Delta (MD) and South Central Coast (SCC) regions with more than 4,000 flood fatalities in the period 1989-2015. The South East (SE) and Red River Delta

(RRD) regions had the lowest death toll with 362 and 409 respectively over the period. The most affected regions are the lowland and coastal areas.

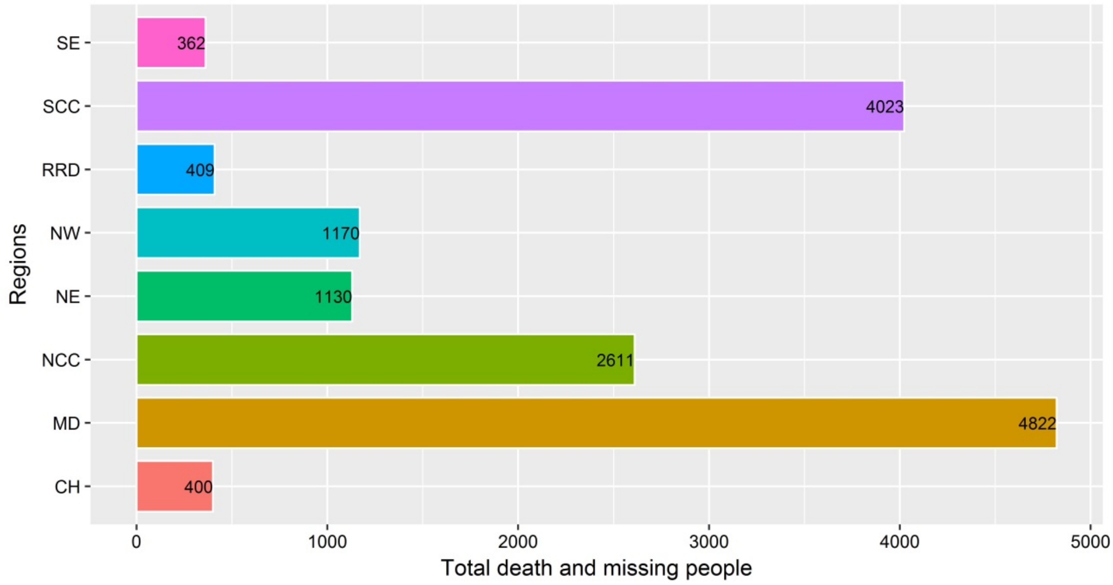


***Figure 6-4**: Total numbers of flood fatalities in 8 regions of Vietnam from 1989 to 2015 (Note: Southeast (SE), South Central Coast (SCC), Red River Delta (RRD), Northwest (NW), Northeast (NE), North Central Coast (NCC), Mekong Delta (MD), Central Highlands (CH))*

## 6.3 Methods and data analysis

### *6.3.1 Data processing and statistical machine learning techniques*

Flood damage attributes used for analysis are fatalities, housing, agriculture, transportation, irrigation and fisheries impacts (**Figure 6-2**). The flood damage data is compiled for 63 provinces in 27 years (from 1989 to 2015) with these six variables. Each year for each province is considered an observation, so there are total 1,701 observations.

Our goal is to investigate the influence of various flood damage attributes to fatality attribute using Vietnam's national disaster database. Therefore, the study focuses on the variable importance measures of models. We employ three supervised machine learning techniques including multiple linear regression, random forest and boosting to explore the variable importance measures of flood damage attributes on fatalities. These techniques offer a convenient and intuitive explanation of variable influence to the overall model. The results are then compared to check and clarify model performance. These techniques are described in further detail in subsections below.

Statistical analyses are applied to investigate the relationship between flood fatalities and other main flood damage attributes using statistical packages in R (R Core Team 2016). Machine learning process applied for analysis in this study is described in **Figure 6-5**. The process includes five steps: (1) setting a sample data, (2) randomly dividing the sample data into two groups: training and testing data sets, (3) developing a model using training data set, (4) validating the model using testing data set, and (5) evaluating model performance using mean squared error index.

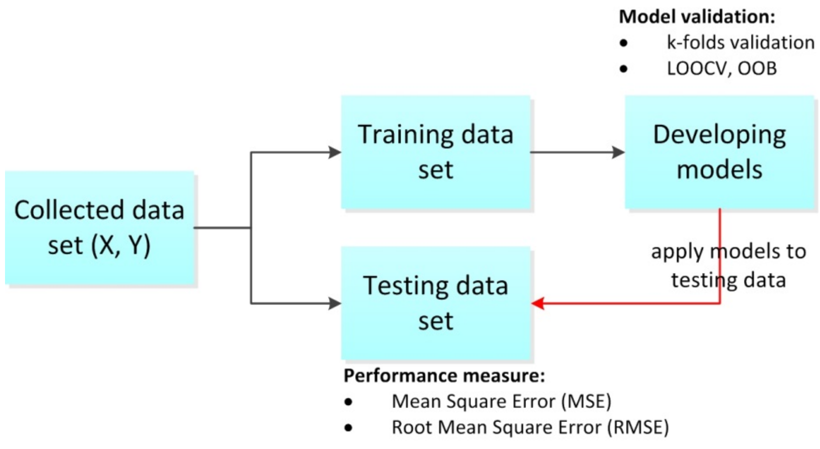


***Figure 6-5**: Machine learning framework in this study*

Statistical distributions of variables are examined by calculating mean, median, range, minimum and maximum. Due to the large variation in the flood damage data, logarithm transformation is used for all the six damage categories for better fitting the normal distribution (Zhou et al. 2017). Following the machine learning framework in

**Figure 6-5**, the sample data is randomly split into two subsets with the ratio of 70% and 30% for training and testing data sets respectively using *‘caTools’* package (Tuszynski 2014) in R (R Core Team 2016). Cross-validation method is carried out to validate the model. The training data set is used for building the model while the testing data set is used for model validation.

#### *6.3.1.1 Multiple linear regression*

Multiple linear regression is a standard statistical modelling technique of which details can be found in any modelling book, for instance, James et al. (2013c). In the study, this technique is used to model flood fatalities as a linear function of other damage attributes, including housing, agriculture, irrigation, transportation and fisheries impacts. It is assumed that there are no interactions between variables. After that, LMG indicator, which is proposed by Lindeman, Merend and Gold (Lindeman et al. 1980), is employed to calculate the relative variable importance of the model. The explanation of LMG indicator is based on the percentage contribution of the multiple coefficient of determination (R-squared) of each variable in the model (Lindeman et al. 1980, Bi 2012, Grömping 2015).

#### *6.3.1.2 Random forest*

Another technique, random forest for regression is applied to the same database. Random forest algorithm, for both regression and classification models, is a panacea for all data science problems. This method constructs of a multitude of decision trees and selects the best as the final result which can be used to build predictive models (James et al. 2013c). In this study, random forest model is established by the ‘*randomForest*’ package (Liaw and Wiener 2002) in R (R Core Team 2016), of which random forest algorithms based on Breiman et al. (1984)’s classification and regression tree (CART).

The random forest algorithm can be presented in the following steps (Liaw and Wiener 2002):

1. Drawing $n_{tree}$ bootstrap sample from the original dataset. A sample of $n_{tree}$ is randomly taken with replacement.

2. For each of these samples, developing an unpruned regression tree: randomly sampling $m_{try}$ of predictors and selecting the best split from these variables at each node.

3. Predicting new data set by aggregating the predictions of these trees (averaging for regression).

#### *6.3.1.3 Boosting*

Similar to the random forest, boosting technique also combines multiple independent weak regression models to build a more robust and accurate ensemble model. However, unlike random forest, boosting is a sequential method in which each of the weak models is added to improve the performance of the previous collection of weak models. In this study, we run '*gbm*' package (Ridgeway 2015) in R (R Core Team 2016) to build a boosting model from a collection of decision trees.

### *6.3.2 Modelling and analysis*

#### *6.3.2.1 Multiple linear regression*

Multiple linear regression model is applied to analyse the relationship between log-transformed flood damage attributes and flood fatality attribute using R (R Core Team 2016). The training data set is used to build the model whereas the testing data set is employed to check the performance of the model. The model of training data set has the multiple coefficient of determination (R-squared) of 0.5932 and residual standard error of 0.856. Next, the predicted value of the model with testing data set is calculated. The Mean Squared Error (MSE) of the testing model is 0.674. After that, we run '*relaimpo*' package (Grömping 2006) to generate relative variable importance measures based on LMG indicator.

The variable importance results in **Table 6-1** show that housing damage attribute is by far the most critical variable with the relative importance of 0.3642. The other variables play a lesser role. All variables have *P* value of less than 0.05.

***Table 6-1*** *Variable importance of flood damage attributes to fatalities in multiple linear regression model with the log-transformed data*

| **Damage attributes** | **Relative importance** | ***P* value** |
|---|---|---|
| Housing impact | 0.3642 | <0.0001 |
| Agriculture impact | 0.1791 | 0.0468 |
| Transportation impact | 0.1548 | <0.0001 |
| Irrigation impact | 0.1527 | <0.0001 |
| Fisheries impact | 0.1492 | 0.0221 |

#### *6.3.2.2 Random forest*

Random forest for regression model is used to measure the relative influence of flood damage attributes on fatalities. The random forest model is built using '*randomForest*' package (Liaw and Wiener 2002) for the training data set. We set the input parameters for the model as follows: the number of trees is 500, and the maximum number of terminal nodes is 15. The training model has the percentage variance explained of 61.64% and the mean of squared residuals of 0.687. The testing model has MSE of 0.612.

Cross-validation method was carried out to validate the model. The percentage of variance explained, and MSR are based on Out-Of-Bag (OOB) estimates, so OOB can be used to assess the performance of random forest (Grömping 2009). OBB uses the left observations from each bootstrap sample as a testing set. The MSE of OOB was adopted to assess the model performance. The approach is also convenient for estimating the MSE of the model on testing data set. We estimated OOB and test error with a function of $m_{try}$ , and the result is showed in **Figure 6-6**. The OOB was computed on the training data set and different with the testing data set. The $m_{try}$ is the number of independent variables in the random forest regression model at each split of each tree, varies from 1 to 5. The testing set error is slightly lower than the OOB error. These error estimates are very correlated, and the curves are quite smooth and flat plateau. The result (**Figure 6-6)** shows that MSEs for $m_{try}$ between 1 and 5 of OOB and test errors are around 0.6 to 0.8. The random forest model has good performance with the MSE on OOB of 0.7 to 0.8.

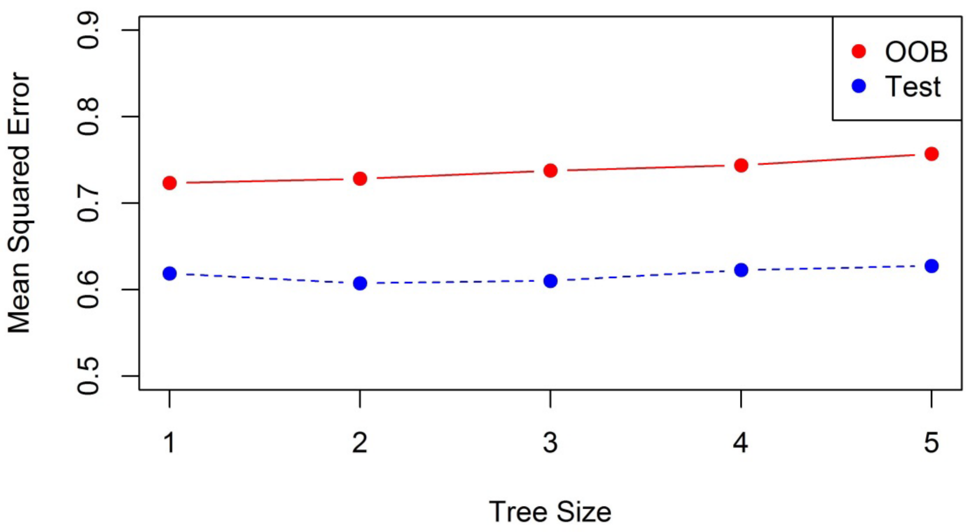


***Figure 6-6****: MSEs of OOB and testing data set estimated as a function of different numbers of terminal nodes ($m_{try}$)*

The variable importance measures of the random forest model are presented in **Table 6-2**. Similar to the multiple linear regression model, the variable importance result of the random forest model exhibit that housing impact is the most significant variable (the relative importance measure of 0.4546), while other variables play a minimal role.

***Table 6-2*** *Variable importance of flood damage attributes to fatalities in random forest model using Mean Decrease Accuracy*

| **Damage attributes** | **Relative importance** |
|---|---|
| Housing impact | 0.4546 |
| Transportation impact | 0.2438 |
| Irrigation impact | 0.1260 |
| Fisheries impact | 0.0906 |
| Agriculture impact | 0.0848 |

### *6.3.3 Boosting*

This study uses '*gbm*' package (Ridgeway 2015) to fit the boosted regression model for the training data set. We set the input parameters for the model as follows: the number of trees is 10,000, the maximum depth of variable interactions is 4, and the distribution assumption is Gaussian. Cross-validation technique is also applied to examine the performance of boosting model. The MSE of testing data set is 0.638, which is similar to the MSEs of random forest model (0.612) and multiple linear regression model (0.674). The differences between MSEs of the applied techniques are very small indicating that the applied models are validated and reliable.

Cross-validation in boosting is ran to select the number of trees. By increasing the number of trees in boosting, it could overfit, so the cross-validation aimed to check the overfitting. A function of the number of trees and their MSEs is displayed in **Figure 6-7**. The trend of increasing number of trees is stable, and this is the evidence of the claim that boosting is reluctant to overfit.

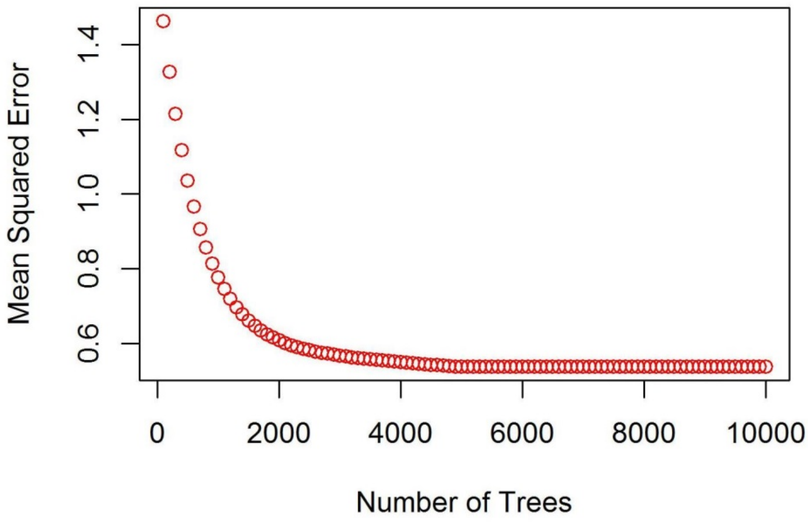


***Figure 6-7***: *Cross-validated MSE profiles for the boosted tree model on the training data set as a function of the number of trees*

The results of variable importance measures of the boosting model are shown in **Table 6-3**. We also find that flood housing damage attribute has the most significant influence on fatalities, and other damage attributes have much lesser influences on fatalities. The analysis results of the three applied models are consistent.

***Table 6-3*** *Variable importance of flood damage attributes to fatalities in boosted regression model*

| **Damage attributes** | **Relative importance** |
|---|---|
| Housing impact | 0.6191 |
| Transportation impact | 0.1372 |
| Irrigation impact | 0.0959 |
| Fisheries impact | 0.0845 |
| Agriculture impact | 0.0633 |

## 6.4 Discussion

### *6.4.1 Variable importance measures*

The results of variable importance measures of three applied models are summed up in **Table 6-4**. In general, all models agree that housing damage attribute has the most significant influence on flood fatality attribute and other damage attributes have much lesser influences on flood fatality attribute. The results from the random forest and boosting models are consistent for all variables. There are some small differences in damage attributes' ranking between linear regression model and other models; however, in the linear regression model, the weights of damage attributes other than housing impact are approximately equal influences to flood fatalities. The differences are due to the assumptions of applied statistical techniques. Multiple linear regression model is conducted with the assumption of no interactions between variables, while random forest and boosting models are undertaken with the assumption that there are interactions between variables.

***Table 6-4*** *Comparision of variable importance measures of flood damage attributes to fatalities in applied statistical models*

| Damage attribute/ Statistical model | Relative importance measures | | | | | |
|---|---|---|---|---|---|---|
| | Multiple linear regression | | Random forest | | Boosting | |
| | Weight | Rank | Weight | Rank | Weight | Rank |
| Housing impact | 0.3642 | 1 | 0.4546 | 1 | 0.6191 | 1 |
| Irrigation impact | 0.1527 | 4 | 0.2438 | 2 | 0.1372 | 2 |
| Agriculture impact | 0.1791 | 2 | 0.1260 | 3 | 0.0959 | 3 |
| Fisheries impact | 0.1492 | 5 | 0.0906 | 4 | 0.0845 | 4 |
| Transportation impact | 0.1548 | 3 | 0.0848 | 5 | 0.0633 | 5 |

### *6.4.2 Practice and policy implications*

Vietnam has been severely affected by floods and storms with a high death toll over the years (**Figure 6-3**). However, there have been no studies on flood-related deaths in Vietnam. This study responds to this gap and examines flood fatalities over an extended period at the country level. The national disaster database is sourced and collected, in which flood damage data includes more than 200 flood and storm events between 1989 and 2015. A statistical machine learning approach is applied to analyse the relative importance measures of flood damage attributes to fatalities. The variable importance analysis results show that housing damage attribute has the most significant influence on flood fatalities whereas other damage attributes have a lesser role.

The results reflect the reality of housing conditions in flood-prone areas in Vietnam. The houses in the rural area are mostly single-story and in poor conditions. They can be damaged by the forces of storms or heavy rain events (**Figure 6-8**). Single-story houses are also not safe for inhabitants in the floodplains vulnerable to high flood depth levels (**Figure 6-9**).

***Figure 6-8****: A house in Central Vietnam collapsed in 2006 Typhoon Xangsane (Tran 2016)*

***Figure 6-9**: Flooded houses in November 2016 flood event in Central Vietnam (source: Central Steering Committee for Natural Disaster Prevention and Control of Vietnam)*

Our finding is consistent with the observation of De Bruijn and Klijn (2009). De Bruijn and Klijn (2009) listed one of the significant causes of death during flooding as collapsing house. However, a high proportion of vehicle-related fatalities have been reported in flood events in developed countries (Ashley and Ashley 2008, FitzGerald et al. 2010, Terti et al. 2017). Jonkman and Vrijling (2008) found that 38.5% death relating vehicles whereas this figure by building was only 9.3% in Europe and the United States. Ashley and Ashley (2008) and Terti et al. (2017) identified 63% of flood fatalities vehicle-related in the United States. FitzGerald et al. (2010) pointed out 48.5% vehicle-related fatalities in Australia. Accordingly, factors influencing casualties in floods are likely related to economic, social and income conditions. The present study could provide a better foundation for decision-making processes in Vietnam for flood risk reduction.

In Vietnam, the people most affected by floods are marginalised or poor groups in rural areas. They face enormous difficulties due to inadequate access to public resources such as insurance and emergency relief (Chau et al. 2014b). The affected households could receive governmental financial support under the Decree 67/2007/ND-CP; however, this funding is extremely meagre compared to their need. The poverty rate, as is common on a global scale, is invariably linked to disaster impact. More attention should be paid to reducing vulnerability and therefore flood risk. This will lead to a reduction of flood losses, especially death toll.

Possible measures to minimise the loss of life caused by floods need to be carefully considered. These measures should address flood risk not only in the short term but also in the long term of development. Based on the present research result, three policy implications are proposed to add a reference to decision makers in setting priorities for flood risk management activities and having appropriate resource allocations.

First, the significant impact of flood housing damage attribute on fatalities indicates that it is needed to improve the housing quality in flood prone areas in Vietnam. Accordingly, the government policies on disaster risk reduction should give priority to support the poor to upgrade their houses for flood risk adaptation. The solution can be the cooperation of government and residents in the reconstruction of houses such as amphibious houses (English et al. 2017) and 2-floors resistant houses (Tran 2016).

Second, flood casualties could also be significantly reduced with appropriate evacuation plans (Coppola 2015f). The evacuation capability of communities in flood and storm events needs to be improved to lessen damages caused by the disasters (Masuya et al. 2015, Liu et al. 2017). Since housing damage factor has a significant influence on flood casualties in Vietnam, it is necessary to set up evacuation plans for hazardous locations based on the combination of flood hazard assessments with population and housing data.

Third, following evacuation plans, flood shelter is one of the appropriate measures to reduce flood-related fatalities in low-income countries where having poor performance and maintenance of engineering structures (Masuya et al. 2015). In Vietnam, flood shelters have been developed in several flood prone areas under NGOs' funds (Anh et al. 2014, Tran 2015). Due to the high influence of housing damage attribute on flood fatalities and the effectiveness of flood shelters, government policies on disaster risk reduction should have a focus on the development of flood shelters in flood-affected areas.

Machine learning approach is increasingly popular in scientific research and commerce with big data. To our best knowledge, this is the first time that a longitudinal investigation on the relative influence of flood damage attributes to flood fatalities is applied by using machine learning algorithms and a national disaster database. Our research generates a more detailed picture of fatalities related to flood risk. The application of statistical machine learning techniques in this study could consolidate the approach of machine learning in FRM and also promote disaster database use in policy applications.

This study is limited to analyse the relative influence of flood damage attributes to fatalities using Vietnam's national disaster database. This limitation relates to the available national disaster loss database, which lacks the information required for the modelling of physical damage (Simpson et al. 2014). However, the relative influence measures of flood damage attributes on flood fatalities may add an essential information for government policies in flood risk management to mitigate mortalities in future flood events. Future research should attempt to focus on developing predictive models and analysing causes and circumstances of flood fatalities in Vietnam, which requires more detailed data on flood hazards, exposure characteristics, demographic characteristics (age and gender) and behaviour of victims.

## 6.5 Conclusion

This study provides an insightful analysis of flood fatalities in Vietnam between the years 1989-2015 based on the national disaster database. Statistical machine learning techniques are used to determine relative predictor importance. The results of variable importance measures show that flood housing damage attribute has the highest significance on fatalities in Vietnam. Our finding has practical implications for government policies to minimise human losses. Some policy recommendations include: improving housing quality for the poor, developing flood shelters in flood prone areas, and establishing evacuation plans for high flood risk locations. The machine learning approach can be applied to analyse the variable importance measures of disaster damage attributes to fatalities in other countries and regions using national and regional disaster databases, in which damages are categorised by attributes and documented for an extended period.

# Chapter 7 Assessing flood hazard using flood marks and AHP approach: a case study for Quang Nam[6]

## 7.1 Introduction

Flooding occurs when water levels overtop riverbanks, lakes, dams or dykes in low-lying areas during significant rainfall events. Its high frequency and widespread damages impact severely on humans (Jongman et al. 2015). While many structural and non-structural measures have been introduced to reduce these adverse impacts, flooding remains one of the most devastating hazards to affect communities globally (Brody et al. 2008). The global disaster database, EM-DAT (**Figure 7-1**), shows that the frequency of flood and storm events is correlated with economic loss.

Flood risk poses a threat to many densely populated areas both in low-lying river basins and coastal regions around the world (Maaskant et al. 2009, Islam et al. 2016). The definition of flood risk is a combination of flood hazard, flood exposure and flood vulnerability (Kron 2005, Winsemius et al. 2013, WMO 2013b, Budiyono et al. 2014). Global flood hazard and exposure are projected to increase, especially in many low-latitude regions in Asia and Africa (Hirabayashi et al. 2013). Meanwhile, tropical cyclone intensity and rainfall are increasing whereas the frequency of such large storms appears to be decreasing or unchanged (Knutson et al. 2010).

Vietnam is particularly vulnerable to flood risk, recently ranking eighth in the ten countries most affected by extreme weather events in the 1996 to 2015 period (Kreft et al. 2016) and fourth in the top 15 countries with the greatest population exposed to river

[6] Luu, C.; Von Meding, J.; Kanjanabootra, S. Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam, Vietnam. Natural Hazards 2018, 90, 1031-1050, https://doi.org/10.1007/s11069-017-3083-0

flood risk worldwide (Luo et al. 2015). Flood risk in Vietnam derives from the tropical monsoon characteristic, dense river systems, long coastline and densely populated riverine and coastal areas (Razafindrabe et al. 2012, Chau et al. 2014b). From 1989 to 2015, floods caused significant losses, including 14,867 dead and missing people, with asset damages equivalent to 1% of GDP for Vietnam (Luu et al. 2015a).

Geographic Information System (GIS) emerged from the 1960s through the work of Roger Tomlinson in Canada (Wieczorek and Delmerico 2009) and has been widely used all over the world. GIS is considered an essential instrument for spatial analysis and has been applied broadly to natural hazard risk assessment (Finn and Thunen 2014). The combination of flood risk assessment and GIS has been implemented in many recent studies at local scales (Fernández and Lutz 2010, Ward et al. 2010, Budiyono et al. 2014, Papaioannou et al. 2014, Foudi et al. 2015) and global scale (Jongman et al. 2012b, Winsemius et al. 2013). Spatial flood risk assessments are useful tools for the identification of at-risk locations and the determination of at-risk components which are a basic foundation to establish relevant mitigation and adaptation measures (Lindley et al. 2007, Mazzorana et al. 2012, Foudi et al. 2015).

The production of flood hazard assessment maps is a first step towards flood risk assessment (Directive 2007/60/EC 2007). Flood hazard assessment maps can inform local managers, planners and communities about levels of flood hazard areas and taking the appropriate response activities (WMO 2013b). Such a map is deemed to be a core tool in developing flood risk mitigation strategies and raising flood risk awareness within communities (Vojinovic 2015).

The traditional method for flood hazard mapping used a hydrological and hydraulic model to show inundation depth and extent for several return periods (Merz et al. 2007, Apel et al. 2008, de Moel et al. 2009, Winsemius et al. 2013, Budiyono et al. 2014).

This approach requires significant observed and simulated input data, and parameters such as meteorological data, river cross-sections and observed discharge (de Moel et al. 2009). This data is often not available for many areas, especially in developing countries with a lack of hydro-meteorological observation stations. Flood hazard maps can also be directly created from flood depth marks and Digital Elevation Model (DEM) (Hagemeier-Klose and Wagner 2009, Ho and Umitsu 2011, Bhuiyan and Baky 2014, Chau et al. 2014b, Shen et al. 2015).

Depth and duration of floods impact severely on the level of flood damage (Lekuthai and Vongvisessomjai 2001, Thieken et al. 2005). The flood depth of disastrous flood events is the most important factor and is always used to assess the flood hazard. Flood duration can seriously affect agriculture areas, particularly paddy field (Kent and Johnson 2001). Orchards or farm produce (Guo et al. 1998) can be destroyed due to a lengthy flood duration. However, previous research has not considered flood duration in flood hazard assessment maps.

Multi-Criteria Decision-Making (MCDM) techniques enable to handle quantitative variables and help decision makers in solving flood management problems such as formulating their values and preferences, quantifying these priorities, and applying them to decision-making processes (Levy 2005). Analytic Hierarchy Process (AHP) is the most implemented MCDM method in flood risk management field (de Brito and Evers 2016). AHP fundamentally works by developing priorities for multi-criteria evaluated by Decision Makers (DMs), stakeholders or experts who are involved in the decision-making process in a given field (Dewan 2013c).

AHP is a decision-analysis tool developed by Saaty (1977). The main advantages of AHP are simple GIS integration (Malczewski 1999), direct DMs' opinion involvement, criteria and sub-criteria systemization, and consistency in evaluation (Ishizaka and

Labib 2009). Besides these advantages, the method has three main negative aspects. The first disadvantage of AHP is that the judgement and ranking of factors is based on the opinion of domain DMs or experts. The dependence upon personal choice and knowledge can lead to subjective preference in the ranking (Schmoldt et al. 2001, Thanh and De Smedt 2011). The second drawback of this method is a high number of pairwise comparisons required which can become overwhelming with a large number of criteria or alternatives (Harker 1987, Carmone Jr et al. 1997). The third disadvantage is that the approach often forces the analyst to make pairwise comparisons based on very vague or general criteria (Soni et al. 1990, Ishizaka and Labib 2009, Velasquez and Hester 2013). However, most of these limitations exist in all MCDM methods, not only in AHP (Ishizaka and Labib 2009).

Weighted Linear Combination (WLC) is a broadly applied technique in integrated MCDM-GIS models (Malczewski 2000). The combination of MCDM and WLC can be implemented for spatial analysis of the decision and assessment situations (Malczewski and Rinner 2015a). The AHP and WLC can be incorporated into a GIS framework when AHP is utilised to determine weights for the criteria and sub-criteria, and the weighted layers are integrated by WLC technique (Dewan 2013c). For example, a combination of AHP and WLC was applied to create flood vulnerability assessment map and flood risk map for Dhaka, Bangladesh (Dewan 2013c, Masuya 2014).

This study aims to provide a method to assess the flood hazard in Quang Nam, Vietnam using flood marks (including both flood depth and duration factors). The AHP method was used to evaluate the criteria and sub-criteria of the flood hazard. The weights of criteria and sub-criteria using AHP method are generated based on the DMs' opinion. This assessment was combined into a single map using WLC integrated with GIS. Besides flood depth, flood duration has a strong influence on local communities' livelihood as previously discussed. Therefore, this study included both flood depth and duration factors in generating the flood hazard assessment map. This map can provide information about past events and therefore is essential for emergency response and long-term flood risk management.

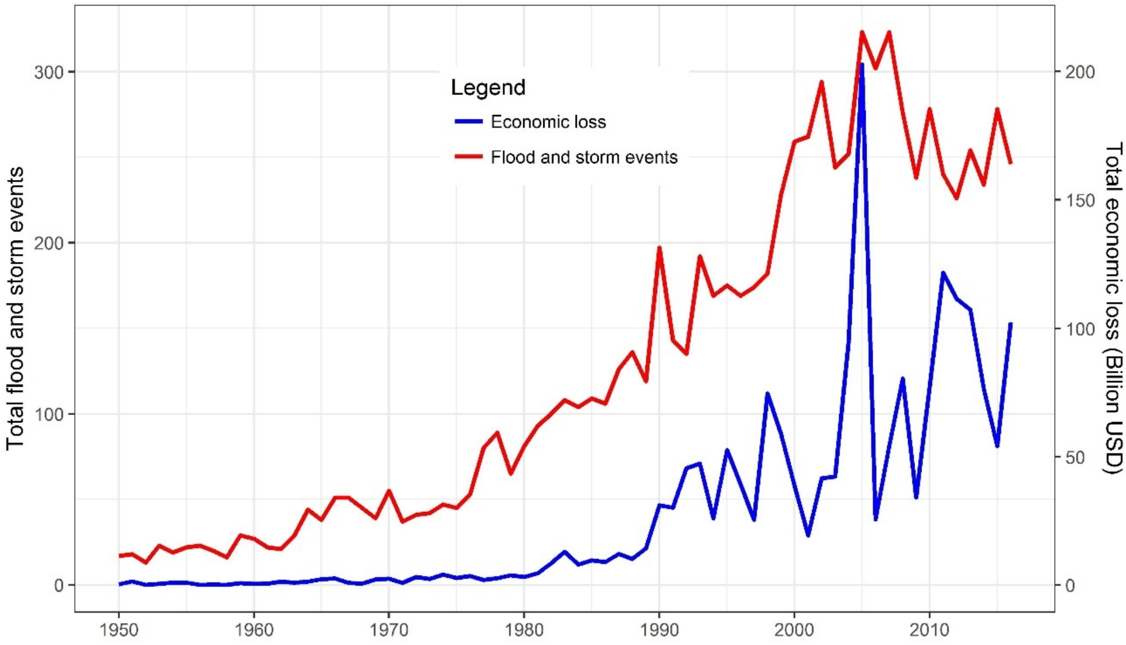


***Figure 7-1****: Global flood and storm events and economic loss between 1950 and 2016 (compiled from data source in http://emdat.be)*

## 7.2 Study area and flood marks

Quang Nam is one of the most vulnerable provinces to flood hazards in Vietnam (Chau et al. 2014a). This province has a total area of 10,575 km$^2$ and a population of 1.48 million in the year 2015 (Quang Nam Statistical Office 2015). Quang Nam has Vu Gia-Thu Bon river basin and a long coastal line of 125 km. It often faces disastrous flooding, especially during the rainy season from October to December.

Some disastrous floods have been recently recorded in Quang Nam, including the events of the year 1999, 2004, 2007, 2009, 2013 and 2016. Flood depth marks are often collected after serious flood events in Quang Nam. The Project on Building Resilient

Societies in Central Region in Vietnam was implemented in 2009 by the Japan International Cooperation Agency and has encouraged this practice (JICA 2009, Chau et al. 2013). The flood duration factor had not been considered or collected in Quang Nam before the year 2013. The Quang Nam Provincial Committee of Natural Disaster Prevention and Control and Search and Rescue (Provincial Committee) collected flood marks for both flood depth and duration factors for the flood event in November 2013 as in **Figure 7-3**.

After super Typhoon Haiyan had affected the Philippines, tropical depression Podul dumped huge amounts of rainfall on provinces in central Vietnam in 14 and 15 November 2013 (Evans and Falvey 2013). The heavy rainfall of 401 to 793 mm caused severe flooding, deaths and other impacts for Quang Nam, Quang Ngai, Binh Dinh and Phu Yen provinces. It resulted in 47 people dead or missing, 425,987 damaged houses and 5,799 hectares of rice and crop damaged (UN Country Team in Vietnam 2016).

In Quang Nam province specifically, tropical depression Podul caused 17 deaths, 230 people injured, 91739 flooded properties, 11530 ha of submerged agricultural land, 85080 animals killed and widespread damage to roads, canals, dykes and embankments. The Quang Nam Hydro-Meteorological Forecasting Station analysed the historical discharge and water level data from 1980 to 2015 at two hydrology stations on Vu Gia-Thu Bon river basin to draw flood frequency curves. They concluded that the 2013 flood event has the frequency of a 1: 20-year event, corresponding to the water level at Giao Thuy hydrology station (**Table 7-1**).

***Table 7-1*** *The flood frequencies measured and calculated at Giao Thuy hydrology station*

| No. | Frequency (%) | $H_{max}$ (cm) | Return period (year) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1 | 1.0 | 1065.52 | 100 |
| 2 | 2.0 | 1031.74 | 50.0 |
| 3 | 5.0 | 982.88 | 20.0 |
| 4 | 10.0 | 941.24 | 10.0 |

The 2013 flood event had $H_{max}$ = 984 cm, equivalent to the frequency of 5%.

Source: The data were provided by Quang Nam Hydro-meteorological Forecasting Station

The Quang Nam Provincial Steering Committee of Natural Disaster Prevention and Control and Search and Rescue collected 300 flood marks of the flood event on 14-18 November 2013 in seven districts in Quang Nam including Dai Loc, Dien Ban, Duy Xuyen, Hoi An, Que Son, Tam Ky and Nong Son. The location of the 300 flood mark is shown in **Figure 7-3**. Each flood mark has a code, coordinates (longitude and latitude), address, flood depth, flood duration, name of information provider. The 300 collected flood marks contain two factors of flood hazard; flood depth and flood duration.

***Figure 7-2****: Flood marks for the 2013 flood event established and collected by the Quang Nam provincial committee (Source: the Quang Nam provincial committee)*

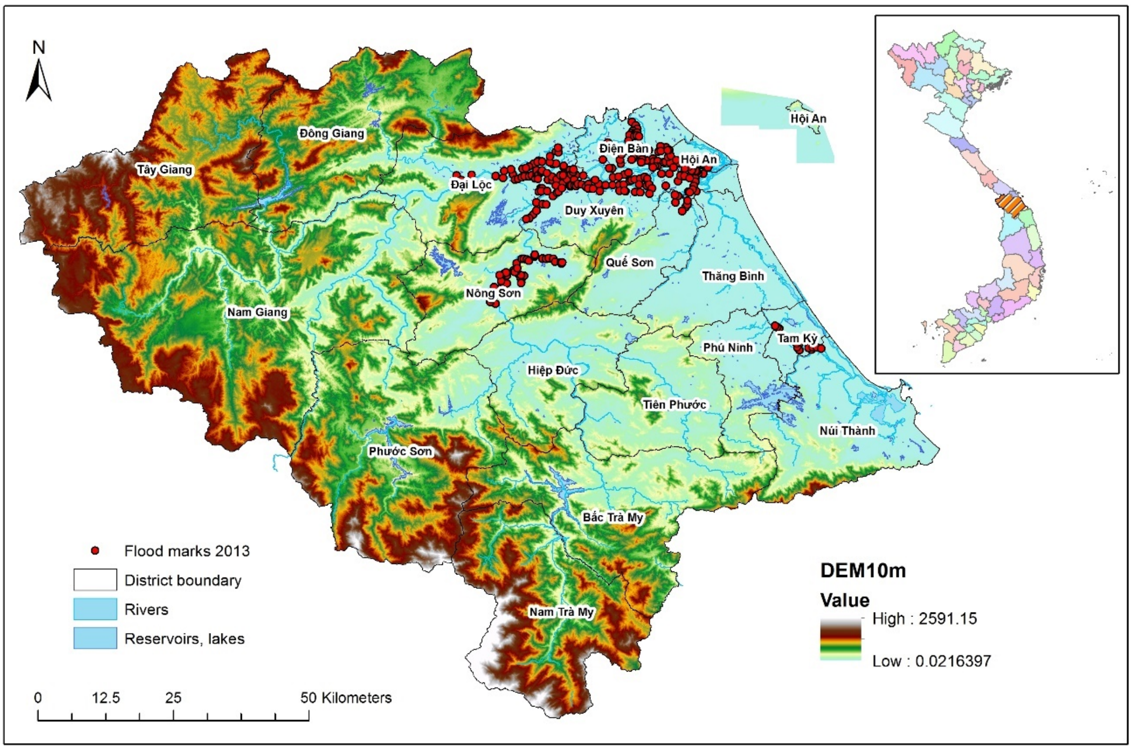


***Figure 7-3**: The location of 300 flood marks for the 2013 flood event collected by the Quang Nam provincial committee, Vietnam*

## 7.3 Methodology

The AHP is used to derive weights of criteria and sub-criteria by evaluation of DMs, stakeholders or experts who involve in the decision-making process (Saaty 1990, Dewan 2013c). This method has been the most widely applied MCDM method in determining flood risk (de Brito and Evers 2016). The DMs can evaluate the relative importance or weights of criteria and sub-criteria by their judgements in pairwise comparison tables.

The assessment of AHP depends on the judgements of DMs or experts, so this method is focused on the quality of DMs rather than the quantity of DMs. The AHP assessment can run with very small groups of DMs, such as one DM (Godfrey et al. 2015), three DMs (Kokangül et al. 2017), four DMs (Al-Awadhi and Hersi 2006, Kienberger et al. 2009), five DMs (Plattner et al. 2006), six DMs (Gao et al. 2007, Zou et al. 2012), nine DMs (Papaioannou et al. 2014), and ten DMs (Wang et al. 2011); or run with the author experience-based assessment (Sarker and Sivertun 2011, Kandilioti and Makropoulos 2012, Dewan 2013c, Li et al. 2013).

First, an AHP model for flood hazard assessment was designed. Second, data was gathered from DMs. Two staff working in the local committees were recruited to judge criteria according to an AHP questionnaire. Finally, the assessment was incorporated with WLC in a GIS framework to generate a flood hazard map.

The case study is in Quang Nam, Vietnam, so staff working in committees of Natural Disaster Prevention and Control and Search and Rescue at provincial and commune levels in Quang Nam were approached to participate as DMs. Participants are decision makers in flood risk management in Quang Nam, Vietnam.

The complexity of AHP algorithms' calculation can be solved by using the Superdecisons software (Whitaker and Adams 2005) and the statistical software R (R Core Team 2016) with '*ahp*' package (Glur 2017). The AHP pairwise comparison judgements of DMs for flood hazard assessment were analysed using these programs. The weights resulting from the analysis were combined with WLC method using ArcGIS 10.1 software (Environmental Systems Research Institute Inc., USA) to create a flood hazard assessment map. The integrated AHP and WLC was implemented within the GIS environment using *Weighted Sum* tool through ArcGIS software.

### *7.3.1 Group decision making and the AHP*

The AHP was originally introduced by Thomas L. Saaty in 1977 (Saaty 1977) as a robust and flexible technique for supporting priority setting and improving decision making. This method has been widely used in a variety of areas, and recently applied to many studies in flood risk assessment (de Brito and Evers 2016).

The AHP is performed in this study using three main steps (Saaty 2005, Tzeng and Huang 2011):

Step 1: Construct a hierarchical decision model as in **Figure 7-4**;

Step 2: Develop a paired comparison matrix for criteria or sub-criteria of the decision model as in Equation (7-1) based on DMs' judgement and reciprocal judgement axiom;

Step 3: Obtain the relative importance or weights of criteria and sub-criteria.

The paired comparison matrix in Step 2 is $A = [a_{ij}], ij = 1,2, \ldots, n$. The entries $a_{ij}$ is defined by reciprocal judgement rule, if $a_{ij} = a$, then $a_{ji} = 1/a\,, a > 0$ in Equation (7-1). The DMs provide their judgements for the pairwise compairison values $a_{ij}$

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (7\text{-}1)$$

***Table 7-2*** *The fundamental scale of absolute number in AHP (Ramanathan 2001, Saaty 2005, Dewan 2013c)*

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two criteria/sub-criteria are equal important |
| 2 | Weak | |
| 3 | Moderate importance | One criterion/sub-criterion is slightly favoured over another |
| 4 | Moderate plus | |

| | | |
|---|---|---|
| 5 | Strong importance | One criterion/sub-criterion is strongly favoured over another |
| 6 | Strong plus | |
| 7 | Demonstrated importance | One criterion/subcriterion is very strongly favoured over another |
| 8 | Very, very strong | |
| 9 | Extreme importance | Evidence favouring one criterion/sub-criterion over the other is the highest possible order of affirmation |
| Reciprocals | If $A_i$ is the judgement value when *i* is compared with *j*, then $A_j$ has the reciprocal value when compared to $A_i$ | A reasonable assumption |

The pairwise judgement scoring is based on the rule of Saaty (1977) with a 9-point scale from 1 to 9 in **Table 7-2**. The consistency of judgements is checked by a consistency ratio (C.R.) using Equation (7-2). Saaty (1988) suggested that C.R. should be less than 0.1, although the greater consistency does not mean the greater accuracy.

$$C.R. = C.I./R.I. \qquad (7\text{-}2)$$

The random index (R.I.) in equation (7-2) is depended on the size of matrices or the number of criteria/sub-criteria *n* and obtained referring to **Table 7-3** by Saaty (1988).

***Table 7-3*** *Random Index (R.I.)*

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| R.I | 0.0 | 0.0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

The Consistency Index (C.I.) is defined as in Equation (7-3).

$$C.I. = (\lambda_{max} - n)/(n - 1) \qquad (7\text{-}3)$$

where

$\lambda_{max}$ is the largest eigenvalue derived from the paired comparison matrix,

*n* is the number of criteria or sub-criteria.

After pairwise comparison judgements of each DM meet the consistency requirement (C.R. < 0.1), it is required to combine the judgements of the group. The AHP allows each DM to specify a value and then combine all individual judgements for the final assessment result according to the geometric mean rule of Saaty (1989) as in Equation (7-4).

$$a_{12} = [a_{12}^{1} \times a_{12}^{2} \times \ldots \times a_{12}^{N}]^{1/N} \quad (7\text{-}4)$$

where

1 … *N* are decision makers

$a_{12}^{1}$ … $a_{12}^{N}$ are judgements of decision makers from 1 to N

### 7.3.2 Flood hazard assessment model

There are several studies on creating flood hazard maps in Quang Nam, Vietnam, such as Ho and Umitsu (2011) and Chau et al. (2013). However, only flood depth marks were used to build the flood hazard map; the flood duration factor has not been considered in these maps. This study implemented flood hazard assessment based on both flood depth and flood duration criteria for the flood event in Quang Nam in November 2013. There are four sub-criteria for each criterion. The AHP structured the criteria and sub-criteria into a hierarchical decision model for flood hazard assessment as in **Figure 7-4**.

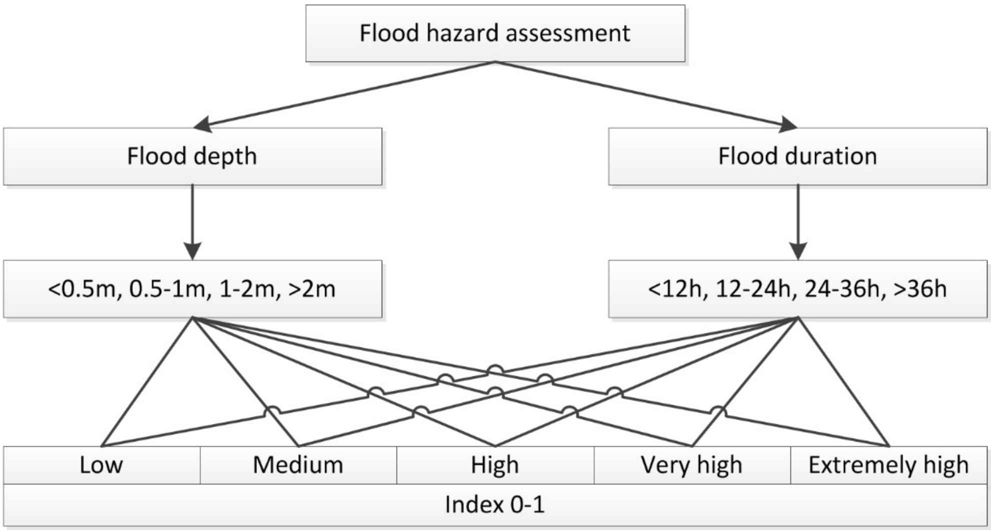


***Figure 7-4****: Development of hierarchical decision model for flood hazard assessment for Quang Nam, Vietnam*

### *7.3.3 The AHP and a GIS framework*

Although many MCDA methods are available (Hwang and Yoon 1981), there are only a few theoretical and applied research studies about GIS-MCDA. These include the weighted linear combination, ideal point methods and outranking methods (Malczewski and Rinner 2015a). The weighted linear combination (WLC) is the most often used technique for dealing with spatial assessment using MCDM (Malczewski and Rinner 2015a). The combination of AHP and WLC in flood risk assessment has been applied in many recent studies (Moeinaddini et al. 2010, Kandilioti and Makropoulos 2012, Rahman et al. 2012, Dewan 2013c).

The WLC method is based on the concept of a weighted average (Malczewski 1999, Malczewski 2006). Each criterion and sub-criterion are handled as a data layer in GIS analysis. A WLC is conducted by multiplying criteria and sub-criteria by the corresponding weights and layers (Dewan 2013c). In this study, the integrated AHP and WLC method is used to create flood hazard map using the following equation:

$$FHA = \sum_{i=1}^{i} \sum_{j=1}^{j} w_i w_{ij} x \quad (7\text{-}5)$$

Where FHA is the flood hazard assessment index for flood depth and flood duration criteria (**Figure 7-4**), $w_i$ and $w_{ij}$ are the weights for of the *i*th and *j*th criterion and sub-criterion and $x$ represents the value of an criterion. The weights represent the relative importance of the criteria and sub-criteria.

## 7.4 Results

This study applied the methodology to the case of Quang Nam, Vietnam. First, criteria and sub-criteria for flood hazard assessment were evaluated by judgements of two DMs using pairwise comparison tables as in **Figure 7-5**. Second, flood mark data were incorporated with GIS data including DEM and province border to create a flood depth map and flood duration maps through tools in ArcGIS software as in **Table 7-6**. Finally, the flood hazard assessment map was built based on the integration of the AHP assessment result and flood depth and duration maps.

### *7.4.1 AHP assessment result*

The pairwise comparison tables for AHP assessment were designed as **Figure 7-5** to obtain the weights of flood depth and flood duration criteria and their sub-criteria. The pairwise comparison questions include flood hazard criteria and sub-criteria as the hierarchical decision model in **Figure 7-4**. The criteria for flood hazard assessment includes flood depth and flood duration. The sub-criteria of flood depth criterion are <0 m, 0-0.5 m, 0.5-1.0 m, 1.0-2.0 m and >2.0 m. The sub-criteria of flood depth criterion are <6 h, 6-12 h, 12-24 h and >24 h.

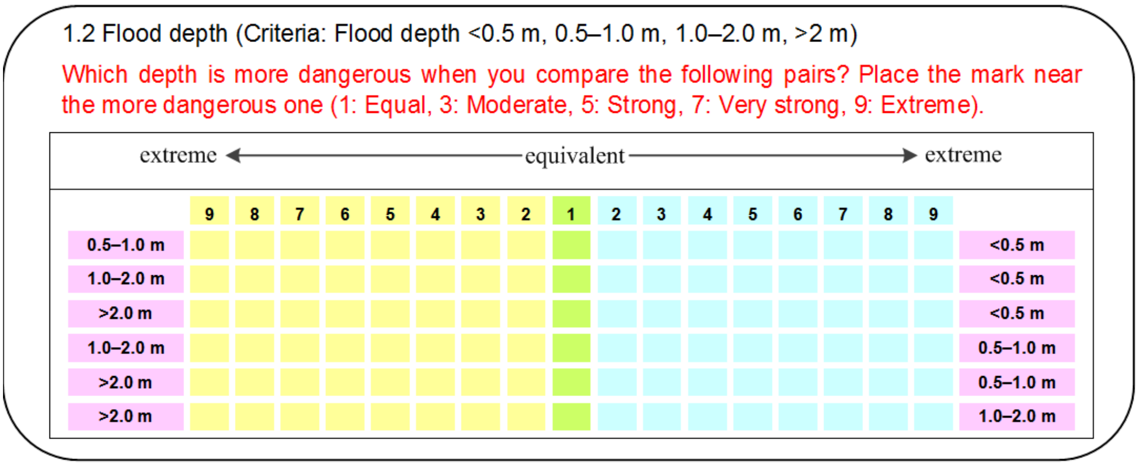


***Figure 7-5****: Format of AHP pairwise comparisons*

Firstly, the pairwise comparison judgements of each DM were put in a matrix of the equation (7-1) as in **Figure 7-5**. Second, the result was checked for consistency using Superdecisions software (Whitaker and Adams 2005). This software also evaluated many different areas for their weight or priority, with a higher value indicating a more dangerous area (**Table 7-4**). After that, the geometric mean of the pairwise comparisons as in Equation (7-4) was used to combine the individual judgements into a representative group judgement.

The Superdecions software allows the integer number only. The result of the group judgement was not an integer number, so we could not use the Superdecisions software to generate weights. The *'ahp'* package (Glur 2017) in the statistical software R (R Core Team 2016) was employed to solve this problem. The final weights of criteria and sub-criteria were generated using *'ahp'* package (Glur 2017). The results are shown in **Table 7-5**.

***Table 7-4*** *Pairwise comparison matrix of flood depth from one of DMs and the priorities of criteria*

| Flood depth | <0.5 m | 0.5–1.0 m | 1.0-2.0 m | >2.0 m | Weights |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| <0.5 m | 1 | 3 | 7 | 8 | 0.04728 |
| 0.5–1.0 m | *1/3* | 1 | 4 | 6 | 0.10075 |
| 1.0-2.0 m | *1/7* | *1/4* | 1 | 2 | 0.32358 |
| >2.0 m | *1/8* | *1/6* | *1/2* | 1 | 0.52838 |
| Consistency Index = 0.03176 | | | | | |

***Table 7-5*** *Final weights after combining the individual judgements into a representative group judgement*

| Flood depth (m) | Weights | Flood duration (hour) | Weights | Hazard criteria | Weights |
|---|---|---|---|---|---|
| <0.5 | 0.056 | <6 | 0.074 | Flood depth | 0.71 |
| 0.5–1.0 | 0.102 | 6-12 | 0.122 | Flood duration | 0.29 |
| 1.0-2.0 | 0.324 | 12-24 | 0.243 | | |
| >2.0 | 0.518 | >24 | 0.562 | | |
| Consistency Index = 0.026 | | Consistency Index = 0.019 | | Consistency Index = 0 | |

### *7.4.2 Flood hazard assessment map*

This study used 300 flood marks of 2013 flood event collected from the provincial committee and 10 m DEM resolution to construct flood hazard map for Quang Nam, Vietnam. The spatial analyses for creating the flood hazard map were implemented in ArcGIS 10.1 using *ModelBuilder* (**Figure 7-6**). *ModelBuilder* is an application that allows the implementation of a series of analytical procedures and transfers it into a tool. The created tool can be reused for similar analytical processes in other areas or regions. The *ModelBuilder* enables an explicit modelling process as in **Table 7-6**. The main disadvantage of *ModelBuilder* is hard to update, modify and replace parameters. The blue blocks are the input layers, the yellow ones are sequence analytical tools, and the green ones are sequence output data as in **Figure 7-6**. The model in **Figure 7-6** includes ten steps from (a) to (j) with three stages. The details are shown in **Table 7-6**.

***Table 7-6** Details of automating processes for creating flood hazard assessment map with 10 steps from (a) to (j) in ModelBuilder*

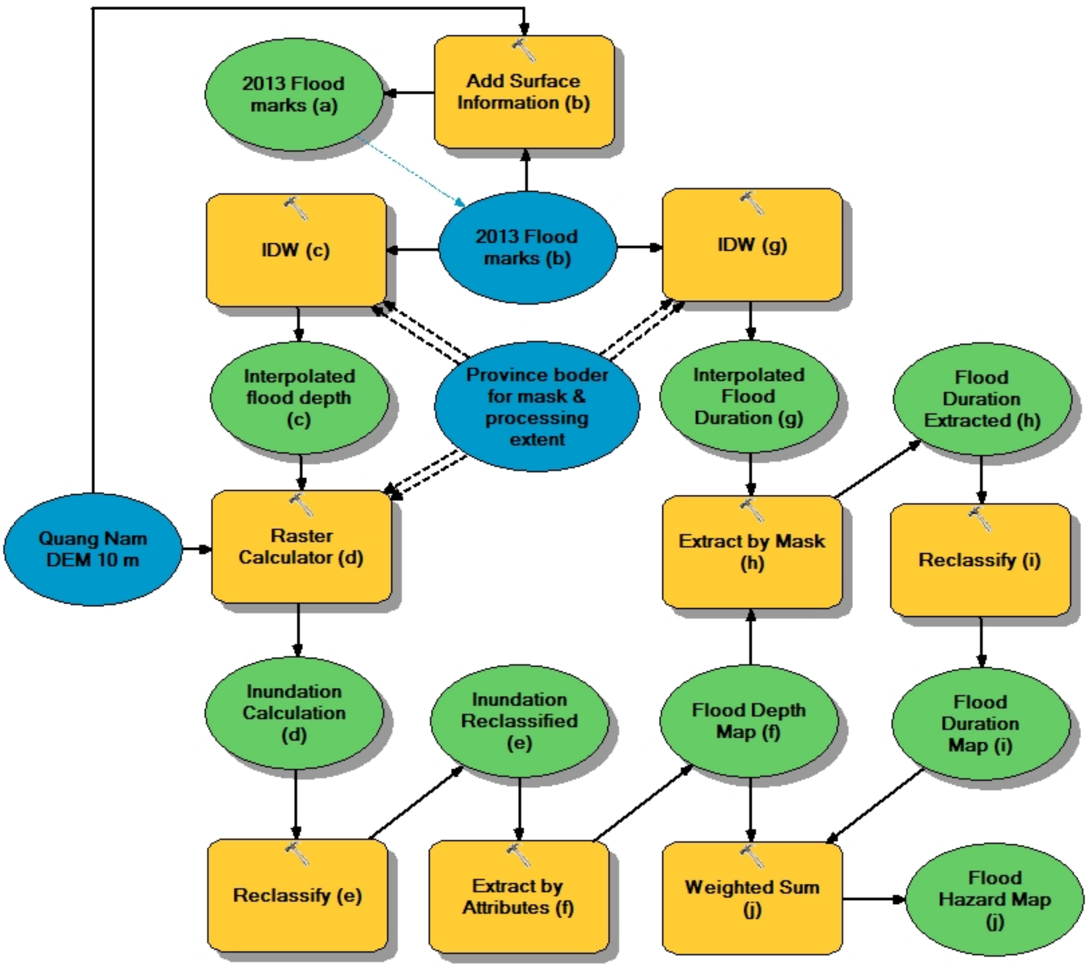


***Figure 7-6**: The ArcGIS model for creating flood hazard map of the 2013 flood event in Quang Nam, Vietnam using ModelBuilder*

The flood depth map in **Figure 7-7** is the result of the geospatial modelling techniques from steps (i) to (f) in stage 1. The flooded areas are located close to and along rivers. The most severe flooded areas are nearby the confluence of Vu Gia river and Thu Bon River in Dai Loc district. The total flooded area in the 2013 flood event in Quang Nam is 60,736 ha, in which 9,340 ha of <=0.5 m, 12,977 ha of 0.5-1.0 m, 25,821 ha of 1.0-2.0 m, and 12,597 ha of >2.0 m.

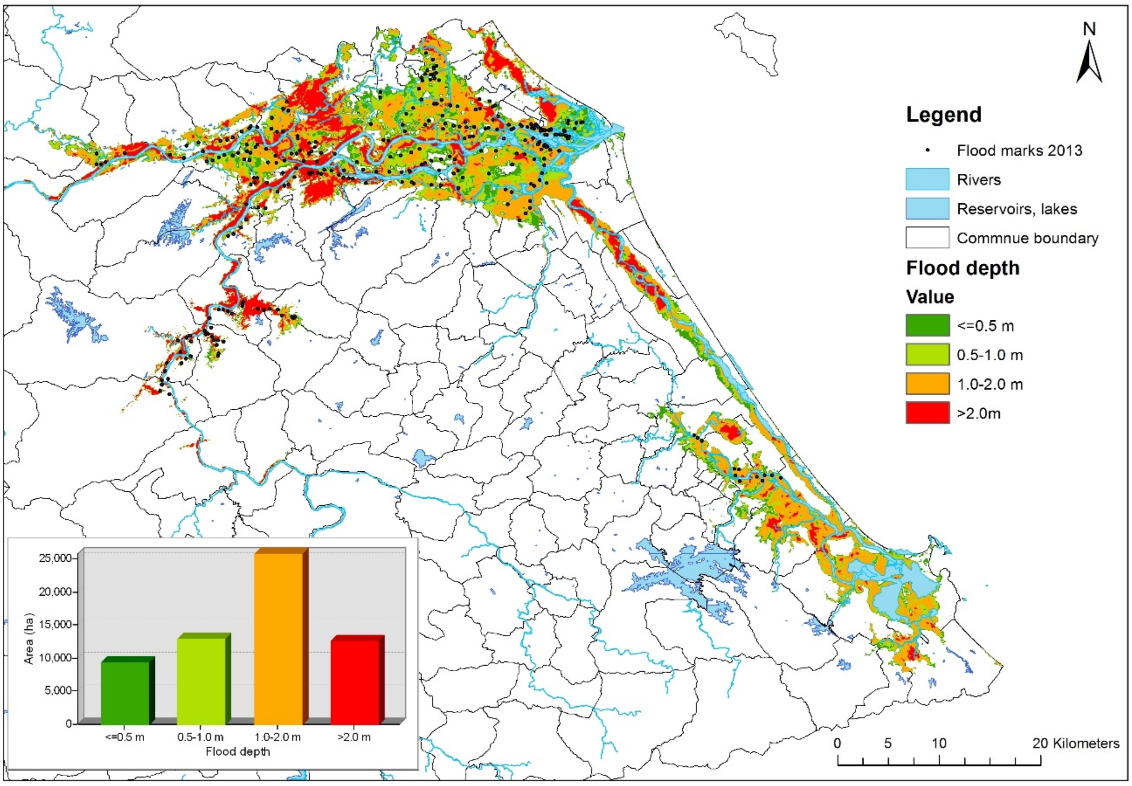


***Figure 7-7**: Flood depth map of the 2013 flood event in Quang Nam, Vietnam*

The flood duration map in **Figure 7-8** is the result of the geospatial modelling techniques from steps (g) to (h) in stage 2. The flooded area is near the sea, so the flood duration is not long. The most frequent flood duration level is 12-24 hours on 52,574 ha. The flood duration levels of 6-12 hours, >24 hours and <=6 hours are on 7,740 ha, 388 ha, and 35 ha respectively.

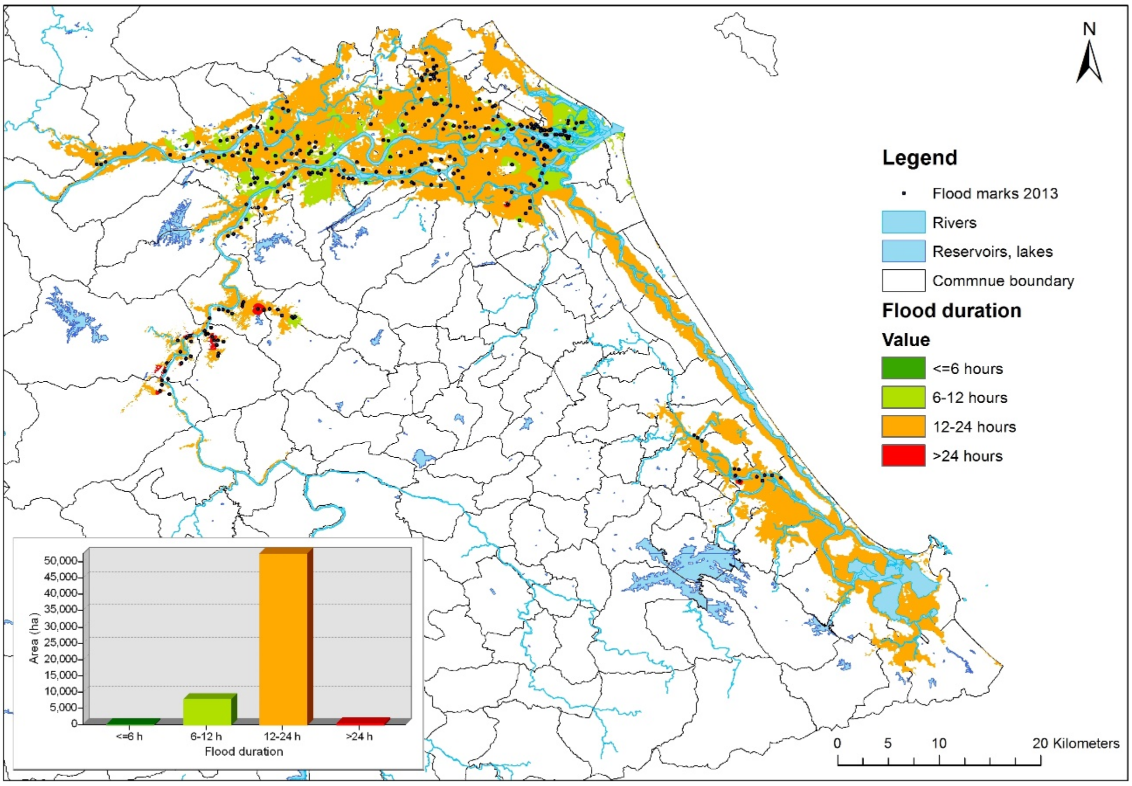


***Figure 7-8**: Flood duration map of the 2013 flood event in Quang Nam, Vietnam*

The ArcGIS software has added a WLC tool called *Weighted Sum*, so the final output as in **Figure 7-8** was produced from running the *Weighted Sum* tool using the weights resulted from AHP method. The flood hazard map was created after implementing the geospatial modelling techniques from steps (i) to (j) as in **Table 7-6**. The flood hazard was quantified based on flood depth and duration factors. The combination of AHP and WLC was implemented within the GIS environment using *Weighted Sum* tool in the ArcGIS software as in stage 3 with step (j). The areas with no value are non-flooded areas. The higher value an area has, the more significant flood hazard is present.

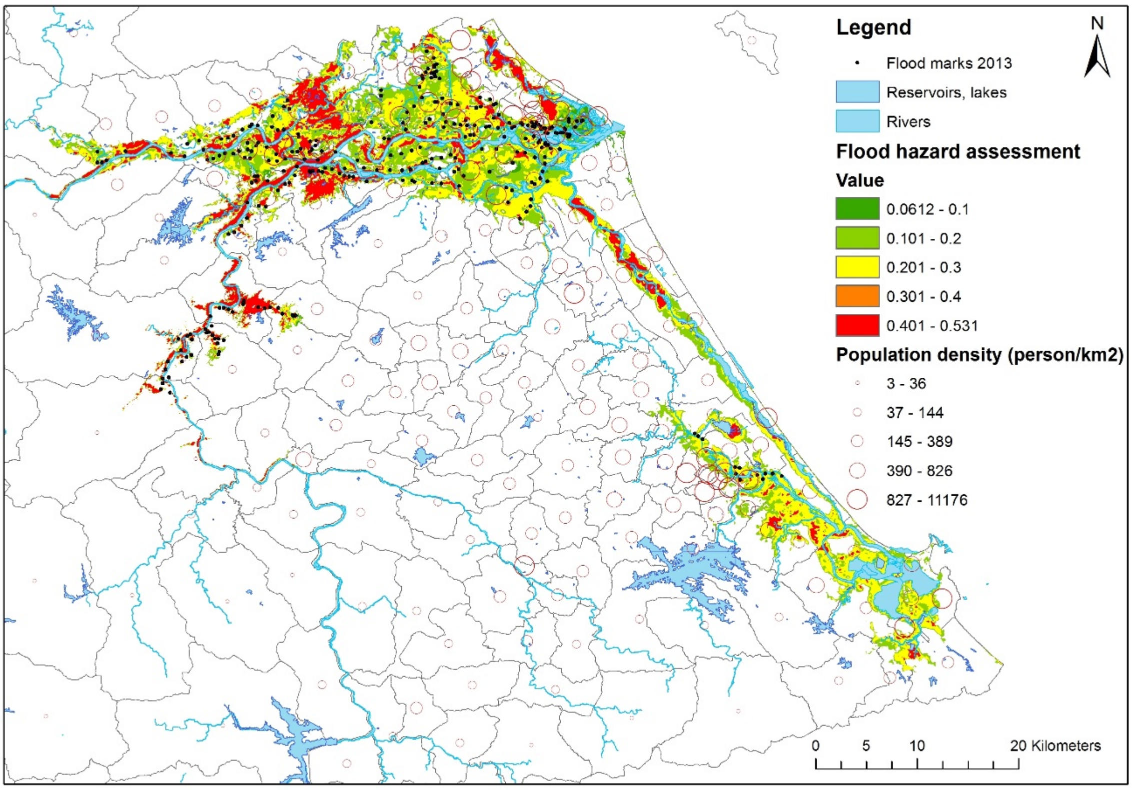


***Figure 7-9****: Flood hazard assessment map of the 2013 flood event in Quang Nam, Vietnam*

## 7.5 Discussion

The selected case study is Quang Nam province, Vietnam since this is one of the most hazard-prone provinces in Vietnam, where significant flooding occurs every year and causes serious impacts on communities. Flooding problems in Quang Nam province relate to the flow of Vu Gia - Thu Bon river basin. This basin is located in the west of Quang Nam with a total area of 5,290 km$^2$. Over the years, successive river floods impacted seriously on the residents' livelihood and social-economic development. Most flooded areas are the farming areas and densely populated (**Figure 7-9**). The low-land area districts along Vu Gia river and Thu Bon river including Dai Loc, Dien Ban, Hoi An, and Duy Xuyen frequently subjected to flooding. Flood duration had not been included in previous studies in this region; this factor was only collected since 2013.

The return period of the 2013 flood event is 20 years as in **Table 7-1**. The total flooded area in the 2013 flood event in Quang Nam is 60736 ha (**Figure 7-7**). This result corresponds to the result produced by the Institute Geography in **Figure 7-10** (b).

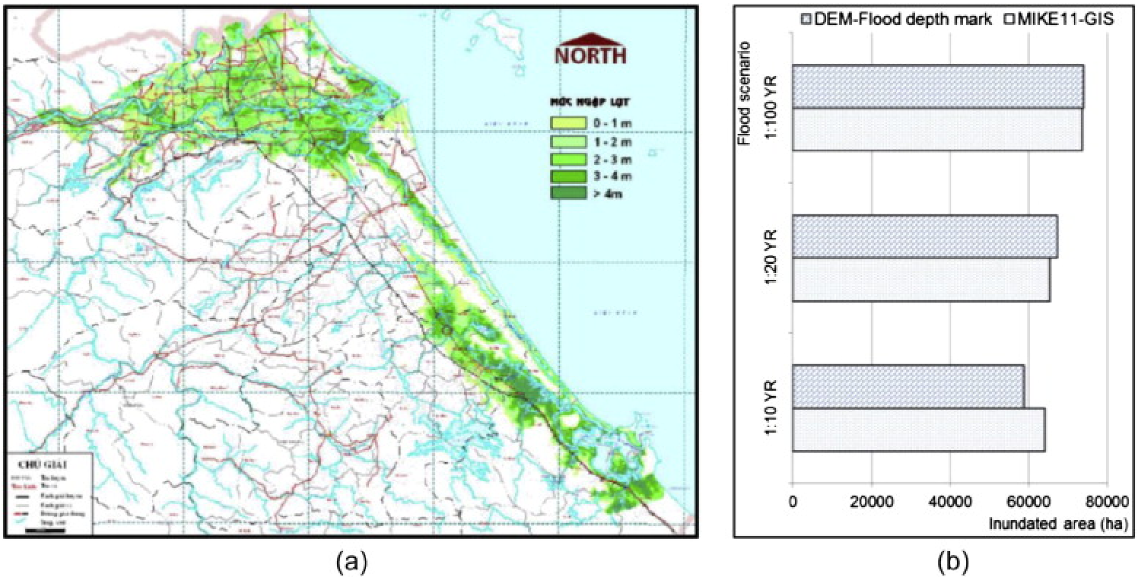


***Figure 7-10****: (a) 100-year flood map created by the Institute of Geography using hydraulic model MIKE11-GIS and (b) total areas of inundation in Quang Nam, Vietnam (Source: Chau et al. (2014b))*

The flood depth map created in **Figure 7-7** used flood depth marks and modelling techniques which were applied and validated in the study of Chau et al. (2013). They created a flood depth map using the 86 flood depth marks of the 2009 flood event and 30 m DEM resolution of Quang Nam, and used this result to assess agricultural impacts. The flood hazard maps for Quang Nam, Vietnam were built on the studies of Ho and Umitsu (2011) and Chau et al. (2013), using only flood depth marks. As discussed previously, flood duration was not considered in their analysis. The present study used 300 flood depth marks from the 2013 flood event and a higher DEM resolution which was built from a contour map at 1:10,000 scale.

As well as combining flood depth and flood duration factors, this study utilised the AHP method for the following reasons: (1) MCDM and GIS combination, (2) DMs' opinion integration, (3) criteria and sub-criteria systemization and (4) consistency in evaluation by checking the consistency index (C.I.). AHP is the most applied MCDM method in the field of flood risk management (de Brito and Evers 2016). The WLC method was utilised to integrate AHP in a GIS framework. The flood hazard map was generated by considering both flood depth and flood duration using the integrated AHP-WLC with the geospatial analysis model in **Figure 7-9**.

The main limitation of the study relates to the application of AHP pairwise comparisons, something difficult for non-academic persons such as staff of the local committees of Natural Disaster Prevention and Control and Search and Rescue. Although these are the most qualified experts to participate, they are part-time workers and were very difficult to recruit due to the onerous nature of the methodology. That only 2 experts participated can be viewed as a limitation, but is within the acceptable limits of similar published studies.

The flood hazard assessment map output can support decision-making in water resource planning and flood risk management in Vietnam. Planners and managers need accurate location-based hazard information. The combination of flood duration and flood depth factors in flood hazard assessment for Quang Nam, Vietnam can lead to a more comprehensive flood hazard assessment than previously available.

The loss of life and injury can be significantly mitigated with proper evacuation plans (Coppola 2015c). Evacuation capability among poor communities is particularly important (Masuya et al. 2015, Liu et al. 2017). Flood hazard assessment maps can be combined with housing data and population data to support decision makers in developing effective evacuation plan for flood-prone areas. It must be emphasised that farmers in Vietnam and in Quang Nam in particular are generally poor. They are highly vulnerable and do not have access to the natural disaster insurance scheme.

The negative consequence of flood hazards can be mitigated through an integrated approach to flood risk management (Dewan et al. 2007). Current management activities in Quang Nam are not adequate to combat flood problems. Decision-making is always based on knowledge, therefore accurate mapping outputs at local scale for flood risk are essential. If knowledge is available, planners can identify the most at-risk areas, assess the effectiveness of various adaptation measures, and design appropriate flood risk mitigation measures.

## 7.6 Conclusions

Flood hazard assessment is the first step in flood risk assessment. This study presented an approach to assess flood hazard using flood mark data combined with DMs' judgements. The assessment was integrated into a GIS framework to provide a flood hazard assessment map. The 2013 flood event in Quang Nam, Vietnam, was used as a case study. The model of DEM and flood depth marks utilised generated a result that corresponds to the hydraulic model MIKE11-GIS.

Flood duration has not been included in flood hazard maps in previous research. An assessment that considers both flood depth and duration factors could provide a more comprehensive perspective on the impacts of flood hazard. A multi-criteria flood hazard assessment and spatial analysis was introduced and applied for Quang Nam, Vietnam in this study. This methodology can be applied to spatial flood hazard assessment in areas with inadequate data for hydraulic modelling, and to generate a preliminary evaluation of flood hazards using flood mark data.

This study analysed flood hazard in the local area and the findings can be useful in defining specific flood risk management plans for Quang Nam province. The local flood hazard assessment map can serve as a tool for decision makers. The results can also be incorporated into a land use map to support land use planning decision-making.

It is important to remember that the local committee officers are local government officers and are DMs in flood risk management activities at the local scale. However, they do not possess expertise in disaster management and the system does not feature a great deal of accountability. For this reason, subject experts, researchers and scientists should in future be engaged in the decision-making process alongside the committees in future.

Flooding is a common occurrence in lowland areas along the rivers in Quang Nam, Vietnam. The residents are familiar with flooding, and on the other hand, most of them, who are farmers, need flooding for fertilising agriculture land (Tran et al. 2010). The impact of flooding could be considerably mitigated through proactive community-led action. A more comprehensive flood hazard assessment with the consideration of flood duration can support such a proactive flood risk management approach.

# Chapter 8 A flood risk assessment of Quang Nam province using spatial multi-criteria decision analysis[7]

## 8.1 Introduction

A flood is a complex phenomenon that links the natural environment, people, and the social system (Slobodan 2012). Flood exposure and flood frequency are forecasted to increase, particularly in the low latitudes of Asia and Africa (Hirabayashi et al. 2013). The impacts of flood risk are expected to increase globally due to population growth, economic development, and climate change (Jongman et al. 2015, Tanoue et al. 2016). Despite efforts to reduce adverse impacts through structural and non-structural measures, flooding remains a significant threat to communities (Brody et al. 2008).

Vietnam is located in tropical monsoon zone with more than 3450 rivers and streams and 3260 km of coastline. Many inhabitants live in riverine and coastal areas, and their livelihoods are dependent on the natural world; therefore, they are vulnerable to the impacts of climate-related hazards. Between 1989 and 2014, floods caused significant damages in Vietnam, with at least 14,867 people dead and missing, and total economic losses being equivalent to 1% of the nation’s gross domestic product (Luu et al. 2015a).

It is critical that Vietnamese decision-makers in flood-prone areas are equipped with the best tools that are available to prepare communities and mitigate disaster losses. Flood risk mapping is a particularly valuable activity. The primary objective of flood risk maps is to provide information on flood hazards combined with other relevant

[7] Luu, C.; von Meding, J. A Flood Risk Assessment of Quang Nam, Vietnam Using Spatial Multicriteria Decision Analysis. Water 2018, 10, 461. https://doi.org/10.3390/w10040461

information that can support decision-making process in flood risk management (WMO 2013b).

The incorporation of flood risk assessment into a Geographic Information System (GIS) framework has been applied at global, regional, and local scales in many recent studies. GIS can process the spatial data, is a beneficial tool to handle spatial data on flood risks (Meyer et al. 2009). GIS has been widely applied to flood risk assessments as a critical instrument for spatial analysis (Finn and Thunen 2014). Spatial flood risk assessment is a useful tool to indicate risk levels and an essential reference to define specific flood risk management action plans (Dewan et al. 2007, Directive 2007/60/EC 2007, Foudi et al. 2015).

At the global scale, Jongman et al. (2012b) used two approaches, the population method and land-use method, to estimate global flooding exposure; while Winsemius et al. (2013) proposed a river flood risk assessment framework on a global scale. At the regional level, de Moel et al. (2009) developed a framework for assessing and mapping flood risk for Europe. At the local level, Ward et al. (2010) established a GIS-based model to simulate flooded areas and exposed assets to evaluate the current and future coastal flood hazard of northern Jakarta, and Budiyono et al. (2014) investigated flood risk assessment in Jakarta by using Damagescanner model, which combined three flood risk components in a flood risk map.

Flood risk can be measured by determining the three flood risk components of hazard, exposure and vulnerability (Kron 2005, de Moel et al. 2009, Winsemius et al. 2013, WMO 2013b, Budiyono et al. 2014, de Moel et al. 2015). A comprehensive flood risk assessment takes into account all the constituents of flood risk, combining many individual parameters (de Moel et al. 2009, de Bruijn et al. 2015). Spatial multicriteria decision analysis can combine and transform different geographical data layers into a decision map (Malczewski 1999). Geospatial techniques have significant potential support in the field of flood risk assessment in a spatial context (Dewan 2013a). Geospatial multicriteria decision-making (MCDM) methods have been investigated and applied, including Analytic Hierarchy Process (AHP), Weighted Linear Combination (WLC), outranking methods, and ideal point methods (Malczewski and Rinner 2015b).

Spatial multicriteria decision analysis has been gaining more and more attention in the field of flood risk assessment. Meyer et al. (2009) used the analysis for assessing flood risk for River Mulde in Saxony, Germany. Kubal et al. (2009) built criteria for three dimensions of economic, social, and ecological indicators to assess the urban flood risk of Leipzig, Germany. Scheuer et al. (2011) measured flood risk by integrating multicriteria of flood vulnerability. Dewan (2013a) utilised AHP and WLC to assess flood vulnerability by combining physical vulnerability, social vulnerability, and coping capacity. Hansson et al. (2013) proposed a MCDM framework for flood risk management in Bac Hung Hai polder.

Studies on flood risk analysis have been increasing in Vietnam (e.g., Tran et al. (2008), Razafindrabe et al. (2012), Chau et al. (2013), Chau et al. (2014a), Chinh et al. (2017), Vu et al. (2015), and Dang et al. (2010)). Tran et al. (2008) and Razafindrabe et al. (2012) adapted a flood risk management framework of AS/NZS 4360:1999 standard for Thua Thien Hue province and Da Nang city, respectively. Chau et al. (2013) applied GIS techniques to map flood impacts on agriculture in Quang Nam province. Chau et al. (2014a) used a cost-benefit analysis tool to assess the economic impact of floods on agricultural production in Quang Nam province. Chinh et al. (2017) built a flood loss model for residential buildings in Can Tho city. Vu et al. (2015) integrated an FLO-2D hydraulic model with several indicators (residential area and road network) to assess the annual flood damage for Quang Ngai province. Dang et al. (2010) used AHP approach to assess flood risk for Day river flood diversion area; however, a flood risk map was not displayed in this research.

This study aims to produce a detailed assessment of flood risk levels for Quang Nam province using a spatial multicriteria decision analysis approach. Quang Nam province is selected as the case study given its particular vulnerability and exposure to flood hazards in Vietnam. Severe floods frequently occur and seriously impact communities (Razafindrabe et al. 2012). The core approach of this study is to integrate AHP with GIS mapping to create a flood risk assessment map. AHP is an analytical decision-making method established by Saaty (1988) and is the most applied MCDM method for flood risk analysis (de Brito and Evers 2016). The study first identifies components of flood risk including hazard, exposure, and vulnerability indicators; and then integrates these components into a hierarchy model using AHP method. Second, the scores of flood risk components are measured by decision-makers' judgements via AHP pairwise comparisons. Finally, a flood risk assessment map is generated from the integration of spatial data on flood hazard, exposure, and vulnerability..

## 8.2 Research area and data used

### *8.2.1 Research area*

Quang Nam is located at $14^0$57'10"N to $16^0$03'50"N and $107^0$12'50"E to $108^0$44'20"E on the south-central coast of Vietnam (**Figure 8-1**) with the area of 10,440 $km^2$ and the population of over 1.4 million in 2015. The province has Vu Gia – Thu Bon river basin with the area of 5,290 $km^2$ and over 100 km of coastline. Dense hydropower reservoirs are allocated along this river basin. The west of Quang Nam is mountainous and sparsely populated, while the east is flat plains that are favourable for agricultural population and urban development. The province has a high exposure to climate events (mainly storms, floods, flash floods, and typhoons) and a relatively high level of poverty at 28% (Bruun 2012).

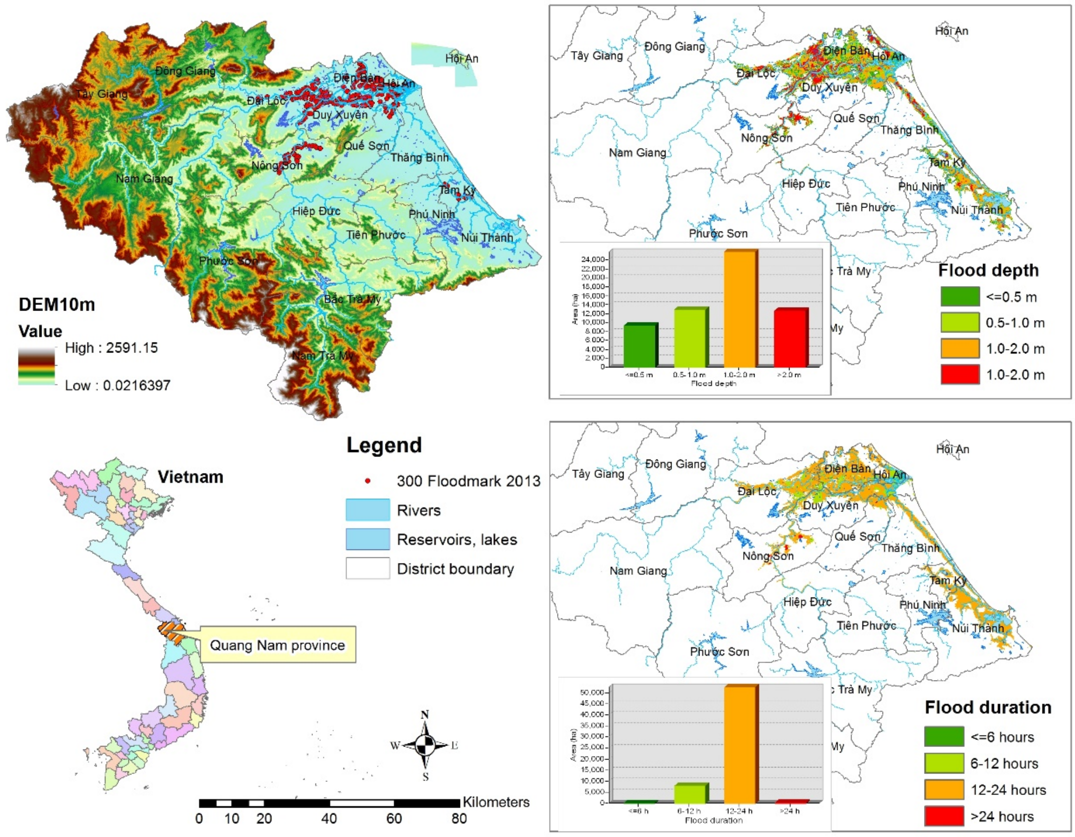


***Figure 8-1****: The location of study area, Quang Nam province and flood hazard mapping*

Flooding in Quang Nam often associates with the flow of Vu Gia - Thu Bon river basin, which is located in the west of Quang Nam with a total area of 5,290 km$^2$. The river basin tributaries originate from elevated mountain ranges, then flow through narrow plains before emptying into the sea (**Figure 8-1**). Due to the increase of rainfall intensity, water-related disasters are growing in the river basin, such as large-scale floods in the rainy season (Nam et al. 2014). Floods have severely affected communities' livelihood and social-economic development in Quang Nam province over the years (**Figure 8-2**). Significant flooding occurrences cause huge loss of life and property in Quang Nam province. The severe floods are increasing due to the pressure of population and economic growth, the human interference leading to environmental damage and the influence of climate change (Duc Le and Thi Thu Vu 2013).

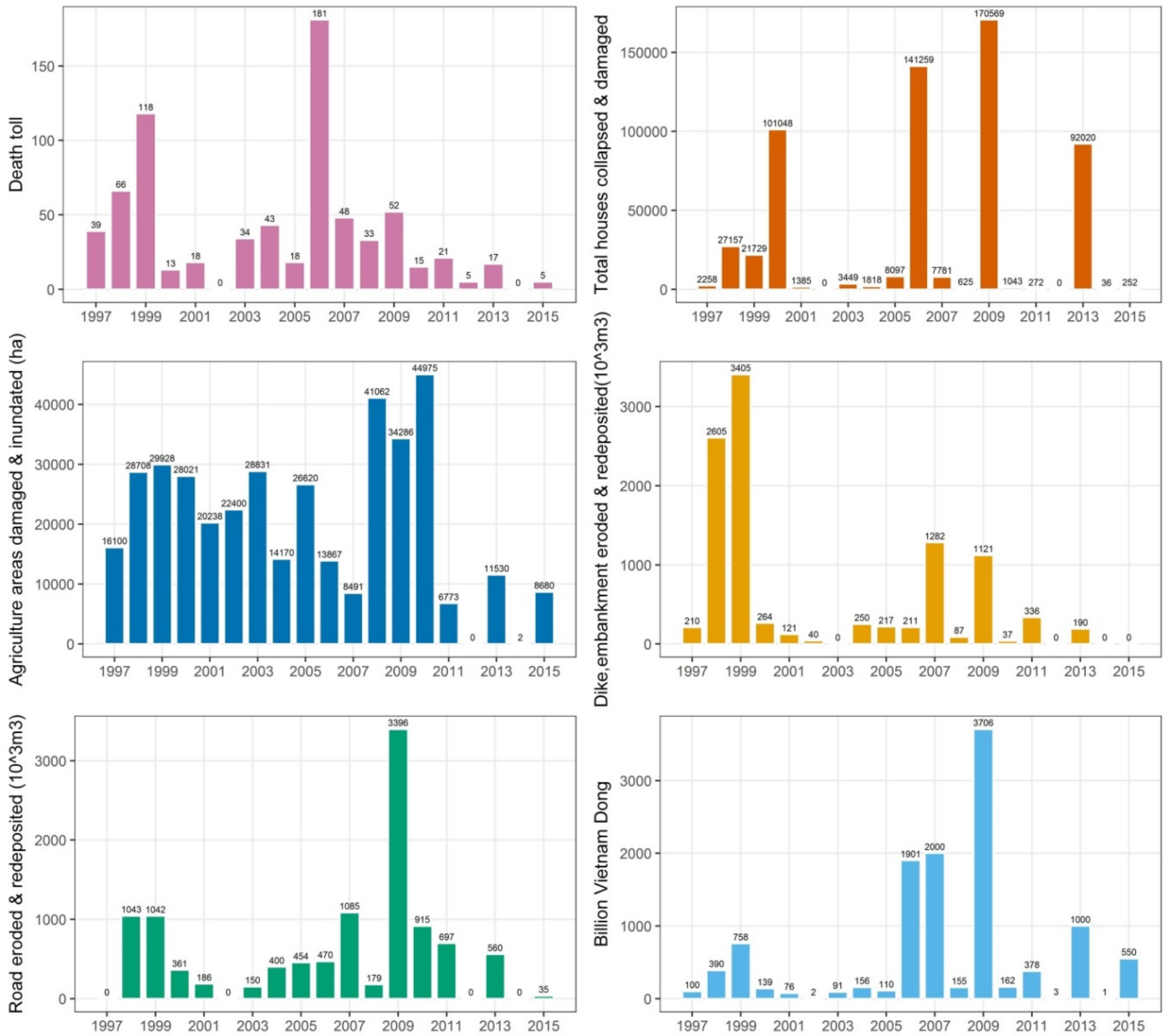


***Figure 8-2****: Flood impacts in Quang Nam, Vietnam between 1997 and 2015 (compiled from flood damage data provided by Quang Nam Provincial Steering Committee on Natural Disaster Prevention and Control)*

### *8.2.2 Data used*

The input data was collected via fieldwork in Quang Nam province in June and August 2016 by the first author. The field work had three main tasks: (1) semi-structured interviews with local staff working in Steering Committees on Natural Disaster Prevention and Control at commune, district and provincial levels to investigate flood risk management activities at their localities, (2) AHP questionnaires with the local staff for their judgements on flood risk factors, and (3) the collection of secondary data, including flood marks, flood damage data, and GIS data. The data of population density, poverty rate, and numbers of doctors and nurses were collected from 2015 Statistical Yearbooks of 17 districts in Quang Nam province. This study was approved by the University of Newcastle Human Research Ethics Committee in June 2016, approval No. H-2016-0125.

## 8.3 Methodology

### *8.3.1 AHP method*

AHP was initially developed by Thomas L. Saaty (Saaty 1988). It is a flexible technique for facilitating the process of setting priorities and decision-making. AHP has been broadly applied in making decisions in economics, education, transportation, planning, resources allocation, and integrated management (Ramanathan 2001, Vaidya and Kumar 2006), and more recently in flood risk management (de Brito and Evers 2016).

Several of the advantages of using AHP include direct Decision-Makers (DMs) or experts' opinion involvement, simple GIS integration (Malczewski 1999), criteria and sub-criteria systematisation (Ishizaka and Labib 2009), and consistency in judgement (Koczkodaj et al. 2017). Besides these advantages, this approach has three main limitations. The first one relates to the evaluation and ranking of indicators based on the personal choice and the knowledge of DMs or experts, which lead to subjectivity in evaluation (Schmoldt et al. 2001). The second weakness is that this approach requires a large number of pairwise comparisons and the high number of alternatives or criteria can make it overwhelming for participants (Harker 1987, Carmone Jr et al. 1997). The third drawback is that the pairwise comparisons of this method are based on very general and vague criteria (Velasquez and Hester 2013). However, these shortcomings present in almost MCDM methods (Ishizaka and Labib 2009).

AHP can be summarised in the following main steps:

- Step 1: Creating a hierarchical system by decomposing the goal into a hierarchy of interrelated clusters;
- Step 2: Making pairwise comparisons between criteria of the decision clusters to form pairwise comparison matrix $A = [a_{ij}]$; and,
- Step 3: Synthesizing individual subjective judgments and computing relative weights.

The assignment of weights has a fundamental role in risk decision-making process. Weighting articulates the importance or preference of criteria and is often a subjective process (Chen et al. 2001). The weights of criteria can be determined by direct judgements of an expert group (Kienberger et al. 2009, Kokangül et al. 2017) or by statistical methods, such as linear regression (Olson 2004), non-parametric resampling (Mojtahedi and Oo 2016), and principal component analysis.

AHP operates by setting priorities for multi-criteria, which are judged by groups (DMs, experts, or stakeholders) involved in decision-making process to derive the best decision (Saaty 1990). The weights of criteria in AHP method rely upon the judgment of experts or DMs, so the method focuses on quality instead of quantity of experts. AHP assessment could operate with a small group of experts, for example, one expert (Godfrey et al. 2015), three experts (Kokangül et al. 2017), four experts (Kienberger et al. 2009), five experts (Plattner et al. 2006), six experts (Zou et al. 2012), and nine experts (Papaioannou et al. 2014). AHP could also run with the author experience-based assessment, for example, Kandilioti and Makropoulos (2012), Li et al. (2013), and Dewan (2013a)

### *8.3.2 Flood risk components*

Flood risk is a common threat to many populous cities, and riverine and coastal regions (Maaskant et al. 2009). Flood risk was first quantified by a combination of flood hazard, exposure and vulnerability as in Eq. (8-1) in the studies of Crichton (1999) and Kron (2005). After that, the application has been formalised in many studies and frameworks such as Winsemius et al. (2013), Budiyono et al. (2014), Gain et al. (2015), Ronco et al. (2015) and UNISDR (2015a). Flood hazard can be determined as the probability of occurring a certain level of danger at one location and as natural and man-made triggers (Kron 2005, Field 2012). Exposure is defined by the extent to which people, property and infrastructure are exposed to a hazard event (Crichton 1999, Field 2012, Winsemius et al. 2013). Vulnerability is specified by the extent to which people are susceptible to, or unable to cope with the impacts (Kron 2005, Maaskant et al. 2009, Jongman et al. 2012b, Kobayashi and Porter 2012).

$$Flood\ risk = Hazard * Exposure * Vulnerability \qquad (8\text{-}1)$$

This study aims to incorporate flood hazard information within the context of data on flood exposure and vulnerability to a hazard event. Therefore, flood risk is assessed based on the components of hazard, vulnerability and exposure as in Eq. (8-1). A hierarchy model using AHP method was designed to integrate the three components. Each component has several criteria, in turn, each criterion contains several sub-criteria. The criteria of flood risk components are adapted from the various studies cited in

**Table 8-1**. The hierarchy framework for assessing flood risk in the present study is illustrated in **Figure 8-3**.

***Table 8-1*** *Criteria and its sources for the assessment of flood hazard, vulnerability, and exposures*

| Components | Criteria | Sources |
|---|---|---|
| Flood hazard | Depth | Zou et al. (2012), Dewan (2013a), Foudi et al. (2015), Gain et al. (2015), Ronco et al. (2015) |
| | Duration | Boudou et al. (2016), Chinh et al. (2017) |
| Flood exposure | Land-use | te Linde et al. (2011), Zou et al. (2012), Dewan (2013a), Ouma and Tateishi (2014), Gain et al. (2015), Ronco et al. (2015) |
| | Distance to rivers | Penning-Rowsell et al. (2005), Dewan (2013a), Terti et al. (2017) |
| | Population density | Wang et al. (2011), Peduzzi et al. (2009), Zou et al. (2012), Dewan (2013a), Gain et al. (2015), Ronco et al. (2015) |
| Flood vulnerability | Poverty rate | Zou et al. (2012), Dewan (2013a), Foudi et al. (2015), Gain et al. (2015), Ronco et al. (2015) |
| | Road density | Boudou et al. (2016), Chinh et al. (2017) |
| | Number of doctors and nurses | te Linde et al. (2011), Zou et al. (2012), Dewan (2013a), Ouma and Tateishi (2014), Gain et al. (2015), Ronco et al. (2015) |

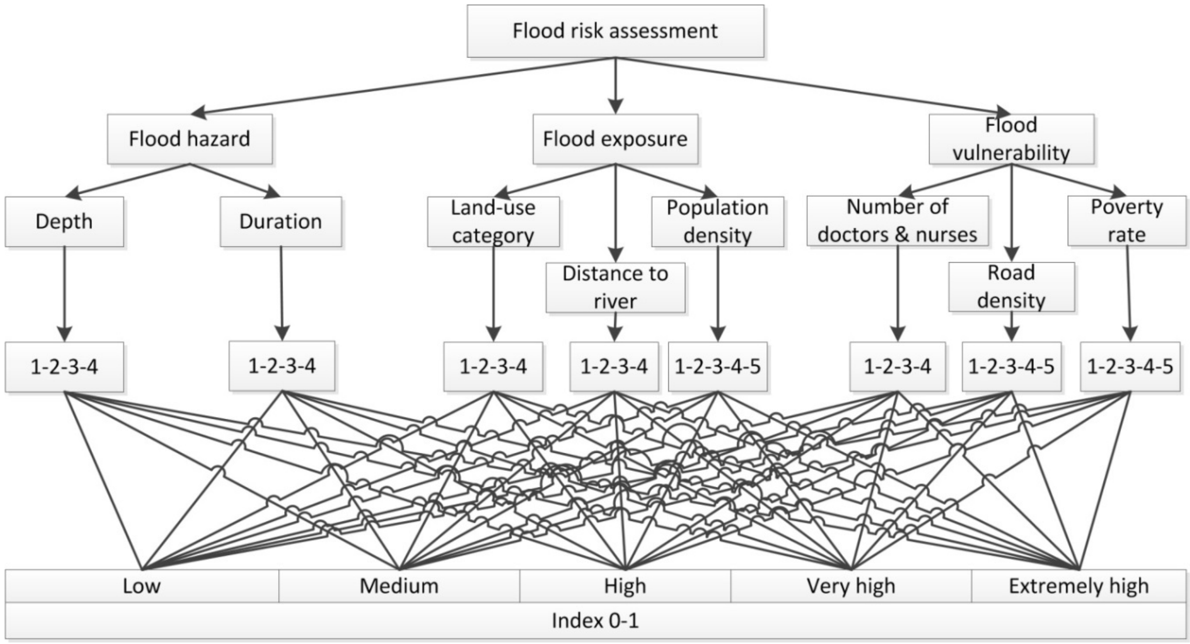


***Figure 8-3****: Decision hierarchy model to measure the flood risk for Quang Nam province*

Flood hazard data, including flood depth and flood duration data (**Figure 8-1**) is used in conjunction with flood exposure and vulnerability data to provide a flood risk map for Quang Nam province.

Three criteria—land-use categories, distance to rivers, and population density—were considered in this study in order to estimate flood exposure. Land-use categories are often used to calculate the losses in flood risk assessment models (Bouwer et al. 2010). The distance to rivers criteria is derived from river network data. It is assumed that people living close to river systems are at higher risk than those who do not (Dewan 2013a). The population density is the most critical criterion in assessing flood risk since it is defined by human settlements. More densely populated areas are at higher risk when floods occur (Peduzzi et al. 2009).

Three criteria are also used in this study to estimate vulnerability; poverty rate, road density, and the number of doctors and nurses. The poor are more likely to be affected by disasters (Winsemius et al. 2015), and poverty is often seen as a structural cause of vulnerability. The poverty rate criterion is therefore critical to this study. Infrastructure, such as roads, play a significant role in response (e.g., evacuation) and recovery activities (Dewan 2013a), and locations without infrastructure suffer. Meanwhile, understanding the number of healthcare facilities in flood-prone areas is critical to our knowledge of the level of preparedness in an area (Dewan 2013a). Quang Nam province lacks data on the number of hospitals but has data on the number of doctors and nurses in each commune, so this criterion is considered in analysing flood vulnerability. More criteria could be added to analyse flood vulnerability, such as gender, age and persons with disabilities; however, such data is lacking in the research area.

### *8.3.3 AHP judgements*

Staff working in the local Steering Committees of Natural Disaster Prevention and Control in Quang Nam province were invited to participate in the study and asked to judge the criteria. The invited staff were the heads or vice-heads of committees. The rationale for this is that they are the most knowledgeable and have the most responsibility for local flood risk management activities. The information statements informed invitees that their participation was entirely voluntary and anonymous. We could only recruit two staff suitable for participation; however, AHP can work with a small group. The staff completed the pairwise comparisons via a questionnaire.

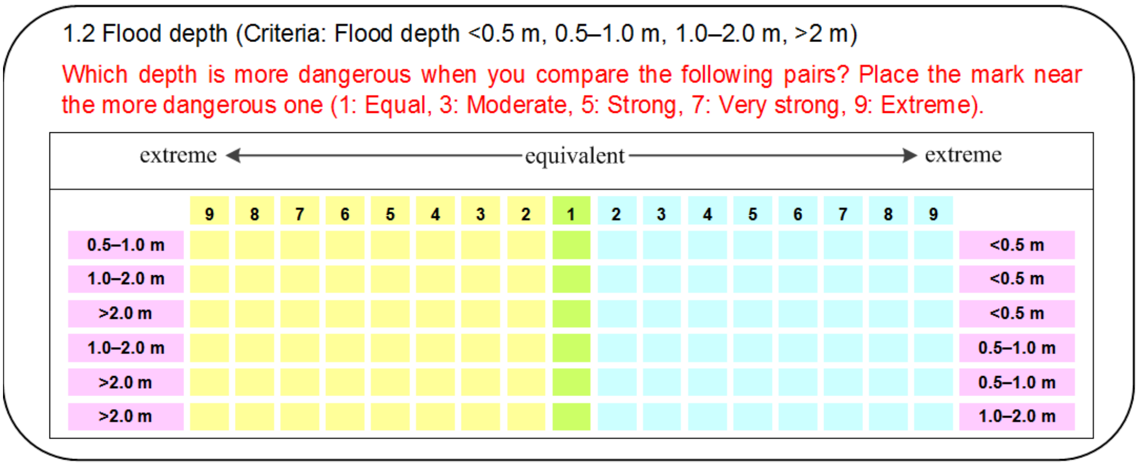


***Figure 8-4****: An example of AHP pairwise comparisons*

After pairwise comparison judgements of each DM meet the consistency requirement of less than 0.1 (Saaty 1977), it is required to combine the judgements of the group. The AHP allows each DM to specify a value and then combine all individual judgements for the final assessment result according to the geometric mean rule of Saaty (1989) as in the following equation:

$$a_{12} = [a_{12}^{1} \times a_{12}^{2} \times \dots \times a_{12}^{N}]^{1/N} \qquad (8\text{-}2)$$

where

1 … $N$ are decision makers

$a_{12}^{1} \dots a_{12}^{N}$ are judgements of decision makers from 1 to N

AHP algorithms are calculated via Supperdecisons software (Whitaker and Adams 2005). The flood risk indicators weighted by AHP is be integrated into GIS framework using spatial analysis techniques to produce mapping outputs. WLC is used to aggregate all weighted layers by the corresponding criteria and sub-criteria weights (Dewan 2013a). The integrated AHP-WLC approach is employed for creating flood hazard, exposure, vulnerability and risk maps in the present study.

## 8.4 Results

### *8.4.1 Flood exposure*

Three criteria including land-use categories, distance to rivers and population density were considered for estimating flood exposure (**Table 8-2** and **Figure 8-5**).

The distance to rivers is derived from river network data. It is assumed that people living close to river systems are higher risk than those who do not (Dewan 2013a). The distance to rivers is calculated via *Euclidian Distance* tool in ArcGIS software (**Figure 8-5**). The more close to rivers is the more severe for flood exposure. Therefore, the highest score is given to the distance of less than 1 km from river systems, and the lowest score is allocated to the distance of greater than 3 km (**Table 8-2**).

The land-use data contained four categories of homestead and built-up, agricultural land, forest and vegetation, and water bodies (**Figure 8-5** and **Table 8-2**). The potential impact of flood is high for homestead and built-up regarding human and infrastructure, so its relative weight is the highest for this land-use category. The agricultural land has the second highest weight when considering the impact on community's livelihood. The water bodies and forest and vegetation have the lowest weights since they do not pose a threat to residents.

The population density is calculated as the total population of a commune over its total area ($km^2$). This criterion is directly related to human populations, so it is judged more important than the other criteria of land-use category and distance to rivers. More densely populated areas are at higher risk if floods occur (Peduzzi et al. 2009). The higher population density is, the higher weight is allocated (see **Table 8-2**).

***Table 8-2*** *Decision hierarchy model for flood exposure indicators*

| **Component** | **Criteria** | **Weight** | **Sub-criteria** | **Weight** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Flood exposure** | Land-use category | 0.135 | Homestead and built-up | 0.670 |
| | | | Agricultural land | 0.201 |
| | | | Water bodies | 0.082 |
| | | | Forest and vegetation | 0.047 |
| | Distance to rivers (km) | 0.253 | <1 | 0.608 |
| | | | 1-2 | 0.229 |
| | | | 2-3 | 0.110 |
| | | | > 3 | 0.053 |
| | Population density (km$^2$) | 0.612 | <=50 | 0.042 |
| | | | 51-200 | 0.065 |
| | | | 201-500 | 0.114 |
| | | | 501-1000 | 0.250 |
| | | | >1000 | 0.529 |

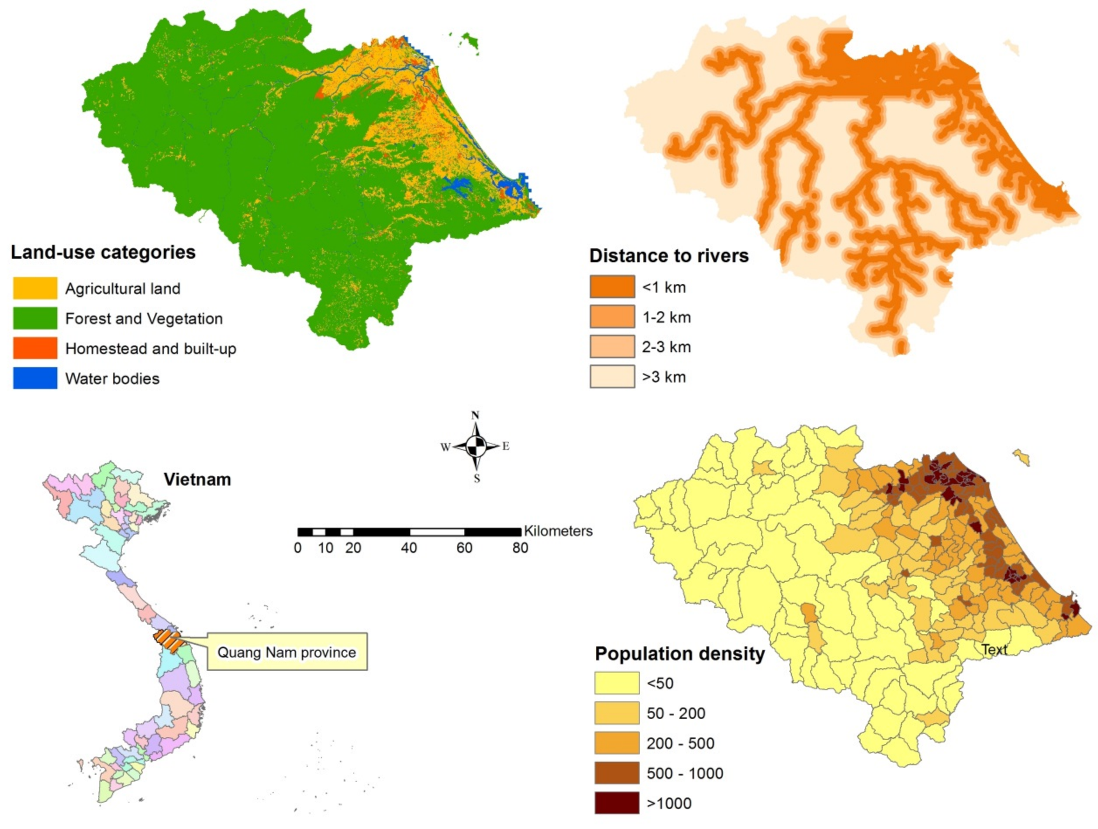


***Figure 8-5**: Distribution of flood exposure criteria and sub-criteria*

### 8.4.2 Flood vulnerability

Three criteria including poverty rate, road density and number of doctors and nurses are considered for estimating flood exposure (**Table 8-3** and **Figure 8-6**).

The poor are more likely to be affected by disasters (Winsemius et al. 2015), so poverty is often seen as a structural cause of vulnerability. Poverty and vulnerability to floods are closely related and mutually reinforced in Vietnam (Tran et al. 2009). The poverty rate criterion is therefore included in flood vulnerability analysis of this study. **Table 8-3** shows that higher relative importance is allocated to higher poverty rate.

Infrastructure facility such as road density played a significant role in response (e.g. evacuation) and recovery activities (Dewan 2013c). The road density is calculated by intersecting road network database with commune boundary feature. The sub-criteria of road density are weighted using AHP (see **Table 8-3**).

Healthcare facilities in flood-prone areas is an important indicator of preparedness activities in flood risk management (Dewan 2013c). Quang Nam province has the data on the number of doctors and nurses in each commune, so this criterion is considered in analysing flood vulnerability of this study (**Table 8-3**). The lower number of doctors and nurses the areas have, the higher the vulnerability.

***Table 8-3*** *Decision hierarchy model for flood vulnerability indicators*

| Component | Criteria | Weight | Sub-criteria | Weight |
|---|---|---|---|---|
| Flood vulnerability | Poverty rate (%) | 0.577 | <5 | 0.062 |
| | | | 5-10 | 0.097 |
| | | | 10-20 | 0.160 |
| | | | 20-40 | 0.262 |
| | | | >40 | 0.419 |
| | Road density (m/km2) | 0.298 | <20 | 0.438 |
| | | | 20-50 | 0.256 |

| | | | |
|---|---|---|---|
| | | 50-100 | 0.149 |
| | | 100-400 | 0.096 |
| | | >400 | 0.061 |
| Number of doctors and nurses | 0.125 | 0 | 0.467 |
| | | 1-2 | 0.277 |
| | | 3-4 | 0.160 |
| | | 5-7 | 0.096 |

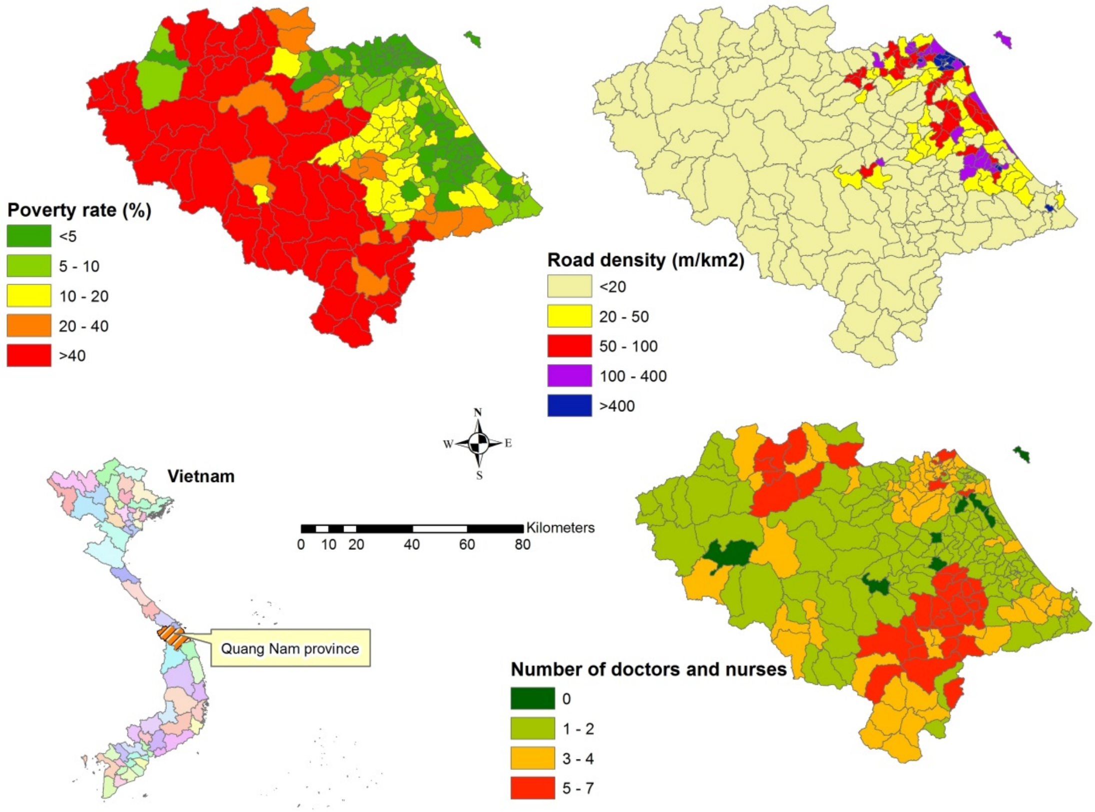


***Figure 8-6**: Distribution of flood vulnerability criteria and sub-criteria*

### *8.4.3 Flood risk assessment*

Flood risk assessment map at a local scale is particularly vital for planners and managers to develop flood risk mitigation measures (Directive 2007/60/EC). Flood risk is quantified in this study by a combination of flood hazard, exposure and vulnerability as in AHP model as in the three previous subsections. The analysis results were shown in **Figure 8-7**.

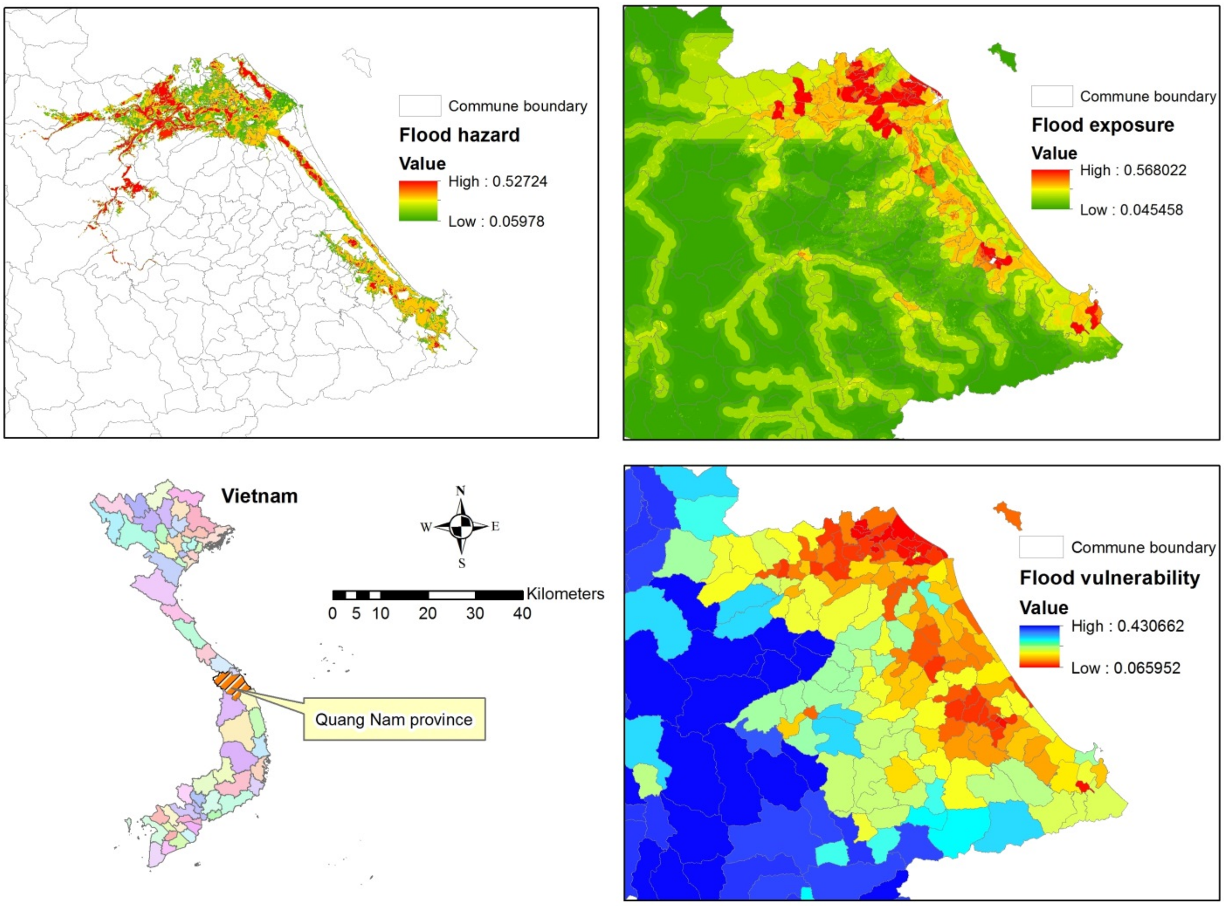


***Figure 8-7**: Spatial analysis of flood hazard, exposure and vulnerability for Quang Nam province*

A flood risk assessment map was created by overlaying flood hazard, exposure and vulnerability maps using *Weighted Sum* technique in ArcGIS software. The final flood risk assessment map was shown in **Figure 8-8**, in which the scores were normalised to a range of 0-1. The high flood risk areas were located close to and along rivers. The total flooded area was 60,327 ha, in which 3,291 ha of low risk (0.264-0.411), 16608 ha of medium risk (0.412-0.558), 25193 ha of high risk (0.559-0.706), 13163 ha of very high risk (0.707-0.853) and 2071 ha of extremely high risk (0.854-1.000).

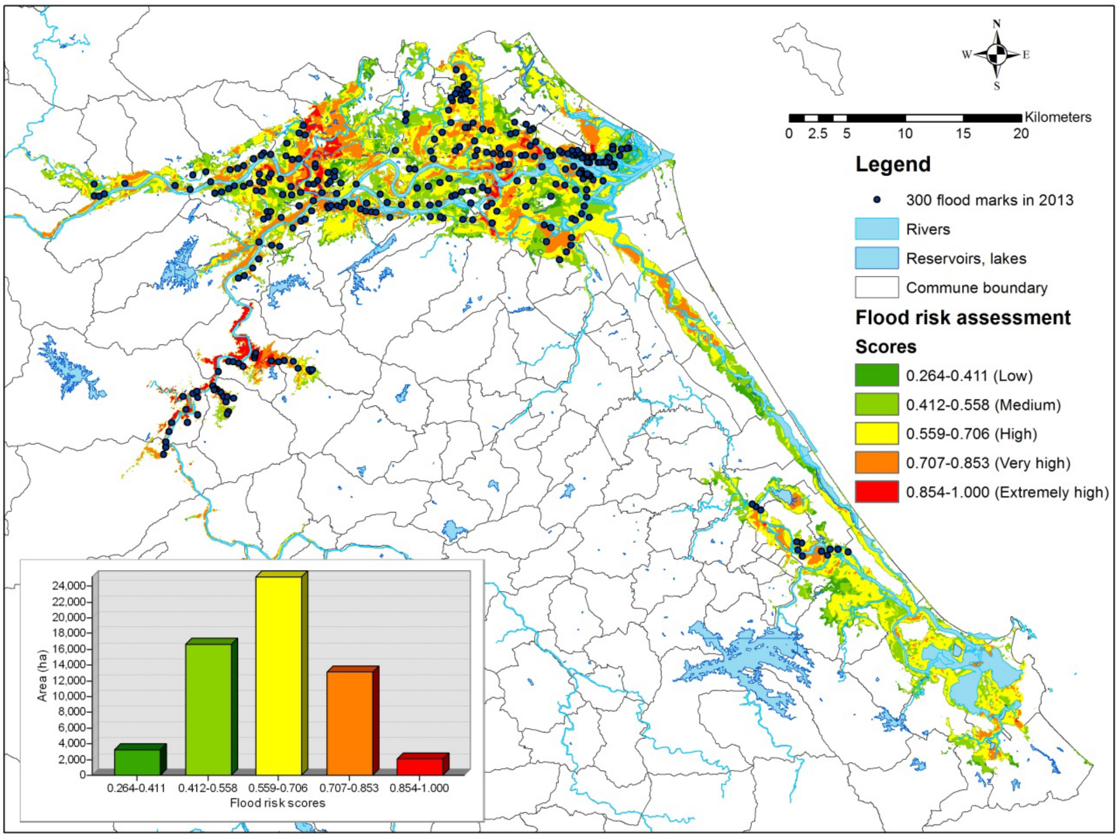


***Figure 8-8****: Spatial assessment of flood risk for Quang Nam province*

## 8.5 Discussion

Flood risk assessment is required to develop effective flood mitigation measures (Directive 2007/60/EC). Understanding risk through risk assessments is essential to the field of disaster risk management. The spatial flood risk assessment is a useful tool for flood risk mitigation measures since the at-risk areas are prioritised (Foudi et al. 2015). The present study provides a new approach to assess flood risk for a local area, which combines historical flood marks with exposure and vulnerability data in the assessment using spatial multicriteria decision analysis. The applicability of this approach is demonstrated in a case study of Quang Nam, Vietnam in relation to the 2013 flood event.

In this study, flood risk is assessed with the integration of various indicators of flood depth, duration, population density, land use category, distance to rivers, poverty rate, number of doctors and nurses, and road density using AHP and spatial analysis techniques. AHP model is selected to combine the flood risk components for four reasons: (1) direct DMs opinion involvement, (2) criteria and sub-criteria systematisation, (3) multicriteria decision analysis and GIS combination, and (4) consistency in judgement. Dang et al. (2010) used AHP approach to assess flood risk for Day river flood diversion area in the North of Vietnam, however, this work did not extend to flood risk mapping. Chau et al. (2013) used 86 flood marks of the hazardous 2009 flood and a 30 m DEM resolution to produce a flood inundation map for Quang Nam province, and applied the result for assessing agricultural impacts. The present study goes further, using AHP method and spatial techniques to assess flood hazard with flood depth and duration indicators, and combining with flood exposure and vulnerability data to provide an integrated flood risk assessment map.

Floods have severely affected people's livelihoods and socio-economic development in Quang Nam over the years (**Figure 8-2**). Low-land areas along Vu Gia-Thu Bon river basin, including agricultural areas with high population densities, are often subjected to flooding in annual rainy seasons (**Figure 8-1**). A local flood risk assessment map is essential since it can support decision-makers and planners to recognise high-risk areas, develop flood risk management strategies, have appropriate flood risk mitigation measures and raise public awareness on flood risk (Vojinovic 2015). Flood hazard maps can be created via a hydraulic modelling approach, which requires various input data such as updated river cross-sections, time series meteorological and streamflow data. This is hardly ever applied to data-scarce areas, especially in developing countries, which often lack gauging stations. The present study uses spatial multicriteria decision analysis to integrate historical flood mark data with flood exposure and vulnerability data into a flood risk assessment map. The final flood risk assessment map can enable policy makers and government departments to make judgments about setting priorities for flood mitigation works and provide potential support for the preparation of flood risk management plans. The map is also essential for accurate communication about the local flood risk situation within floodplain areas; this affects not only government managers but the affected communities.

This study combines flood mark data with flood exposure and vulnerability data to produce a flood risk assessment map for Quang Nam province. This province is lacking this kind of assessment map (Luu et al. 2018c), and it can be used by local decision-makers in defining specific flood risk management plans. The methodology can also potentially be applied to other provinces to generate flood risk assessment maps using flood mark data.

However, the present study must be interpreted in the context of three main limitations, similar to other MCDM models. First, we could only recruit two DMs in the local steering committees suitable for participation, but this limitation is within the acceptable limits of other published studies. The reason is that the AHP model requires a significant number of pairwise comparisons of 55 for our model. This requires much time to read and answer the questionnaires and is particularly difficult for non-academic participants. In Vietnam, the staff working in the local steering committees are local government officials, who work in the committees as a part-time job. While they make key decisions on local flood risk management activities, and always take cognisance of the local flood hazard features to make the most appropriate assessment, they are not academic persons. Second, our model lacks validation, which belongs to MCDM approach of subjective judgments in weighting indicators (Schmoldt et al. 2001) and subjective model validation (de Brito et al. 2018). Third, more data could be added to analyse flood vulnerability such as gender, and persons with disabilities; however, such data is not available in the research area.

## 8.6 Conclusion

This study provides a new approach to assess flood risk for Quang Nam province and present the analysis on a GIS-based map, which combines historical flood marks with exposure and vulnerability data in the assessment using spatial multicriteria decision analysis. We develop a flood risk assessment model that is capable of rapidly simulating a flood risk map. The result produces a comprehensive flood risk assessment map for Quang Nam province, which can be utilised by planners and managers to develop flood risk mitigation measures. Our study contributes to a methodology to build flood risk assessment maps using flood mark data, which can be applicable to other provinces in Vietnam. This approach is potentially of particular interest in areas where there is inadequate data for hydraulic modelling.

# Chapter 9 Flood risk management activities: a study of local practice in Quang Nam province[8]

## 9.1 Introduction

A flood is a very complex phenomenon that involves links between the natural environment, people and social systems (Slobodan 2012). Flood risk can be determined as the combination of the likelihood of a particular flood event and its impacts (Sayers et al. 2002b, WMO 2013b). Flood exposure and flood frequency are forecasted to increase globally, particularly in low latitudes in Asia and Africa (Hirabayashi et al. 2013).

Flood risk is a common threat to many densely populated cities, and low-lying riverine and coastal areas around the world (Maaskant et al. 2009). Flood risk management (FRM) has gradually undergone a shift from a traditional approach based on design standards to a risk-based decision-making perspective (Sayers et al. 2002b, Molinari et al. 2014). A standards-based approach focuses on structural flood prevention measures. A risk-based approach provides informed choices and focuses on non-structural measures; these do not reduce the exposure to flood risk, but aim to mitigate the vulnerability and susceptibility of people and their properties in the flood-prone areas (WMO 2013a).

Vietnam is highly vulnerable to flood and storm impacts, being eighth most affected country by extreme weather events 1996-2015 (Kreft et al. 2016). The high flood risk in Vietnam is due to its tropical monsoon climate, dense river systems, long coastline, and

[8] Luu, C.; Von Meding, J.; Kanjanabootra, S. Flood risk management activities in Vietnam: A study of local practice in Quang Nam province. *International Journal of Disaster Risk Reduction* 2018, 28, 776-787, http://dx.doi.org/10.1016/j.ijdrr.2018.02.006

dense populations established along rivers and coastal areas (Razafindrabe et al. 2012, Chau et al. 2014b). Besides natural factors such as weather and topography, human interference such as deforestation (McElwee 2004, McElwee 2009) and land-use management (Chau et al. 2013) contribute to the high flood risk in Vietnam. In addition, a significant proportion of Vietnam's population is concentrated in areas prone to flooding, increasing their disaster risk (Shaw 2006, Davis 2014, Tukker and Ngo 2014).

Developing economies often suffer more severe consequences from natural hazards than developed ones (Hansson et al. 2008). Toya and Skidmore (2007) found that higher income, education, and trade openness reduced the impacts of natural hazards, in terms of economic losses and fatalities. Flood fatalities and economic impacts on GDP have been recorded as being higher in developing countries. The scale of the problem in Vietnam can be illustrated by the flood damage data in **Figure 9-1**, showing that floods caused over 14,927 deaths and economic damage equivalent to 1% of GDP between 1989 and 2015.

Flood damage data suggest that floods have had severe impacts on communities in Vietnam, especially the loss of life (**Figure 9-1**). Population growth, agricultural expansion and industrial development have increased flood exposure and vulnerability, particularly in river basins and coastal areas in Vietnam (Tran et al. 2008). Floods tend to affect low-income communities when the communities in coastal and rural areas have all sources of income dependent on the natural environment. Socio-economically marginalised groups face grave difficulties in disaster resilience when they lack public hazard protection such as emergency relief and insurance (Garschagen et al. 2014).

An effective FRM approach can help to reduce adverse impacts of floods and improve flood resilience (Bosher et al. 2009a). FRM activities include mitigation, preparedness, response, and recovery (Moe and Pathranarakul 2006, Mojtahedi and Oo

2017). FRM decision-making processes in Vietnam use a top-down approach, which often has insufficient involvement of stakeholders (Almoradie et al. 2015). Vietnam's top-down approach to FRM is based on centralised government roles at national and provincial levels (Chau et al. 2014b).

There has been an increasing number of case studies on FRM in Vietnam. Tran et al. (2008) explored the coping mechanisms to flood risk by rural communities in Thua Thien Hue province. Bubeck et al. (2012) studied flood risk perceptions in a case study in Thua Thien Hue province. Chau et al. (2014b) undertook an evaluation of the current centralised institutional framework in Vietnam and found that local governments are not proactive about flood management planning. Chinh et al. (2016) investigated FRM in terms of preparedness, response, and recovery of private small businesses and households in Can Tho city. However, there is still a lack of studies on the practice of FRM activities under the legal and institutional frameworks in Vietnam, and how the legal framework of FRM delivers effective flood risk reduction and mitigation.

Although all levels of the political system are involved in disaster management, the role and activities of local administrations are of particular importance (Col 2007). Therefore, this study aims to understand FRM activities at local levels in Quang Nam province, along with the legal and institutional frameworks that are intended to focus, but often restrict, policy and practice. First, Vietnam's legal and institutional frameworks are analysed to provide an overview of the operation of FRM activities and a proposed conceptual FRM framework for Vietnam. Second, we introduce a case study in Quang Nam province, in which we investigate FRM activities at local levels. The study includes 27 individual interviews with decision makers in FRM at provincial, district and commune levels. Finally, following the empirical evidence, we discuss gaps in policy and practice in FRM activities at local scales.

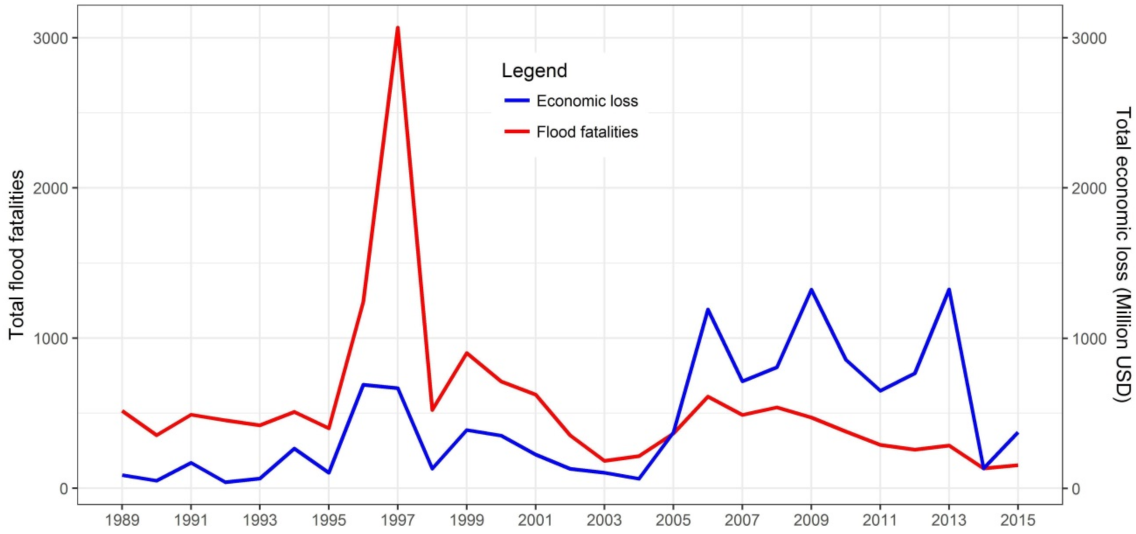


***Figure 9-1****: Death toll and total economic loss caused by flood and storm events between 1989 and 2015 in Vietnam (compiled from national disaster database of Vietnam)*

## 9.2 Legal and institutional frameworks for FRM in Vietnam

### *9.2.1 Legal framework*

Vietnam's legal documents pertaining to disaster management are diverse, are issued by many government agencies, and are frequently modified and updated. The Law on Natural Disaster Prevention and Control (the Law), which came into effect in May 2014, is the first law on disasters in Vietnam and provides the core elements of the country's disaster management system. As stipulated in the Law, disaster management activities consist of prevention, response, and remediation of consequences. Detailed activities of prevention, response and remediation are specified in the Law.

The Law regulates disaster management activities including prevention, response, and remediation of consequences; however, it lacks a focus on mitigation. Where mitigation would help to reduce the consequences of hazards before they occur, the current approach is reactive: preparedness, response, and recovery react to current disasters or anticipate future events (Coppola 2015b). A proactive approach would allow mitigation, preparedness and early warning for disasters before they occur (Moe and Pathranarakul 2006), and would help vulnerable communes to become safer and to respond better to natural hazards. It is suggested that all four disaster management activities should be established in Vietnam: mitigation, preparedness, response, and recovery.

### *9.2.2 Institutional framework*

The Vietnamese constitution has four administrative levels: national, provincial, district, and commune. At the provincial level, Vietnam has 58 provinces and 5 municipalities (effectively 63 provinces). A province includes many districts, and each district consists of many communes. The hierarchical institutional structure in FRM also includes these four levels (**Figure 9-2**); governmental units in a hierarchal order have national, provincial, district, and commune levels. The National Steering Committee for Natural Disaster Prevention and Control has a national-level responsibility, and local governments, which include provincial, district and commune levels, are the decision makers in FRM activities.

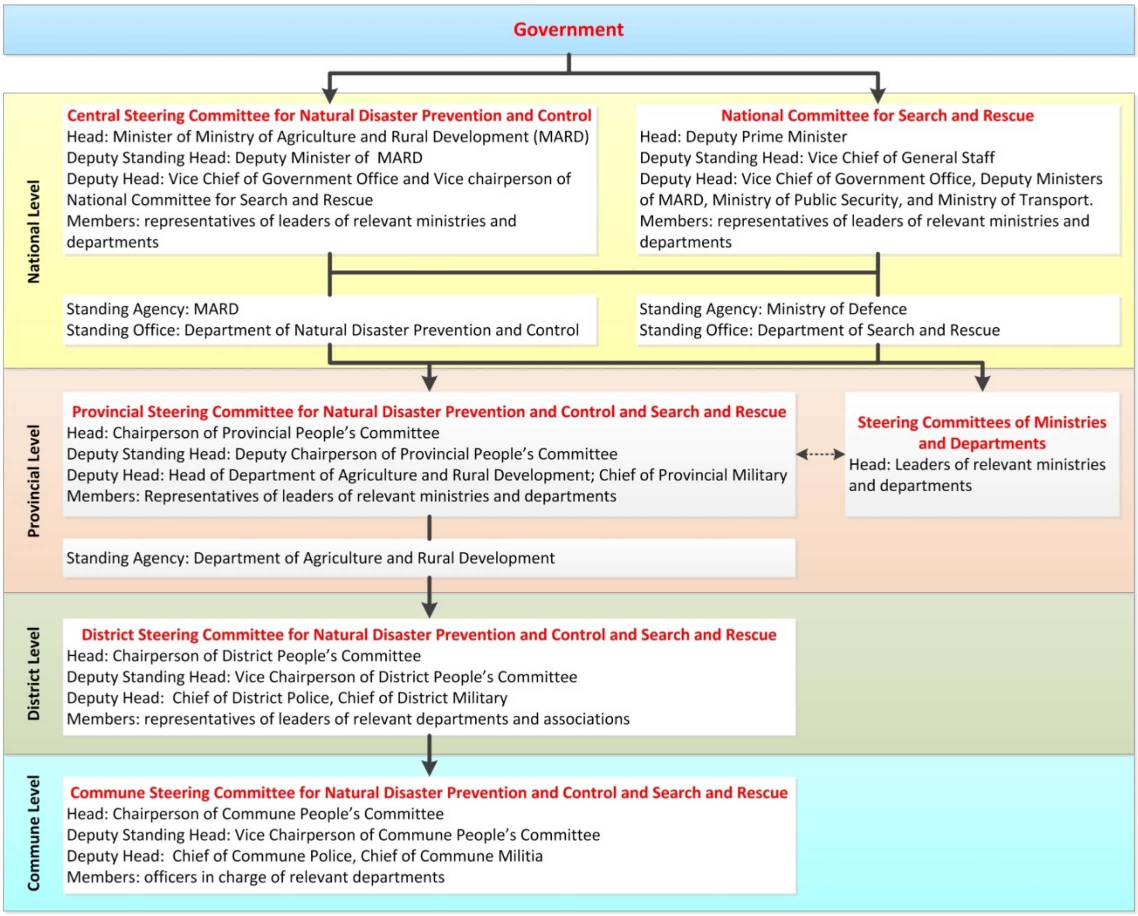


***Figure 9-2**: Institutional framework for FRM in Vietnam (adapted and translated from http://phongchongthientai.vn/he-thong/so-do-chung/-c2.html)*

The overview of the institutional framework for FRM in Vietnam (**Figure 9-2**) shows the involvement of the entire political system in FRM steering committees. The hierarchical structure of the administrative system in **Figure 9-2** is a top-down approach that highlights the responsibilities of various government agencies. This approach leads to inequitable and unsustainable outcomes in disaster risk management (Bollin and Hidajat 2006). There is a transition underway to more resilient approaches such as bottom-up initiatives (Zevenbergen et al. 2008) and community-based systems (van Aalst et al., Bollin and Hidajat 2006). The ideal approach is a combination of top-down and bottom-up approaches (Almoradie et al. 2015), which enables the involvement of all stakeholders and ensures equity (WMO 2006a). Stakeholders include local people, government agencies, emergency management agencies, local authorities, nongovernment organisations, media, and social scientists (Kootval et al. 2005, Mojtahedi and Oo 2014, Almoradie et al. 2015).

The institutional framework for FRM in Vietnam in **Figure 9-2** shows that public administrations are wholly responsible for FRM activities. Decision makers on steering committees are government officials, who often do not possess expertise in disaster management. The lack of involvement of experts, researchers, and scientists could affect the decision-making process. The steering committees should aim their activities not only at directing administrative management, but also at studies on mitigation and preparedness. The involvement of only the public administration system in FRM is not sufficient: decision-making should be based on a combination of the latest scientific knowledge and a deep sensitivity to the local context. It is essential to have the participation of experts, researchers, and scientists on the steering committees.

## 9.3 Conceptual framework

Peek and Mileti (2002) reviewed the history of disaster research and summarised a four-stage cycle of mitigation, preparedness, response, and recovery. Many studies in disaster management have been organised around these four stages (Altay and Green 2006, Moe and Pathranarakul 2006, Khan et al. 2008, Bosher et al. 2009a, Slobodan 2011). These can be further categorised as proactive (mitigation and preparedness) and reactive (response and recovery) (Moe and Pathranarakul 2006, Mojtahedi and Oo 2017). Regardless, a disaster management strategy is generally devised based on the objective of reducing disaster losses and impacts, be they physical, economic, environmental, or social.

Disaster management aims to lessen the impact of disasters by interconnecting the actions associated with mitigation, preparedness, response, and recovery (Peek and Mileti 2002, Moe and Pathranarakul 2006, Slobodan 2011). Mitigation contains structural and non-structural measures taken to mitigate the negative impacts of natural hazards (Coppola 2015b). Preparedness consists of activities undertaken in advance to respond to natural hazards, including temporary evacuation of people from threatened sites, and early warnings (Coppola 2015c). Response involves providing intervention or assistance during or immediately after a disaster event to preserve the lives and basic needs of affected people (Coppola 2015d). Recovery consists of decisions and activities launched after a disaster to restore or improve the living conditions of affected communities (Coppola 2015e).

Moe and Pathranarakul (2006) first developed an integrated framework for disaster management, based on a conceptual public project management process. This framework was then applied in analyses of stakeholders' engagement in FRM by Mojtahedi and Oo (2014), and Mojtahedi and Oo (2017). We have adapted this framework to propose a conceptual integrated FRM framework for Vietnam, with the focus on FRM activities, as presented in **Figure 9-3**.

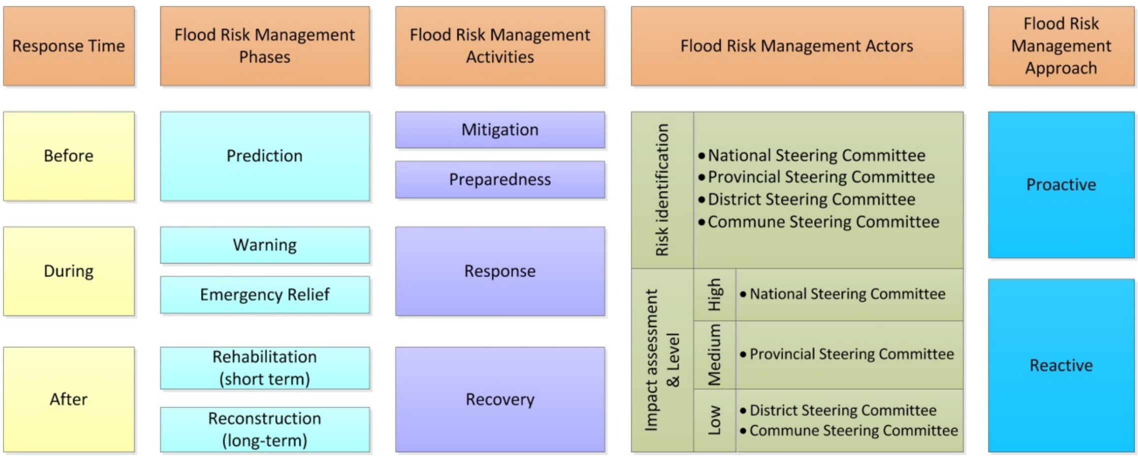

***Figure 9-3****: An integrated FRM framework for Vietnam adapted from Moe and Pathranarakul (2006)*

In the conceptual framework in **Figure 9-3**, a portfolio of FRM measures is implemented during the pre-event, event and post-event stages. The FRM approach is divided into proactive and reactive strategies (Moe and Pathranarakul 2006). The proactive approach requires risk identification (including mitigation, preparedness, and partial response activities), and prediction and warning phases. The reactive approach includes assessment of impact and level, to enable response and recovery activities (which may include emergency relief, rehabilitation, and reconstruction phases). The development of FRM programs can prove the most effective when incorporating all four activities and both proactive and reactive approaches (Peek and Mileti 2002, Moe and Pathranarakul 2006, Slobodan 2011).

Assessment of impacts is necessary since it can be used for rehabilitation and reconstruction phases. The impact levels can be categorised into high, medium and low (Moe and Pathranarakul 2006). Priorities for addressing the impact levels are associated with the different hierarchical government levels as indicated in **Figure 9-3**.

The lack of a proactive approach in disaster management can cause more death and damage (Moe and Pathranarakul 2006). The high flood-fatality rate in Vietnam (**Figure 9-1**) suggests that proactive FRM activities are needed, including mitigation and preparedness. The shift of FRM to a proactive approach requires developing risk-reduction strategies along with policies and programs to bring these strategies into effect (Slobodan 2012). Therefore, this study investigates overall approaches to FRM activities at local levels in Vietnam, from policy to practice. The investigation can contribute to the process of developing a holistic FRM framework for Vietnam.

## 9.4 Research approach

This study begins by analysing legal and institutional frameworks; then presents a case study in a flood-prone province. The data are analysed using a codebook (DeCuir-Gunby et al. 2011) to scrutinise to what extent FRM activities have been implemented in practice.

### *9.4.1 Description of study area*

The institutional framework for disaster management (**Figure 9-2**) is applied across Vietnam. Steering Committees for Natural Disaster Prevention and Control and Search and Rescue are established at national, provincial, district and commune levels in Vietnam. Quang Nam province, among the most flood-prone provinces in Vietnam, was selected for a case study.

Quang Nam, located at 15°35′N, 107°55′E on the south-central coast of Vietnam, has an area of 10,440 $km^2$ and had a population of over 1.4 million in 2015. This province is the sixth-largest in area and the ninth-most populous of Vietnam's 63 provinces. It has 100 km of coastline and the Vu Gia-Thu Bon river basin with dense cascades of hydropower dams. The west of Quang Nam is mountainous and sparsely populated, while the east is flat plains that are favourable for agricultural populations and urban development (**Figure 9-4**). Residents in the province are highly dependent on agriculture, with many small-scale farms, so weather extremes seriously affect communities' livelihoods in this sector.

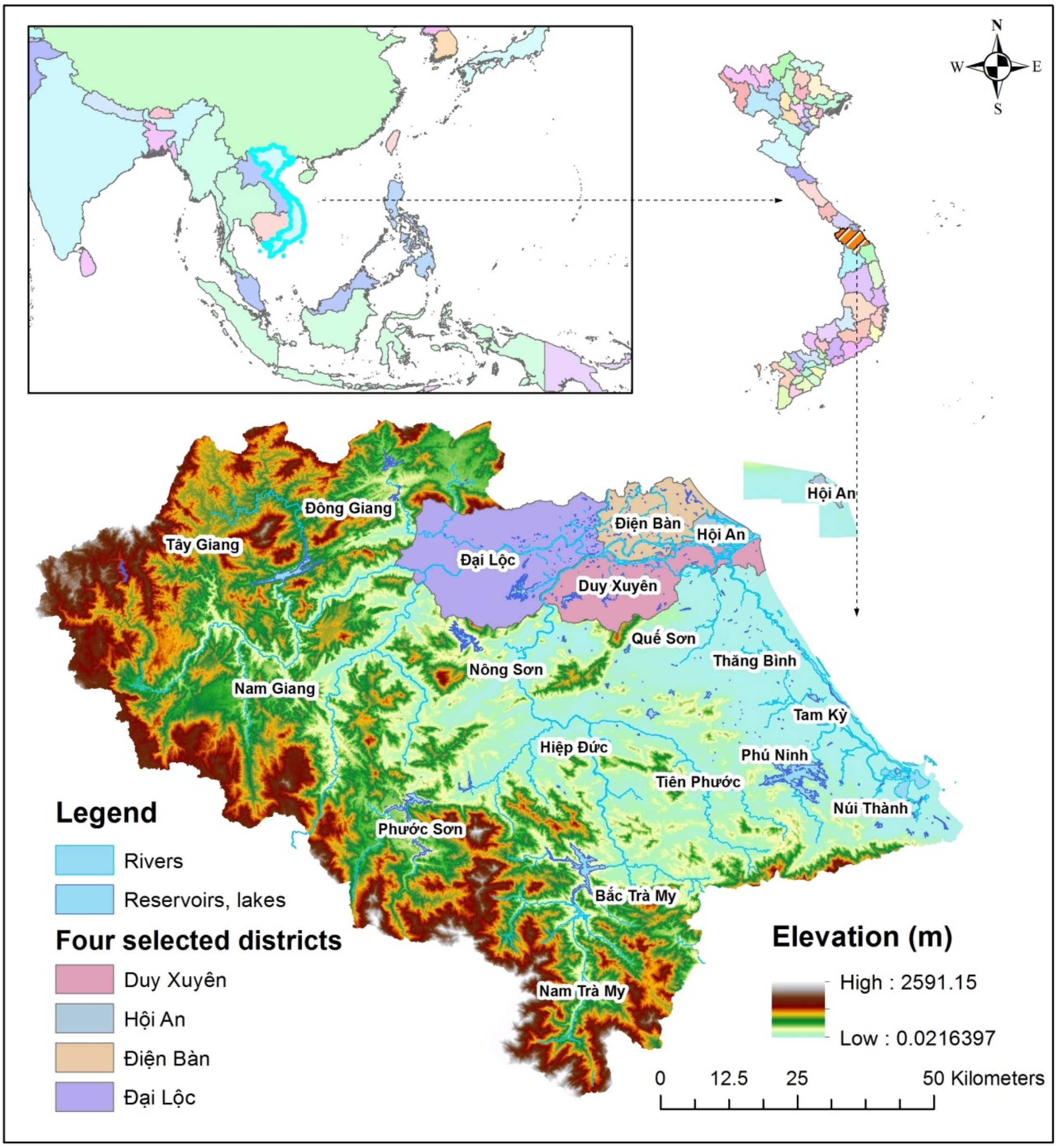


***Figure 9-4****: The study area, Quang Nam province in Vietnam*

Quang Nam is exposed to riverine and coastal flood risk during weather extremes of storms, floods, flash floods, and typhoons (Chau et al. 2013). Vu Gia-Thu Bon river basin, in the western part of Quang Nam, has a total area of 5.290 km$^2$ and is one of the largest river basins in Vietnam. Over the years, successive river floods have had severe impacts on the residents' livelihoods and socio-economic development (Chau et al. 2014a). FRM activities in the province are under increasing pressure due to population and economic growth, human interference leading to environmental damage, and the influence of climate change.

### *9.4.2 Method*

Quang Nam province was selected as a case study based on the research question and the institutional framework for FRM in Vietnam (**Figure 9-2**). The case study involves design, data collection, and analysis (Yin 2014). The research was designed to invite decision makers from the hierarchical levels of institutional structures, including provincial, district and commune levels, to take part in interviews. 27 individual interviews were conducted in June and August of 2016 with representatives of Steering Committees for Natural Disaster Prevention and Control and Search and Rescue at provincial, district, and commune levels in Quang Nam province. The interviews focused on overall approaches to FRM activities.

The study aimed to achieve a deeper understanding of FRM at local scales. We undertook semi-structured interviews with decision makers at the three local levels, since FRM activities at local levels in Vietnam were implemented according to the hierarchical structure of the political system (**Figure 9-2**). We designed interview questions based on the conceptual framework (**Figure 9-3**).

The invited interviewees were the heads or vice-heads of committees. The rationale for this is that they are the most knowledgeable and have the most responsibility for their local FRM activities. The staff work directly in the decision-making process of FRM and always take account of flood hazards at their localities. They are the primary decision makers in FRM activities in Quang Nam.

The individual information of invited interviewees was not in the public domain, so the author directly contacted organisations in government agencies at the province, district, and commune levels. The author provided them with information statements and asked them to participate in an interview with the author, to be held at a time and workplace/public place of the participants' convenience. The information statements informed invitees that their participation was entirely voluntary and anonymous.

The contact for interviews followed the hierarchical structure of the political system as shown in **Figure 9-2**. First, we contacted the Quang Nam Provincial Steering Committee for Natural Disaster Prevention and Control, and invited a representative to take part in our interview. The provincial committee then suggested that we work with the district level, specifically Dai Loc, Dien Ban, Duy Xuyen districts and Hoi An city (which exists at the same level as a district). These four districts are located along Vu Gia-Thu Bon river basin (**Figure 9-4**), and are frequently subjected to flooding. Second, we contacted and interviewed representatives of the four selected districts, who then introduced us to their communes. Third, we worked with 22 communes that were identified by their districts; these communes are the most vulnerable to flood risk in the four districts. A total of 27 personal communications were conducted with representatives of provincial, district and commune levels, with 1, 4 and 22 communications respectively.

This study adopted the qualitative analysis procedure presented in Creswell (2014). The detailed steps for data analysis were: (1) collecting raw data, (2) organising and preparing the data for analysis, (3) reading through all the data, (4) coding the data into themes via a codebook, (5) interrelating these themes, and (6) interpreting the meaning of themes. Seven themes were coded from the raw data:

- inundation maps
- FRM activities in practice (mitigation, preparedness, response and recovery)
- stakeholders' involvement

- budget allocations
- impacts of cascaded hydropower projects
- community-based disaster risk management programs
- staff capacity.

Data analysis focused on issues related to practice and was restricted to FRM activities at local levels in Quang Nam province along with the legal and institutional frameworks. First, all interview transcripts were originally coded by the seven themes in a procedure similar to DeCuir-Gunby et al. (2011). To establish rigour in the interview analysis, we followed four strategies of Baxter and Eyles (1997): rationale for methodology, interview quotations, appeals to interpretive community, and rationale for verification. Quotations and summaries of responses were used to elucidate research findings. All names were replaced by pseudonyms. Relevant literature was consulted in relation to the data to further examine the findings.

## 9.5 Research findings and discussions

In this section, we present interpretation of the seven themes, with discussions on local-scale FRM activities.

### *9.5.1 Inundation maps*

Flood inundation maps are considered the core tools in developing FRM activities (Foudi et al. 2015). Accurate flood inundation maps can assist decision makers in developing appropriate evacuation plans for flood prone areas (Masuya et al. 2015). The available inundation maps were different between the three institutional levels and within an institutional level. The provincial level stored several inundation maps which were created by various projects as in **Table 9-1**. Three of the four responses at the district level had one inundation map on paper for the whole province, and it was not detailed for the district level. Six of the twenty-two communes had a hand-drawn inundation map (see **Figure 9-5** for an example from the Dai Thanh commune). These six communes were involved in Community Based Disaster Risk Management (CBDRM) programs. The other communes did not have an inundation map, although respondents in the communes said that they had information from personal experience about the frequently flooded areas in their communes.

***Table 9-1*** *Summary of responses to existing inundation maps at local levels*

| Local level | Responses |
|---|---|
| **Provincial** | Four projects for building inundation maps for Quang Nam have been developed, including:<br>(1) Project Cr.4114-VN "Natural Disaster Risk Management", funded by a World Bank loan, was implemented by the Vietnam Institute of Geography. The project results included an inundation map for Quang Nam at the scale of 1:25,000 in 2011, and an additional information map at the scale of 1:10,000 for floodplain areas in 2012.<br>(2) Project "GIS technology application for flood prevention map for Quang Nam province" was developed by the Quang Nam Hydro-Meteorological Forecasting Station. The project's outcomes included an inundation map for the low-lying areas in the downstream portion of Vu Gia-Thu Bon river basin using MIKE 11, MIKE 21 and ArcGIS.<br>(3) Project "Developing a toolkit for supporting disaster risk management decision-making for river basin system in central Vietnam" was prepared by the Vietnam Academy for Water Resources. The project's outcome provided hydrological and hydraulic modelling of the Vu Gia-Thu Bon river basin, including dam failure scenarios and inundation maps at 1:50,000 for low-lying areas and 1:100,000 for the whole river basin.<br>(4) The Vietnam Academy for Water Resources is currently implementing the Project "Developing inundation maps in a situation of sea level rise for violent storms and hurricanes" for Quang Nam province. |
| **District** | Dai Loc: the district had one inundation map, created by Hue University of Agriculture and Forestry.<br>Dien Ban: the district received an inundation map from the project "GIS technology application for flood prevention map for Quang Nam province", developed by the Quang Nam Hydro-Meteorological Forecasting Station. This inundation map is no longer accurate because there have been many infrastructure changes since the map was created.<br>Duy Xuyen: the district did not have an inundation map. The district had flood column marks and recorded disastrous flood events. |

| | |
|---|---|
| | Hoi An: the district had an inundation flood map from the project "GIS technology application for flood prevention map for Quang Nam province", developed by the Quang Nam Hydro-Meteorological Forecasting Station. |
| **Commune** | Six of the twenty-three communes had a hand-drawn inundation map from the CBDRM programs (for an example, see Fig. 5). |

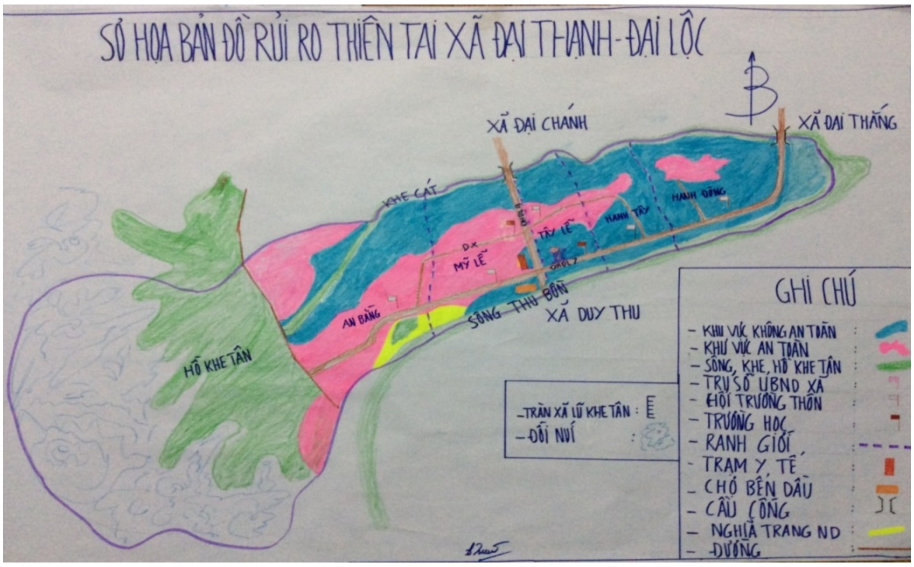


***Figure 9-5**: A flood risk map drawn by residents in Dai Thanh commune under the CBDRM program (Dai Thanh commune 2016)*

The hierarchical institutional levels only issued directives; they did not carry out studies on FRM. The provincial and district budgets did not provide grants for research or to build flood-risk maps. Several of the available flood-risk maps (**Table 9-1**) were received from external projects, and many of them were created long ago and need updating to respond to local FRM activities.

Many of the programs and projects listed in **Table 9-1**, and other studies such as doctoral theses (Ho 2013, Chau 2014), were implemented to develop inundation maps for Quang Nam. They should be summarised, synthesised and systematised to build a comprehensive database for further studies, and to spread information to districts, communes, and communities. This would help to utilise existing resources and provide a consolidated database for further studies.

### *9.5.2 FRM activities*

As discussed previously, FRM activities can be considered by incorporating mitigation, preparedness, response, and recovery (**Figure 9-3**). The success of preparedness and mitigation measures significantly depends on the participation of local communities (Jha et al. 2012). However, following the top-down perspective as in **Figure 9-2**, FRM activities at local levels are planned without the involvement of affected communities or the cooperation of other stakeholders such as researchers, experts, and scientists.

The hierarchical institutional structure at local scales includes province, district and commune; although management is from top to bottom, reporting is from bottom to top. The main preparedness activities of Steering Committees for Natural Disaster Prevention and Control at local scales were to hold meetings to review FRM activities of the last year and prepare implementation plans for the current year. These meetings were organised annually from May to August at commune, district, and provincial levels, and were formalities in the political system. The attendees were the leaders of departments or divisions in the political system, so there was no discussion or opinion in the meetings. See **Figure 9-6** for an example of such a meeting, held in the Dai Loc district to review disaster prevention and control activities in 2015, and propose orientations and tasks for 2016.


***Figure 9-6****: 2016 summary meeting of Dai Loc district Steering Committee for Natural Disaster Prevention and Control and Search and Rescue (source: author)*

Based on the responses about specific FRM activities at the three institutional levels, we summarised four main observations. First, FRM activities were focused on a reactive approach with response and recovery. Second, the involvement in mitigation and preparedness was primarily on preparing the annual action plans and storing food for flood events. Third, the mitigation and preparedness activities were primarily based on the experience of local staff, and lacked appropriate research from the steering committees. Fourth, responses mainly focused on activating the action plans.

The response below is typical of the responses received:

*In the commune, mitigation activities are the organisation of annual summary meetings and the preparation of annual action plans; preparedness activities are the food storage for flood events, and the preparation of boats for rescue; response activities are the implementation of the "four on-the-spot" motto including command on-the-spot, workforce on-the-spot, means and supplies on-the-spot, and* *logistics on-the-spot; recovery activities are the quick reports on damages to district level, and the mobilisation of commune staff to support residents in recovery. (Commune 1 of District 1; note: the motto is stipulated in the Law on disaster management)*

FRM activities at provincial and district levels focused on directive roles such as monitoring and reviewing the FRM activities of lower levels, managing dykes and embankment reinforcement, and monitoring irrigation structures; there was a lack of focus on studies. FRM activities at the commune level focused on response (emergency situation) and recovery. The only mitigation activities were the preparation of annual plans for disaster prevention and control. Preparedness activities included some material for first aid and some food storage for flood events, and annual summary meetings (**Figure 9-6**). Recovery was mainly based on the funding allocation from the district and provincial levels.

Although the decision-making process at provincial, district and commune levels followed a top-down approach as outlined in the institutional framework (**Figure 9-2**), FRM action plans were prepared using a bottom-up approach. FRM action plans were developed annually by all levels. First, administrative staff at the commune level prepared the action plans, which were submitted to the district level. Finally, the provincial steering committee synthesised the action plans from districts to provide an action plan at the provincial level. The action plans were prepared based on the experience of staff working in the political system and the characteristics of each locality, rather than relying on robust research; therefore, they were largely administrative documents.

The content of these action plans was primarily a list of FRM activities and stakeholders' involvement, rather than actions based on research and practice. Only three districts had specific action plans based on their unique characteristics (**Table 9-2**). Dai Loc district had an evacuation plan since this district is the most flood-prone area of the low-lying delta at the intersection of Vu Gia river and Thu Bon river. Duy Xuyen, which has a low-lying coastal area in Duy Hai commune, had a guideline plan for safe mooring and avoiding storms for boats and vessels. Hoi An, a low-lying area and an old city, had a guideline plan for tourists and foreign visitors dealing with storms. A mechanism is needed to monitor and evaluate the implementation of these action plans.

***Table 9-2*** *Summary of specific action plans unique to characteristics of Dai Loc, Duy Xuyen and Hoi An districts*

| District | Summary of specific action plans |
|---|---|
| **Dai Loc** | General evacuation plan in Dai Loc district, as follows:<br>• If having floods, households in weak houses are moved to strong houses (e.g., concrete roofs) in the same village. Households in landslide risk areas are relocated to safe houses in the same village. The evacuation plan establishes alarm levels (1, 2 and 3).<br>• If flooding exceeds alarm levels, residents are evacuated to shelters, commune offices and schools.<br>• Police, military, and militia of communes are assigned to evacuate people.<br>• Department of Labor, Invalids and Social Affairs of communes are assigned to store food and drinking water for evacuation.<br>• Commune clinics are assigned to prepare essential medicine for evacuation. |
| **Duy Xuyen** | A guideline plan for safe mooring and avoiding storms for boats and vessels in Duy Xuyen district, as follows:<br>• In the case of mooring on the shore: anchoring the driving front towards the coast; mooring to piles and dropping two more anchors at the front boat; up to three adjacent anchored boats; and requiring an anti-shock buffer and bonding wire between boats.<br>• In the case of mooring outside the anchorage:<br>Anchoring a boat alone, isolating from other ships, and being away from cliffs and other obstacles.<br>Selecting the lee of the area and loading boats with bags of sand or clay.<br>Dropping one or two anchors in front of a boat, anchoring rope length by five to seven times of depth, so that when the anchor is stuck to the bottom, the boat can turn downwind and return without collisions. |

| | |
|---|---|
| **Hoi An** | A guideline plan for tourists and foreign visitors dealing with storms in Hoi An city, as follows:<br>• Department of Tourism and Commerce is responsible for directing accommodation agents in the city. Accommodation agents must have plans for disaster prevention and control and ensure the safety of tourists. The plans focus on evacuating tourists from dangerous areas.<br>• Evacuation time: at least ten hours before a storm occurs, or when flood water level exceeds the alarm level 3 of 0.5 m. When a storm or flood event occurs, forced evacuation is applied for all tourists in accommodation in floodplain and coastal areas.<br>• Evacuation locations: accommodation agents must arrange their own systems, the city authority will support in case of no organised location.<br>• Evacuation facilities: accommodation agents are responsible for these.<br>When storms or floods occur, transportation of tourists is prohibited, especially in flooded areas. In emergencies, all vehicle owners and visitors must wear life jackets and follow prescribed routes. |

FRM activities in Vietnam lack a proactive approach. The high death toll and economic losses (**Figure 9-1**) reflect the passive response of populations and managers in flood events. FRM activities at local levels, therefore, should focus mitigation and preparedness activities prior to the occurrence of floods.

### *9.5.3 Stakeholders' involvement*

Actual and potential stakeholders include local people, government agencies, local authorities, nongovernment organisations, media, scientists and academia (Kootval et al. 2005, Mojtahedi and Oo 2014). Flood-prone communities are key stakeholders, and at the centre of all FRM activities (WMO 2006b). The whole political system is mobilised to work in the steering committees as in the institutional framework in **Figure 9-2**. The level of participation of stakeholders varied according to the particular institutional framework. Although stakeholders' involvement was mentioned in the action plans and legal documents, there was no concrete intervention. At local levels, including provincial, district and commune levels, stakeholders were all departments and organisations in the governmental system, as captured in the following response:

*All administrative agencies in the district are involved as members of the Steering Committees for Natural Disaster Prevention and Control, such as People's Committees; Department of Agriculture and Rural Development; Department of Economy and Infrastructure; Department of Labour, Invalids and Social Affairs; military; police; healthcare sector; electricity; post; telecommunication; radio; and television. The involvement was specified in detail in the annual action plans of disaster prevention and control of the districts. (District 1)*

Although all forces in the political system were mobilised, there is still a lack of involvement of two critical stakeholder groups in FRM activities: researchers, experts, and scientists in the FRM steering committees from national level (**Figure 9-2**) to local levels; and public participation at local scales. We only discovered via interviews that the communes that implemented the CBDRM program had public meetings in their villages to collect opinions for an action plan and hand-drawn flood-risk maps (**Figure 9-5**).

### *9.5.4 Budget allocations*

Vietnam has been applying the natural hazards funding mobilisation for all Vietnamese organisations, households, individuals and foreign agencies since 1997, with Decree 50/CB regarding regulations on the establishment and operation of funds for flood prevention and control. Decree 94/2014/ND-CP has replaced Decree 50/CP, and came into effect in December 2014. This decree regulates the establishment and management of natural disaster prevention and control funds; its scope of application covers all practising financial organisations and Vietnamese citizens.

Respondents at the commune level all confirmed processes for funding mobilisation as in Decree 94/2014/ND-CP. First, communes collect the fund from residents and organisations at their localities. This fund is then submitted to district level, after which the provincial steering committee collects the funds from districts. According to Decree 94/2014/ND-CP, between 3% and 5% of the total collected is paid to the collectors at the commune level. Of the remaining funds, 40% is allocated to district level and 60% to provincial level.

Currently, there is no insurance program for the impacts of natural hazards in Vietnam. Compensation for individuals or households suffering from natural hazards is allocated from higher levels to lower ones (i.e., provincial level allocates to district level, and then district level allocates to commune level). All respondents at commune and district level commented about the shortage of funds, and that the limited resources are the most prominent difficulties in implementing FRM activities; comments included the following:

> *The local budget is mainly used for recovery activities and some stockpiling food. The allocated budget from district level is very minimal. The commune has to deduct a part of the commune fund for agriculture for FRM activities. A large proportion of the fund is based on mobilisation from charities and benefactors. (Commune 5 of District 1)*
>
> *The major difficulty is the lack of funds to equip the means for rescue. The district budget is not enough for other disaster prevention activities; in fact, it is mainly used for recovery activities only. (District 3)*
>
> *The main difficulty is that the recovery often requires substantial funding, while the local budget is limited. Therefore, the local budget only supports a small part for affected residents to overcome impacts. (Commune 3 of District 3)*

The limitation of financial resources is one of the possible hindrances in initiating and maintaining the participatory process (WMO 2006b). The disaster prevention fund is currently mobilised annually from individuals and organisations in Vietnam, as prescribed in Decree 94/2014/ND-CP. The total value of this fund for the whole country is not available, but it must be a large amount given the figures from some provinces (available at http://phongchongthientai.vn/t-t/quy-pctt/-c46.html). For example, the sum collected from independent practicing financial organisations in Ho Chi Minh city in 2016 was VND342 billion (US$16.28 million); total funds collected in Tra Vinh province in 2015 was VND4.7 billion (US$224,840); total funds collected in Dong Nai province in 2016 was VND41.7 billion (US$1.99 million); and total funds collected in Binh Duong province in 2015 was VND20.79 billion (US$1.0 million). Also, Vietnam has other funding sources from the World Bank (WB), international aid organisations, and domestic organisations for disaster risk reduction. For example, WB provided loans valued at US$150 million for disaster risk reduction projects P073361 and P119684 from 2002 to 2010; and US$5.96 million for project Cr.4114-VN from 2006 to 2011. Vietnam is also one of the top recipients of disaster-risk reduction funding from international donors, with a total of US$303.81 million for 135 projects in 20 years from 1991 to 2010 (Kellett and Caravani 2013).

Despite these levels of funding, all respondents at the commune level commented on the difficulties regarding limited funds to implement FRM activities. This raises a requirement for a more efficient mechanism to manage the funds' allocation and investment, to ensure transparency and accountability, and maximise effectiveness. There should be an independent organisation, which is not in the government system, to monitor and evaluate the implementation. More funds are needed for proactive approaches (mitigation and preparedness activities).

### *9.5.5 Impacts of cascaded hydropower projects*

A region with densely cascaded dams would face a relatively higher risk (Luu et al. 2017), particularly in a case where a multi-reservoirs operation procedure is not correctly followed. There are nine large hydropower plants with an installed capacity greater than 60 MW and 33 small and medium hydropower plants with a capacity less than 60 MW on the Vu Gia-Thu Bon river system in Quang Nam province alone (Luu et al. 2015b). Sixteen of the twenty-two respondents from commune level and three of the four respondents from district level commented that the discharge of the cascaded hydropower reservoirs on Vu Gia-Thu Bon river basin in previous years could have caused adverse flooding impacts to downstream communities. They also agreed that the reservoirs could be effective for flood control when the flood discharges of reservoirs are properly operated following a multi-reservoirs operation procedure. These are some typical comments:

> *The commune authorities do not know very well about the cascaded hydropower reservoirs on the Vu Gia-Thu Bon river system. However, the development plans of these projects are not linked to disaster prevention plans of downstream localities in general, including our commune. Over the past few years, in rainy seasons, these projects discharged large amounts of water into downstream rivers without planning and timely notifications, causing serious damage to farmers in many aspects. (Commune 4 of District 2)*
>
> *The reservoirs begin to store water at the beginning of a rainy season and help to control flood peaks for downstream areas. However, when the reservoirs are full of water, and heavy rain occurs, if they discharge water at the same time, they will cause deep flooding for downstream areas. The development plans of these projects were linked to the disaster management action plan of the district. (District 1)*

Considering the dense hydropower cascades on Vu Gia-Thu Bon river basin, each reservoir must comply strictly with the reservoir operation procedure for the whole system. The proper operation of cascaded hydropower reservoirs requires the enhancement of meteorological forecasting accuracy, close collaboration between forecasters and hydropower operators, and monitoring by local authorities. These reservoir dams should have monitoring equipment to provide data on reservoir water levels and discharges. These data would be used to develop an effective operation procedure for the whole river system.

### *9.5.6 CBDRM programs*

Increasing awareness of disaster risk for vulnerable groups is a critical component of a risk reduction campaign (Coppola 2015a). FRM has shown effectiveness in preparing and planning responses of communities to emergencies (WMO 2006b). Preparing communities to respond to disasters is a key to saving lives (UNISDR 2015b). Several CBDRM programs have been carried out in some communes, including CBDRM of program 1002 of the Vietnamese government; and CBDRM disability inclusive from German Humanitarian Assistance and Malteser International organisations.

CBDRM of program 1002 was approved in 2014 by the Ministry of Agriculture and Rural Development under the Vietnamese government. The program focused on strengthening the implementation of disaster management activities in communities, with priority given to vulnerable areas. The program aimed to cover over 3000 communes, 50% of the communes in Vietnam, with the implementation plan from 2014 to 2020. The required budget for the program was VND988.7 billion (equivalent to US$50 million). The budget sources were identified, comprising 55% of government budget, 5% of people’s contribution, and 40% of official development assistance from foreign governments and international organisations. Until September 2016, this program was only implemented in Dai Loc district, which is the most vulnerable district to flood risk in Quang Nam province. Six of eighteen communes in Dai Loc district were implementing the CBDRM (Dai Tan, Dai Thanh, Dai Chanh, Dai Phong, Dai Minh and Dai Cuong). The CBDRM program was enforced by the Red Cross Quang Nam province directly to the commune level.

Besides the CBDRM program of the Vietnamese government, CBDRM disability inclusive program from German Humanitarian Assistance and Malteser International organisations was implemented in six communes of three districts in Quang Nam province (Duy Thu, Duy Thanh, Dien Tho, Dien Minh, Dai Lanh and Dai Hong communes). Several other programs funded by NGOs were being implemented at the commune level in Quang Nam province, such as the Green Shield project from Catholic Relief Services of the United States; and a project on raising the capacity of students and coastal residents to minimise disaster risks, funded by SEEDS-ASIA of Japan.

The respondents from the communes that implemented a CBDRM program all confirmed that the programs were beneficial and necessary for their localities. The programs provided support to: (1) raise the awareness of residents on disaster prevention with the organisation of rehearsals; (2) enhance the capacity of staff with training courses on disaster management; and (3) provide more equipment and materials for first aid, and search and rescue activities. For example, after training from CBDRM programs, the members of commune steering committees had enhanced skills on first aid rescue, lifesaving, and evacuation to better support people in disasters. Equipment and materials for first aid, research, and rescue activities were sponsored, including life jackets, life-saving ropes, medical kits, portable loudspeakers, and rescue boats. Some typical comments were as follows:

*The CBDRM program is being implemented in the commune. Commune officials have been trained twice on the implementation of the program. The program equipped some facilities and tools to support FRM activities such as boats for rescue, office computers, and storm shelters. Residents can access information relating FRM and see benefits from the program; they are very supportive of the program. (Commune 5 of District 1 with CBDRM of the program 1002)*

*The project has practically supported the commune on FRM activities, such as providing equipment and material for first aid, and search and rescue activities, enhancing staff capacity for disaster response, and raising people's awareness on FRM. (Commune 1 of District 3 with CBDRM disability inclusive program)*

*The implementation of this program was very good for the commune; it helped to raise people's awareness of disaster prevention. The locality was well-involved in implementation of the program, and the results were reported directly to Catholic Relief Services organisation. (Commune 2 of District 4 with Green Shield project)*

The programs aimed toward community-based involvement proved their effectiveness. CBDRM programs raised public awareness of flood risk and increased the ability to cope with natural disasters, via public meetings and rehearsals. They also enhanced disaster management capacities for staff. The positive results from CBDRM programs consolidated preparedness activities at the grass-roots level. Corruption challenges in Vietnam often keep funds away from programs and their potential beneficiaries (Give2Asia 2014). It is recommended that programs from NGOs, governments, international aid, and domestic organisations should be implemented at the grass-roots level.

### *9.5.7 Staff capacity*

All interviewees commented that staff on their FRM steering committees worked on a part-time basis, had no additional allowance, and undertook the role as a duty in combination with their other job duties in the government agencies. The standing agencies and number of members in the steering committees at provincial, districts and commune levels are as follows:

- At the provincial level, the standing agency is the Department of Water Resources and the committee comprises 15 members.
- At the district level, the standing agency is the Department of Agriculture or the Department of Economy, and the committee comprises about 30 to 53 members.
- At the commune level, the standing agency is the Commune People's Committee, and the committee comprises about 20 to 50 members. A commune consists of villages, and the heads of villages are also recruited as members of the commune steering committees.

The staff in the steering committees at all levels were temporary, and often changed every four years or less when they were assigned or promoted to other positions in the political system. The respondents provided two recommendations about staff capacity. First, the staff should have an additional allowance for working in the FRM activities, especially those staff working on research and rescue tasks with much higher risk. Second, at least one specialised staff member should work as a paid full-time position on steering committees in the most affected localities; the staff would synthesise the annual data and fully understand the specific situations at their localities over the years. Some common comments are as follows:

*It is needed to have a specific policy for staff working in the steering committees. It is necessary to have specialised staff working in steering committees from national to local levels, who are assigned to a full-time job. (District 3)*

*The staff working on FRM activities should receive allowances for the part-time basis since they often face many risks in response and rescue activities. It is necessary to have specialised and full-time staff working in the steering committees. (Commune 4 of District 1)*

Staff capacity in FRM committees in Vietnam still requires the development of technical skills such as project management and financial planning (UNDP 2015). Local governments were instrumental in implementing FRM activities. Decision makers in FRM steering committees were government officials. They worked on a part-time basis with no additional allowance, and with little accountability in FRM activities. They had a full understanding of specific situations in their localities, but they did not possess expertise in FRM management.

## 9.6 Conclusion and Recommendations

This study presented an investigation on FRM activities at local scales, along with the legal and institutional frameworks and discussions about gaps in practice and policy. First, we argued that the activities of steering committees of FRM be aimed at directing administrative management, and lack participation of qualified experts, researchers, and scientists. Second, our study investigated FRM activities at commune, district and provincial levels. We showed that FRM activities at local levels are implemented according to the hierarchical structure of the political system, which highlights the responsibilities of various government agencies. Third, following the empirical evidence, we identified and analysed gaps in FRM activities at local scales, which are the basis for the following recommendations:

1. The participation of experts, researchers, and scientists is vital in decision-making processes, so they should participate in FRM steering committees.

2. A shift towards a proactive approach, including mitigation and preparedness activities, needs to be emphasised because of its effectiveness in minimising damages to people and property.

3. The commune level has the best understanding of local conditions; therefore it is necessary to empower this level in planning and decision-making in FRM. This is one of the solutions to reducing the cumbersome nature of FRM activities.

4. FRM activities at local scales in Vietnam lack public participation, so the establishment of communication between communities, authorities, and agencies should be integrated into FRM activities in the future.

5. The staff in flood-prone localities should be assigned to a specific position in the steering committees, and this should be a paid full-time position.

# Chapter 10 Discussion

## 10.1 Introduction

This chapter reflects on the key themes emerging from the study and on the five papers, presented as chapters 5-9, while linking back to the literature and considering the practical implications of the research findings.

## 10.2 Policy environment in Vietnam

Vietnam faces extensive flood impacts periodically. The country sustains heavy losses in terms of human life, and damages to housing, agriculture, water resources, and transportation. However, flood risk in Vietnam is not widely understood beyond a very hazard focused conceptualisation, which often neglects to consider human vulnerability (Tran et al. 2008). FRM is gradually shifting from a traditional approach based on design standards to a risk-based decision-making approach (Sayers et al. 2002a). Governance plays a key role in this transition (Ward et al. 2013). Although the Vietnamese government issues many legal documents related to disaster management, most of them are fragmented, overlapping and repetitive (Chau et al. 2014b).

The research findings reported in the fifth paper (Chapter 9) (Luu et al. 2018b) revealed that the institutional framework for FRM is a centralised bureaucratic administration, which can reduce the effectiveness of the FRM activities. The organisational chart (**Figure 9-2**) shows that the public administration at all the levels from the central to the local levels (provincial, district and commune levels) is entirely responsible for disaster management activities. There is a big gap between policy and reality in disaster management in Vietnam (Tran and Shaw 2007).

Several FRM activities demonstrate a heavy focus on propaganda and bureaucratic measures, and have a very small practical effect. For example, when the storm occurs the steering committees always hastily convene meetings, announces, discusses, plans, and commands, and most importantly sends out urgent dispatches. The main contents of urgent dispatches include the information of storms, the rain and flood situation in rivers, and the tasks of localities although all the information of storms is disseminated via newspapers, radio and television. There is no new information in these urgent dispatches, and the meetings only play an administrative role. After storms, the government issues telegraphs on the damage and duties of 14 ministries although all the information of the damages is available on the media, and the duties are very general such as finding missing persons, helping the victims, repairing houses, restoring traffic, electricity, environmental sanitation and food supply.

The heads of committees, who have directives for the FRM activities, do not have the knowledge and experience in FRM, nor the best understanding of the local conditions to be able to make specific decisions. When storms occur, the Deputy Prime Minister always goes to the most affected area with many government officials, and reporters and photographers. For example, to respond to the typhoon Doksuri on 13-14 September 2017 (http://phongchongthientai.vn), Deputy Prime Minister, Trinh Dinh Dung, directed the response activities, and Minister of Ministry of Agriculture and Rural Development, Nguyen Xuan Cuong, checked the response activities on 15$^{th}$ September. After that Prime Minister, Nguyen Xuan Phuc, directed the recovery activities on 16$^{th}$ September. In this case, the decision-makers, the government officials, only said some general sentences or a few slogans, while filming and taking photos. Such bureaucratic top-down decision making inhibits local mitigation capacities.

The Law on Natural Disaster Prevention and Control No.33/2013/QH13 stipulated specific disaster management activities of the prevention, response and recovery of consequences. However, after each flood or storm event, which occurs every year and in many localities, it lacks review and evaluation of the specific effectiveness of disaster preparedness, response and mitigation measures.

The interview results reported in the fifth paper (Luu et al. 2018b) showed that the steering committees at the local levels annually prepare disaster preparedness plans for their localities, but all of them are limited to administrative documents and are based on the experience of government officials. All levels of governmental administration have been mobilised to participate in disaster management activities. However, the presence of public administration is not sufficient as decision-makers, who are the government officials, do not have expertise in disaster management. There should be the participation of experts, researchers and scientists working in these committees as decision-makers. There is also a need for investment in research, mainly focusing on proactive approaches, to improve the effectiveness in minimising damage to people and property. Decisions must be made on the basic of the combination of the latest scientific knowledge and a deep sensitivity to local circumstances.

The interviewees (in Chapter 9) commented that specific inundation maps are not available at the district and commune levels. Further, six of the twenty-two communes had hand-drawn inundation maps. That is, only communes, which implemented Community-Based Disaster Risk Management programs, had hand-drawn inundation maps. The decision-making is based on the experiences of government officials at the local levels. Because of the lack of the local flood risk maps, this research aimed to develop a model to assess the flood risk at the local scales by using the available data on hazard, exposure and vulnerability. The output model and results are presented in Chapter 7 (Luu et al. 2018a) and Chapter 8 (Luu and von Meding 2018b).

It is important to have an effective mechanism to ensure the transparency, accountability and efficiency of FRM investment. Funding for disaster management activities is collected according to Decision 94/2014/ND-CP, together with a number of projects funded by the World Bank and the external funding sources. Disaster risk reduction showed that Vietnam is one of the countries receiving the most funding and disaster risk reduction loans in the world (Kellett and Caravani 2013). However, interviewees at communes and districts commented that the shortage of funds is the most prominent difficulties in implementing FRM activities (Luu et al. 2018b).

The Vietnamese economy relies heavily on agriculture with small-scale farms, so weather extremes seriously affect the community's livelihoods in this sector. The decision-making process in FRM of Vietnam is based on a top-down approach with the centralised government’s roles at the national and provincial levels. FRM in Vietnam lacks proper studies, and the management is administrative in nature. This leads to the lack of professionalism and accountability in FRM activities.

## 10.3 Best practice FRM is local

The first paper (Chapter 5) evaluated the flood risk at the national scale by using the national disaster loss database and the MCDM method. The result showed that Quang Nam province is a particularly high flood risk area in Vietnam. Therefore this study selected Quang Nam as a case study for flood risk assessment and FRM at the local scales.

Chapter 7 (Luu et al. 2018a) and Chapter 8 (Luu and von Meding 2018b) provided the flood hazard assessment map and flood risk assessment map for Quang Nam province. The specific flood risk maps at the local level would contribute a good reference for decision-makers to implement FRM activities.

Chapter 9 (Luu et al. 2018b) analysed the institutional and legal frameworks for FRM. The top-down approach in FRM results in passive responses from the local (provincial, district and commune) levels. Following this approach, the local levels have to wait for the directive of the upper levels. This leads to the cumbersome procedures in FRM, especially response activities.

The role and actions of the local government are particularly critical for disaster risk reduction (Col 2007). The commune and village organisations are active in the response activities during flood event (Tran et al. 2008). As the commune level has a better understanding of their localities, empowering them in planning and decision-making is essential for the sustainability of the measures. The local committees should make the specific decisions, and the central committee should only monitor, or can directly receive the request and move the force from other places to support. The national steering committee needs to cooperate and collaborate with the local levels to bridge the gap between theory and practice (UNISDR 2015b). The establishment of communication among community, authorities and agencies should be in the integrated flood risk management framework in the future.

The interview survey result (Chapter 9) showed that the FRM action plans are prepared on the basic of staff experience and the characteristics of the localities instead of proper studies. The action plans just list out the FRM activities and the stakeholders' involvement on paper, and their roles are administrative. Therefore, a mechanism to evaluate the effectiveness of these plans in practice is needed.

The CBDRM programs are implemented at the commune level; however, the interviewee at the provincial level does not have the details of the communes. An interviewee from District 1 said that no CBDRM was implemented in the district. The upper level did not have sufficient information for management activities. The reports are from the bottom to the top levels although the management hierarchy follows a top-down approach. This demonstrates the cumbersome nature of FRM activities.

All the interviewees from communes with CBDRM programs confirmed that the implementation of the programs is very good and necessary for their localities. The programs helped to raise the awareness of residents on disaster prevention via rehearsals, to enhance the capacity of the staff via training courses on disaster management and to support more equipment and materials for first aid, search and rescue activities. For example, after completing the training program that is a part of the CBDRM programs the members in the commune steering committees have enhanced first aid rescue, lifesaving and evacuation skills to better support people in disasters. The equipment and materials for the first aid and research and rescue activities are sponsored including life jackets, life savers, lifesaving ropes, medical kits, portable loudspeakers, and rescue boats. The programs via public meetings and rehearsals enhanced the public awareness and increased the ability of communities to cope with natural hazards. The community-based programs proved the effectiveness of and raised the hazards awareness.

An adequate approach is to develop FRM activities by incorporating mitigation, preparedness, response and recovery. The success of the preparedness and mitigation measures significantly depends on the participation of local communities (Jha et al. 2012). However, following the top-down approach, FRM activities are planned without the involvement of the affected communities and the cooperation of other stakeholders such as researchers, experts, and scientist.

Flood-prone communities are the key stakeholders and are at the centre of all FRM activities (WMO 2006b). Communities have wisdom and indigenous knowledge to cope with natural hazards (Tran et al. 2009). Although the communities' involvement is increasingly recognised to reduce disaster risks (van Aalst et al., Bollin and Hidajat 2006), FRM activities at the local scales in Vietnam lack public participation. Therefore, it is essential to establish more robust communication channels between communities, authorities, and agencies to support the FRM legal framework and FRM activities.

The results of this study (Chapters 7, 8 and 9) provided further support for the paradigm of empowering local governments and communities involved in FRM.

## 10.4 Vulnerability define FRM

Vietnam had approximately 95 million people in 2016 and 71.4% of the population was exposed to disaster risks (Davis 2014). The high level of exposure is attributed to the differential vulnerability of the  communities and the insufficient capacity to cope with the potential adverse impacts of hazards (Esnard and Sapat 2014). Floods and storms caused 14,927 dead and missing people, and economic loss equivalent to 1% of the GDP in the years 1989-2015.

Floods and storms have caused considerable damage to houses, crops and infrastructures. The economy of Vietnam is heavily reliant on agriculture, and appropriately 70% of the population lives in rural areas. Therefore, a series of floods cause havoc in poor communities. Losing crops and homes in floods and storms keeps many rural Vietnamese trapped in a cycle of poverty. Flood fatalities are unacceptably high. Therefore, FRM should be emphasised as a proactive approach to mitigation and preparedness activities for flood events. The government should focus the investment on holistic risk management strategies which requires accurate risk assessments (Jongman 2018).

The poor are more likely to be affected by disasters (Winsemius et al. 2015), and poverty is often seen as a structural cause of vulnerability. Poverty and vulnerability to floods are closely related and mutually reinforced in Vietnam (Tran et al. 2009). The poverty rate criterion is therefore included in the flood vulnerability analysis. The fourth paper (Luu and von Meding 2018a) combined the flood exposure criteria (population density, land use categories, and distance to rivers), flood vulnerability (poverty rate, number of doctors, and road density) and flood hazard (flood depth and duration) in assessing the flood risk for a local area, Quang Nam province.

The analysis of the FRM institutional framework in the fifth paper Luu et al. (2018b) showed that the FRM policy focuses on hazards rather than vulnerability. In addition, an integration of vulnerability data in FRM in Vietnam is required. The data are often fragmented and held by many agencies, which often leads to difficulties in collecting data for flood risk assessments.

FRM is a continuing cycle of assessing, implementing and maintaining the FRM measures to achieve acceptable risks (Tran et al. 2008). The spatial flood risk assessment model from this study should be applied to the updated data (flood hazard, exposure and vulnerability) and in a series of years to predict the flood risk trend for the area. The FRM plans and activities should also be updated following the updated flood risk assessment maps.

## 10.5 Better models/data can help decision-makers

We need to increase the scientific foundation of FRM (UNISDR 2015b). Flood risk assessments should be undertaken or utilised to support the decision-making process (Tran et al. 2008). The development of methods for rapidly mapping and assessing flood risks is essential for effective emergency response and flood risk mitigation. The research outcomes include (1) flood risk assessment at the national level, (2) a holistic flood risk assessment model for a local area using spatial multi-criteria decision analysis, and (3) an investigation of FRM activities at the local levels. The research results provided visualised flood risk assessments at both the national and the local levels and investigated the FRM activities at local scales along with the legal and institutional frameworks.

In this study, Vietnam's national disaster database is sourced, collected and analysed to examine the flood risk of the regions and provinces in Vietnam using multi-criteria decision techniques and statistical analysis. The flood damage modelling depends on the relevance of the flood damages and the available national disaster database, whose accuracy depends on the measurement methodologies, loss indicators and data documentation procedures (Simpson et al. 2014). Therefore, to improve the quality of flood risk assessment, we require studies on a standard for flood damage data collection, which will consider both direct and indirect damages, and tangible and intangible costs. In addition, to develop predictive models for flood fatalities in Vietnam, we require more detailed data of flood hazards, exposure characteristics, demographic characteristics (age and gender) and behaviour of victims.

At the local levels, there are several difficulties in data collection (hazard, exposure and vulnerability) for the assessments. First, the data are often fragmented and held by many agencies. Second, the lower levels must wait for the direction of the upper levels for sharing data because of the top-down decision-making mechanism. Third, the data for the previous periods are often not available as the newly assigned staff are not on duty for those periods. (The staff in the steering committees at all the levels were temporary, and often changed every four years or less when they were assigned or promoted to other positions in the political system).

This study developed a new assessment tool to assess the flood risk at the national scale by using the national disaster loss database in the first paper (Chapter 5), and developed a novel flood risk assessment model that can rapidly simulate a flood risk map at the local scale by using historical flood mark data in the third paper (Luu et al. 2018a) and the fourth paper (Luu and von Meding 2018a). The rank of the flood risk for the considered regions and provinces and a flood risk map on the national scale provide accessible risk information for decision makers and planners to classify the most at-risk areas and have implications for FRM in Vietnam. The flood risk assessment map at a local scale is crucial as it can support the decision-making process of the FRM activities.

The use of GIS in FRM decision-making in Vietnam is still limited (Chau 2014). This study developed a new flood risk assessment model that can easily and rapidly simulate a flood risk map by using historical flood marks, and exposure and vulnerability data. The flood risk mapping outputs from this study can support decision makers and planners to prepare FRM plans, and develop flood risk mitigation measures for the area. The maps are also invaluable tools for community communication. The information can be used to improve warning systems and procedures and to generate decisions related to evacuation and other response tasks.

The decision-making process in FRM should be based on a combination of the latest scientific knowledge with the state-of-art models, holistic frameworks, and a deep sensitivity to the local context. The research result, the spatial flood risk assessment model in the fourth paper (Luu and von Meding 2018a), provides a rapid flood risk mapping output by using historical flood mark data and flood exposure and vulnerability data. These data are available in other areas of Vietnam, and the assessment model can be easily replicated in the other provinces.

The flood risk assessment mapping tool is helpful for decision-makers at all levels, to determine the flood risk scores and have appropriate flood risk mitigation measures. Population growth and urban development increase vulnerability; therefore, it is essential to understand the spatial flood risk assessment, which can allow effective flood mitigation measures in the future. Simultaneously, the output model needs to be tested in practice, and the model should be improved and completed by using the updated data from the practice.

## 10.6 Practical implications

### *10.6.1 For practitioners*

1. Decision makers should utilise flood risk assessment maps for developing FRM action plans such as recognising high-risk areas, and setting priorities for flood mitigation measures.
2. Flood risk assessment maps are valuable tools for communication, so they can be used to develop warning systems and procedures and to generate decisions related to evacuation and other response tasks.

3. The spatial flood risk assessment model from this study should be applied to updated data (flood hazard, exposure and vulnerability) and in a series of years to predict the flood risk trend for the area.
4. Research results from programs and projects in the area should be summarised, synthesised and systematised to build a comprehensive database for application and further studies.
5. The establishment of communication between communities, authorities, and agencies should be integrated into FRM activities.

### *10.6.2 For policy makers*

1. It is necessary to develop a comprehensive disaster management framework, which considers empowering local governments and communities involved to improve the effectiveness of FRM activities.
2. Steering Committees for Natural Disaster Prevention and Control need to seek more participation of experts, researchers, and scientists in the decision-making processes.
3. FRM activities of Steering Committees should shift towards a more proactive approach, including mitigation and preparedness activities.
4. A mechanism must be instated to consistently monitor and evaluate the implementation of disaster risk management action plans.
5. The staff in flood-prone localities should be assigned to a specific position in the steering committees, and this should be a paid full-time position.

### *10.6.3 For communities*

1. Local communities should make clear demands for engagement and participation in risk decision-making.

2. All citizens should undertake to obtain knowledge (education and training) about the risks.
3. Communities should explore ways to create a culture of protection of fellow citizens.

# Chapter 11 Conclusion and recommendations

## 11.1 Meeting the objectives

This research presented a detailed view of the flood risk in Vietnam. We went beyond the historical loss statistics at the national level and collected data on flood hazards, exposure and vulnerability for a case study of the Quang Nam province.

First, we investigated the flood risk at the national scale by using Vietnam's national disaster database. A novel approach was proposed to rank the flood risk for the provinces and regions of Vietnam by using a combination of the multiple linear regression technique and the MCDM method. The result was then integrated into a GIS environment to produce a flood risk map for the provinces and regions in Vietnam.

Second, we developed a new flood risk assessment model that can rapidly simulate a flood risk map. The model was applied to assess the flood risk for the Quang Nam province and present the analysis on a GIS-based map, which combines historical flood marks with the exposure and vulnerability data in the assessment by using a spatial multi-criteria decision analysis. The new model can be updated with the data of the hazards, exposure and vulnerability for future flood events. The result was a comprehensive flood risk assessment map for the Quang Nam province, which can be utilised by planners and managers to develop flood risk mitigation measures.

Third, we investigated the FRM activities at the local scales, along with the legal and institutional frameworks and discussions on the gaps in practice and policy. The result showed that the FRM activities at the local levels in Vietnam are implemented according to the hierarchical structure of the political system and the responsibilities of various paramount government agencies, and that there is a lack of participation of the experts, researchers and scientists in the steering committees. A detailed analysis of the

FRM activities at the local levels has implications for future efforts to mitigate flooding in Vietnam.

Five research objectives were outlined in Chapter 1, and the following sections will explore the level to which the study has successfully achieved them.

### *11.1.1 Objective 1: Evaluation of flood risk at the national scale using multi-criteria decision-making analysis*

The first objective of this research was to evaluate the flood risk at the national level on the basis of Vietnam's national disaster database. The research approach was presented in Chapter 5; it is a novel approach to investigate the flood risk at the national level. The multiple linear regression - TOPSIS method was used to examine and rank the flood risk for the 8 regions and 63 provinces in Vietnam. A flood risk map was created on the basis of the TOPSIS ranking results. The results provided a detailed flood risk assessment on the national scale, which provided accessible risk information for decision makers and planners to classify the most at-risk areas, and had implications for the FRM in Vietnam.

Vietnam is often in the path of tropical depressions and storms forming in the East Sea. Severe storms are accompanied by strong winds, high waves, tides and heavy rainfall. High waves and tides threaten coastal areas, while prolonged torrential rainfall often causes serious flooding. Rapid population growth, industrial development and agricultural expansion have increased the flood risk, particularly in the riverine and coastal areas of Vietnam. The MADM-GIS approach in this study can support the FRM activities by providing flood risk assessment results and a visualised map. The results can provide a reference for planners, policy makers and researchers to build a holistic FRM framework for Vietnam. In addition, the approach of multiple linear regression–

TOPSIS and a GIS framework can be potentially applied to analyse disaster databases in other countries or regions, which are categorised on the basis of their attributes and recorded over an extended period.

### *11.1.2 Objective 2: Exploring the relative influence of flood damage attributes to fatalities and policy implications*

The results presented in Chapter 6 addressed the second research question and objective, and provided an insightful analysis of the flood fatalities in Vietnam for the years 1989–2015 on the basis of the national disaster database. Statistical learning techniques were used to determine the relative predictor importance. The results of the variable importance measures showed that the flood housing damage attribute had the highest significance with respect to the fatalities in Vietnam. The finding has implications for government policies on disaster risk reduction. The policies should give priority to housing improvements, flood shelter development and evacuation plan establishment in flood-prone areas for better flood risk adaptations. The machine learning approach can be applied to analyse the variable importance measures of flood damage attributes to fatalities using disaster databases, which are categorised by attributes and documented for an extended period at national and regional scales.

The machine learning approach is increasingly popular in scientific research and commerce with big data. To the best of our knowledge, this is the first time that a longitudinal investigation on the relative influence of the flood damage attributes on the flood fatalities is applied by using machine learning algorithms and a national disaster database. Our research has generated a more detailed view of the flood risk-related flood fatalities. The application of statistical learning techniques in this study could consolidate the approach of machine learning in FRM.

The finding reflects the reality of housing conditions in flood-prone areas in Vietnam. The houses in the rural area are mostly in poor conditions and single-storey high. The forces of storms can damage the houses, or the houses can get deeply flooded. In addition, single-storey houses are not safe for inhabitants in the case of high flood depth levels.

Possible measures to minimise the loss of life caused by floods need to be carefully considered. These measures should address the flood risk not only in the short term but also in the long term. The significant impact of the flood housing damage attribute on the fatalities indicates that we need to improve the housing quality in the flood-prone areas of Vietnam. The government policies on disaster risk reduction should give priority to support the poor to upgrade their houses for flood risk adaptation. The analysis may also provide a reference to decision makers in Vietnam to set priorities for FRM activities and to have appropriate resource allocations.

Flood casualties could also be remarkably reduced with appropriate evacuation plans (Coppola 2015f). The evacuation capability of communities in flood and storm events needs to be improved to minimise the damages caused by the disasters (Masuya et al. 2015, Liu et al. 2017). In the case of Vietnam, the housing factor has a significant influence on the flood casualties; therefore, the government policies on disaster risk reduction should also focus on the development of flood shelters in flood-affected areas. Flood risk assessments should be combined with population and housing data to support decision makers in establishing appropriate evacuation plans for at-risk locations.

### *11.1.3 Objective 3: Assessing flood hazard for Quang Nam province using flood marks and analytic hierarchy process approach*

This research approach addressed the third research question and objective, and proposed a method to assess flood hazards by using the flood mark data combined with the DMs' judgements. The assessment was integrated into a GIS framework to provide a flood hazard assessment map. The 2013 flood event in Quang Nam, Vietnam, was used as a case study. The model of DEM and the flood depth marks utilised generated a result that corresponds to the hydraulic model MIKE11-GIS developed by the Institute of Geography.

Flood duration has not been included in the flood hazard maps in previous research. An assessment that considers both the flood depth and duration factors could provide a more comprehensive perspective on the impacts of flood hazards. A multi-criteria flood hazard assessment and spatial analysis was introduced and applied for Quang Nam, Vietnam. This approach can be applied to spatial flood hazard assessment in areas with inadequate data for hydraulic modelling, and to generate a preliminary evaluation of flood hazards by using the flood mark data.

This approach analysed flood hazards in the local areas, and the findings can be useful in defining specific flood risk management plans for the Quang Nam province. The local flood hazard assessment map can serve as a tool for decision makers. The results can also be incorporated into a land use map to support land use planning decision-making.

### *11.1.4 Objective 4: Assessing flood risk for Quang Nam province using spatial multi-criteria decision analysis*

The results presented in Chapter 8 addressed the fourth research question and objective. The study developed the spatial multicriteria decision analysis approach to assess the hazard, exposure and vulnerability to floods jointly and to present the estimation on a GIS-based map. The applicability of this approach was demonstrated in a case study of

Quang Nam, Vietnam with the 2013 flood event. The local flood risk assessment map can support the proactive flood risk management activities at the local scale when it specifies the levels of flood risk areas. It can serve as the primary information for spatial planning, emergency planning and technical protection measures.

Floods and storms affect low-income communities disproportionately. The decision making of the FRM activities has to be based on the flood risk assessments. The local flood risk assessment map is essential as it can support decision makers in formulating the FRM policies and practices. A hydraulic modelling approach for creating flood hazard maps requires many input parameters and a considerable amount of observed data, such as updated river cross-sections and time series meteorological and streamflow data. These data are often not available for areas that lack hydrology stations, particularly in developing countries. This study used a spatial multi-criteria decision analysis to integrate the flood mark data (flood hazard data) with the flood exposure and vulnerability data into a flood risk assessment map for the Quang Nam province. The approach could be applied to the areas with scarce data. The final flood risk assessment map, which was developed from a combination of hazard, exposure and vulnerability maps, can enable policy makers and government departments to make judgments about setting priorities for flood mitigation works and provide potential support for the preparation of FRM plans. The map is also essential for communication about the local flood risk situation with the floodplain areas.

### *11.1.5 Objective 5: Investigating local practice in Quang Nam province for flood risk management activities*

The results presented in Chapter 9 addressed the fifth research question and objective, and presented an investigation on the FRM activities at the local levels, along with the legal and institutional frameworks and discussions about gaps in practice and policy. The decision-making process for disaster risk management in Vietnam is based on a centralised, top-down approach at the national and provincial levels. The highest level of the government alone makes the meaningful decisions. This implies the exclusion of the relevant subject experts. Not only are decisions made without the involvement of experts, but they are also made with insufficient or incomplete data about the disaster risk.

It is critical that experts, researchers and scientists be involved in the steering decision-making about the disaster risk in Vietnam. There must be a shift to a more proactive approach, focused on reducing risk by targeting systemic and chronic vulnerability. Decisions must be made on the basis of a combination of the latest scientific knowledge and a deep sensitivity to the local context.

First, it was argued that the activities of the steering committees of FRM are aimed at directing administrative management, and lack the participation of qualified experts, researchers and scientists. Second, we investigated the FRM activities at the commune, district and provincial levels. It was shown that the FRM activities at the local levels are implemented according to the hierarchical structure of the political system, which highlights the responsibilities of various government agencies. Third, following the empirical evidence, gaps in the FRM activities at the local levels were identified and analysed, which are the basis for the recommendations for future flood mitigation efforts in Vietnam.

## 11.2 Limitations of the research

This research presented a detailed view of the flood risk in Vietnam. We went beyond the historical loss statistics at the national level and collected data on the flood hazards, exposure and vulnerability for a case study of the Quang Nam province. The limitations of the research were as follows:

In the case of the first research objective, flood risk evaluation at the national level, the modelling depended on the relevance of the damages and the quality of the dataset. Any errors in the disaster damage data could be related to many factors such as measurement methodologies, loss indicators and data documentation procedures. These errors led to outliers and affected the linearity of the regression model of this study. The article has to accept these errors to generate the attributes' weights. These also led to a recommendation that a comprehensive procedure and standard for documenting the natural hazards' impacts for Vietnam should be developed and applied. To improve the flood risk assessment, studies on a standard for flood damage data collection, which consider both direct and indirect damages, and tangible and intangible costs, should be conducted.

In the case of the second research objective, analysing flood fatalities, this approach was limited to the analysis of the relative influence of the flood damage attributes to fatalities and was based on the available national database of Vietnam. The relative influence measures of the flood damage attributes on the flood fatalities may add essential information for government policies on FRM to mitigate the mortalities in future flood events. Future research should attempt to focus on developing predictive models and analysing the causes and circumstances of the flood fatalities in Vietnam, which requires more detailed data on flood hazards, exposure characteristics, demographic characteristics (age and gender) and behaviour of victims.

In the case of the third research objective, assessing the flood hazards for the Quang Nam province, the major limitation of this approach is associated with the drawback of the AHP pairwise comparisons. The pairwise comparisons were difficult for non-academic persons. The DMs in the FRM activities of this province were the staff of the local committees of Natural Disaster Prevention and Control and Search and Rescue. Although they were the most qualified DMs to participate in the study, they did not have expertise in this field as they were all local government officials. It was very difficult to recruit suitable DMs because of the onerous nature of this method. That only two DMs participated is another limitation of this approach, but it is within the acceptable shortcomings of other published journal articles.

In the case of the fourth research objective, the flood risk assessment map for the Quang Nam province, the limitation of this approach also refers to the AHP pairwise comparisons.

In the case of the fifth research objective, investigating the FRM activities of the local practice in the Quang Nam province, this study was limited to the understanding of the FRM activities at the local levels in the Quang Nam province from policy to practice. Therefore, we need to develop an integrated FRM framework for Vietnam. The detailed analysis of the FRM activities at the local level provides a background for the development of this framework in the future.

## 11.3 Recommendations for further research

While this study provides a flood risk analysis at the national level and a holistic flood risk assessment for the local level, it also offers some promising avenues for further research.

First, the study investigated the relative importance of various flood damage attributes in relation to the flood fatality attribute (in the second approach). The future studies can expand the research scope by determining the main variables or the causes of the flood fatalities in Vietnam and explore the correlation between these variables and the flood fatalities.

Second, the model for the flood risk assessment in the Quang Nam province used a real case study for a specific area using real data from the year 2013. A future study can extend to the data from other years and use the results from different years to verify the model.

Third, here, we presented a new approach to local flood risk assessment mapping, which combines historical flood marks with the exposure and vulnerability data. Future studies can expand the assessment by incorporating the damage data in monetary terms or considering the environmental damage.

# Appendix A. Questionnaire for AHP analysis

**1. Flood hazard**

**1.1 Flood hazard subcomponent**

Which is more important when assessing flood risk; depth or duration? Mark the scale near the more important one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flood depth** | | | | | | | | | | | | | | | | | | **Flood duration** |

**1.2 Flood depth (Criteria: Flood depth <0.5 m, 0.5–1.0 m, 1.0–2.0 m, 2.0–3.0 m, >3.0 m)**

Which depth is more dangerous when you compare the following pairs? Place the mark near the more dangerous one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.5–1.0 m** | | | | | | | | | | | | | | | | | | **<0.5 m** |
| **1.0–2.0 m** | | | | | | | | | | | | | | | | | | **<0.5 m** |
| **2.0-3.0 m** | | | | | | | | | | | | | | | | | | **<0.5 m** |
| **>3.0 m** | | | | | | | | | | | | | | | | | | **<0.5 m** |
| **1.0–2.0 m** | | | | | | | | | | | | | | | | | | **0.5–1.0 m** |
| **2.0-3.0 m** | | | | | | | | | | | | | | | | | | **0.5–1.0 m** |
| **>3.0 m** | | | | | | | | | | | | | | | | | | **0.5–1.0 m** |
| **2.0-3.0 m** | | | | | | | | | | | | | | | | | | **1.0–2.0 m** |
| **>3.0 m** | | | | | | | | | | | | | | | | | | **1.0–2.0 m** |
| **>3.0 m** | | | | | | | | | | | | | | | | | | **2.0-3.0 m** |

**1.3 Flood duration (Criteria: Flood duration < 1 day, 1-3 days, 3-5 days, >5 days)**

Between the following pairs, which is more dangerous for Flood Duration? Place the mark near the more dangerous one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-3 days** | | | | | | | | | | | | | | | | | | **<1 day** |

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3-5 days | | | | | | | | | | | | | | | | | | <1 day |
| > 5 days | | | | | | | | | | | | | | | | | | <1 day |
| 3-5 days | | | | | | | | | | | | | | | | | | 1-3 days |
| > 5 days | | | | | | | | | | | | | | | | | | 1-3 days |
| > 5 days | | | | | | | | | | | | | | | | | | 3-5 days |

**2. Flood exposure**

**2.1 Flood exposure subcomponent**

When comparing the following pairs of factors, which is more important in determining how serious Flood Exposure is? Place the mark near the more important one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Population density | | | | | | | | | | | | | | | | | | Distance to river |
| Population density | | | | | | | | | | | | | | | | | | Land-use |
| Distance to river | | | | | | | | | | | | | | | | | | Land-use |

**2.2 Population density (Criteria: Population density <500 persons, 500-1000 persons, 1000 - 2000 persons, 2000-4000 persons, >4000 persons)**

Compare the following population density pairs as to which is the more serious for flood exposure. Place the mark near the more serious one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500-1000 | | | | | | | | | | | | | | | | | | <500 |
| 1000-2000 | | | | | | | | | | | | | | | | | | <500 |
| 2000-4000 | | | | | | | | | | | | | | | | | | <500 |
| >4000 | | | | | | | | | | | | | | | | | | <500 |
| 1000-2000 | | | | | | | | | | | | | | | | | | 500-1000 |
| 2000-4000 | | | | | | | | | | | | | | | | | | 500-1000 |
| >4000 | | | | | | | | | | | | | | | | | | 500-1000 |
| 2000-4000 | | | | | | | | | | | | | | | | | | 1000-2000 |
| >4000 | | | | | | | | | | | | | | | | | | 1000-2000 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **>4000** | | | | | | | | | | | | | | | | | | **2000-4000** |

**2.3 Distance to river (km) (Criteria: Distance to river <1 km, 1-2 km, 2-3 km, 3-4 km, >4 km)**

Compare the pairs of distance to river as to which is the more serious for flood exposure. Place the mark near the more serious one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **<1 km** | | | | | | | | | | | | | | | | | | **1-2 km** |
| **<1 km** | | | | | | | | | | | | | | | | | | **2-3 km** |
| **<1 km** | | | | | | | | | | | | | | | | | | **3-4 km** |
| **<1 km** | | | | | | | | | | | | | | | | | | **>4 km** |
| **1-2 km** | | | | | | | | | | | | | | | | | | **2-3 km** |
| **1-2 km** | | | | | | | | | | | | | | | | | | **3-4 km** |
| **1-2 km** | | | | | | | | | | | | | | | | | | **>4 km** |
| **2-3 km** | | | | | | | | | | | | | | | | | | **3-4 km** |
| **2-3 km** | | | | | | | | | | | | | | | | | | **>4 km** |
| **3-4 km** | | | | | | | | | | | | | | | | | | **>4 km** |

**2.4 Land-use category**

Compare the pairs of Land-use category as to which is the more serious for flood exposure. Place the mark near the more serious one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Homestead and built-up** | | | | | | | | | | | | | | | | | | **Agricultural & aquacultural land** |
| **Homestead and built-up** | | | | | | | | | | | | | | | | | | **Forest/Vegetation** |
| **Homestead and built-up** | | | | | | | | | | | | | | | | | | **Water bodies** |
| **Agricultural & aquacultural land** | | | | | | | | | | | | | | | | | | **Forest/Vegetation** |
| **Agricultural and Aquacultural land** | | | | | | | | | | | | | | | | | | **Water bodies** |
| **Forest/Vegetation** | | | | | | | | | | | | | | | | | | **Water bodies** |

### 3. Flood vulnerability

### 3.1 Flood vulnerability subcomponent

Compare the following factors as to which is more important in determining Flood Vulnerability. Place the mark near the more important one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | | | | | | | | | | | | | | | | | | **Gender** |
| **Age** | | | | | | | | | | | | | | | | | | **Poverty rate** |
| **Gender** | | | | | | | | | | | | | | | | | | **Poverty rate** |

### 3.2. Age (Criteria: Age 0-4 years, 5-9 years, 10-14 years, >60 years)

Compare the following pairs of ages as to which is more vulnerable to flood risk. Place the mark near the more vulnerable one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0-4 (years)** | | | | | | | | | | | | | | | | | | **5-9 (years)** |
| **0-4** | | | | | | | | | | | | | | | | | | **10-14** |
| **0-4** | | | | | | | | | | | | | | | | | | **>60** |
| **5-9** | | | | | | | | | | | | | | | | | | **10-14** |
| **5-9** | | | | | | | | | | | | | | | | | | **>60** |
| **10-14** | | | | | | | | | | | | | | | | | | **>60** |

### 3.3. Gender

Compare male and female as to which is the more vulnerable to flood risk. Place the mark near the more vulnerable one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Female** | | | | | | | | | | | | | | | | | | **Male** |

### 3.4. Poverty rate (Criteria: Poverty rate <5%, 5-10%, 10-20%, >20%)

Compare the following pairs of poverty rates as to which is the more vulnerable to flood risk. Place the mark near the more vulnerable one (1: Equal, 3: Moderate, 5: Strong, 7: Very strong, 9: Extreme).

extreme ← equivalent → extreme

| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **<5%** | | | | | | | | | | | | | | | | | | **5-10%** |
| **<5%** | | | | | | | | | | | | | | | | | | **10-20%** |
| **<5%** | | | | | | | | | | | | | | | | | | **>20%** |
| **5-10%** | | | | | | | | | | | | | | | | | | **10-20%** |
| **5-10%** | | | | | | | | | | | | | | | | | | **>20%** |
| **10-20%** | | | | | | | | | | | | | | | | | | **>20%** |

# Appendix B. Interview questions

1. How long have your province/district/commune stored and recorded flood damage data?
2. Could you list any disaster risk management plans which have been developed in your province/district/commune? Could you please explain about how your province/district/commune develops such plans?
3. Is disaster risk reduction integrated into your provincial/district/commune socio-economic development plan according to Article 15 in the new Law on Natural Disaster Prevention and Control? Could you refer to these integrations and any difficulties met in the implementation?
4. How do you assess about effect of the cascade hydropower reservoirs on Vu Gia-Thu Bon river in flood control? Has the development of these projects been aligned with any disaster risk reduction efforts?
5. Have floodplain risk management studies been undertaken for your province/district/commune? Who undertook the studies? Does your province/district/commune have these documents?
6. Have inundation maps (flooding map) been developed for your province/district/commune? Who undertook development?
7. Could you list any activities undertaken by your province/district/commune involving the implementation of <u>prevention/mitigation</u>? Who are your main partners? What are the main problems you faced during the implementation?
8. Could you indicate activities of your province/district/commune in the implementation of <u>preparedness</u>? Who are your main partners? What are the main problems you faced during the implementation?

9. How would your province/district/commune undertake the response activities (including warning and emergency relief phases)? Who are your main partners? What are challenges/problems faced during the implementation?
10. How does your province/district/commune go about implementation of recovery activities (including rehabilitation (short-term) and reconstruction (long-term) phases)?
11. How has the disaster risk management budget been used in your province/district/commune? What are the main funding sources?
12. Has the agriculture insurance pilot been implemented in your province/district/commune? In your opinion, should agriculture insurance be implemented in your province/district/commune? What are the main barriers for the implementation?
13. Has the Community-based Disaster Risk Management (CBDRM) program been implemented in your province/district/commune? What are the constraints/barriers/difficulties in the implementation of CBDRM in your province/district/commune? How do you assess the implementation of CBDRM in your province/district/commune? Is there any specific monitoring and reporting mechanism for the implementation?
14. How many staff are currently involved in disaster management in your province/district/commune committee? Are they working part-time or full-time?

# Appendix C. Human ethics approval

HUMAN RESEARCH ETHICS COMMITTEE

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

**Notification of Expedited Approval**

| | |
|---|---|
| To Chief Investigator or Project Supervisor: | **Doctor Jason Von Meding** |
| Cc Co-investigators / Research Students: | **Mrs Thi Dieu Chinh Luu**<br>**Doctor Sittimont Kanjanabootra** |
| Re Protocol: | **Developing an integrated flood risk management framework for Vietnam** |
| Date: | **17-Jun-2016** |
| Reference No: | **H-2016-0125** |
| Date of Initial Approval: | **17-Jun-2016** |

Thank you for your **Response to Conditional Approval** submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under **Expedited** review by the Chair/Deputy Chair.

I am pleased to advise that the decision on your submission is **Approved** effective **17-Jun-2016**.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. *If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.*

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal *Certificate of Approval* will be available upon request. Your approval number is **H-2016-0125.**

**If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants** You may then proceed with the research.

**Conditions of Approval**

This approval has been granted subject to you complying with the requirements for *Monitoring of Progress*, *Reporting of Adverse Events*, and *Variations to the Approved Protocol* as detailed below.

PLEASE NOTE:
In the case where the HREC has "noted" the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University's HREC.

- ***Monitoring of Progress***

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

- ***Reporting of Adverse Events***

1. It is the responsibility of the person **first named on this Approval Advice** to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form (via RIMS at https://rims.newcastle.edu.au/login.asp) within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
    - Causing death, life threatening or serious disability.
    - Causing or prolonging hospitalisation.
    - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
    - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
    - Any other event which might affect the continued ethical acceptability of the project.
5. Reports of adverse events must include:
    - Participant's study identification number;
    - date of birth;
    - date of entry into the study;
    - treatment arm (if applicable);
    - date of event;
    - details of event;
    - the investigator's opinion as to whether the event is related to the research procedures; and
    - action taken in response to the event.
6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

- ***Variations to approved protocol***

If you wish to change, or deviate from, the approved protocol, you will need to submit an *Application for Variation to Approved Human Research* (via RIMS at https://rims.newcastle.edu.au/login.asp). Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. **Variations must be approved by the (HREC) before they are implemented** except when Registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

**Linkage of ethics approval to a new Grant**

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

Best wishes for a successful project.

Professor Allyson Holbrook
**Chair, Human Research Ethics Committee**

*For communications and enquiries:*
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***Linked University of Newcastle administered funding:***

| Funding body | Funding project title | First named investigator | Grant Ref |
|---|---|---|---|

# Appendix D. Authors Contribution Statement

## Authors Contribution Statement

**Jason von Meding,** attest that Chinh Thi Dieu Luu contributed to research design, data collection, data analysis and writing process of the publication:

- Luu, C., von Meding, J. & Kanjanabootra, S. 2018, Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam, Vietnam. *Natural Hazards,* Vol. 90 No. 3, pp. 1031-1050. https://doi.org/10.1007/s11069-017-3083-0

29/6/2018

___________________________________________ Date _______________________

Co-Author: Dr Jason von Meding

29/6/2018

___________________________________________ Date _______________________

RHD candidate: Chinh Thi Dieu Luu

02/07/2018

___________________________________________ Date _______________________

Assistant Dean Research Training (ADRT)

# Authors Contribution Statement

**Jason von Meding,** attest that Chinh Thi Dieu Luu contributed to research design, data collection, data analysis and writing process of the publication:

- Luu, C. & von Meding, J. 2018, A flood risk assessment of Quang Nam province using spatial multi-criteria decision analysis. *Water*, Vol. 10 No. 4, pp. 461. https://doi.org/10.3390/w10040461

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Co-Author: Jason von Meding

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RHD candidate: Chinh Thi Dieu Luu

02/07/2018

_________________________________________ Date _____________________

Assistant Dean Research Training (ADRT)

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- Luu, C., von Meding, J. & Kanjanabootra, S. 2018, Flood risk management activities in Vietnam: a study of local practice in Quang Nam province. International Journal of Disaster Risk Reduction. Vol. 28, pp. 776-787. https://doi.org/10.1016/j.ijdrr.2018.02.006

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Co-Author: Jason von Meding

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02/07/2018

# Authors Contribution Statement

**Jason von Meding,** attest that Chinh Thi Dieu Luu contributed to research design, data collection, data analysis and writing process of the publication:

- Luu, C. & von Meding, J. 2018, Chapter 15: Analyzing Flood Fatalities in Vietnam Using Statistical Learning Approach and National Disaster Database. In: Asgary A. (eds) *Resettlement Challenges of Refugees and Disaster Displaced Populations*. Springer, Chennai

29/6/2018

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Co-Author: Jason von Meding

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# Authors Contribution Statement

**Sittimont Kanjanabootra,** attest that Chinh Thi Dieu Luu contributed to research design, data collection, data analysis and writing process of the publication:

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- Luu, C., von Meding, J. & Kanjanabootra, S. 2018, Flood risk management activities in Vietnam: a study of local practice in Quang Nam province. International Journal of Disaster Risk Reduction. Vol. 28, pp. 776-787. https://doi.org/10.1016/j.ijdrr.2018.02.006

29/6/2018

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29/6/2018

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02/07/2018

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