SMALL SCALE DAM BREAK FLOOD SCENARIO STUDIES FOR RISK REDUCTION IN JIAN RIVER, SICHUAN, CHINA

SHAH MD. RAJIBUL ISLAM
February, 2012

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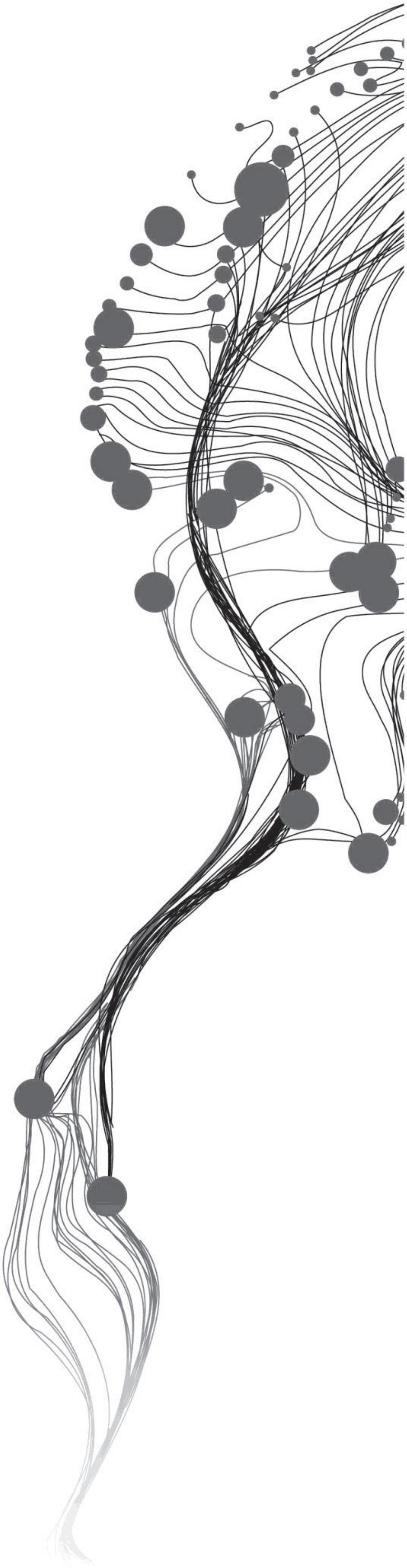

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SHAH MD. RAJIBUL ISLAM
Enschede, The Netherlands, February, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Applied Earth Sciences

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ABSTRACT

Lack of a dam break flood study is problem for understanding the dynamics and consequences of dam break floods and hampers the development of appropriate risk reduction measures and strategies. Therefore this study aimed to estimate the dynamics and impact of a landslide-dam break flood in Jian River, Sichuan China; for disaster preparedness. With this regard, three specific objectives guided this research to assess the impact of a landslide dam break flood: to prepare flood maps for different dam break scenarios, to investigate the elements at risk and their vulnerability in the downstream area and to evaluate the results for disaster preparedness. Several scientific methods and techniques were used to achieve these objectives: SOBEK 1D2D flood modelling, elements at risk identification by image interpretation and ground truth survey, stage-damage function of Netherlands for vulnerability assessment, event damage calculation, spatial multi criteria evaluation for risk assessment, local officials' interview, group discussion with local people, questionnaire survey were carried out. The results reveal that, the spatial extent of the flood for 50% dam break scenario is five times higher than the spillway. Furthermore, the elements at risk investigated in the study area are population, buildings, agricultural products, forest, and essential facilities such as schools, hospitals, fire brigades and police station. Vulnerability results obtained from the stage-damage function shows that in case of 25% dam break and 50% dam break scenarios the level of the vulnerability for different elements at risk are noticeable. The comparison of three different scenarios in SMCE has revealed that the percentage of high risk level has increased consecutively for spill way, 25% and 50% dam break flooding. In addition, risk is highly associated with population and resource distribution. For a developing country case study, small scale flood scenario could be a very effective way for risk assessment especially concerning the data poor environment. In conclusion, lack of awareness among the people about the evacuation policy and potential flood danger make the people more susceptible to flood that indicates the need of awareness generation for effective disaster preparedness.

Key words: DTM, SOBEK 1D2D, Friction, Hazard, Elements at Risk, Vulnerability, Event damage, Risk

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Shah Md. Rajibul Islam
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1. INTRODUCTION

1.1. Research background and justification

Flood is considered as the most common and frequent natural hazard all over the world. About sixty percent of the total world population is living in low lying lands very close to river and coasts are highly exposed to flooding. Floods are not only local they can also affect the entire river basin. Different types of flood exist depending on geophysical and climatic characteristics of an area. Some develop slowly caused by heavy rainfall over days or nights, some develop quickly like flash floods[1]and some floods are caused by a sudden dam break or lake outburst scenario. This study is going to focus on landslide dam break floods.

Natural landslide dams triggered by earthquakes are a common feature and a significant hazard in high-relief, tectonically active areas (X. Chen et al., 2011). In steep terrain mass movement results temporary or permanent stream blockages which are highly unstable and unpredictable by nature. These types of natural dams may pose serious threats to people and property due to the substantial volume of water accumulated in the impounded lake and the subsequent rapid release of the impounded water when the dam fails.

Most of the cities in mountainous areas are located on river valleys and are most susceptible to flooding. Moreover, these cities located in the downstream areas have accumulated a large number of population and development activities. The consequences of floods become worse for those who are unprepared to cope with flood sand those that have limited resources, weak safety measures, and those that lack good disaster preparedness and evacuation plans,,

The 2008 Wenchuan Earthquake in Sichuan province, China produced 257 landslide dams situated along the Eastern boundary of the Quinghai-Tibet plateau which captured attention of the geo-hazard researchers. The Tangjiashan landslide dam is the largest landslide dam of this area which blocked 3550 km^2drainage area of Jian River. According toO'Connor and Costa (2004), this landslide dam has a mass of 20.37 million m^3which formed a blockage of 803 m in length along Jian river channel. The apex of the scar is 600 m above the river channel. This type of landslide dam is one of the causes for devastating floods in the known history of floods. Most of the floods among 27 largest documented floods with discharges greater than 100,000 cubic meters per second of Quaternary Period resulted from breaches of natural dams formed by landslides and glaciers (O'Connor & Costa, 2004).

Therefore dam break flood scenario study needs more research focus. The problem is that itis hard to predict the formation, stability and failure of landslide dams precisely. Most of the research focused on physical and geomorphic characteristics of dam or hazard identification and mitigation (Cui et al., 2009; Dai et al., 2009; L. Liu et al., 2009; N. Liu et al., 2009; Wang et al., 2008; Yu & Pengxiao, 2009)while none of them studied the potential vulnerability of the downstream area. While most of the potential damages and losses will occur along the downstream valleys, e.g. in this the Tangjianshan landslide case Myanyang city, are at great risk with its 1.3 million inhabitants. In this regard, it is necessary to carry out a hazard and vulnerability study to assess thedam break flood risk in this area.

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[1] FEMA: http://www.fema.gov/hazard/flood/index.shtm

Therefore, this study will focus on an integrated spatial vulnerability assessment of this area with the aim of formulating better strategies that contribute to risk reduction. By simulating different dam break scenarios it is possible to gain better understanding of such extreme events. Hence, this study intends to perform scenario analysis to assess the extreme flood events in the future and incorporate this with vulnerability assessment and risk assessment.

1.2. Research Problem

This study will focus on Lake Outburst or landslide dam flooding, its consequences in downstream areas and the evaluation of existing evacuation planning. This study will follow an integrated approach to assess landslide dam break flood vulnerability in the study area. Most of the studies on landslide dams have been done in a mainly descriptive character, GIS-based modelling or quantitative approachesare recent attempts in this field (Korup, 2002). No doubt hazard identification is first step of disaster management but without considering human or socio-economic vulnerability any study in disaster risk is inadequate. To ensure human security, hazard analyses itself are not adequate. Therefore this study will focus on an integrated approach to vulnerability assessment in combination with dam break flood modelling and evacuation planning.

The Wenchuan magnitude 8 earthquake on 12 May 2008; 14:28 in the Sichuan Province of China triggered 257 landslide lakes by blocking the rivers which were distributed along the fault rupture zone and river channels. Among these 33 landslide-dammed lakes were in high risk category in terms of uncontrolled lake outburst which may occur potential damage of 130 million people living in downstream area(Cui, et al., 2009).

However, this type of lakes is a common geo-hazard in mountainous earthquake-prone areas and may cause upstream flooding due to water level rise in the lake and downstream flooding as a result of dam failure (Costa & Schuster, 1988; Dai et al., 2005; Kallen et al., 2006). For the same potential energy, downstream flood peaks are higher in case of unexpected landslide dam failure than those from glacier-ice dam failure because of differences in failure mechanism (geometry and material characteristics of the dam) and can make the downstream areas more vulnerable (Costa & Schuster, 1988; Cui, et al., 2009).

The prediction of landslide dam stability is difficult due to many internal and external factors (such as geometry and material characteristics, rate of inflow)of the dam that control the triggering mechanisms of breach and basic dam stability (Costa & Schuster, 1988; Ermini & Casagli, 2003; Korup, 2004). In order to distinguish stable from unstable dams; morphometric and watershed based quantitative indices have been successfully used locally (Ermini & Casagli, 2003; Korup, 2004) but the predictive power is low (Korup, 2004).Though, Ermini and Casagli (2003) reported on the research of the stability of earthquake triggered landslide dams, these is no detailed report of the risk that will result from a dam failure (Cui, et al., 2009). Therefore it is necessary to study the vulnerability of the highly built-up downstream area to reduce disaster risk.

Though, Ermini and Casagli (2003) reported the research on the stability of earthquake lake and their dams, these is no detail report of the risk assessment that can be resulted from dam failure (Cui, et al., 2009). As it is already known from the history that landslide dam breaking can be deadly, some of them 11 have resulted hundred and thousand of deaths. Therefore it is necessary to study the vulnerability of the highly built-up downstream area to reduce disaster risk.

About 1.3 million people of Mianyang city in the downstream area were in danger by the Tangjiashan landslide-dammed lake located in Beichuan County (Cui, et al., 2009). In addition, the level of risk to the huge downstream population and resources increased in the rainy season with the increasing water level. Lack of a dam break flood study is problem for understanding the dynamics and consequences of such dam break floods and hampers the development of appropriate risk reduction measures and strategies. Hence, an integrated small scale flood scenario study is needed for flood hazard assessment, vulnerability assessment and disaster preparedness as input to risk management.

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1.3. General objective

The general objective of this study is to estimate the dynamics and impact of a landslide-dam break flood in Jian River, Sichuan China; for disaster preparedness.

1.4. Specific objectives and research questions

1. To prepare flood maps for different dam break scenarios.
    a. What are the realistic dam break scenarios and input values for those?
    b. What would be the flood extent, water depth and flow velocity of dam break flood scenarios in this valley?
    c. What are the uncertainties in my data?
    d. How the uncertainties in my data will affect the flood maps?

2. To investigate the elements at risk and their vulnerability in the downstream area.
    a. What are the elements at risk in the study area?
    b. What is the geographical distribution of elements at risk in the study area?
    c. What is the appropriate scale for this study to represent the elements at risk?
    d. What is the awareness situation at different stakeholder level (local authority, experts and people) of study area?
    e. What is the vulnerability level of study area?

3. To evaluate the results for disaster preparedness.
    a. What is the flood risk in the area?
    b. Is there any evacuation rule exist in study area?
    c. What are the limitations of existing evacuation planning or rules?
    d. What measures should be included to improve the evacuation rules?

1.5. Thesis outline

The entire thesis has been divided into 8 chapters.

1.5.1. Chapter 1: Introduction

The first chapter starts with the problem definition and ends up with finalizing research objectives and questions.

1.5.2. Chapter 2: Literature review

This chapter focuses mainly on the relevant background knowledge and concepts that have been developed through the course of time. By giving a detail literature review this chapter explains methods and techniques were used for this of study. At the same time it also illustrates the approaches taken for this study. It discusses about the worldwide flood fact, flood situation in China, short description about the causes and consequences of flood and eventually it enter in depth of Lake Outburst flooding. These are the descriptive knowledge regenerated from different facts and sources. Furthermore this chapter gives a brief description about flood modelling, flood hazard assessment techniques, vulnerability and risk assessment.

1.5.3. Chapter 3: Study area

The third chapter describes about the background of the study area including physical and socio-economic dimension.

1.5.4. Chapter 4: Methodology

The fourth chapter describes about the data collection, analysis and methods applied in this study. It also describes the methodology used in the research for each objective.

1.5.5. Chapter 5: Flood hazard assessment

This chapter analyse the flood model also incorporates model validation and calibration. Hazard assessment by using SOBEK 1D2D flood modelling is the main focus of this chapter. It also describes parameters of flood, hydrograph, friction map and DTM analysis. Finally it ends up by generating several input maps which was applied in the next phase of the study in order to achieve other goal.

1.5.6. Chapter 6: Elements at risk and flood vulnerability assessment

The sixth chapter dealt with the elements at risk and vulnerability assessment. Generating a group of elements at risk map was the initial out of this chapter. Later on these elements at risk map were used by overlay function in order to show the flood vulnerability for different elements at risk. On the other hand, by means of vulnerability curve physical vulnerability were assessed. Finally this chapter ends up with event damage assessment.

1.5.7. Chapter 7: SMCE approach for semi quantitative risk assessment

By means of spatial multi criteria evaluation approach semi quantitative risk assessment was performed in this chapter. A risk index indicating the spatial variation of risk is the final output of this chapter. Group of attribute maps generated from chapter 5 and 6 were the main input used in this chapter.

1.5.8. Chapter 8: Conclusion and recommendation

This research ends up in chapter 8 by concluding the entire research. Recommendation for the further research is given at the end of this research.

2. LITERATURE REVIEW

This chapter tried to extract relevant knowledge from the available literature. Reviewing the relevant past studies and concepts developed by the researchers are the base of this study. Several methodologies and techniques developed in the course of time are the main support in order to carry out a step by step disaster risk assessment study.

2.1. Worldwide flood scenario

Flood is the most common and destructive hydro-meteorological natural hazards all over the world. Every year on average 6753 people die; 6.8 million people are affected and 13 billion USD economic damage occur due to the consequence of flood (PreventionWeb, 2011).

2.2. Flood in China

China is one of the highly flood affected county in the world (Figure 2-1) and it is a most common and devastating natural disaster in China. Every year a large number of populations get affected by flooding.

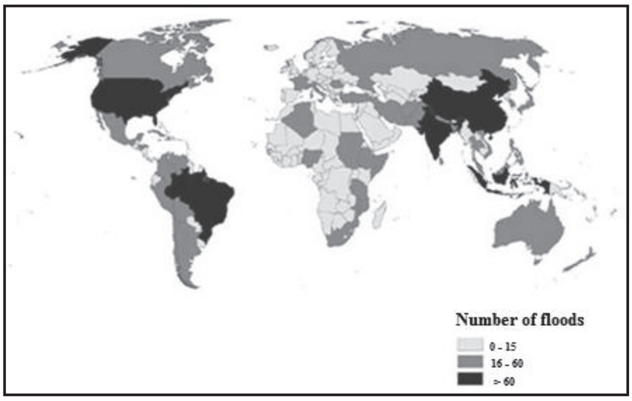


Figure 2-1 Number of occurrence of flood disaster by country from 1974-2003 (Source: (CRED, 2011)

According to the International Disaster Database (CRED, 2011) among the world top ten flood (based on number of people died) for the period of last 100 years (1900 to 2011), 7 occurred in China. Developing countries like China is highly susceptible to these kind of natural hazard due to its' high exposure level (e.g., high dense population, resource allocation in high flood hazard zone, large number of poor people).

2.3. Causes and consequences of flood

Flood is a hydro-meteorological hazard which occurs due to the deviations in normal water cycle or overflow of bodies of water usually caused by the rising of water levels. Two types of flood are most common i.e., flash flood and general flood. The term general flood comprises the accumulation of water on the surface due to long-lasting rainfall (water logging) and the rise of the groundwater table above the ground surface. Furthermore, inundation by melting snow and ice, backwater effects, and special causes such as the outburst of a glacial lake or the breaching of a landslide dam are subsumed under the term general flood(CRED, 2011). The probability of general flood occurrence is significantly higher at a certain locations (e.g. along rivers, downstream of natural dam) than at others.

2.4. The 2008 earthquake and its' impact

Natural hazards can cause thousands of death, damaging houses, destroy facilities, lifelines, roads, agricultural damage etc. Hazards such as earthquakes can induce other natural hazard which is known as 'domino effect'. The 2008 Wenchuan Earthquake was a big disaster for China which directly caused 69,181 deaths 18,498 missing persons and 374,171 injured persons(FACTS&DETAILS, 2011), an estimated 123 billion USD in economic loss) severe and environmental loss. These were the direct impacts of this earthquake. Beside these it has produced 257 landslide dam which are highly sensitive to heavy rainfall, can lead to Lake Outburst. As soon as this lake outburst will occur it will accumulate huge amount of water overflow in the surrounding areas.

2.5. Lake outburst or dam breach flooding

These type of flooding can cause enormous death, injury and loss of property due to its' unpredictable nature. For example, on June 10, 1786 a landslide dam created by an earthquake and blocked the Dadu River in Sichuan Province. The dam burst after ten days of its emplacement and caused a huge flood which extended 1400 km downstream and killed 100,000 people (Schuster & Wieczorek, 2002). In addition, Diexi dam which overtopped on 9 October, 1993, 45 days later of formation and caused a flood that extended 250 km downstream and killed more than 2,500 people (Chai et al., 2000; Huang & Xu. Q. et al., 2008). Moreover, the Yigong landslide dam was breached on 10 June and the water level rose sharply in the downstream by at least 50 m and the maximum discharge was about 120 000 m3/s which caused terrible flood resulted in 30 deaths and more than 100 people missing (Huang & Xu. Q. et al., 2008; Shang et al., 2003).

2.6. Flood modelling for dam breach scenario analysis

Flood modelling can be helpful to identify the areas which are likely to be affected by flood hazard. The hydraulic model simulates the movement of flood water and calculates flood levels and flow patterns. There are two types of hydraulic model available, i.e., 1D and 2D.

In the ID flood model, a series of cross-section which are perpendicular to the flow direction are used for terrain characterization and this model requires less computation time compared to the 2D model (Werner, 2001). This type of model works well in well defined narrow valleys where there is clear one dimensional flow towards downstream but in case of wide valleys with relatively flat alluvial plain or in large delta area this model is not valid (Alkema, 2007).

2D flood propagation model can calculate flow in both X and Y direction and require a continuous representation of the terrain topography. The application of this flood model became possible due to the availability of cheaper high configured computers, accurate terrain models and land cover data (Alkema, 2007). As it gives additional data like flow velocity and propagation characteristics, it is suitable for more complex topography. Due to larger computation time and high quality data requirement (Werner, 2001), applicability of this model is not always feasible for data poor developing countries.

Benefits and drawbacks of these two models encouraged integration of both for modelling (M. Z. A. Rahman & Alkema, 2006) and SOBEK is this kind of flood modelling software which consists of both 1D domain within the river channel and 2D domain on the overland part. This software is developed by WL Delft Hydraulics. The flood modelling in this study will be conducted by SOBEK dynamic model.

2.7. Digital Terrain Model (DTM)

Digital Terrain Model (DTM) has emerged an indispensable dataset for representing surface topography accurately and effectively such that it plays a critical role to support various types of inquires in geosciences particularly natural hazard assessment and natural process modelling. A DTM is continuous depiction of surface topography sometimes referred to as spaced elevation data (Li & Wong, 2010) and a hydrologically correct DTM is an important input for the SOBEK flood modelling. The more accurately the terrain is represented by the DTM the more reliable output can be generated. During modelling, a lower resolution DTM can increase the flooded area while LIDAR DTM could provide best output (Sanders, 2007). Before modelling the DTM accuracy could be simply checked by visual interpretation through generating hill shade (Maune, 2007). For contour derived DTM, accuracy is highly dependent on the interpolation method, sampling strategy and terrain character (Robinson, 1994).

2.8. Flood hazard assessment

UNISDR (2009) defined hazard as “a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage”. In addition, according to UNISDR (2004) “a hazard has a probability of occurrence within a specified period and within a given area and has a given intensity”. Flood hazard is the probability that a flood event of a certain magnitude will occur in a given area within a specified period. After having the potential hazard next step is to understand the characteristics of that hazard like the extent, controlling factors and so on (Alkema, 2007). In case of flood only the extent of the flooded area is not a good indicator to characterize the hazard and hence other parameters like flood depth, flow velocity, duration, warning time, sedimentation etc. are equally important for meaningful assessment of the hazard (Alkema, 2007).

2.9. Elements at risk and flood vulnerability assessment

Elements at risk are population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. According to (Nott, 2006) the elements at risk can be defined as the level of exposure with reference to buildings/ infrastructures, population, economic activities, public services and utilities which can be impacted by hazard. Elements at risk can be spatial and non-spatial by characteristics. The interaction of elements at risk and hazard defines the exposure and the vulnerability of the elements-at-risk (Westen & Kingma, 2010).

According to Birkmann (2007) one of the most important aims of developing tools for measuring vulnerability is to help link the gap between the theoretical concepts of vulnerability and day-to-day decision making. This study will focus on characterising elements at risk and vulnerability assessment in order to help the decision making process of local authority.

UNISDR (2007) defined vulnerability as ‘The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.’ In other word vulnerability is “The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards “(UNISDR cited in (Westen & Kingma, 2010). However, vulnerability can vary in a particular environment (community or a system) and over time. Based on these definitions Westen (2010) characterise vulnerability as multi-dimensional, dynamic, site specific and scale-dependent. Therefore, this study will put emphasize on place based vulnerability assessment approach and will apply an integrated flood vulnerability assessment method. Who and what is going to be vulnerable to the environmental changes and where (Turner et al., 2003) are main key questions of vulnerability assessment.

2.10. Vulnerability/damage assessment by flood damage function

Flood damage function describes the relationship between the hydraulic parameters and the relative damage or damage factor of the elements at risk. Micro, meso and macro are the three different scale limits for this type of approach (Apel et al., 2009). Several countries of Europe like United Kingdom, Germany and Netherlands use flood damage function more frequently than other countries. In this study, the damage assessment will be carried out by using damage function of Dutch standard method and the functions are mainly depth-damage functions. The degree of damage is represented on a scale from 0 to 1, where 0 refers to no damage and 1 refers to total damage. By using damage functions it is possible to assess the damage very quickly but assessing the damage by using only one parameter like flood depth is a limitation of this method as the damage is also caused by other parameters like flow velocities, duration, sedimentation, warning time and so on (Alkema, 2007).

2.11. Spatial multi criteria evaluation

Westen & Kingma (2010) defined vulnerability assessment as most of the complicated component of disaster risk management because of its' wide range of interpretation. Vulnerability assessment based on curves and tables are widely used (Bhattacharya, 2010) mainly to quantify physical vulnerability. From the above definition it is clear that vulnerability is not only physical characteristics of a system, but also combination of economic, social and environmental characteristics of a system. In this regard it is needed to assess vulnerability from an integrated approach (Figure 2-2).

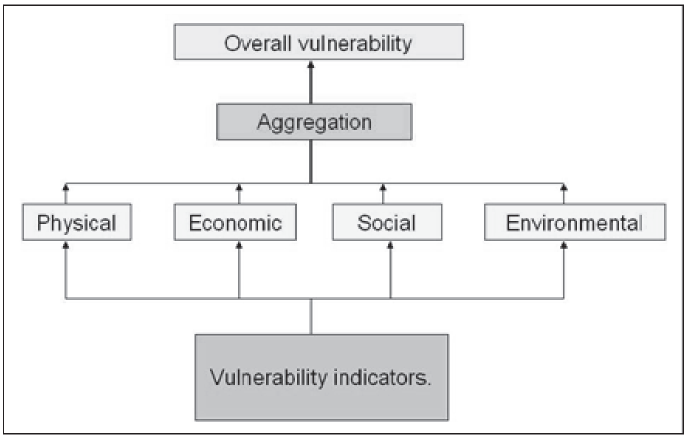


Figure 2-2 Overall vulnerability (Source: (Westen & Kingma, 2010)

GTZ (2004) developed an expert-opinion index method, for defining physical, economic, social, and environmental vulnerability cited in (Westen & Kingma, 2010). Each type of vulnerability is characterized by a number of indicators. The vulnerability indicators, defining the physical, economic, social, and environmental vulnerability can be aggregated and combined into an overall vulnerability value by means of multi criteria analysis (MCA) techniques (Figure 2-3).

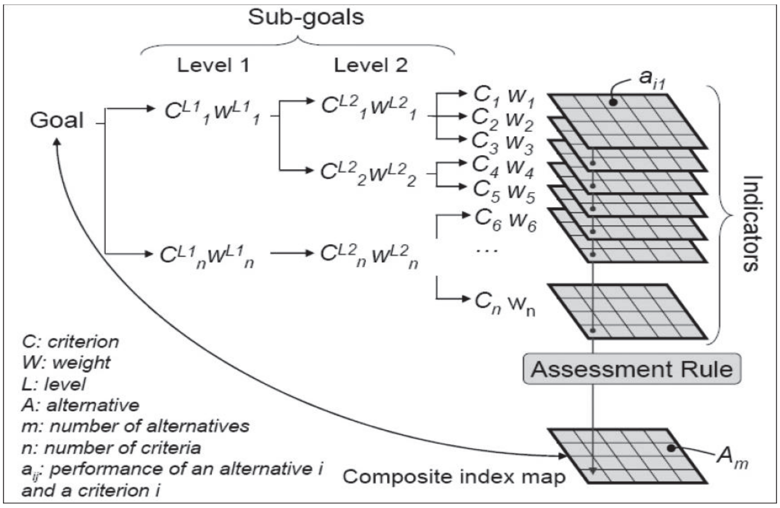


Figure 2-3 Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process (Abella & Van Westen, 2007)

MCA is an appropriate method of incorporating all relevant types of consequences and Geographical Information system with its ability to handle data is an appropriate tool for processing spatial data on flood risk (Meyer et al, 2008). This paper will combine these two methods: multi criteria analysis in GIS environment. Spatial multi criteria analysis technique is mainly based on the theory of Analytical hierarchy process developed by Saaty (1980) cited in (Westen & Kingma, 2010). Extensive research has been carried out to apply AHP to risk assessment (Westen & Kingma, 2010). Consequently, several studies (Guarin, 2008; Meyer et al., 2009; S. Rahman, 2011) has proved SMCE is a very strong and effective method to integrated flood vulnerability assessment.

The SMCE application assists and guides users when performing multi-criteria evaluation in a spatial manner (ITC 2001cited in (Westen & Kingma, 2010).The input is a set of maps that are the spatial representation of the criteria and the output is final composite index map (Figure 2-3).

2.12. Risk assessment

Risk assessment is an integrated part of disaster management. According to Geohazars (2009), Risk Assessment is the process of making a decision or recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Following equation used for calculating quantitative risk by using only physical vulnerability in relation to the intensity of the hazard and the characteristics of the elements at risk.

$\mathbf{Risk = P_T * P_L * V * A}$ (Geohazards, 2009)

Where,

$\mathbf{P_T}$ is the temporal probability of occurrence of a specific hazard scenario within a specified return period in an area;

$\mathbf{P_L}$ is the spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk;

V is the physical vulnerability, specified as the degree of damage to a specific elements-at-risk given the local intensity caused due to the occurrence of specific hazard scenario:

A is the quantification of the specific type of element at risk evaluated. The elements at risk can quantified as numbers (e.g. number of buildings that might suffer damage) or in economic terms.

Risk assessment method can be classified as qualitative, semi quantitative and quantitative. In addition, risk can be divided as risk for direct losses and risk for indirect losses. The qualitative approach is based on the experience of the experts and the risk areas are categorized with terms as 'very high', 'high', 'moderate', 'low' and 'very low' risk. Semi-quantitative approaches consider a number of factors that have an influence on the risk and can be assessed by SMCE method. For quantitative risk assessment, risk curve can be generated based on the total monetary loss for different return periods to obtain annual average risk. The total area under the curve corresponds to the total annual risk for flooding (Geohazards, 2009). Correctness of risk assessment is relied on the proper valuation of the elements at risk and information on risk characteristics and damage factor (Badilla, 2002; Jonkman et al., 2008).

2.13. Disaster preparednes and evacuation planning

Evacuation planning is an essential part for disaster preparedness. Source and credibility of evacuation warnings, warning time, routs, public information, strategies for enhancing citizen compliance with evacuation warnings etc are very important for evacuation planning and emergency management (Perry, 1983). According to UNISDR (2009) preparedness is the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions. Sutton & Tierney (2006) divided the disaster preparedness in different units for analysis i.e., household, business and community & organizations and proposed preparedness measures across the units of analysis.

3. STUDY AREA: JIAN RIVER VALLEY

This chapter describes the physical and socio-economic characteristics of the study area including geographical location. This chapter will provide a better understanding about the background of the study area. However, the available secondary information about study area were limited though the researcher tried to depict a generous description of the study area through field observation and primary data collection.

3.1. Location of study area

The study area is the Jian river valley which is located nearMianyangin the Sichuan province; a south-western province of China. The geographical boundary of the study area is 31°42'57"N 104°24'51"E and 31°52'57"N 104°37'18"E. The upstream river bed elevation at the landslide dam location is 638 m while the downstream end point elevation is 522 m. On the other hand, the width of the river varies from 50 m to 215 m at different locations.

3.2. Selection of the boundary

The boundary of the study area is defined s as the river bed elevation to the end of next 40 m contour interval based on the contour line. However, the boundary was modified in several locations by using Google earth image in order to include important elements like roads, settlements as well as to exclude areas that are very far from the river channel.

3.3. Description and characteristics of study area

The study area consists of the Tangjiashan landslide dam, landslide-dammed lake, river and the settlements along the river valley with an area of about 31 sq km. The Tangjiashan landslide dam had created a landslide lake upstream and this study will focus on the possible impact of this landslide dam in case it breaches on the downstream areas up to the town of Xiangshui, about 45 km from Tangjianshan along Jian River valley - see Figure 3-1. Mianyang city, the second largest city of Sichuan province situated 75 km away from the dam and several small towns and villages are located along the river valley that could be affected by sudden failure of this landslide dam. This study will focus on Beichuan, Dengjia, Tonkou, Hanzeng and Xiangshui as well several smaller villages along the river.

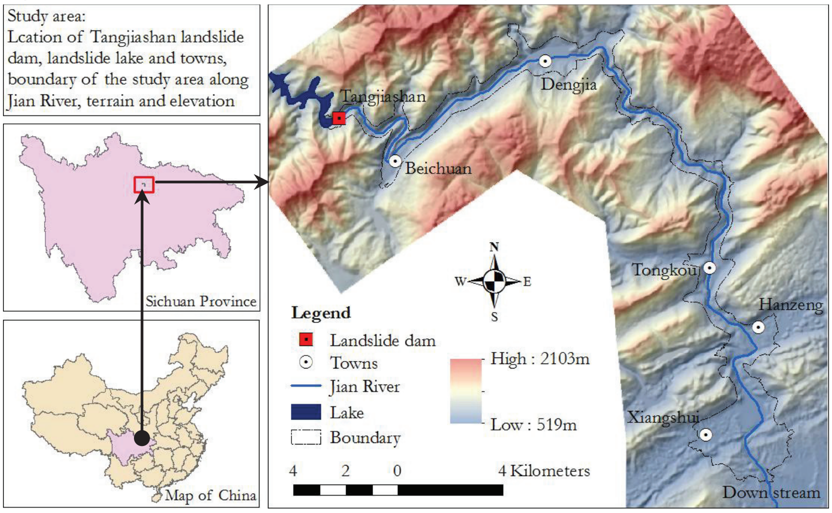


Figure 3-1 Study area (Source: created by author)

3.3.1. Geology

The landslide-dammed lake created by the blockage of Tangjiashan dam (Figure 3-2) was located 3.2 km upstream of the Beichuan town. This lake had a water storage capacity of 3.15x108 m3 with 23 km long submerged area (Cui, et al., 2009). Tangjiashan landslide dam created in a bedrock sequence of weathered metamorphic slate, sandstone, and pelite. The dam was composed of 2.37x10^7 m3 of landslide mass. The length of the dam along the river was 803m and the width across the river was 611m with a thickness of 83-124m (Cui et al., 2010).

Figure 3-2 Tangjiashan landslide dam blocking Jian River (Cui, et al., 2010); Photo from Ministry of Land and Resources)

3.3.2. Hydrology

Jian River is the tributary of Fu River and it has a drainage area of 3,550 km^2. According to Beichuan weather station, the average annual precipitation is 1355 mm. 86.3% of this total is received between May and October. Daily maximum recorded precipitation is 323.4 mm(Cui, et al., 2010).

Tangjiashan dam has approximately 2.91 billion m^3 of annual runoff. From the emplacement of the dam, the daily impounded water was approximately between 8 and 13.4 million m^3 (J. C. Chen et al., 2008). According to the calculation of Cui, et al. (2010) using 1:50000 DEM, the maximum storage capacity of Tangjiashan landslide lake is about 315 million m^3

3.3.3. Socioeconomic condition

The study area is facing massive out migration particularly among the younger generation. Most of them are working in the cities as well as in the industries located within or nearby the study area. During field work it was discovered that in most of the areas older and children are the majority. In addition, most of the old people are basically engaged in the non commercial agricultural activities. After the 2008 Wenchuan earthquake a huge displacement took place all over the affected areas and hence it also badly affected the social safety-net of the inhabitants. The affected people now have new house constructed by different government and non government authorities but they have to repay the money that also influence their household expenses. However, the common people of the study area are very cooperative and they like to share their stories with visiting people.

3.3.4. Land use

The study area consists of different types of land uses i.e., residential, industrial, agricultural, forest, water body, roads, and essential facilities like hospitals, schools, police stations, fire brigade station. The settlements in the study area have developed along the river and the regional road. The mountains are mostly covered by the forests. In addition, some of the mountain slopes have been converted as agricultural lands. Most of the agricultural lands are located in the downstream part where the land is more or less flat. Industrial land use is also significant in the study area and the industrial activities are mostly steel mills, cement factories and stone quarries.

4. METHODOLOGY

The objective of this chapter is to present the research methods and techniques that were applied in different phase of this research in order to answer the research questions. At first the data sources and data collection techniques were explained then the methods of data analysis are described.

4.1. Methodology of the study

This study was conducted in three different stages and these are pre-fieldwork phase, fieldwork phase and post fieldwork phase. A logical workflow is given in Figure 4-1. To carry out this integrated study several methods were applied at different stages.

In the pre-field stage a research proposal was developed to justify the necessity of this study by means of literature review and existing dataset investigation. After defending the proposal evaluation and processing of the existing data (Google earth image, digital elevation model (DEM) and different shp files) was carried out. The Google earth image was used to identify the land cover of the study area and digitizing the elements at risk by means of homogeneous unit identification. In addition, a detailed listing was made in this stage of the required data that was to be collected from the field.

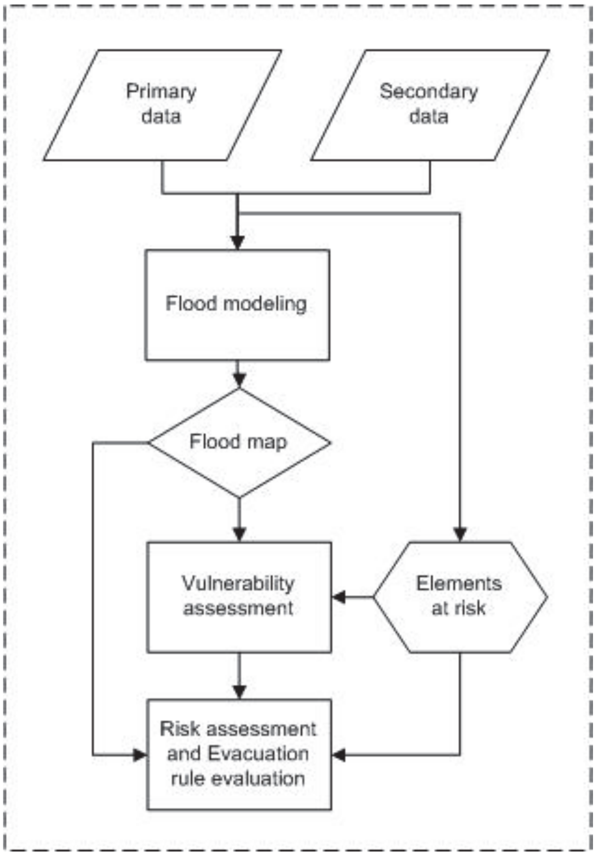


Figure 4-1 Logical workflow of the study

In the fieldwork stage, different sources like municipal office, disaster management office, weather station and hydrology office, local university archive were visited to collect the required data. Moreover, interviews with local officials and experts were also conducted to know their view and concern about flood and flood evacuation rules. Simultaneously, measurement of the cross-section of the river, land use survey, building survey, identification of essential facilities like hospitals, fire brigades etc was carried out. Furthermore, local peoples' perception was investigated by interviewing village leader, flood affected people and senior persons.

Post fieldwork phase was divided into flood modelling, vulnerability and risk assessment and evacuation planning. After completing the fieldwork; data organization and processing was started. Updating the existing data in combination with field survey data was accomplished. Preparation of the input data for SOBEK flood modelling and flood model running for different dam break scenarios was carried out. The model output was analysed and used as input for vulnerability assessment. Physical vulnerability for residential settlements has been carried out by using Damage functions of the Dutch Standard Method for low rise and medium rise dwellings and the event damage has also calculated. Thereafter, risk assessment is carried out for specific scenario by using the hazard, vulnerability and elements at risk. Finally, recommendation on existing evacuation rules is provided. A detail technical workflow is given in Figure 4-2

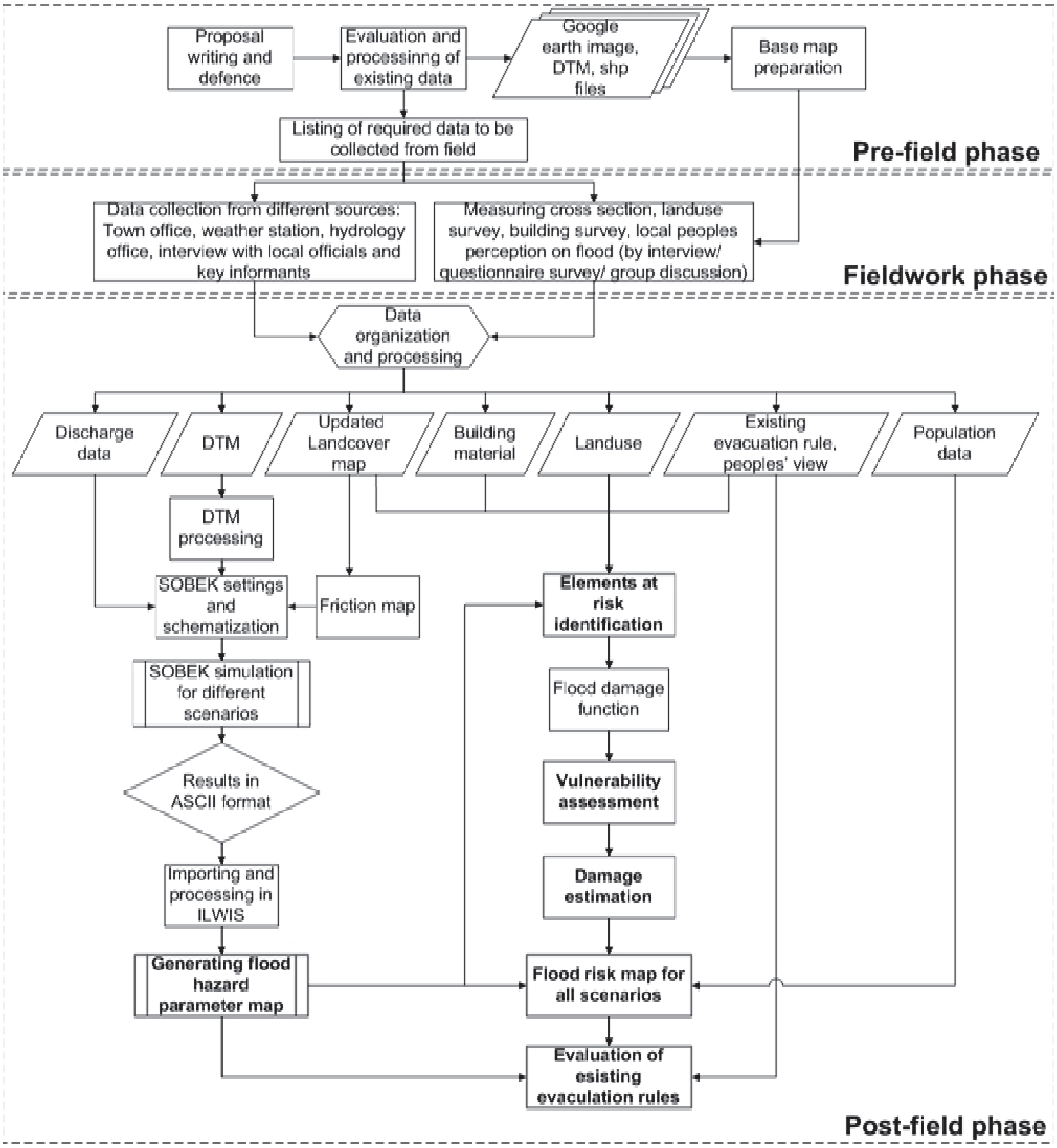


Figure 4-2 Technical workflow of the research work

4.2. Data

From literature survey a check list of required data sets was prepared for this study before the fieldwork. Based on that inventory, search for secondary data was started. One of the major challenges for this study was to work in a data poor environment. This study faced a major challenge to work in China and that is because most of the data sets are restricted by government. Therefore there was an urge to prepare own datasets from the field survey and office visit. A five weeks field work was planned that enabled to collect the required data. In Table 4-1 a comprehensive data list used in this study is given depending on their source, type and format.

Table 4-1 Shows the used data sets in this research

Data	Type	Format	Source
Data in hand before fieldwork			
25 m DTM, based on interpolation of 20 m contour lines	Spatial	Raster	CDUT (Chengdu University of Technology, China)
High resolution imagery of 2010	Spatial	Raster	Google Earth (GeoEye 2012)
Landslide dam location, geology of the upstream area, map of China, province of China, location of towns and villages	Spatial	Shp	CDUT (Chengdu University of Technology, China)
Data required			
Land use and land cover	Spatial	shp	Constructed by author from google earth image and field survey
Elements at risk	Spatial	shp	Constructed by author from google earth image and field survey
Awareness situation	Non-spatial	questionnaire	Interview with local expert (Government officer) and people
Existing evacuation rule	Non-spatial	questionnaire	Local expert interview (Government officer)
Socio-economic	Non-spatial	Tabular and questionnaire	Municipality and Field survey
Discharge data	Non-spatial	Tabular	Literature review and hydrologic station at study area
Cross section data of the river channel	Spatial	Y-Z profile	Field Measurement (Laser distance finder and GPS), DTM

4.2.1. Data collection

Possible survey locations were selected from Google earth image based on image interpretation, accessibility and settlement locations before starting the fieldwork. In addition, the survey points (72 locations) were distributed over the study area in such a way that would allow getting a good overview of the area. Different types of data collected at different locations by means of questionnaire, group discussion, GPS point collection etc. The survey locations are shown in Figure 4-3 and briefly given below as bullet format.

- Interview with the town officers of Hanzeng, Tongkou, Dengjia and Xiangshui
    - Information on evacuation rules
    - Price of buildings by type, agricultural land, forest
    - Population

- Physical survey to identify the types of buildings and location of essential facilities
- Group discussion and questionnaire survey to get in-depth information about socioeconomic conditions, flood information, awareness and so on.
- Village leader, senior citizens and flood affected people were interviewed in different areas to get peoples perception about flood. In addition, general information like name of the village, boundary delineation in the image and population was also collected.
- Location identification by GPS of essential facilities like school, hospitals, fire brigade station, police station etc.
- Collecting discharge data from hydrologic stations.
- Measuring 12 cross-sections at different locations by using GPS and laser distance finder.

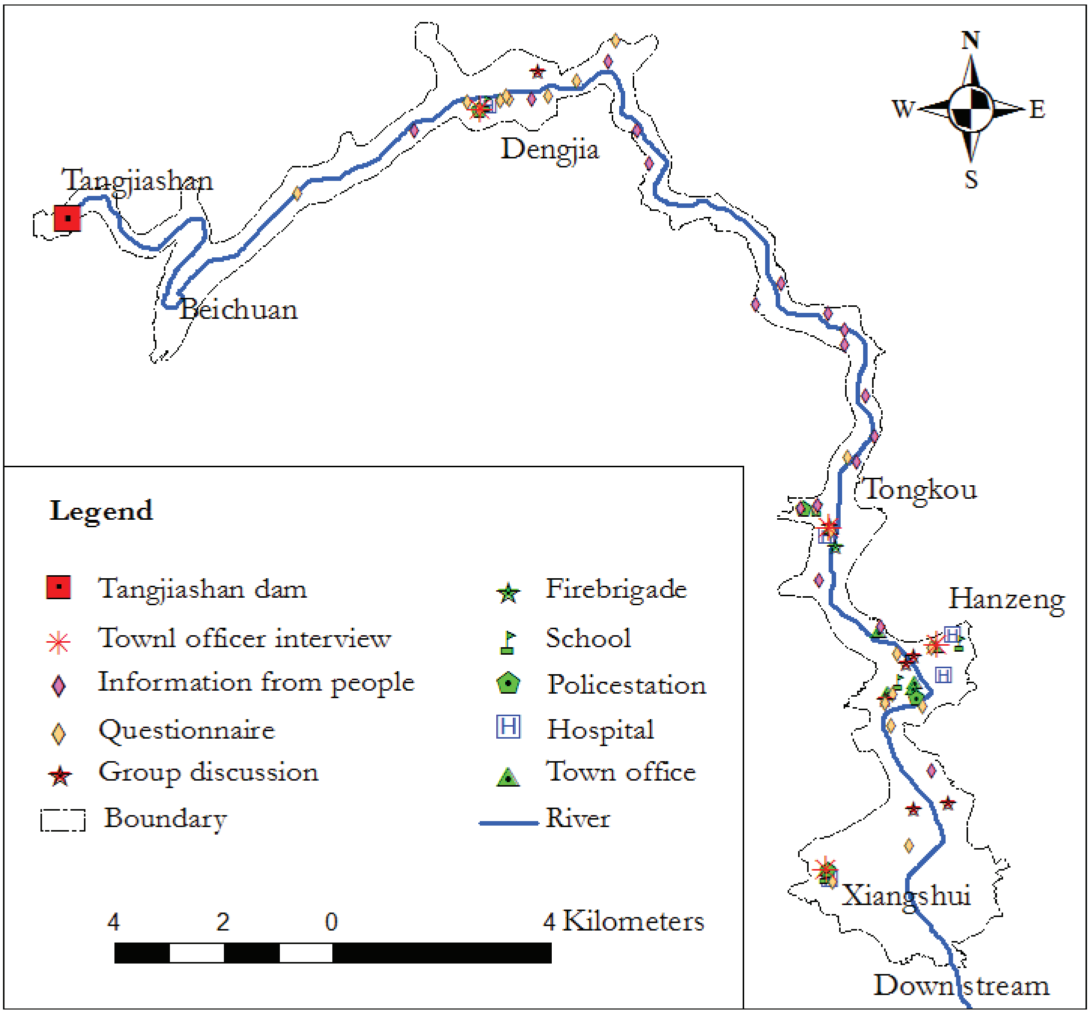


Figure 4-3 Field survey map of the study area

4.3. Methods and techniques of data analysis

4.3.1. 1D2D Flood modelling in SOBEK

In this research SOBEK-rural 1D2D model was selected in order to reconstruct comprehensive flood scenarios based on available secondary data and field measurement. The input data set of the model is mainly requires two types of datasets such as spatial and non-spatial data. As spatial data an interpolated

DTM (25m), based on 20 metre contour lines, was used. Another spatial component was friction map prepared based on land cover types. In the urban area surface roughness coefficient was defined by vegetation, buildings, roads etc that would influence flood water flow direction or velocity and transformed into manning surface roughness coefficient (Alkema, 2007). SOBEK 1D2D is a fully dynamic model which allows the computation of both one dimensional channel flow and two dimensional overland flow modelling. Poor DTM quality was one of the major challenges to achieve good and reliable results.

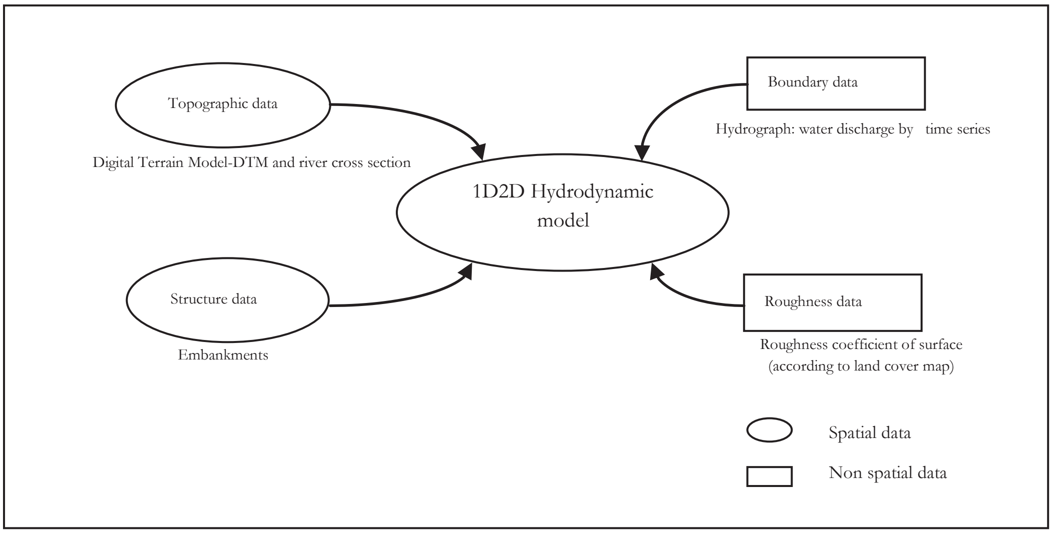


Figure 4-4 Parameter input for 1D2D hydrodynamic modelling adapted from (Guarin, 2008)

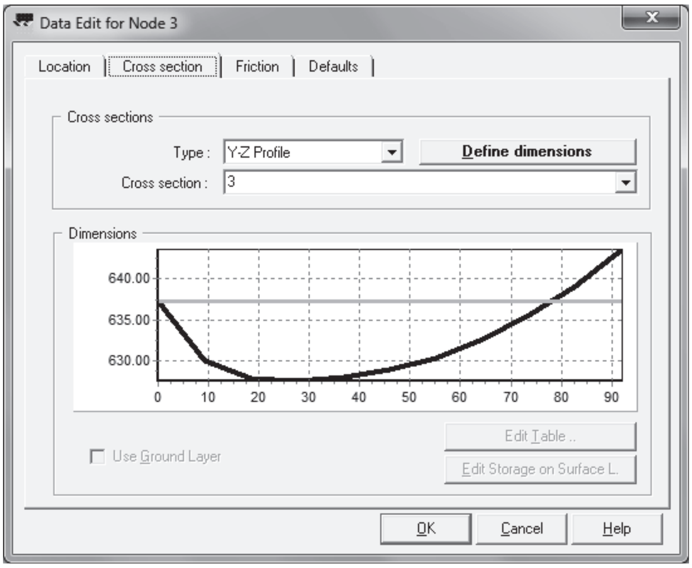
4.3.1.1. Boundary condition

According to Alkema (2007), "the boundary conditions describes the exchange of water mass between the study area and the rest of the universe during the model run." There are two boundary conditions i.e., upstream and downstream, where the upstream boundary condition describes the amount of water entering in the river and the downstream boundary condition describes the amount of water leaving. In this study the upstream boundary conditions is a time series with discharge (m3/s) which was generated from a discharge hydrograph see chapter 5 subsection 5.3.2. The downstream boundary condition was defined as 1D and 2D with uniform water level.

4.3.1.2. Model construction and schematization

A new project was developed in SOBEK for flood modelling following the SOBEK exercise of Alkema (2005) in order to get the required output. A number of tasks carried out for model setup i.e., defining the river channel, cross section location selection and adding the cross section, adding history stations and so on. ID Flow (rural) and overland flow (2D) module was selected in such a way that both of these run simultaneously. In the downstream a 2D boundary node was also added to accommodate the water that flows out the study area as overland flow.

Cross-sections along the river channel provide the bathymetry of the river and also the interpolation of the river bed and the water flow depends on the cross-sections. So having the accurate cross-section definition is very important to get more reliable output for the flood model. In this study both measured cross-sections and DTM derived cross-sections were used as Y-Z profile (Figure 4-5).



Type : Y-Z Profile

Cross section : 3

Figure 4-5 Data editor window of river cross-section

In the 2D grid options a friction layer was added with variable friction values according to land cover type by using Manning's surface roughness coefficients. Furthermore, a number for history stations were added to record the water depth and several line measurements were added to record all fluxes through these measurement cross-sections. An example of the schematization is presented in Figure 4-6.

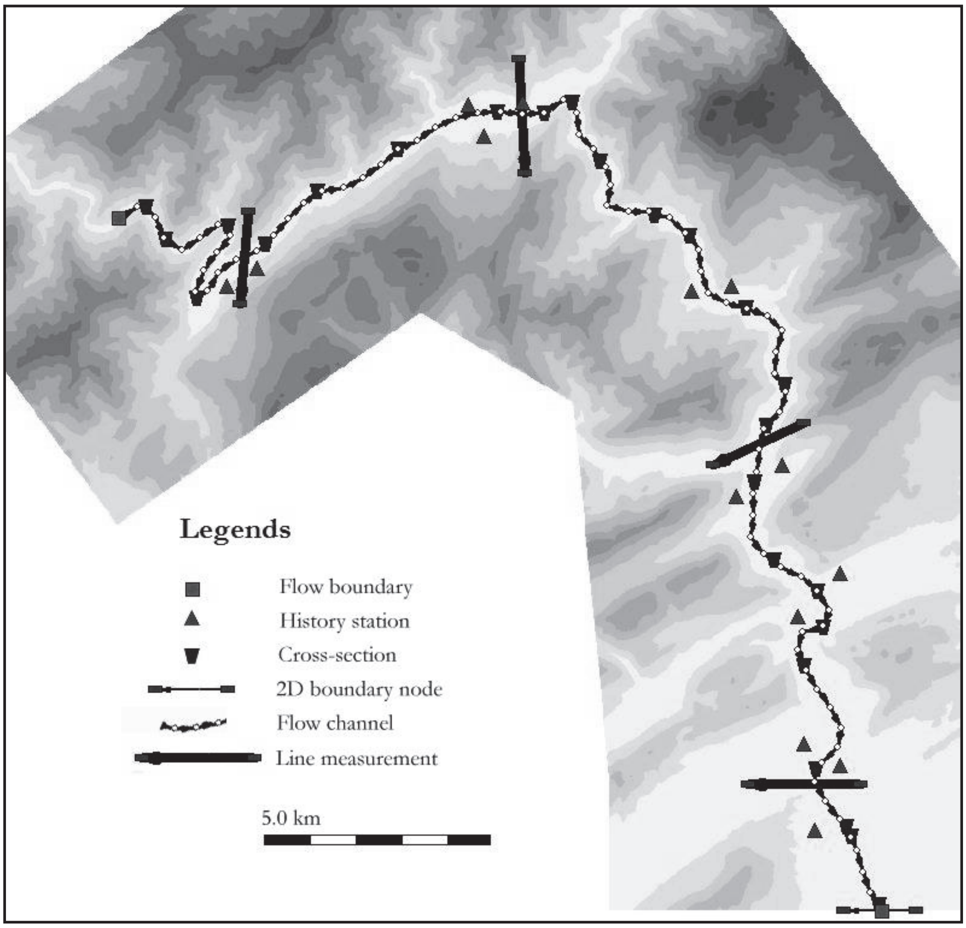


Figure 4-6 Schematization of SOBEK 1D2D flood model

4.3.2. Generation of parameter map from SOBEK output

The output data from SOBEK consist of a series of flood characteristics maps that show flood depth and flow velocity at different time steps and the output format is ASCII. In this study, five flood hazard parameter maps are generated by using an aggregation procedure (Figure 4-7) developed by Alkema (2007).

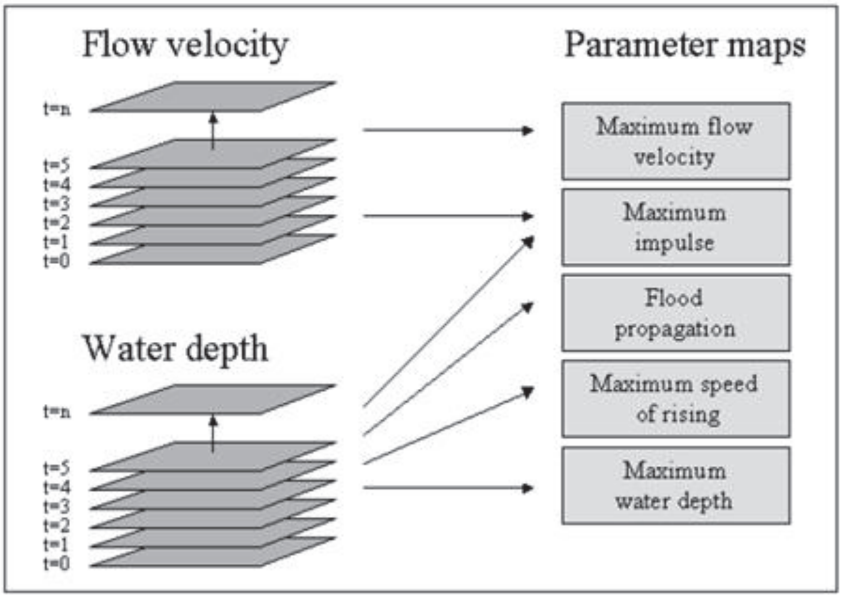


Figure 4-7 Transformation of model output maps into flood hazard parameter maps, aggregation procedure adopted from (Alkema, 2007)

Out of these five maps, Maximum flow velocity, maximum water depth and flood propagation maps are direct output from the SOBEK. In addition to these, one more hazard parameter map (sedimentation) that estimates the sedimentation and scouring is generated based on the method recommend by Kleinhans (2002) and the procedure described by Alkema (2007). A detailed description of the calculation for estimating scouring and sedimentation by this method is available in page 143-145 of Alkema (2007). However, the hazard parameter maps are briefly described in Table 4-2.

Table 4-2 Flood hazard parameter maps

Parameter maps	Unit	Descriptions
Maximum water depth	m	This map illustrates the maximum water depth achieved during inundation based on the specific scenario. The more the water depth the more the vulnerability of the elements at risk. This information is very helpful for model calibration as flood depth can be easily collected after flood event by using wetting signs.
Maximum flow velocity	m/s	This map illustrates the maximum flow velocity achieved during inundation based on the specific scenario. The high flow velocity can be dangerous for people as well as for cars because of chance to sweep. However, high flow velocity with low water depth may not be dangerous while low flow velocity with higher depth can be much more devastating.
Flood propagation/ warning time	h	This map shows the time at which a pixel is flooded for the first time. This information can be very helpful for evacuation planning as it provides the areas that are going to be affected earlier and thus have less warning time for preparation.

Maximum impulse	m^2/s	This map shows the maximum impulse achieved during inundation based on the specific scenario. It is calculated at each time step by multiplying water depth and flow velocity. Higher water depth with high flow velocity generates huge momentum and the damage will also be higher in this case or vice versa.
Maximum rising of water level	m/h	This map shows the maximum speed of rising of water level during inundation based on the specific scenario. It is calculated by subtracting two consecutive water depth maps and the obtained difference is divided by the interval between those two maps. This map gives an indication of highly dangerous areas where water level rise very fast and moving to higher ground may not be possible.
Sedimentation	-	This map gives an indication of potential areas to be affected by certain degree of scouring and sedimentation without estimation. The parameter map is helpful to identify areas with high sedimentation that requires more cleaning cost and time thus will delay the time to move back home after flood event.

4.3.3. Generation of Land use and land cover maps

There were no land use and land cover map available for study area. Therefore a land use and land cover map was generated from the available Google earth image (2010), but still there were requirement for validation and updating, because it was necessary to ensure whether the area had gone through any major changes for development activities within the year 2010 and 2011 or there is any new addition to update the available database. A physical survey of different land use classes was carried out to identify the changes or new additions. It was found from the ground truth checking that after the 2008 earthquake a large number of new buildings were constructed. One of the most important observation was the old Beichuan town is completely abandoned and under the government supervision it is going to be preserved as a earthquake museum and the affected people were rehabilitated in New Beichuan town which is located about 34 kilometre away from this area. Later on these observations were used to update the land use and land cover map which was generated from the Google earth image.

4.3.4. Elements at risk identification

The exposure and the vulnerability of the elements at risk varies on the spatial interaction of elements at risk and hazard (Westen & Kingma, 2010). As it was mentioned in chapter 2 section 2.9 who, what and where these three are the main key of spatial vulnerability assessment (Turner, et al., 2003); an element at risk map were prepared. In order to assess spatial vulnerability, firstly the elements at risk identification were performed in this research. The elements at risk were identified from the Google earth image. Then the elements at risk map were updated by the ground truth checking during field survey. The entire study area were classified in different land use type such as residential area, industrial area, roads, agricultural land, essential facilities (fire service, hospitals, schools) and so on. Considering the large area the buildings were aggregated by the characteristics of buildings in particular number of floors. The final output of this section was an element at risk map which is source of different indicator maps. The following classification was followed for elements at risk:

Table 4-3 Classification of elements at risk (adapted from (Westen & Kingma, 2010))

Physical elements Building height	**Transportation facilities** Roads
Population Population density per pixel	**Economic value** Buildings, agricultural lands, forest
Essential facilities Emergency shelters, Schools, Hospitals, Fire Brigades, Police station.	

4.4. Hazard Assessment and generation of indicator Maps

From 1D2D SOBEK flood modelling a group of parameter maps derived for three specific scenarios such as spill way, 25% dam break and 50% dam break. These maps were used as input for flood hazard assessment. The result of hazard assessment will be discussed in chapter: 5. In addition, the flood hazard maps were used as indicator maps to assess vulnerability of the elements at risk and semi quantitative risk assessment. From the result of 2D flood modelling six indicator map were prepared e.g. maximum water depth, maximum flow velocity, maximum impulse, maximum rising of water level, warning time and sedimentation. On the other hand from elements at risk identification another group of indicator maps were produced e.g. population density map, land use map, building map by no. of floors, road network map, hospital accessibility map, shelter centre accessibility map.

4.5. Vulnerability assessment

The focus of this study is mainly on physical vulnerability. The Dutch damage function (see chapter 6 and section 6.2) is applied for physical vulnerability assessment of residential building. Damage function is the relation between hazard intensities and degree of damage (Westen & Kingma, 2010). Two types of damage functions are adopted i.e., damage function for low rise dwelling and damage function for medium rise dwelling and applied for single storied and multi storied buildings respectively. Vulnerability was assessed in ILWIS. First the residential buildings were divided into two categories i.e., single storied and multi storied. Then two functions were created in ILWIS by using the flood damage functions for two different building types. After that, two functions are assigned to respective building types. For each grid cell no. of floors of the building and water depth was known and hence by using the function the vulnerability for each gird cell was calculated.

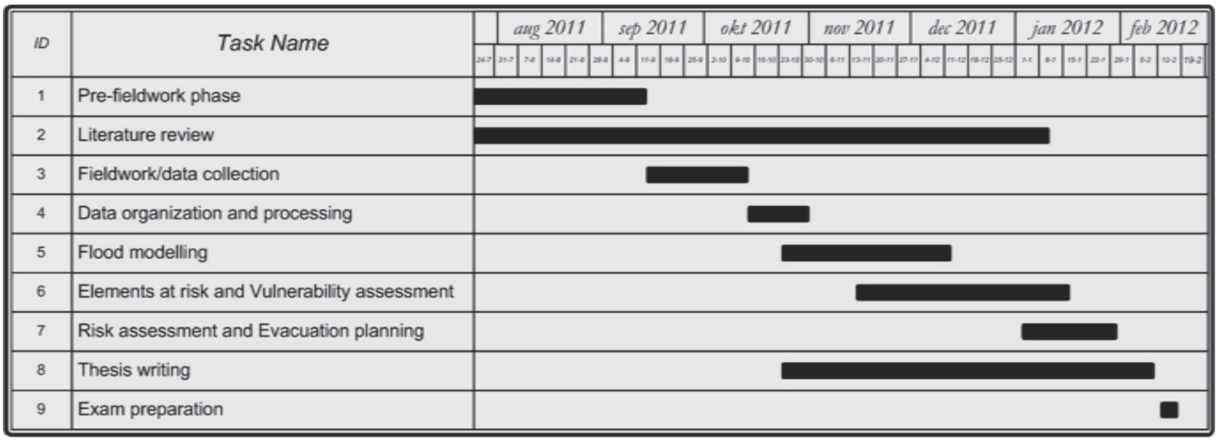
4.6. Risk assessment

Semi quantitative approach for risk assessment was carried out for this study. To carry out this approach, several factor maps were generated from the elements at risk such as affected population map, accessibility to shelter centre map, accessibility to hospital map etc (see chapter 6). Furthermore, all the indicator maps from flood hazard assessment output, event damage map from flood vulnerability assessment and factor maps from elements at risk are incorporated to conduct the risk assessment (see chapter 7). The output map is a semi-quantitative flood risk map.

4.7. Research challenge

This study has been carried out in a data poor environment which is further influenced by the restricted government policy for the foreigners as well as language impeded the data collection process. As in SOBEK huge computational time is required for flood modelling of a large area in this case 45 km long river channel, therefore the risk of the model crush and reduction of the DTM resolution was another big challenge. For calibrating the model several changes were made such as cross-section modification, friction map adjustment etc, but as for each simulation it took about 14 hours hence the model calibration became very difficult and time consuming.

4.8. Work plan



5. FLOOD HAZARD ASSESSMENT

Flood hazard assessment is one of the objectives of this study. This chapter is mainly about flood hazard assessment by using 1D2D flood modelling in SOBEK. In addition, this chapter will also incorporate the generation of the input maps for further vulnerability and risk assessment.

5.1. Digital Terrain Model (DTM) Processing

The DTM that is used for this study was generated from interpolation of 20 m contour liens. As the contour lines being considered as secret document hence from the CDUT authority only the interpolated 10m and 25m metre DTM was provided for this study. The DTM was processed in ILWIS by using the tool DEM hydro processing. Firstly the DTM was visualized as a colour composite raster maps which is a combination of three different shadow maps to see the relief of the study area. Thereafter, the local depressions of the DTM were filled by using fill sink operation in ILWIS. Next to this, all the sub operations under the "flow determination" and "Network and Catchment Extraction" operation was carried out to extract the drainage network, catchments and the longest flow path of the study area (Figure 5-1). The outputs confirmed that the DTM is hydrologically correct and afterwards the DTM was exported to ASCII format to use as 2D grid input in SOBEK.

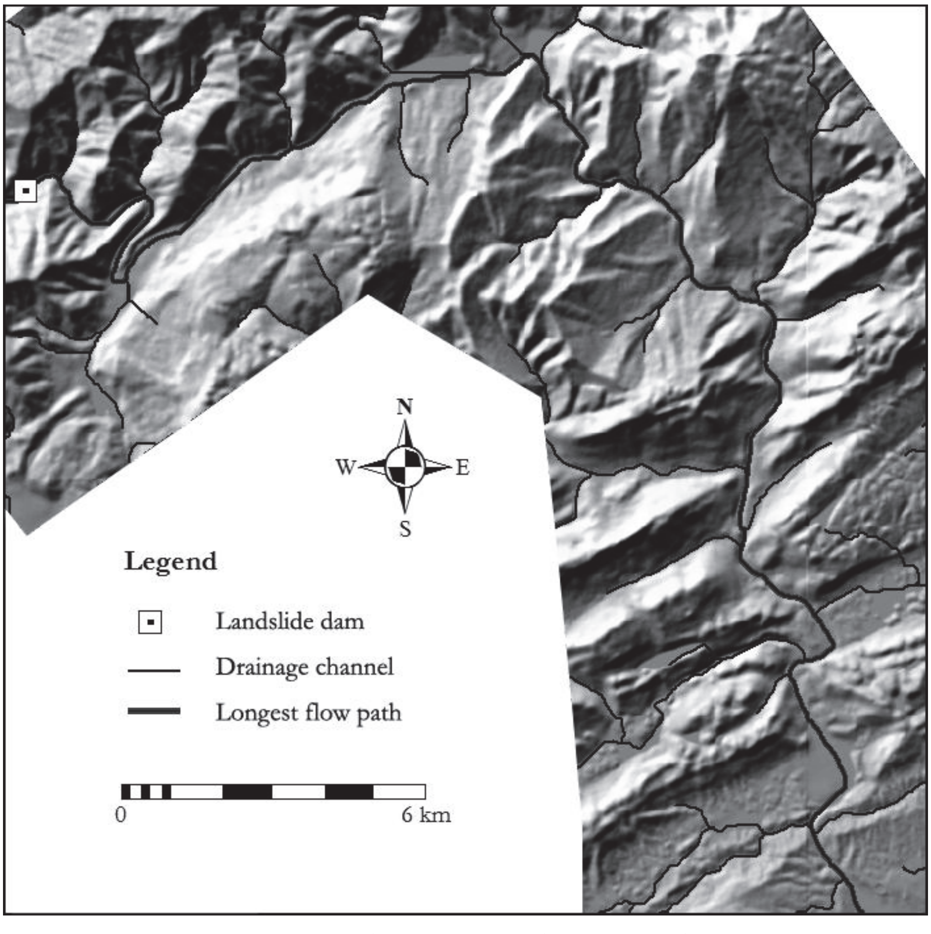


Figure 5-1 Processed DTM visualised as color shadow map

5.2. Generation of Friction Map

The DTM represents the terrain without considering real world surface components like buildings, water bodies, forest and so on. Thus to generate a real world surface a friction was constructed from the land cover map by assigning the Manning's surface roughness coefficient to the respective land cover types (Figure 5-2). In addition, the surface roughness coefficient of the water body was adjusted to improve the output results from the SOBEK 1D2D dynamic flood modelling. After preparing the friction map it was exported as ASCII file to use as a 2D friction data in SOBEK.

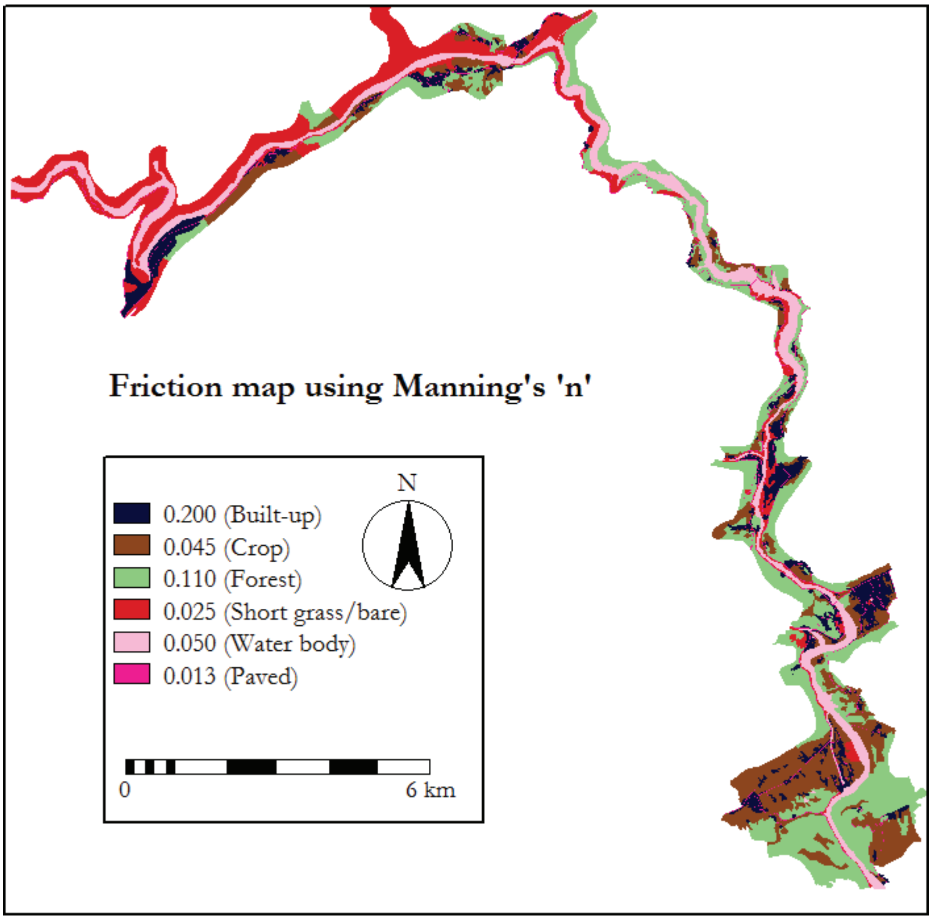


Figure 5-2 Friction map according to land cover type using Manning's 'n' (Alkema, 2007; Chow, 1959; Guarin, 2008)

5.3. Hazard Assessment using SOBEK 1D2D

5.3.1. Flood Hazard Scenario

The scenarios that are going to be developed in this study are not a regular flood situation. The flood hazard that exists in this case is a quaternary effect of 2008 Wengchuan earthquake. Firstly, the earthquake happened then as a secondary effect landslide occurred that blocked the river and caused tertiary hazard as upstream flooding. This study is going to assess the quaternary hazard as landslide dam break flood and its consequences downstream along Jian River. Hence, the flood hazard scenarios for this study were developed based on literature as spillway flood, 25% dam break and 50% dam break. Spillway flood is the controlled discharge operated by Chinese government between June 8 and 11, 2008. 25% dam break and

50% dam break scenario are adopted from Cui, et al. (2010) which correspond to 25% and 50% failure of the total dam volume respectively.

5.3.2. Generation of Input Hydrographs

Hydrograph is a very important input for simulating the SOBEK flood model. For the spillway scenario the measured hydrograph was used which was adopted from Liu, et al. (2009) and it is shown in Figure 5-3. The hydrographs for 25% break and 50% break scenarios (see Figure 5-3) were adopted from Cui, et al. (2010) where the peak discharge corresponds to his peak discharge of 25% break and 50% break respectively. The hydrographs of 25% break and 50% break were generated by multiplying the spillway hydrograph approximate with 2 and 4 respectively. However, in a similar study conducted in 2012 by Tang (in press), these 25% break and 50% break scenario corresponds to 45% break of the total dam volume and whole collapse scenario respectively considering the total volume of outflow.

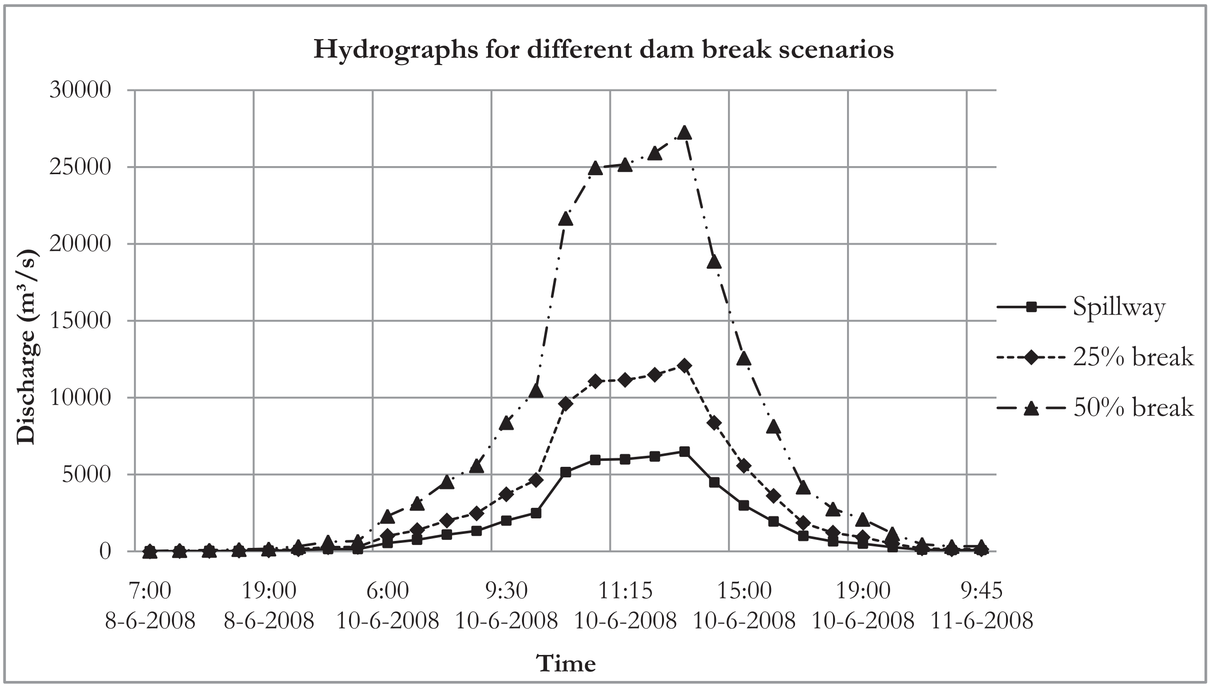


Figure 5-3 Hydrographs for different flood scenarios used as upstream boundary condition
Spillway hydrograph adopted from (Liu, et al., 2009)

5.4. Boundary Conditions

For SOBEK 1D2D flood model upstream boundary condition was specified by the generated hydrographs (see Figure 5-3). The downstream boundary condition was defined as uniform water level both for 1D and 2D. The water level was changed for calibrating the model and the water level that used finally for simulation is 523 m above datum.

5.5. Reconstruction of Spillway scenario

The flood model was constructed as described in chapter 4 subsection 4.3.1.2. The spillway scenario was used for calibrating the model as field measurements available from literature and filed survey. Spillway flood is a known situation that could be used to make the model more realistic and hence this scenario was reconstructed by calibrating the model. The results of the spillway flood scenario were used to validate the model as well.

5.5.1. Calibration and sensitivity analysis

The flood model was calibrated in different ways through a series of test run. Firstly the model was schematized and simulated with uniform friction coefficient of Manning's n 0.03 (in S.I. units). This uniform value is selected as the river is mountainous with gravel and boulder. Thereafter, the friction layer generated from the land cover map was added to make the make model more realistic with the real world scenario. Besides, addition or elimination of cross sections at different locations and adjustment of the mismatch of the cross sections with 2D grid were also carried out to achieve better results (see Figure 5-5).

Figure 5-4 shows a comparison among the volume of water entering in the upstream and the volume of water discharging in the downstream boundary. From the comparative figure it is visible that simulation using the friction layer with higher friction value delayed about 1 hour to reach water volume of 80 million m^3 compared to the simulation using uniform friction 0.03.

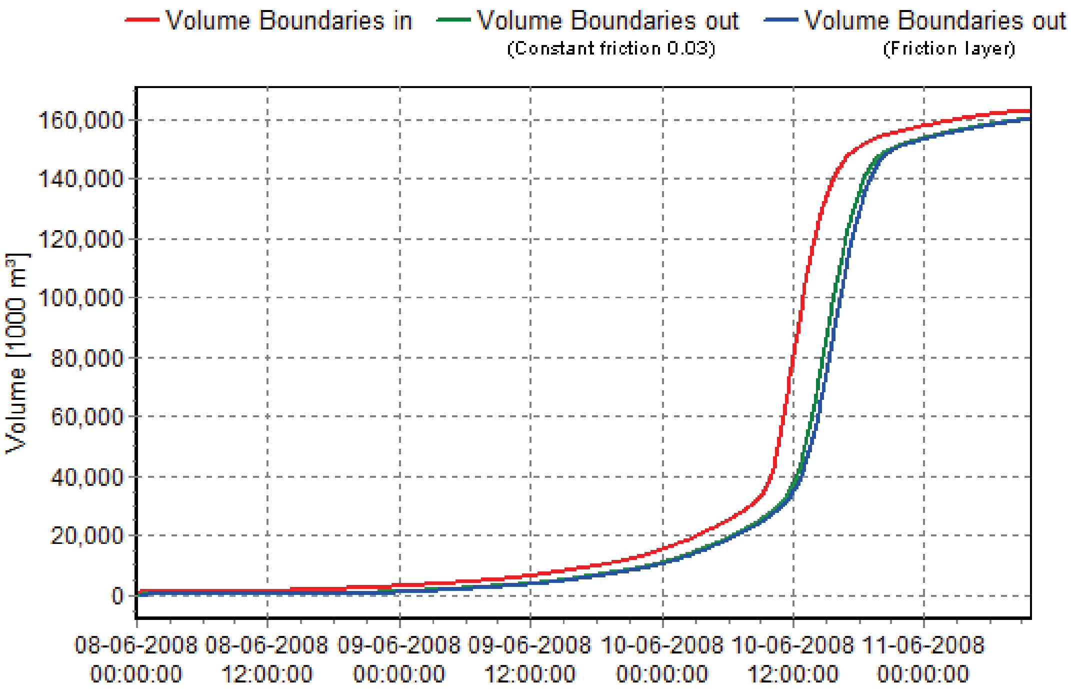
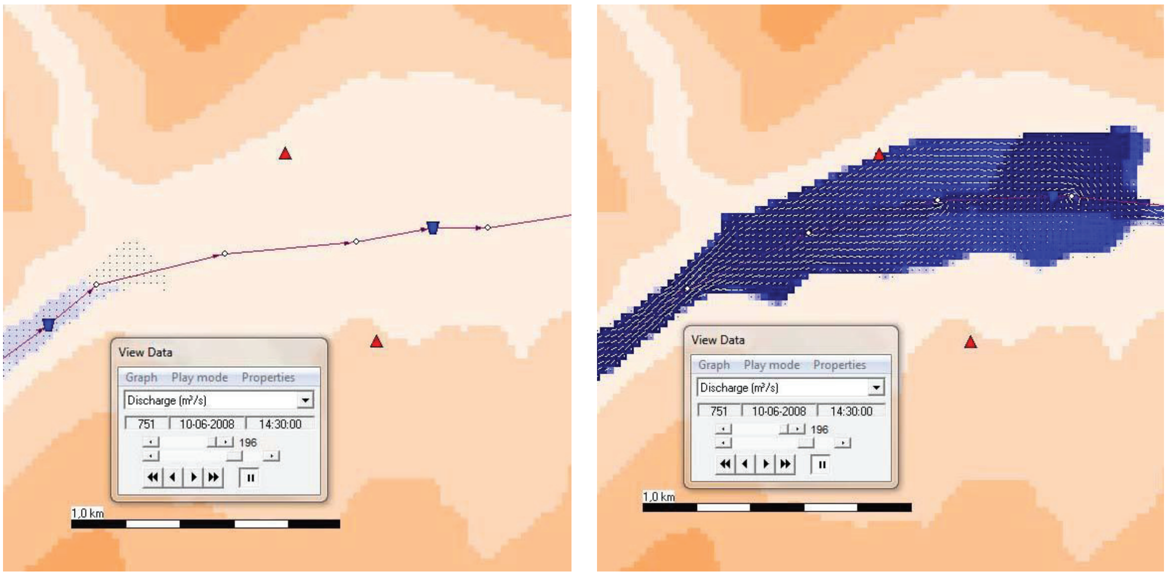


Figure 5-4 Comparison of water balance boundaries in and boundaries out for different friction coefficient



Discharge (m³/s)
751 10-06-2008 14:30:00
196

Discharge (m³/s)
751 10-06-2008 14:30:00
196

Figure 5-5: Adjustment of the cross section and effect on water flow near Dengjia village

5.5.2. Validation

During field survey, flood depths at several locations were collected from the flood affected people as well as by observing the wetting marks in the wall (see Figure 5-6). The figure shows that the first floor of the building flooded with a water depth of about 4.5 meter while the maximum water depth achieved in this house by the model is 5 meter. Table 5-1 shows a comparison of observed water depth collected during field survey and modelled water depth.

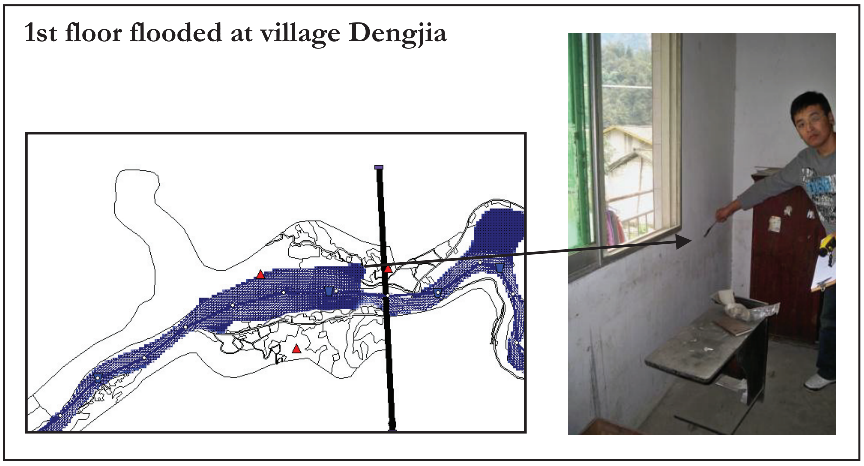


Figure 5-6 Flood depth observed in the field and compared with model; wetting mark

Table 5-1 Comparing observed and modelled water depths

Location	Observed water depth (m)	Modelled water depth (m)
1 (Dengjia)	4.5	4.8
2 (Hanzeng)	0.15	Not flooded
3 (Yuanping, Xiangshui)	2.5	3.12

The measured flood characteristics i.e., measured peak discharge and water level at different locations of the spillway flood were described in the study of (Liu, et al., 2009). These measurements are used for validating the model developed in this study. A comparison of measured peak discharge and water level with the modelled peak discharge and water level is presented in Table 5-2.

Table 5-2 Comparing peak discharge and water level between measured (Liu, et al., 2009) and modelled

	Peak discharge (m^3/s)		**Peak water level (m)**	
Location	**Measured**	**Modelled**	**Measured**	**Modelled**
Beichuan Hydrological Station	6500	6300	620.5	621.5
Tongkou Hydrological Station	6100	6000	549.75	551

From the table it is exposed that at both of the locations the modelled peak water level is about 1 m meter higher than that of the measured level. Modellded peak discharge at Beichuan hydrological station is lower than measured and at Tongkou the discharge is very close. The differences is occurred may be due to the quality of DTM, cross section, friction layer as well as uncertainties of the SOBEK flood model itself.

5.6. Generation of parameter map from SOBEK output

As described in the chapter four subsection 4.3.2, six parameter maps were generated for each flood hazard scenario. The parameter maps for spillway scenarios, 25% dam break scenario and 50% dam break scenario are presented in Figure 5-7, Figure 5-8 and Figure 5-9 respectively.

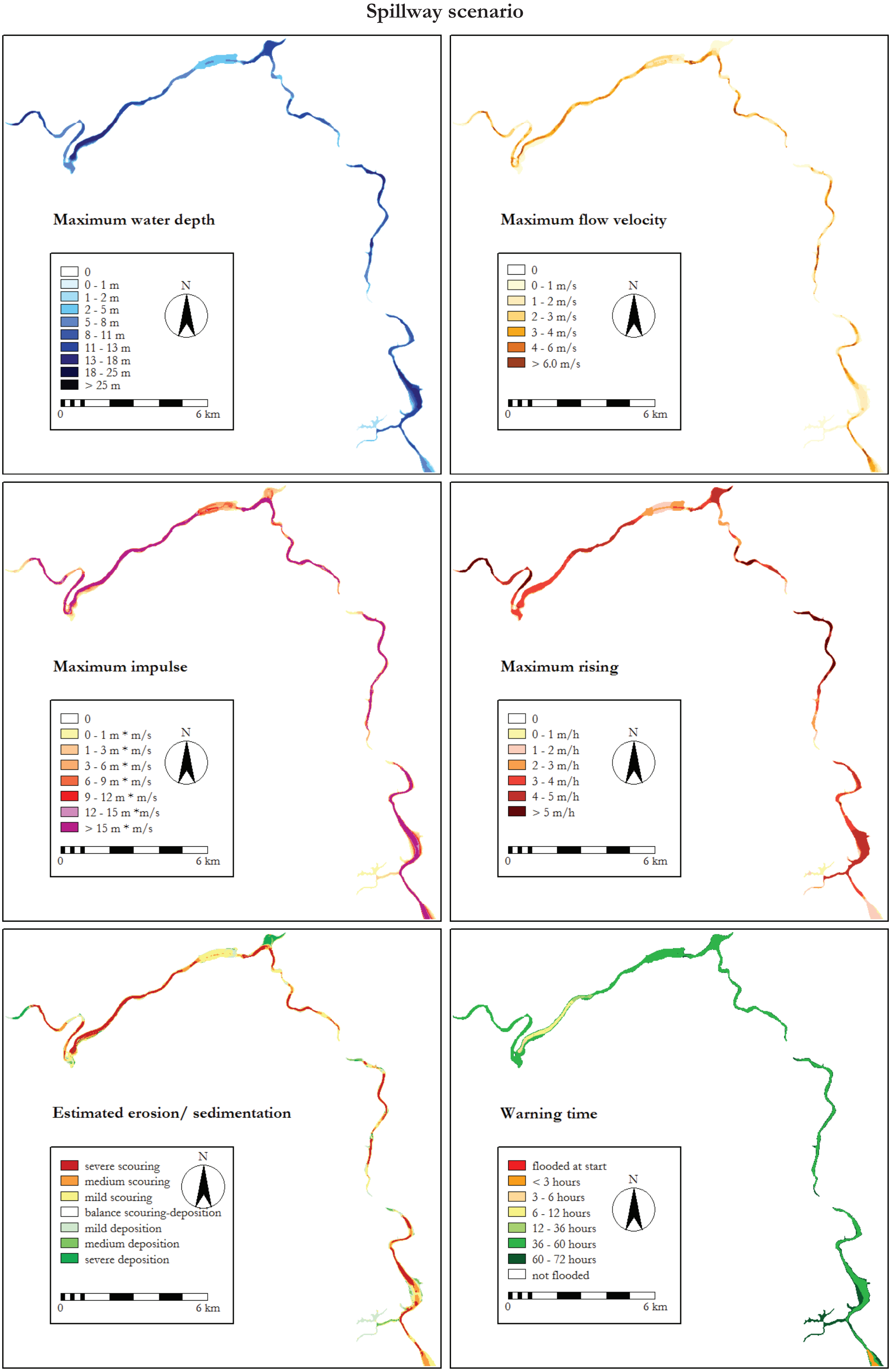


Figure 5-7 Flood parameter maps for spillway scenario

25% dam break scenario

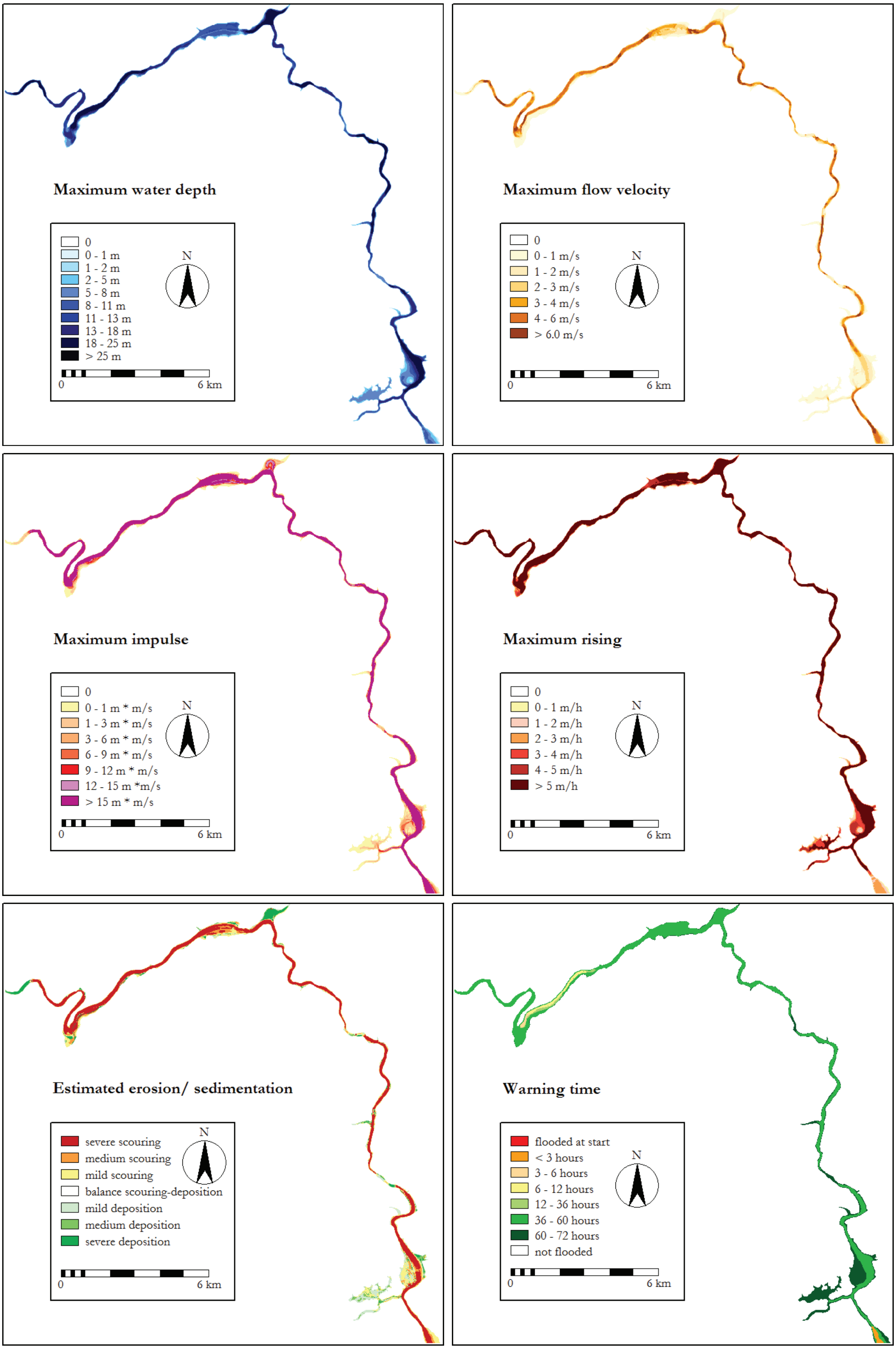


Figure 5-8 Flood parameter maps for 25% dam break scenario

50% dam break scenario

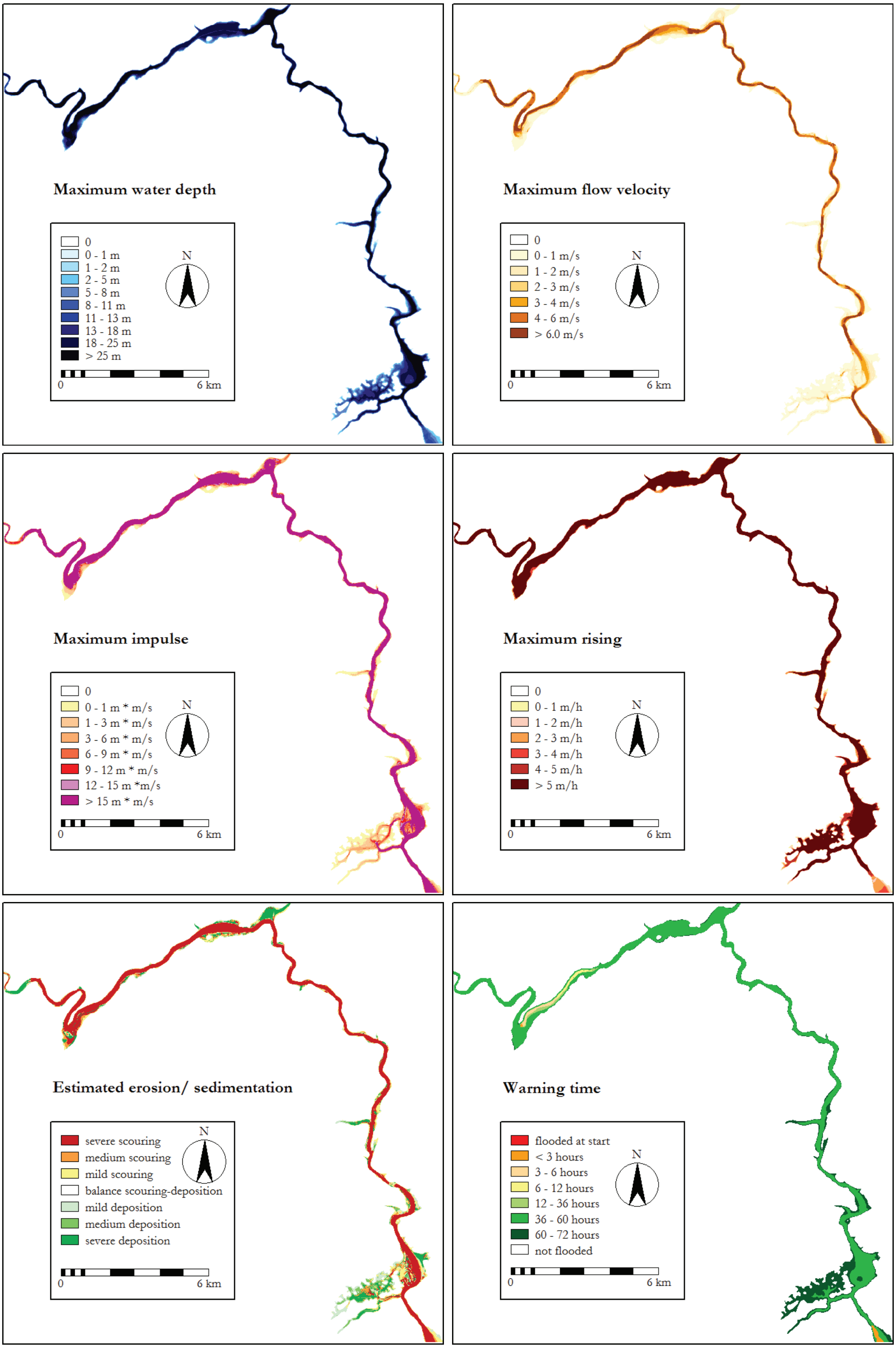


Figure 5-9 Flood parameter maps for 50% dam break scenario

5.6.1. Comparing maximum water depths

The maximum water depths achieved during different scenarios are varying a lot. In the spillway scenario the maximum water depth is about 17.6 m while in 25% break and 50% break the maximum water depth is about 25 m and 41 m respectively. A comparison is made among three scenarios based on the classified water depth maps and the results are shown in Figure 5-10.

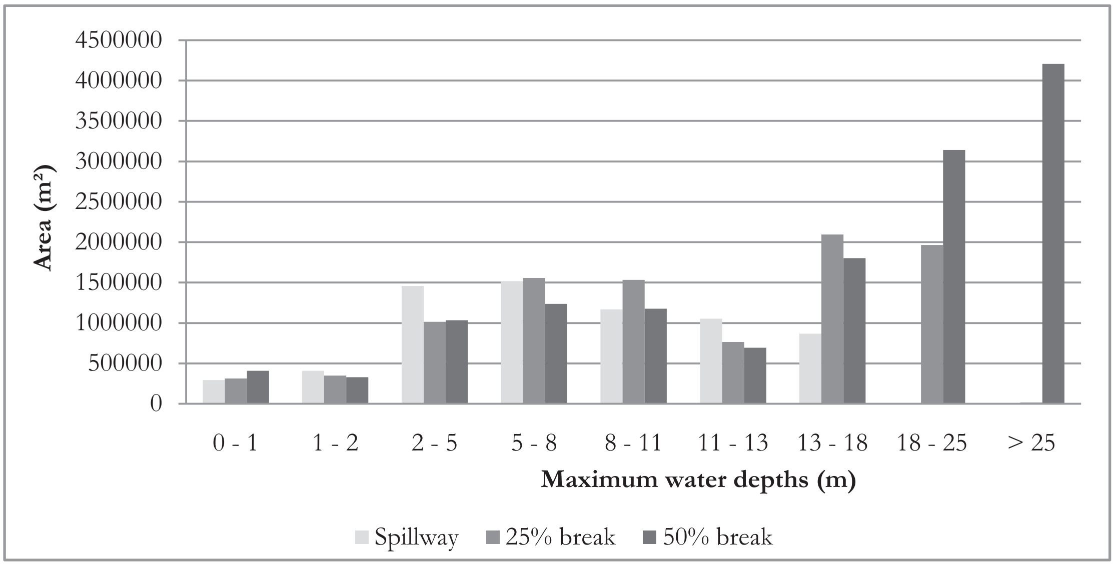


Figure 5-10 Comparing maximum water depths

From the figure it is exposed that, the water depth is increased tremendously according to level of dam breaks and the higher the percentage of dam break the higher the level of damage will be.

5.6.2. Comparing maximum flow velocities

Maximum flow velocities generated from different scenarios are compared in the Figure 5-11. The figure shows that in all scenarios the maximum area covered by the flow velocity category of 0 -1 m/s. On the other hand, the in 50% dam break scenario about 2.46 km² area was affected by flow velocity more than 6 m/s which is 17.5% of the total flooded area.

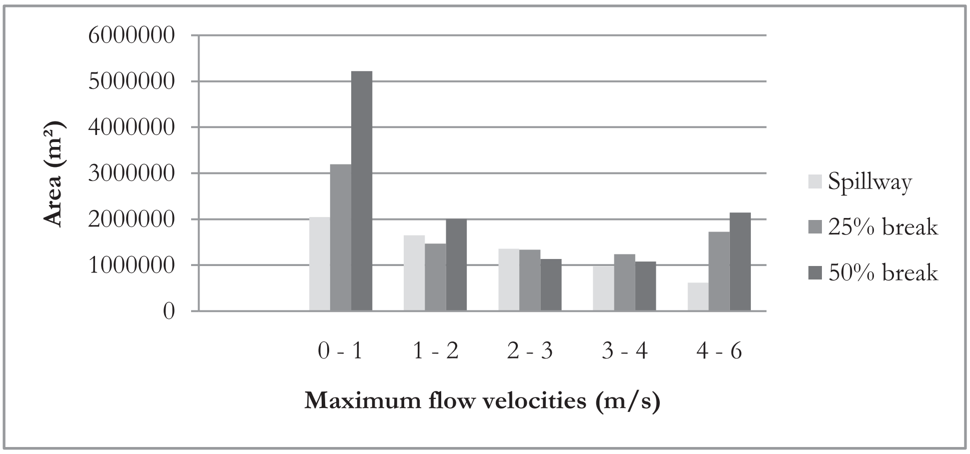


Figure 5-11 Comparing maximum flow velocities

5.6.3. Comparing maximum impulse

According to the illustration of chapter four subsection 4.3.2 it can be said that, the maximum impulse is a very good indicator for flood hazard assessment. Based on different flood scenarios a comparison was made and it is presented in Figure 5-12. From the figure it is evident that, in all the scenarios about 50% of the total flooded area has a maximum impulse more than 15 m²/s.

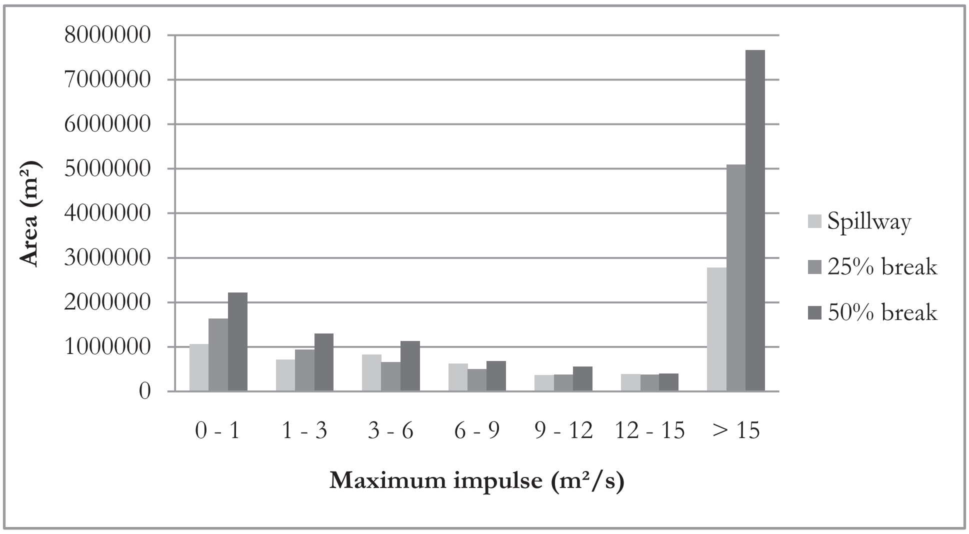


Figure 5-12 Comparing maximum impulse

5.6.4. Flood extent map

Maximum water depth maps were used to make the flood extent map (see Figure 5-14). In addition, maximum flood extent maps for different dam break scenarios were compared by using the flooded area and the result is shown in Figure 5-13. From the figure it is visible that the flooded area is increased gradually according to the increase of the dam break. In addition, from the spillway scenario, the flooded area increased about 2.85 km^2 in 25% break scenario while in 50% break scenario the affected area increased about 7.28 km^2.

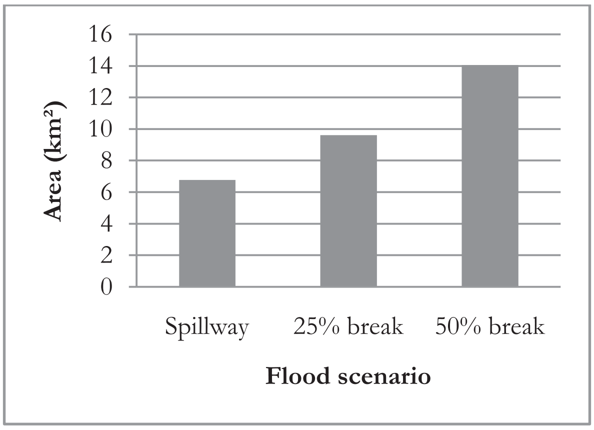


Figure 5-13 Flood affected area for different scenarios

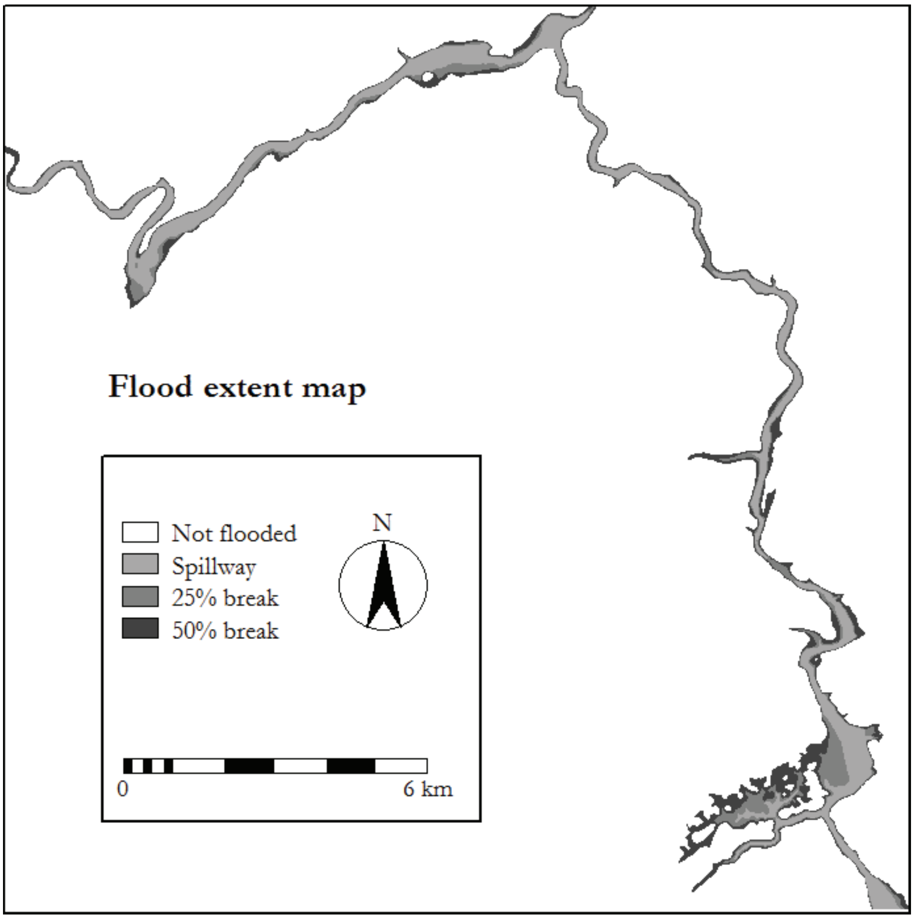


Figure 5-14 Maximum flood extent map for different dam break scenarios

5.7. Limitation of the model

This model did not consider the huge amount of sediment that could be transported along downstream with the water. Tangjiashan landslide dam is composed of metamorphic slate, sandstone, sedimentary rock with fine fragments of clay and mud. The blockage length was about 803 meter along the channel and the width is 611 meter across the channel with a total mass of 20.37 million m3 (Cui, et al., 2009). According to (Cui, et al., 2010) “the outflow deposited 5 million m^3 of sediment downstream from the dam”. Therefore, it is very devastating for the study area and it is one of the limitations as it is not considered in this study. In addition, the flood characteristics including sediment could be different as well as could provide more realistic results.

6. ELEMENTS AT RISK AND FLOOD VULNERABILITY ASSESSMENT

One of the main objectives of this study is to assess flood vulnerability for the elements at risk. Therefore it was needed to identify the elements at risk in study area. Image interpretation, elements at risk map overlaying in GIS, vulnerability curve to assess physical vulnerability and event damage calculation are the main techniques applied in this chapter. Analysis result from chapter 5 and field data are the main input for this chapter to perform vulnerability assessment of the elements at risk.

6.1. Elements at Risk assessment

The total elements at risk exists in the study area is represented in the land use map (Figure 6-1). The land use of the study area has been identified from the Google earth image and necessary modification is carried out according to the cross check during field visit.

6.1.1. Total elements at risk map

Forest and agriculture are the prominent land use type in the study area. Moreover, open space on mainly the steep slope area of the deep river valley and water body mainly the river also cover a significant percentage. While commercial land use comprise the lowest percentage of the total area. Table 6-1 below gives the over view of the land use category in the study area.

Table 6-1 Land use category of the study area (Author 2012)

Land use category	**Area (sq km)**	**Percentage (%)**
Residential	1.64	5.22
Residential mixed with commercial	0.18	0.59
Industrial	0.86	2.73
Recreational	0.60	1.90
Agriculture	6.25	19.92
Forest	9.77	31.17
Essential facilities	0.13	0.42
Commercial	0.02	0.06
Road	1.04	3.32
Open space	5.78	18.42
Water body	5.09	16.24
Total	**31.36**	**100**

The elements that are exposed to flood hazard are considered as elements at risk and this is identified by overlaying the land use map with the flood extent map. The total elements at risk for different land use class based on 50% dam break scenario are shown in Figure 6-2. A comparison between exposed elements at risk in relation to the total area is presented in Table 6-2.

Table 6-2 Percentage of exposed Elements at risk for different scenarios

Elements at risk	**Scenario**					
	Spillway (% area exposed)		**25% dam break (% area exposed)**		**50% dam break (% area exposed)**	
	in terms of total area	**within land use type**	**in terms of total area**	**within land use type**	**in terms of total area**	**within land use type**
Residential	0.24	4.69	1.20	22.94	2.34	44.88
Residential mixed with commercial	0.00	0.65	0.16	27.45	0.27	45.58
Industrial	0.46	16.89	0.78	28.72	1.37	50.26
Recreational	0.98	51.49	1.38	72.87	1.66	87.47
Agriculture	2.45	12.29	4.85	24.32	7.74	38.87
Forest	1.25	4.01	2.06	6.62	3.99	12.82
Essential facilities	0.00	0.04	0.09	21.09	0.17	40.30
Commercial	0.01	16.32	0.03	45.98	0.04	67.36
Road	0.42	12.76	0.85	25.54	1.46	43.91
Open space	3.31	17.95	4.44	24.11	6.21	33.72
Total	**9.13**	--	**15.84**	--	**25.26**	--

The flooded area increased as the level of landslide dam break flood water volume increased. In case of spillway flood the percentage of flooded area is about 9% while in 50% dam break scenario, the flooded area increased to 3 times than the spillway and hence will cause severe damage in the study area.

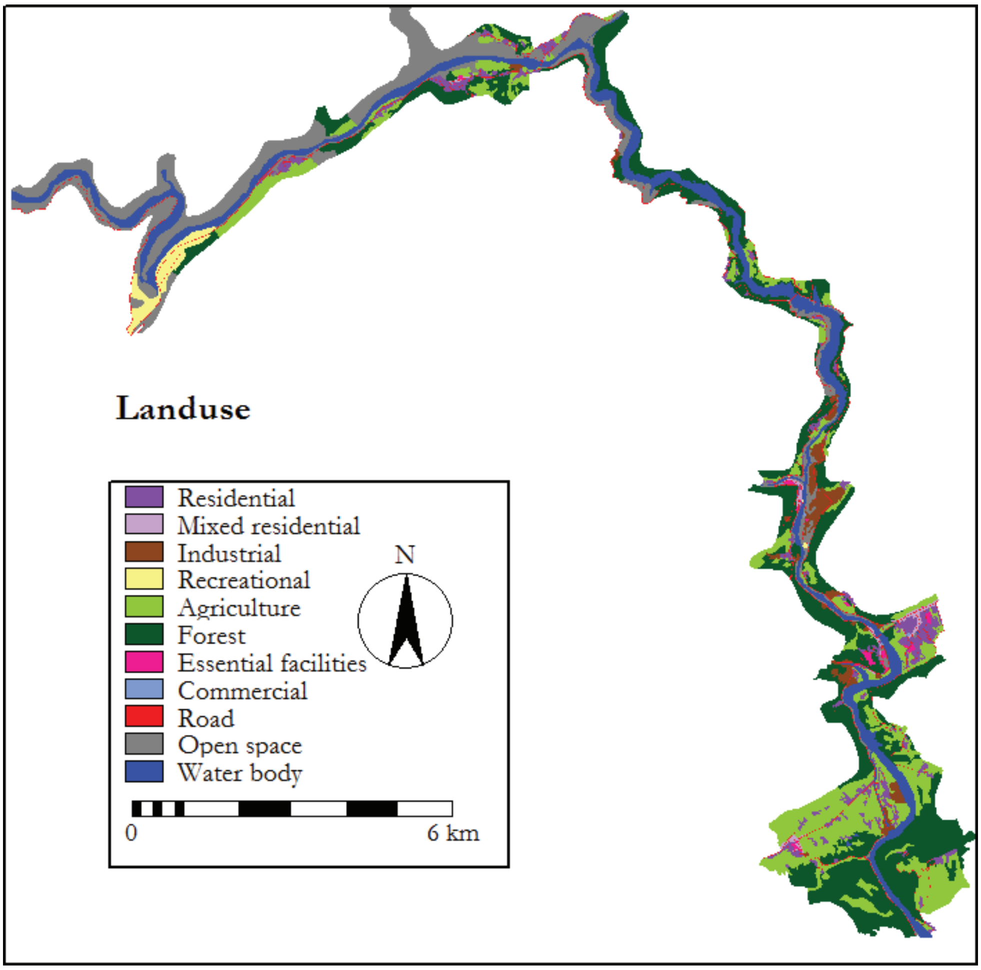


Figure 6-1 Land use map of the study area

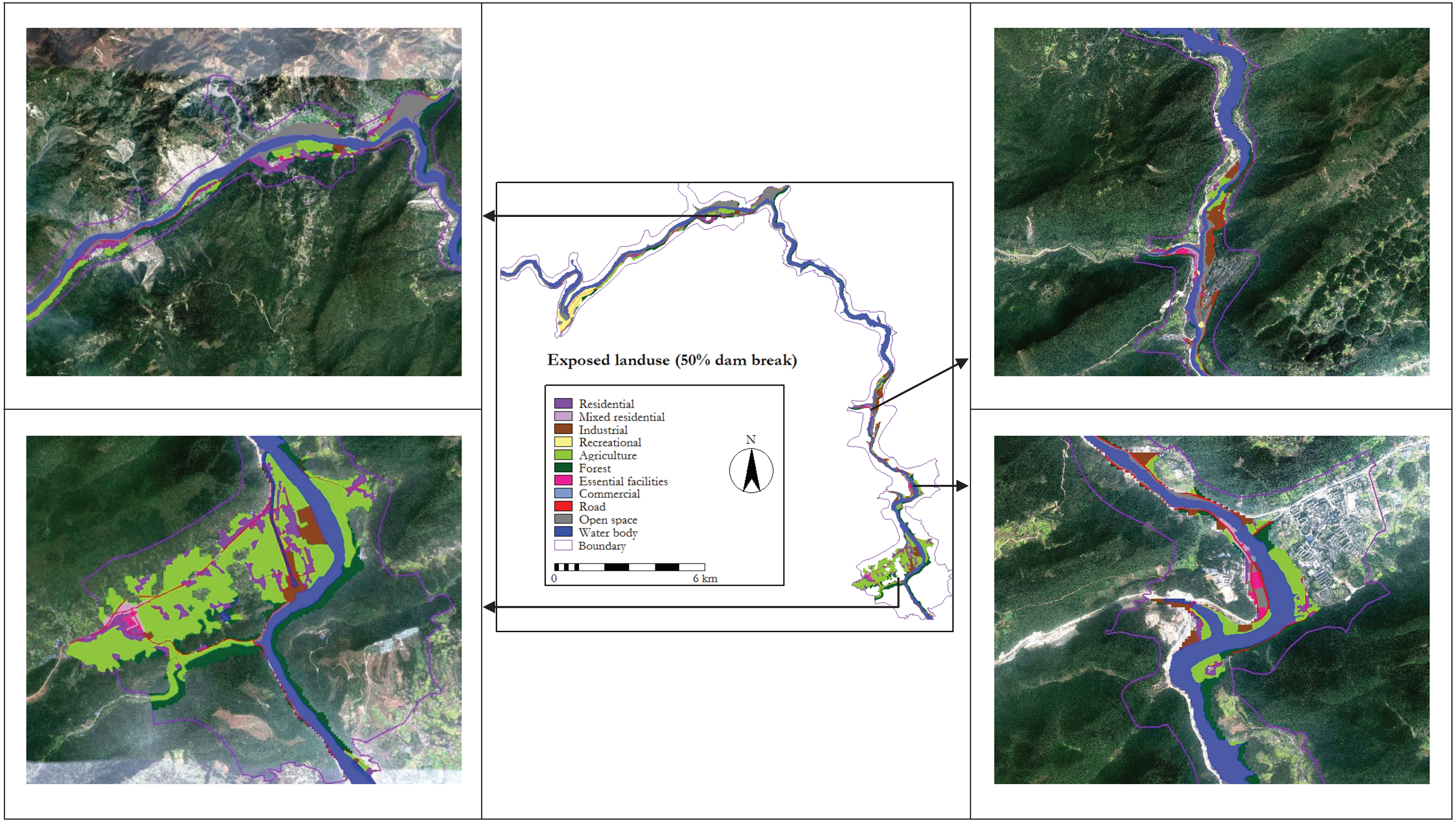


Figure 6-2 Elements at risk for land use in the study area due to 50% dam break flood

As the 50% dam break flood is affecting larger area hence it is considered as worst case scenario. In addition, the individual element at risk is identified based on the flood characteristics of 50% dam break scenario. Firstly, a comparison has been made between total area and exposed area in Figure 6-3. From the figure it is evident that, about 40% of the total area is exposed to flood in case of 50% break scenario.

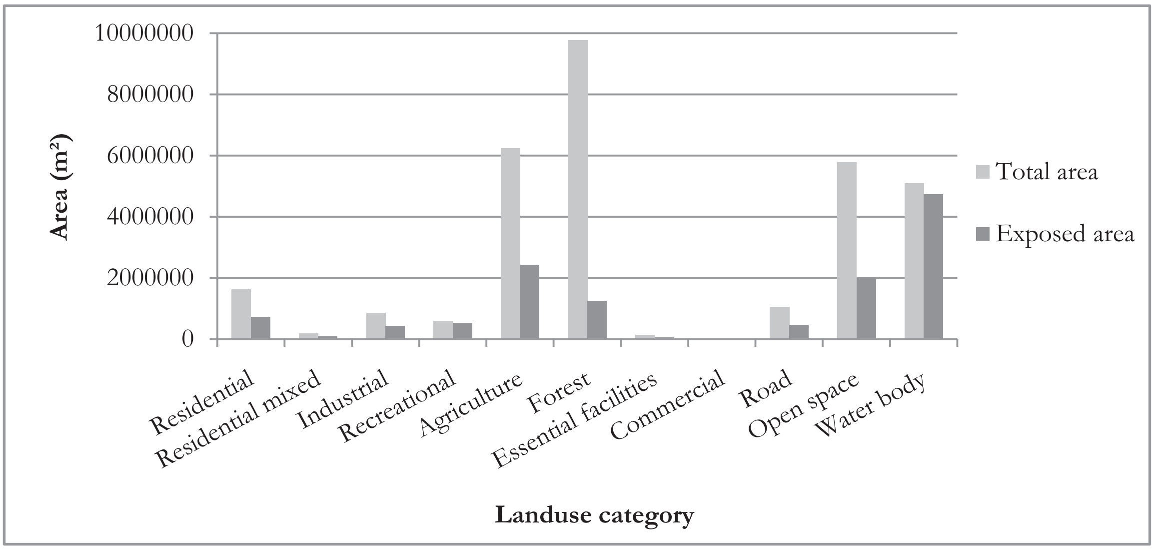


Figure 6-3 Comparing total area and exposed area by land use categories (50% break scenario)

6.1.2. Elements at risk map for residential building

Elements at risk map for residential building were generated by overlaying building map with maximum water depth map in GIS. This map is showing building blocks in flooded and non flooded zone for 50 % dam break scenario (see Figure 6-5). Total number of building of the study area was calculated by using average family size, number of floors and area of the buildings blocks. Average family size of China is 3.1 (CHINA.ORG.CN, 2008) and area and number of floors of the each building blocks are known from GIS. Hence the area of each building block is divided by the respective floor numbers and family size. According to the calculation the total number of buildings in the study area is approximately 2545 and the affected building by flood hazard for worst case scenario is about 1239 which is 49%.

6.1.3. Elements at risk map for road network

Road networks are classified into three major categories in study area e.g., primary, secondary and local road. Regional roads that connect the towns or villages considered as primary roads which plays important role for transportation of agricultural and industrial goods. Therefore these roads considered as very important for local economy. Major roads of the towns are considered as secondary roads. Access roads of the towns and villages are considered as local roads. Elements at risk map for road network is presented in length (km) by road type in Table 6-3 and Figure 6-4 is showing the comparison between the affected and not affected roads. This analysis result is derived from the overlaying of flood extent map with road network map in GIS (see Figure 6-6). It is found from the worst case scenario analysis that in total 46.57 km road will be affected which is around 44% of the total road network.

Table 6-3 Affected road by type

Road Type / Area	Total road (km)	Affected road (km)	Not affected (km)
Primary	64	27	36
Secondary	24	12	12
Local	17	7	10
Total	105	46	58

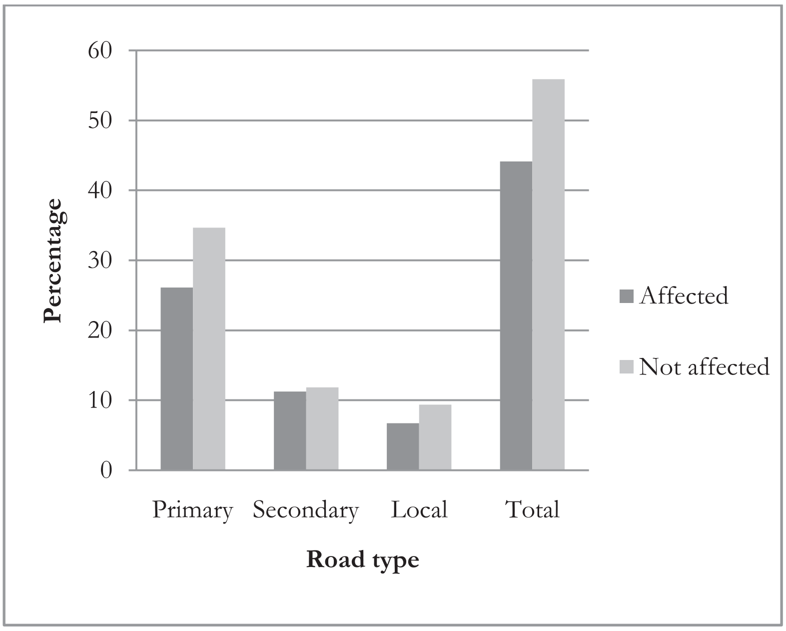


Figure 6-4 Percentage of affected road and not affected road

6.1.4. Elements at risk map for essential facilities

Essential facilities such as hospitals, schools, police stations and fire brigade are crucial at the moment of crisis. Therefore it is necessary that these facilities remain uninterrupted during occurrence of disaster. Properly distributed facilities with good accessibility can be very helpful to reduce casualties. From GIS analysis, it is found that, in the study area a noticeable number of essential facilities are located in flood hazard zone in case of 50% dam break flood scenario except the Hanzeng town area (see Figure 6-7).

6.1.5. Accessibility map preparation

By using distance calculation in ILWIS accessibility to hospital and accessibility to shelter centre map were prepared considering the road network and river channel (see Appendix 1). The roads were considered as highly accessible and the river is considered as inaccessible with this assumption weight map was prepared and used as input for distance calculation. The output maps were classified based on accessibility analysis of Perry (1983) and field observation. The classification are based on accessibility i.e., very high (0-0.4km), high (0.4-1 km), moderate (1 -2 km), low (2 – 3 km), very low (3 – 15 km) and inaccessible (> 15 km).

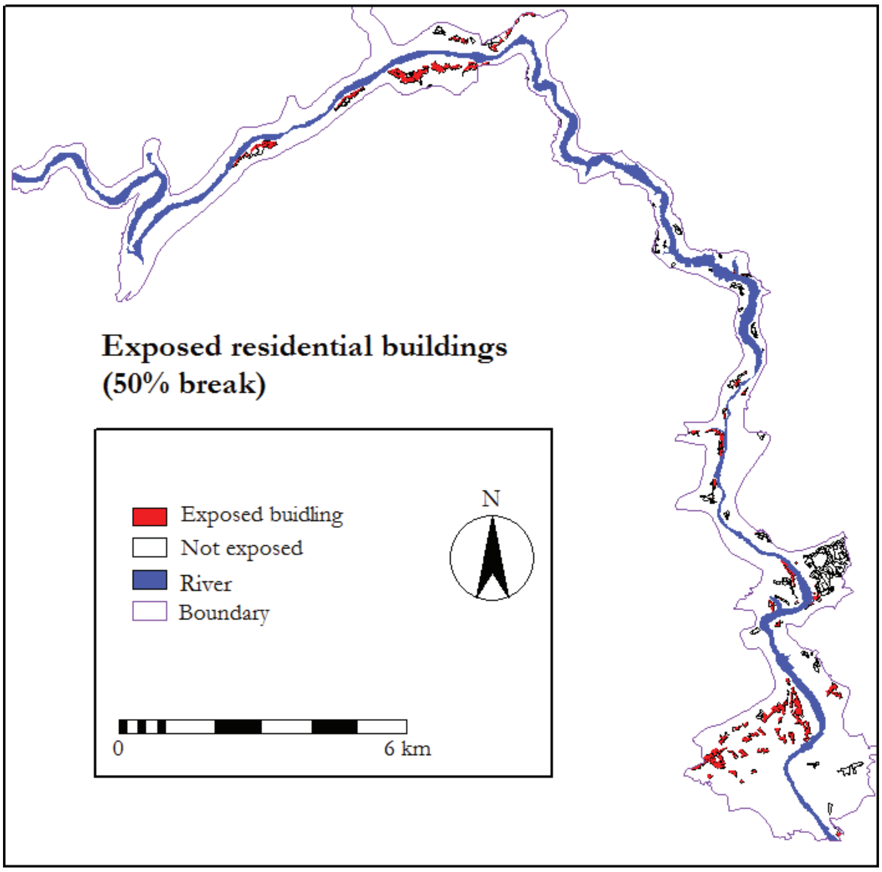


Figure 6-5 Elements at risk map for residential buildings for 50% dam break scenario

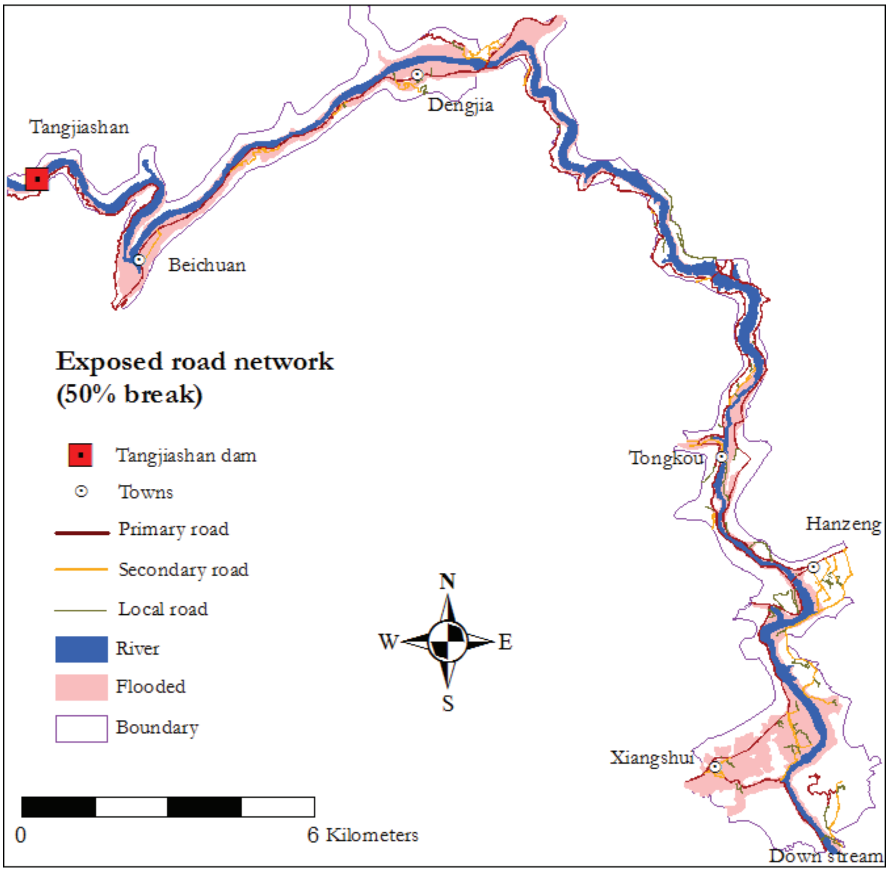


Figure 6-6 Exposed road network in 50% dam break (see Table 6-3 flood see for calculation result)

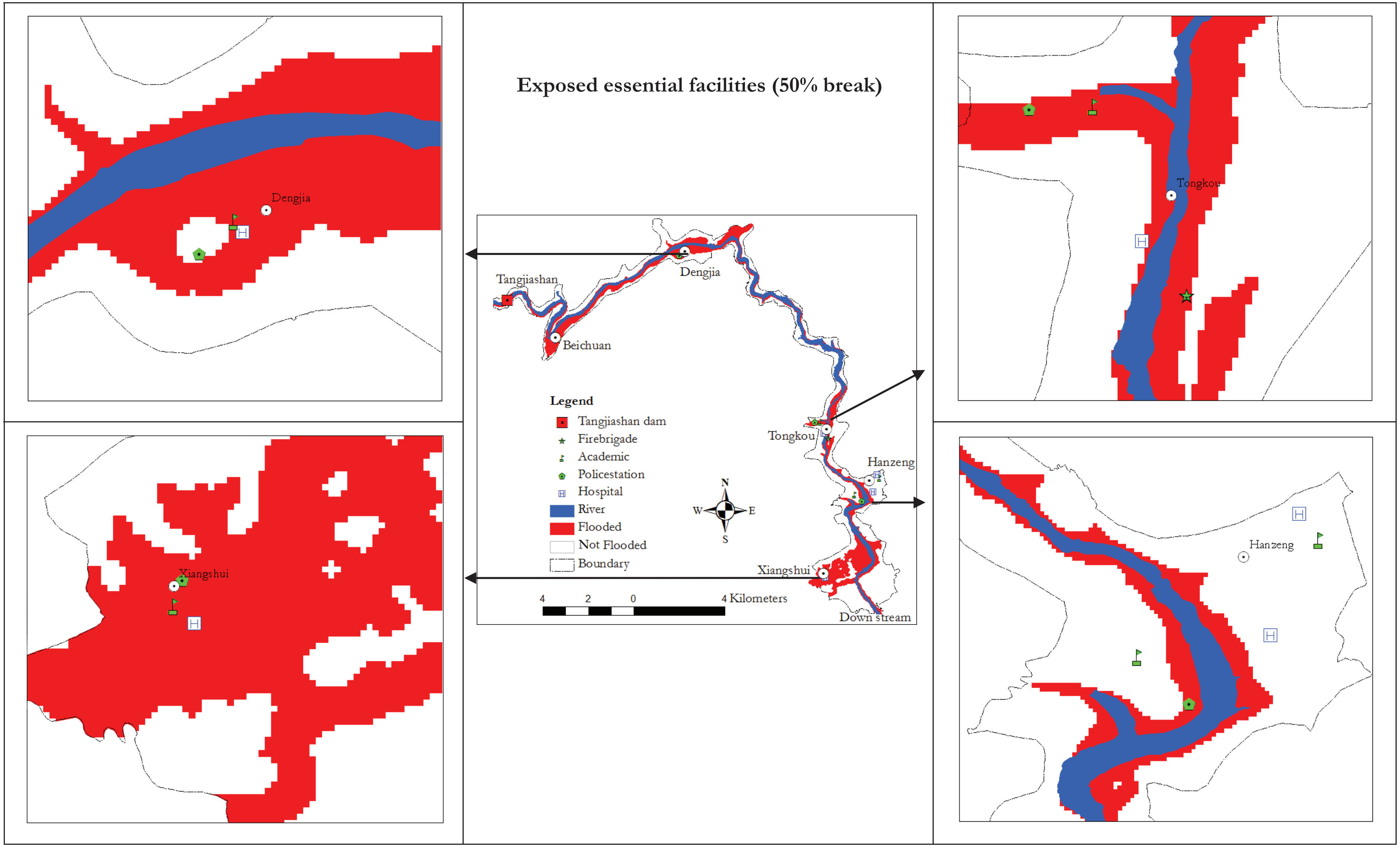


Figure 6-7 Exposed essential facilities (50% dam break scenario)

6.1.6. Elements at risk for population

Population data of the towns was collected from the town offices and for the villages the population data was collected during interviewing the village leader and senior citizens in the villages. Total population of the study area is about 22000 with an average population density of about 709 persons per square kilometre. As the boundary of the towns and villages was unknown; the study area was divided into 35 settlement groups during field survey and for each group total number of population was collected. With the assumption that all the people live in the residential building blocks; the population has been disaggregated and assigned only to the residential building blocks according to the floor area of the blocks. Floor area has been calculated by multiplying the area of the building blocks with the number of floors of the respective building blocks. Thereafter, the population density has been calculated per 25 square meters using population by floor area and used as the population value per pixel (5x5m). An example of the calculation is given in Table 6-4. The density distribution over the study area is shown Figure 6-8.

Table 6-4 Example of calculation of population by area and floor area (Author 2012)

Settlement group (SG) name	Total number of population	No. of floors per building blocks	Area of building blocks (m^2)	Floor area of building block (m^2)	Population by floor area	Population density per pixel (5x5m)
SG-24 (cluster of 5 building blocks)	140	1	5500	5500	12	0.054
		1	2525	2525	5	0.054
		2	12600	25200	55	0.108
		2	10900	21800	47	0.108
		2	4775	9550	21	0.108
		Total	36300	64575	140	0.434

Affected population for different scenarios is identified from GIS overlay. Total number of population affected is approximately 10000 by the 50% dam break which comprise 45% of the total population. In case of 25% dam break and slipway scenario the number of affected population is about 4500 and 500 respectively.

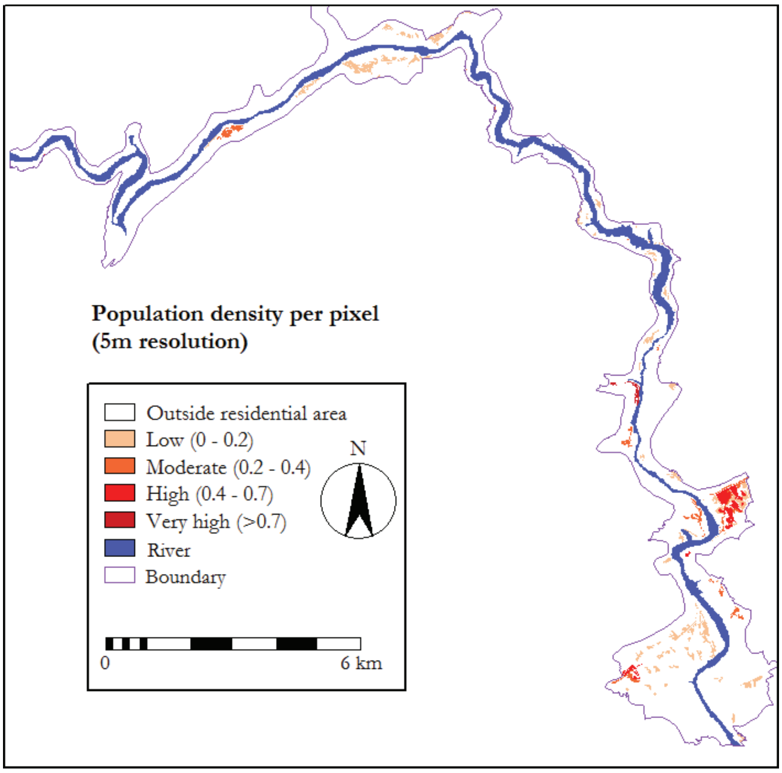


Figure 6-8 Population density distribution per pixel over the study area within the residential building blocks

6.2. Vulnerability assessment

Vulnerability is assessed based on vulnerability functions for the residential and mixed residential buildings, agriculture and forests for different flood scenarios. Assessment of vulnerability is carried out by following a number of steps as illustrated in Figure 6-9.

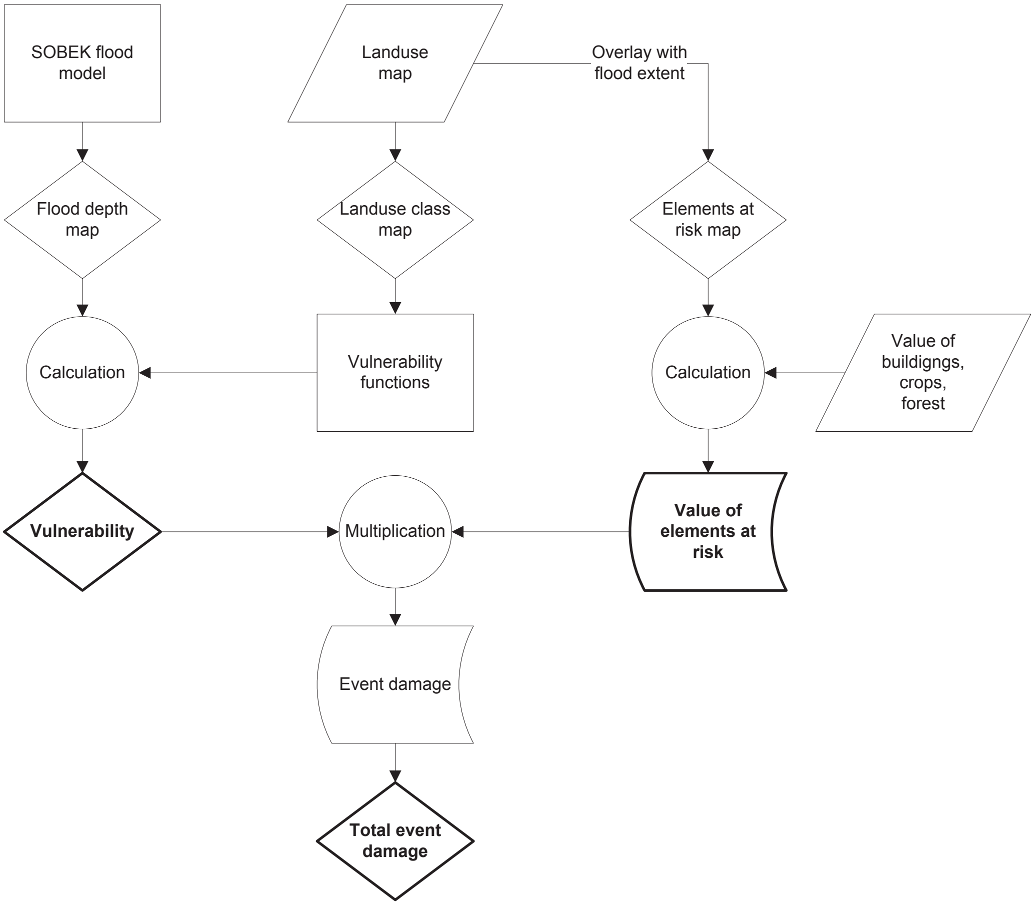


Figure 6-9 Procedure followed for vulnerability and damage assessment

6.2.1. Residential building vulnerability

The vulnerability assessment for residential and residential mixed buildings is carried out by using depth damage function of Dutch standard method for low rise dwelling and intermediate high rise dwelling. The adopted vulnerability curves are shown in Figure 6-8.

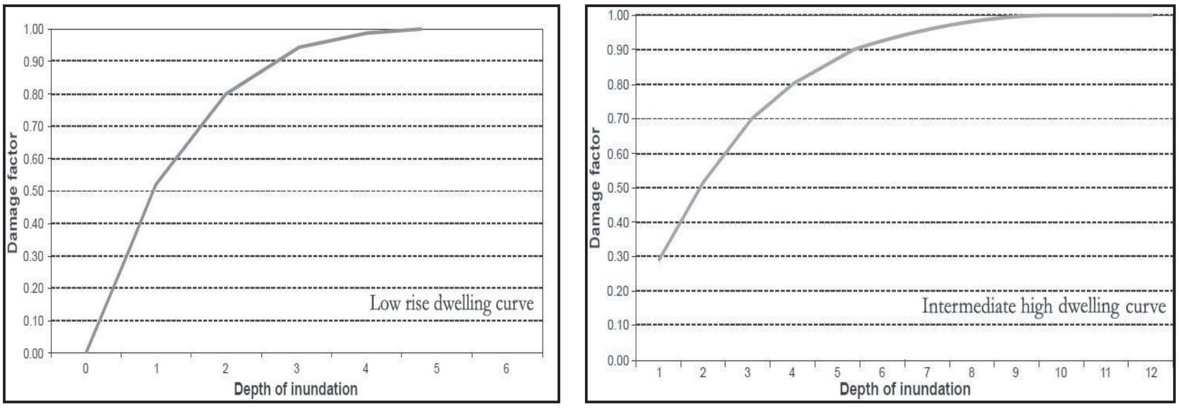


Figure 6-10 Depth damage function of the Dutch standard method of 2004 for dwellings (Huizinga et al., 2004) cited in (Westen & Kingma, 2010)

For vulnerability assessment, single storied buildings are considered as low rise dwelling and multi storied buildings are considered as intermediate high rise dwellings and respective damage functions are applied. The level of vulnerability (damage factor) derived from the respective curve are shown in Figure 6-11. From the figure it is evident that the 50% dam break flood is severely devastating and most of the affected buildings are in extremely high level of vulnerability class. Moreover, in case of 50% dam break the extremely high vulnerability level comprise about 35.69% area of the total residential and mixed residential buildings while this is only 14.8% and 1.3% in case of 25% dam break and spillway flood respectively.

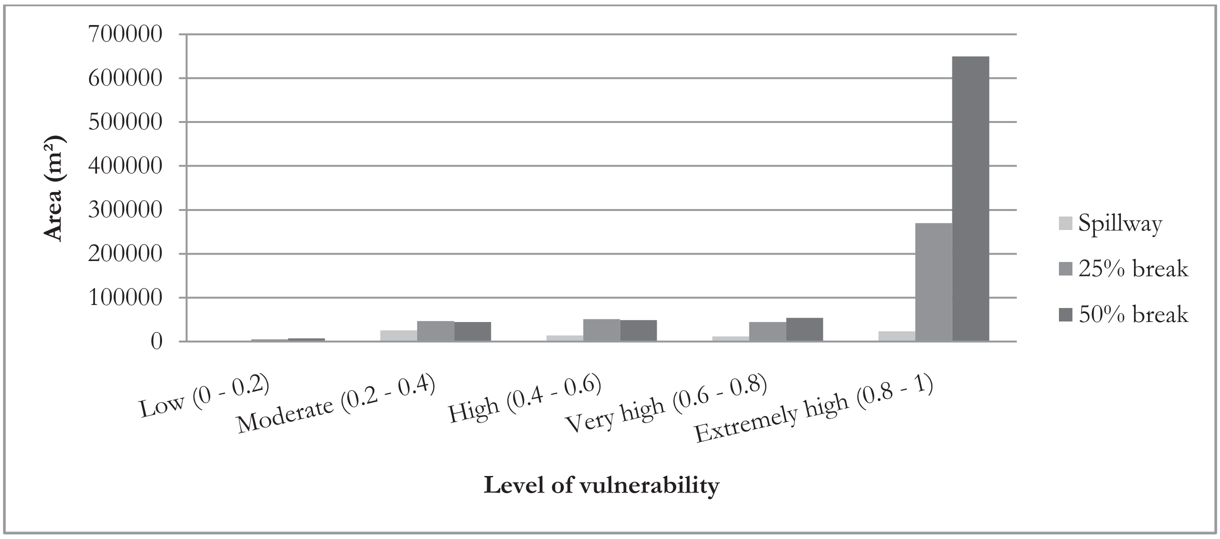


Figure 6-11 Level vulnerability result derived from damage function

In addition, as the number of buildings per pixel is known from subsection 0, the number of buildings per vulnerability class is calculated by multiplying the number of pixels in different vulnerability class and the number of building per pixel. Table 6-5 shows the affected buildings for different scenarios.

Table 6-5 Number of buildings per vulnerability class for different scenarios

	Nr. of buildings		
Level of vulnerability	**Spillway**	**25% dam break**	**50% dam break**
Low (0 - 0.2)	1	7	11
Moderate (0.2 - 0.4)	26	61	78
High (0.4 - 0.6)	14	75	67
Very high (0.6 - 0.8)	8	57	64
Extremely high (0.8 - 1)	27	402	1019
Total	**76**	**602**	**1239**

Based on the vulnerability functions, the vulnerability maps for residential and mixed residential buildings are identified for different dam break scenarios and shown in Figure 6-12, Figure 6-13 and Figure 6-14. As the study area is a narrow long river valley hence the important locations (towns/villages) are shown in detail by making zoom of the specific locations.

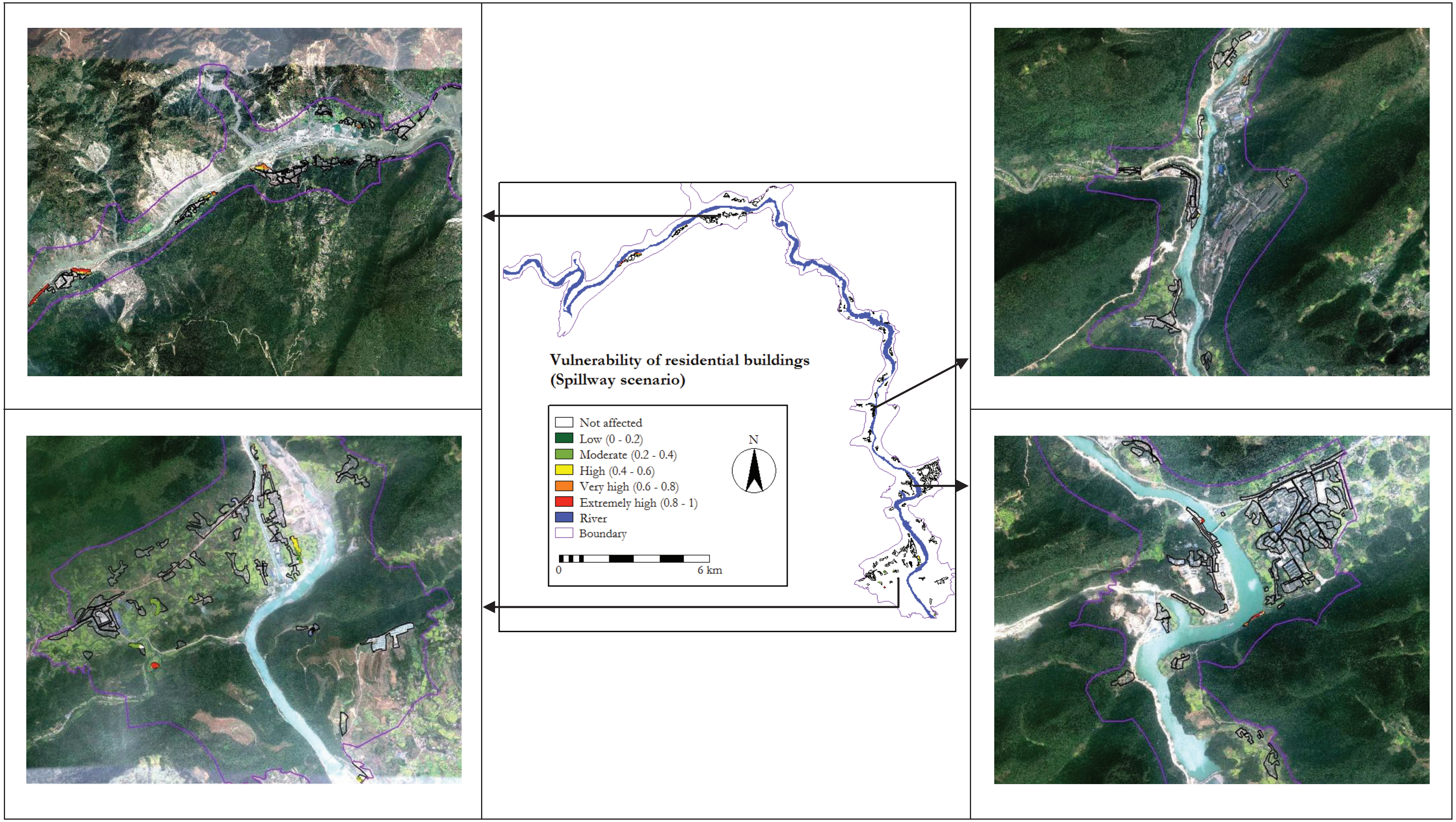


Figure 6-12 Residential building vulnerability by using vulnerability curve (Spillway scenario)

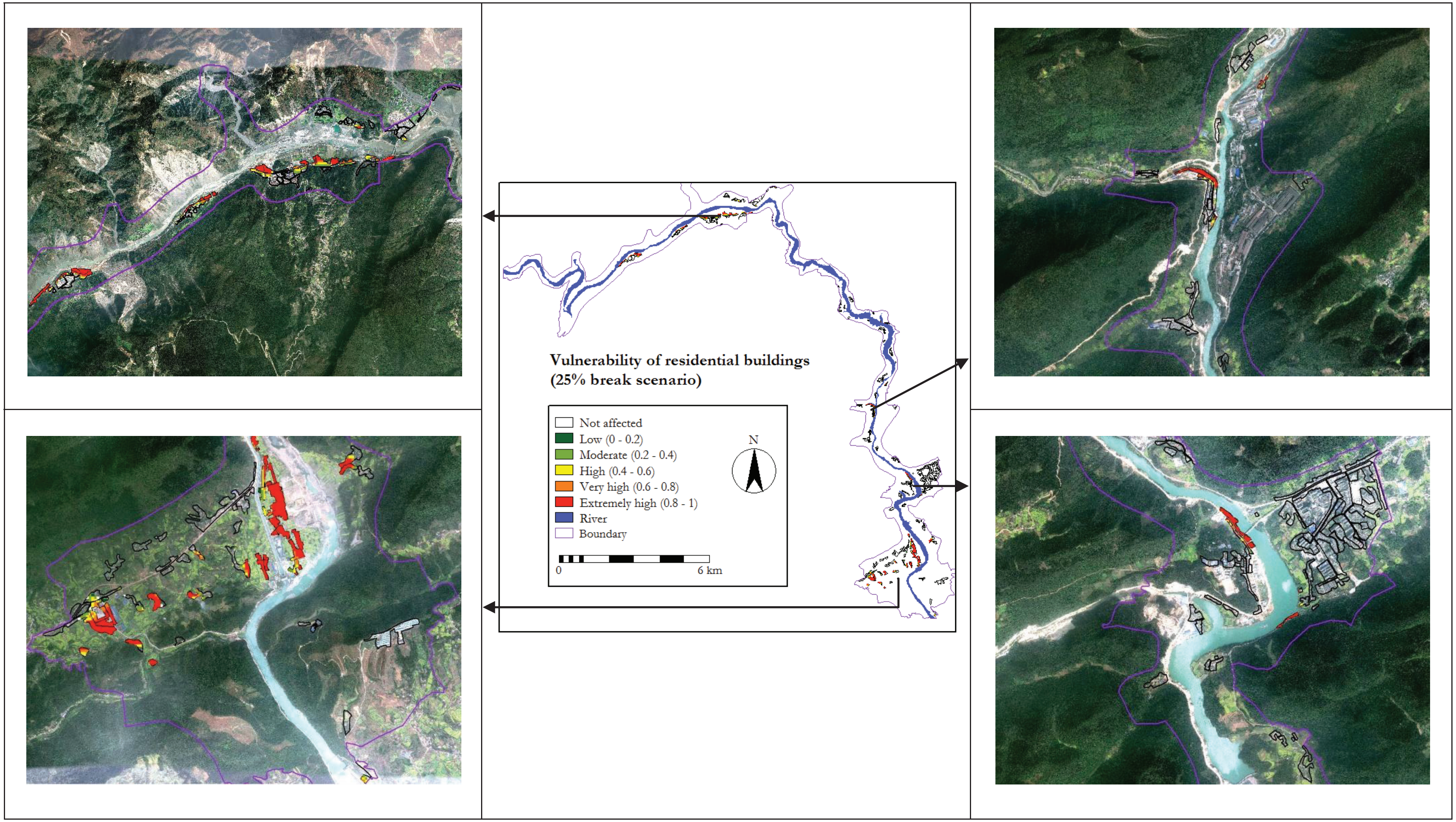


Figure 6-13 Residential building vulnerability by using vulnerability curve (25% dam break scenario)

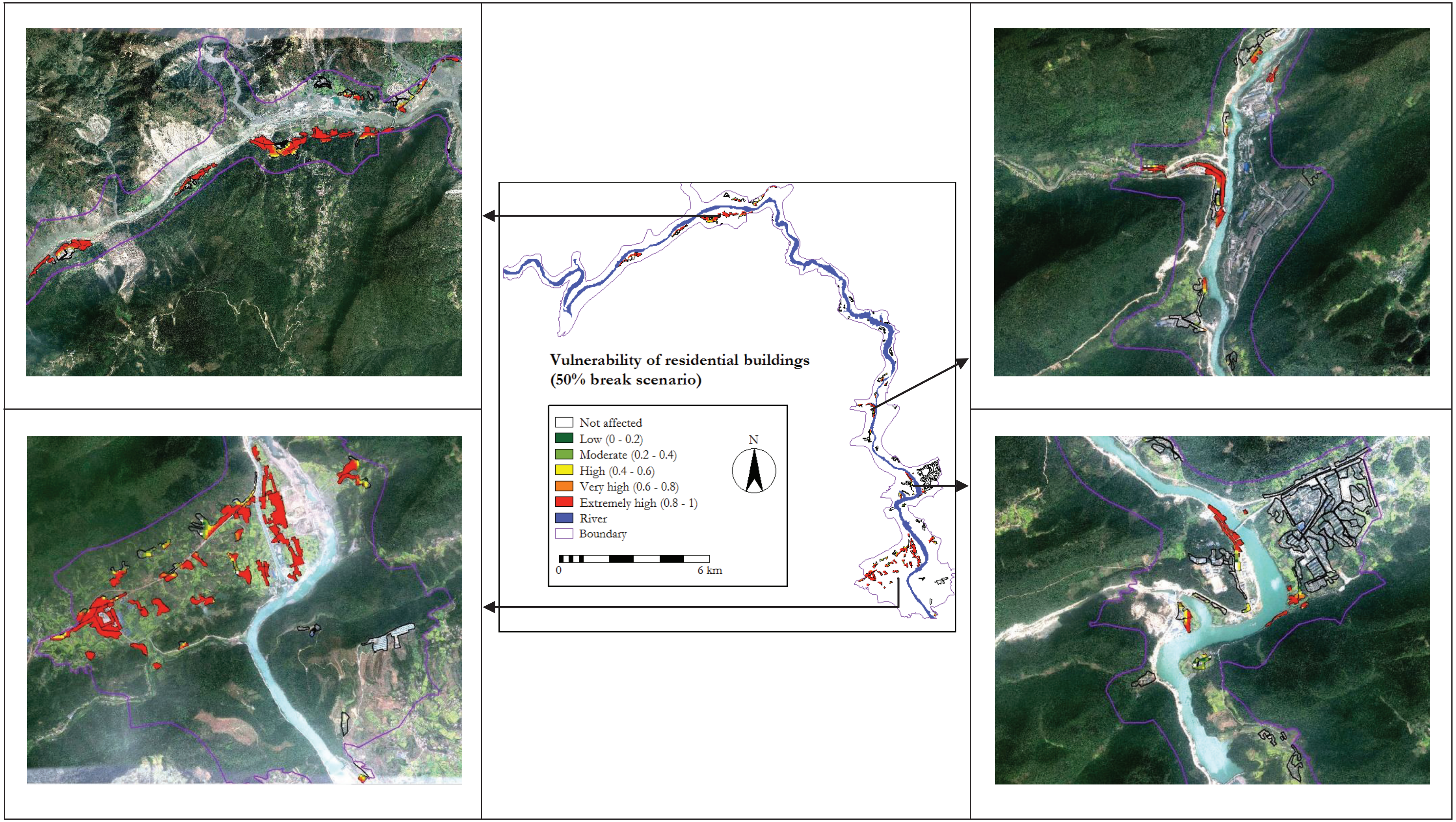


Figure 6-14 Residential building vulnerability by using vulnerability curve (50% dam break scenario)

6.2.2. Agricultural product vulnerability

The vulnerability curve used for assessing the vulnerability of agriculture (Corn) is presented in Figure 6-15. Based on the vulnerability curve the level of vulnerability for different flood scenarios are derived and compared in Figure 6-16. Agricultural vulnerability map for different flood scenarios is presented in Figure 6-18.

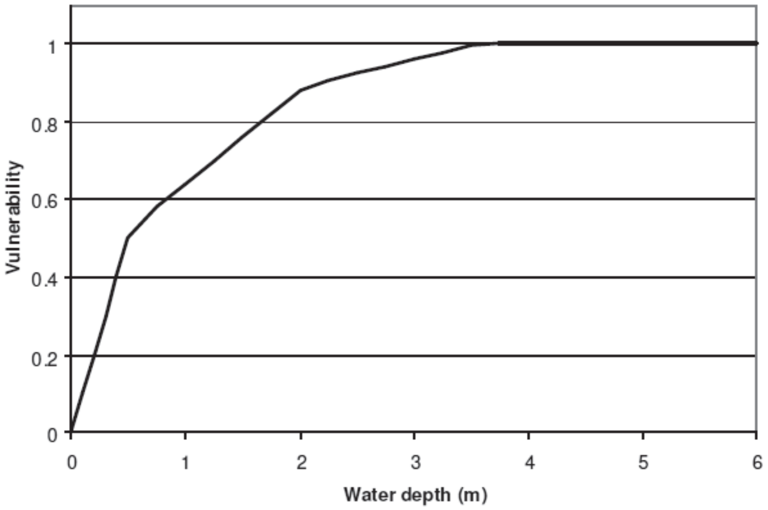


Figure 6-15 Vulnerability function for agriculture and recreation (Vrisou Van Eck et al., 1999)

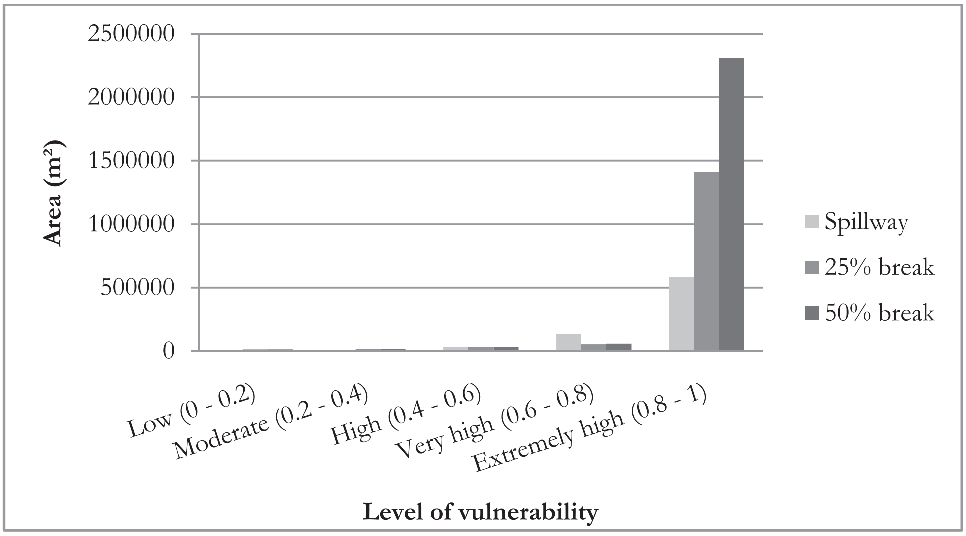


Figure 6-16 Vulnerability of agriculture for different flood scenarios

Figure 6-16 shows that, in all flood scenarios the affected agricultural activity is in extremely high vulnerability level and comprises 9.38%, 22.56% and 36.98% agricultural area for spillway, 25% dam break and 50% dam break flood respectively.

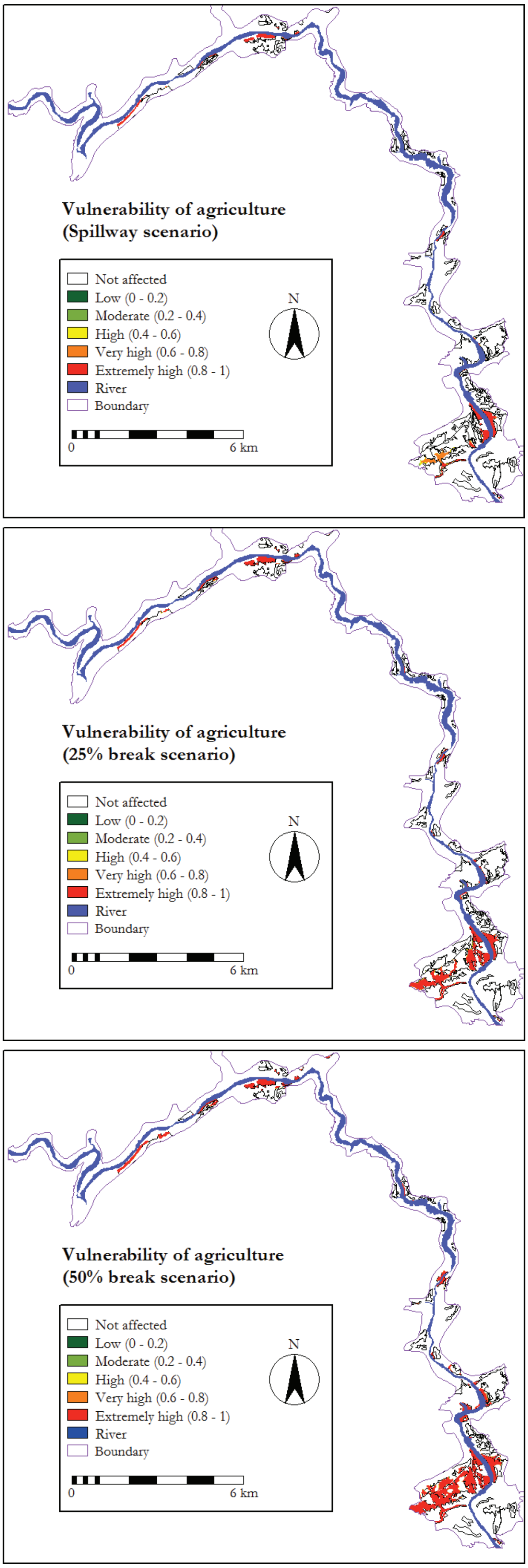


Figure 6-18 Vulnerability of Agriculture for different flood scenarios

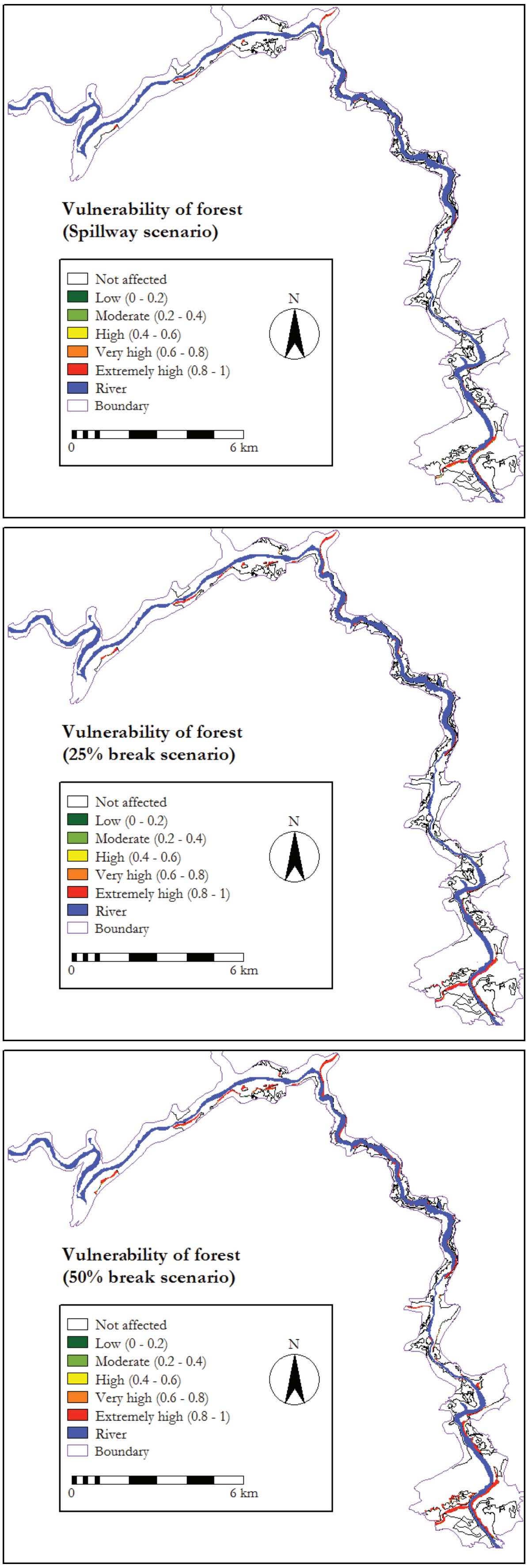


Figure 6-17 Vulnerability of forest for different flood scenarios

6.2.3. Forest vulnerability

Forest covers the highest portion of the study area. The vulnerability curve used to assess the vulnerability of forest is presented in Figure 6-19. The derived vulnerability level is compared in Figure 6-20. The vulnerability map for the forest is given in Figure 6-17. In case of 50% dam break scenario 125.27 hectare forest area will be inundated. The event damage for the inundated forest is 32695621 Chinese Yuan (¥) calculated from per hectare price as it is 260996 Chinese Yuan (¥).

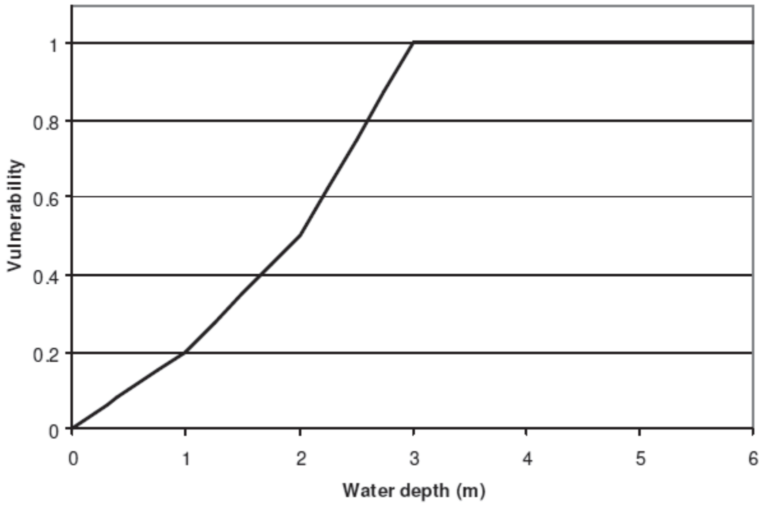


Figure 6-19 Vulnerability function for forest (Vrisou Van Eck, et al., 1999)

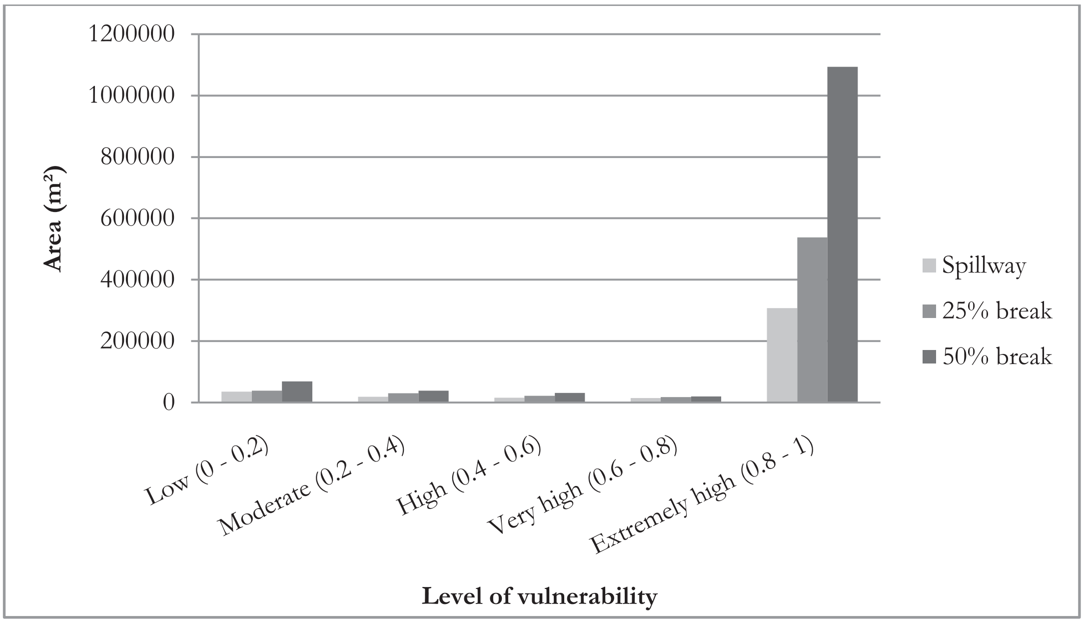


Figure 6-20 Comparing vulnerability of forest for different flood scenarios

From the figure it is exposed that most of the affected forests are in extremely high risk category and comprised 3.15%, 5.51% and 11.19% forest area for spillway, 25%dam break and 50% dam break scenarios respectively.

6.3. Event damage calculation

6.3.1. Damage calculation for residential buildings

From the field, building price was collected per square meter according to the type of buildings. As the buildings of the study area has been aggregated by the height of the buildings hence the floor area is calculated for the building blocks as described in subsection-6.1.6. Thereafter, the damage is calculated by multiplying the building price, vulnerability and the floor area. Total damage for residential and mixed residential buildings is presented in Table 6-6. From the table it is exposed that, 50% dam break flood causes approximately 13 times higher damage compared to spillway flood.

Table 6-6 Damage for residential and mixed residential buildings for different scenarios

Flood scenario	**Event damage in Euro (€)**
Spillway	12.4 million
25% dam break	72.5 million
50% dam break	155.5 million

6.3.2. Damage calculation for agriculture

According to the field survey it was found that during the spillway, corn and rice was the main agricultural crop as well as May-July is the peak season for flood in the study area. Therefore, considering the cropping pattern corn and rice is identified the most likely agricultural product to be affected. Type of agricultural crop, yield, price and their cropping season is given below in Table 6-7.

Table 6-7 Agricultural products likely to be affected in study area (Source: Hanzeng Town Office, 2011)

Crop Type	Yield per hectare (kg)	Price per kg	Yield price per hectare in Euro (€)	Cropping Season
Corn	9000	2.4	2541.2	May-July
Rice	10500	2.4	2964.7	April-July
Wheat	6000	2.8	1976.5	October-May
Rape	2625	2.6	802.9	September-April

The total damage for agriculture is calculated based on the average yield price of rice and corn. The damage is derived by multiplying average yield price, the vulnerability of inundated crop and the inundated area and is presented in

Table 6-8.

Table 6-8 Damage for agricultural yield

Flood scenario	**Event damage in Euro (€)**
Spillway	0.46 million
25% dam break	0.96 million
50% dam break	1.56 million

6.3.3. Damage calculation for forest

The value of forests was collected as per hectare wood stock from Tongkou town office during the interview (see Table 6-9). Thereafter, per pixel forest value is calculated from the collected per hectare wood stock value.

Table 6-9 Value of total forest area in terms of wood stock (Tongkou Town Office, 2011)

Total forest area in hectare	**Wood stock per hectare in m³**	**Value per m³ in Chinese Yuan (¥)**	**Total value in Euro (€)**
977	81	564	5.25 million

The per pixel forest value is multiplied with the level of vulnerability and number of pixels to derive the total damage for forest. For different flood scenarios the damage is presented in Table 6-10. From the table it is evident that, the more severe the flood the more the damage.

Table 6-10 Damage for forest for different flood scenarios

Flood scenario	Event damage in Euro (€)
Spillway	0.18 million
25% dam break	0.31 million
50% dam break	0.61 million

6.3.4. Event damage calculation

Event damage for different flood scenarios is calculated by summing the individual damage for buildings, agriculture and forest and is presented in Table 6-11.

Table 6-11 Event damage calculation for different flood scenarios

Flood scenarios	Residential building damage (million €)	Agriculture damage (million €)	Forest damage (million €)	Event damage (million €)
Spillway	12.35	0.46	0.18	12.99
25% dam break	72.47	0.96	0.31	73.74
50% dam break	155.53	1.56	0.61	157.70

From the table it is exposed that, the event damage for 25% dam break flood is about 6 times higher than the spillway flood and in case of 50% dam break flood the event damage is about 12 times higher than spillway flood.

7. SEMI QUANTITATIVE RISK ASSESSMENT

The previous chapters 5 and 6 discussed hazard assessment by flood modelling and vulnerability of elements at risk respectively. In addition, event damage and physical vulnerability were also discussed in chapter 6. This study is thus also interested about flood risk assessment. The major aim of this chapter is to analyze the flood risk level for different type of land use by using semi quantitative risk assessment approach. This approach will consider multi dimension of flood risk including hazard, economic and social risk.

7.1. Constructing the multi criteria index

Flood cannot be describe by one single parameter(Alkema, 2007). It has multi dimensional effect on society and nature some are quantifiable and some are non-quantifiable. Therefore, it is difficult to study flood risk considering its' all dimension especially when parameters are in different unit of measurement. In this regard (Meyer, et al., 2009) has identified Multi criteria evaluation as an effective method for considering all relevant consequences of flood risk without measuring them on one monetary scale. However, the multi-dimensional consequence of flood risk were studied successfully in several literature described as spatial multi criteria approach for semi quantitative risk assessment (Alkema, 2007; Guarin, 2008; Meyer, et al., 2009; Westen & Kingma, 2010); the method actually follows the concept of analytical hierarchy process (AHP) given by Saaty, 1980 (Westen & Kingma, 2010). The multi-dimensional aspects of flood identified from literature mainly reconstructed from (Meyer, et al., 2009) and hazard dimension was followed from (Alkema, 2007). In this study dimension of risk were arranged in a two level hierarchical modelFigure 7-1. Under each dimension several attributes were formed. The output maps of chapter 5 and 6 were used as attribute map in this chapter.

7.1.1. Flood risk dimension

Risk assessment is the main goal of this chapter. During the problem structuring phase a criteria (Figure 7-3) tree was constructed which starts with defining the main goal. Under the main goal three dimensions of flood risk were included: hazard, economic vulnerability and social vulnerability. Here the hazard dimension was completely considered as physical characteristics of the flood. The economic dimension considered only the damage value for different land use. The social dimension considered human exposure level and their capacity to reduce flood risk.

7.1.2. Attributes

Attributes are contributing features of intermediate goal in this case three flood dimensions. Finally the values gained from each dimension were added in the root problem or the degree of the flood risk. A number of attributes were grouped under each type of flood risk dimension. A group of quantifiable features were identified from the flood hazard and vulnerability assessment chapters and used as attributes in order to assess flood risk. A schematic view of criterion tree is illuminated in Figure 7-1.

7.1.3. Constraint

A constraint in the SMCE application is a criterion that determines in the calculation of the main goal and it appears directly under the goal. Areas that are absolutely not performing for the criterion tree are considered as constraint will be obtaining 0 values in the final output map. In this study, river and non flooded area were considered as constraint for risk.

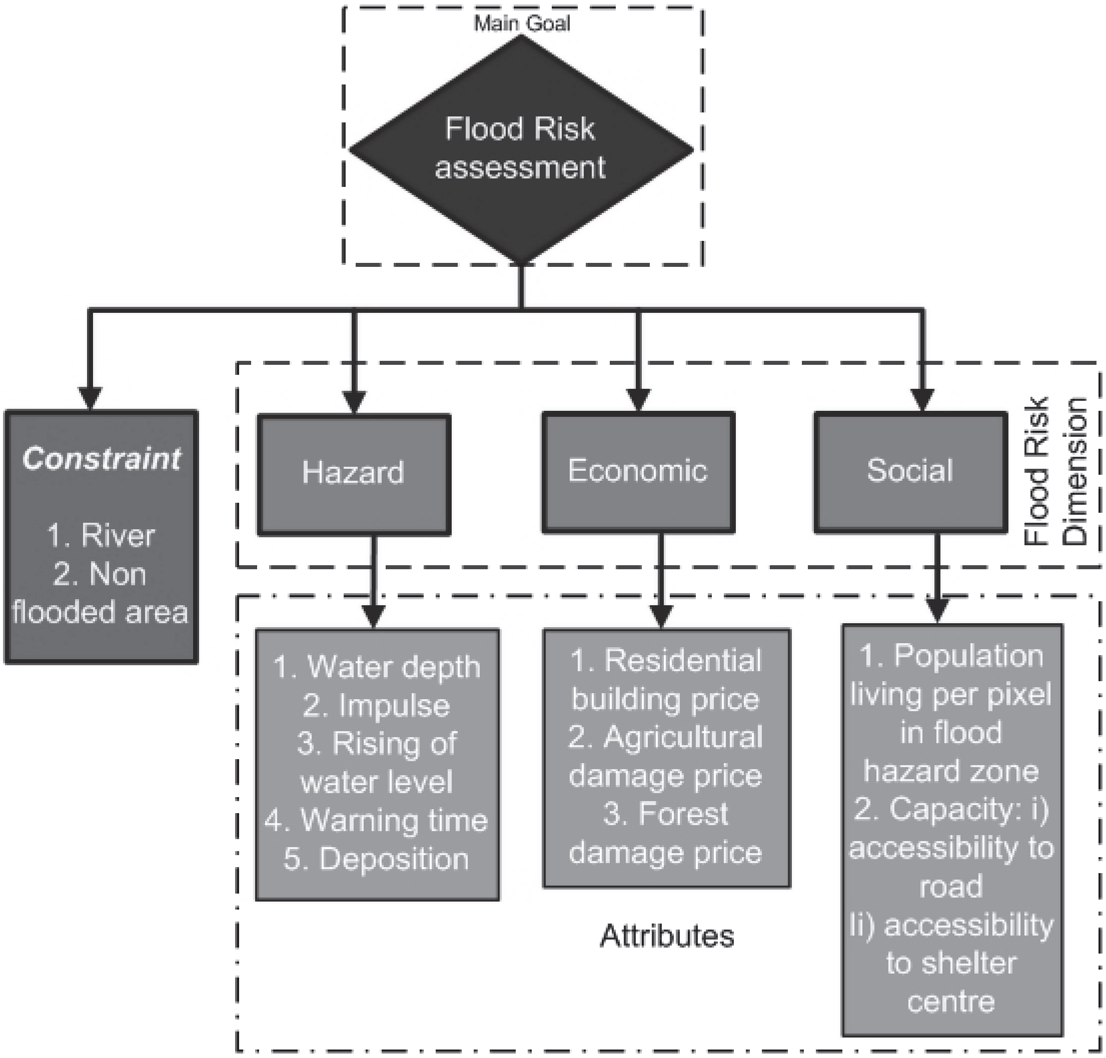


Figure 7-1 Schematic representation of criteria tree used in SMCE

7.2. Procedure followed

According to the procedure for the SMCE, described in chapter 4, the 'Goal' of the current analysis was to assess semi quantitative flood risk in order to see the spatial distribution of risk. In order to implement spatial multi criteria evaluation techniques following the AHP procedure three steps need to be performed. First phase is structuring the problem into a hierarchy. Second step is to define the attributes as cost or benefit and third step is to weigh the attributes using direct, pair wise or ranking methods. Here every attributes is a raster layer and every pixel is an alternative. Each level of hierarchy can be considered as goal phase as level one is final goal, level two sub goals as it is flood risk dimension. At lower level of the problem tree it mainly generates values for the layers of the intermediate levels that are obtained by using summation process and considers the performance of the attributes for the alternatives.

7.2.1. Characterizing, Standardizing and weighing the criteria

The first step is to determine the negative or positive contribution of the attributes in order to achieve main goal of the tree. In this case when higher values contribute to increase risk level it is considered as benefit attributes and when decreasing values contribute to reduce risk level considered as cost attributes. An example of this procedure is given in Figure 7-2. For example rate of deposition increase the pollution and cleaning cost it is considered as benefit attributes. On the other hand when warning time increase it contributes to decrease the risk level therefore it is considered as cost attributes for flood risk assessment.

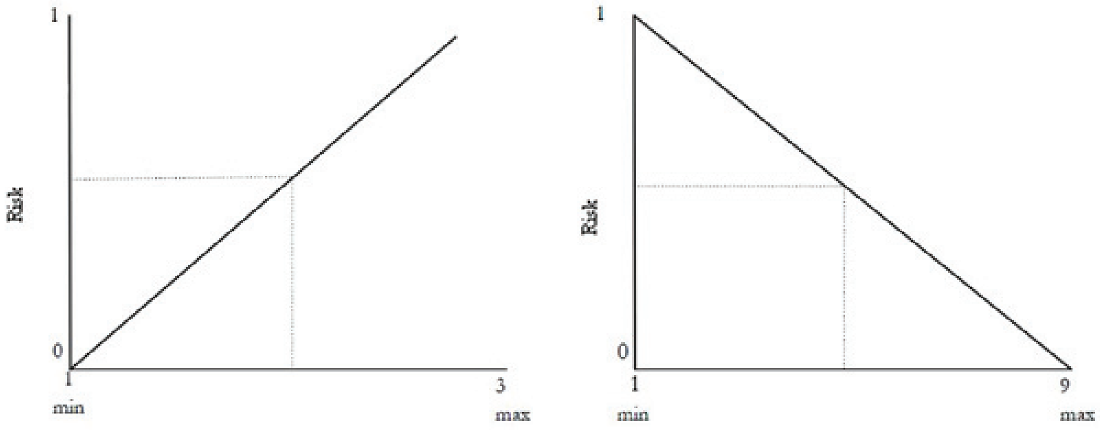


Figure 7-2 Benefit and Cost in linear standardized method

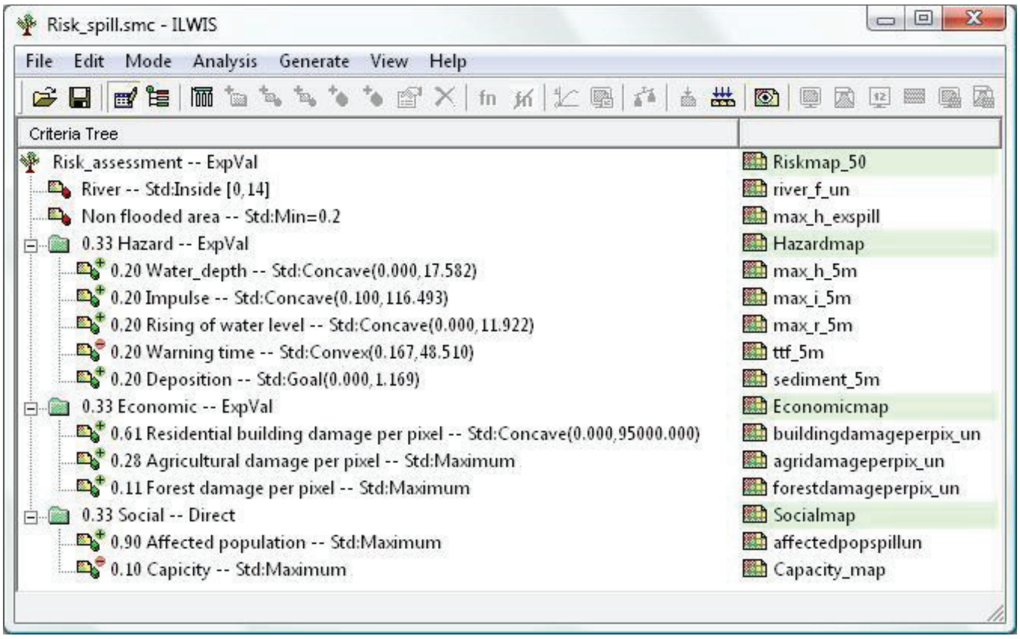
The next step is to standardize the attributes. The purpose of standardizing is to bring all attributes in same measurements units. In reality the values in values input maps have different meanings and they are expressed in different units of measurement. In order to make different criteria comparable all values need to be standardized or transformed to the same unit of measurement. In ILWIS criterion tree the standardized value always range between 0 and 1. For example measurement units were in time, money or in distance unit. All of them were standardize in order to bring them in same measurement unit 0 to 1 and to make them comparable.

The last and final challenge is to prioritize different attributes in SMCE the term 'weighing' is commonly used by the researchers. For multi criteria evaluation weighing is its' strength on the other hand this is the most critical part of this approach. Weighing can be subjective because different person or group can have different perspective for the same decision problem. As it is described since the beginning that group of flood risk attributes were used in order to assess flood risk so that all the dimensions of the flood risk could be covered. In order to avoid the subjectivity this study aims to weigh the attributes and sub goals equally.

Table 7-1 Criterion tree used for Spatial multi criteria evaluation

	Dimension/ Constraint	Attributes		B/C	Description	Unit
Flood Risk (total value 1.00)	Hazard (.33)	Water depth (.20)		B	The more the water depth the more the risk	metre
		Impulse (.20)		B	The more the momentum the more the risk	m2/s
		Rising of water level (.20)		B	The faster level of water rising the more the risk	m/h
		Warning time (.20)		C	The less the warning time the more the risk	hour
		Deposition (.20)		B	Higher deposition higher risk (in terms of pollution and cleaning cost)	-
	Economic (.33)	Residential building damage value per pixel (.61)		B	The more the damage value the more the risk	¥
		Affected agricultural land value per pixel (.28)		B	The more the damage value the more the risk	¥
		Affected forest price per pixel (.11)		B	The more the damage value the more the risk	¥
	Social (.33)	Affected population per pixel (.90)		B	The more the number of population affected per pixel the more the risk	Population number
		Capacity level (.10)	Accessibility to road (B)	C	The more the capacity the less the risk/the more the accessibility the more the capacity	km
			Accessibility to shelter centre (B)			
	River	n/a				
	Non flooded area	n/a				

In order to create an output map this method sums up all values from each level of criteria tree following the AHP method. In this study flood risk were perceived as a combination of physical, economic and social dimension. Under the social dimension two attributes were considered: affected population and their capacity level. Since this method can only sums up the value for each alternative pixel cell but capacity is such an attribute which contribute to reduce risk. Therefore in another small criteria tree a capacity map were prepared by using two criteria accessibility to road and shelter centre and equal weights were given. Later on this map were used as capacity map and as a cost attribute for risk assessment.



Criteria Tree	
Risk_assessment -- ExpVal	Riskmap_50
River -- Std:Inside [0,14]	river_f_un
Non flooded area -- Std:Min=0.2	max_h_exspill
0.33 Hazard -- ExpVal	Hazardmap
0.20 Water_depth -- Std:Concave(0.000,17.582)	max_h_5m
0.20 Impulse -- Std:Concave(0.100,116.493)	max_i_5m
0.20 Rising of water level -- Std:Concave(0.000,11.922)	max_r_5m
0.20 Warning time -- Std:Convex(0.167,48.510)	ttf_5m
0.20 Deposition -- Std:Goal(0.000,1.169)	sediment_5m
0.33 Economic -- ExpVal	Economicmap
0.61 Residential building damage per pixel -- Std:Concave(0.000,95000.000)	buildingdamageperpix_un
0.28 Agricultural damage per pixel -- Std:Maximum	agridamageperpix_un
0.11 Forest damage per pixel -- Std:Maximum	forestdamageperpix_un
0.33 Social -- Direct	Socialmap
0.90 Affected population -- Std:Maximum	affectedpopspillun
0.10 Capicity -- Std:Maximum	Capacity_map

Figure 7-3 Risk assessment criteria tree in ILWIS

7.3. Flood risk in study area: Interpretation of the SMCE result

Figure 7-4 illustrates the initial result of risk analysis using spatial multi criteria analysis in case of spillway, 25% break and 50% dam break scenario. The result reveals that the percentage of moderately affected area is high for all scenarios. For spillway scenario as it is around 75%. On the contrary for the other two scenarios the percentage of moderate risk level decreases gradually. In contrast, a considerable amount of area is at high risk level as it is around 30% for 50% dam break scenario. For other two scenarios the percentage of high risk level decreases as well. In the southern part of the dam break affected area it is found that risk is highly associated due to fertile agricultural land and densely populated area. Figure 7-4 is showing the visual interpretation of flood risk level in study area. To conclude it can be said that in case of 50% dam break scenario the percentage of high risk is highest and for spillway the percentage of low risk area is highest. A considerable amount of area is at moderate risk level in case of all scenarios.

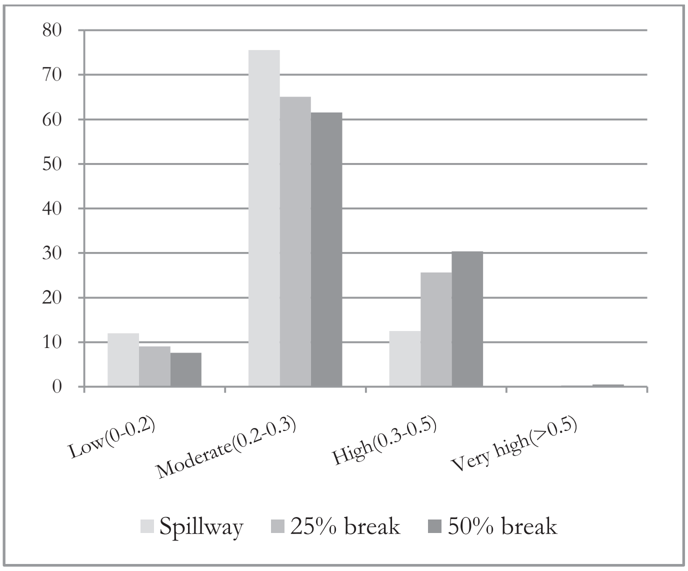


Figure 7-4 graph is showing the percentage of the affected area in each risk level within flood affected area

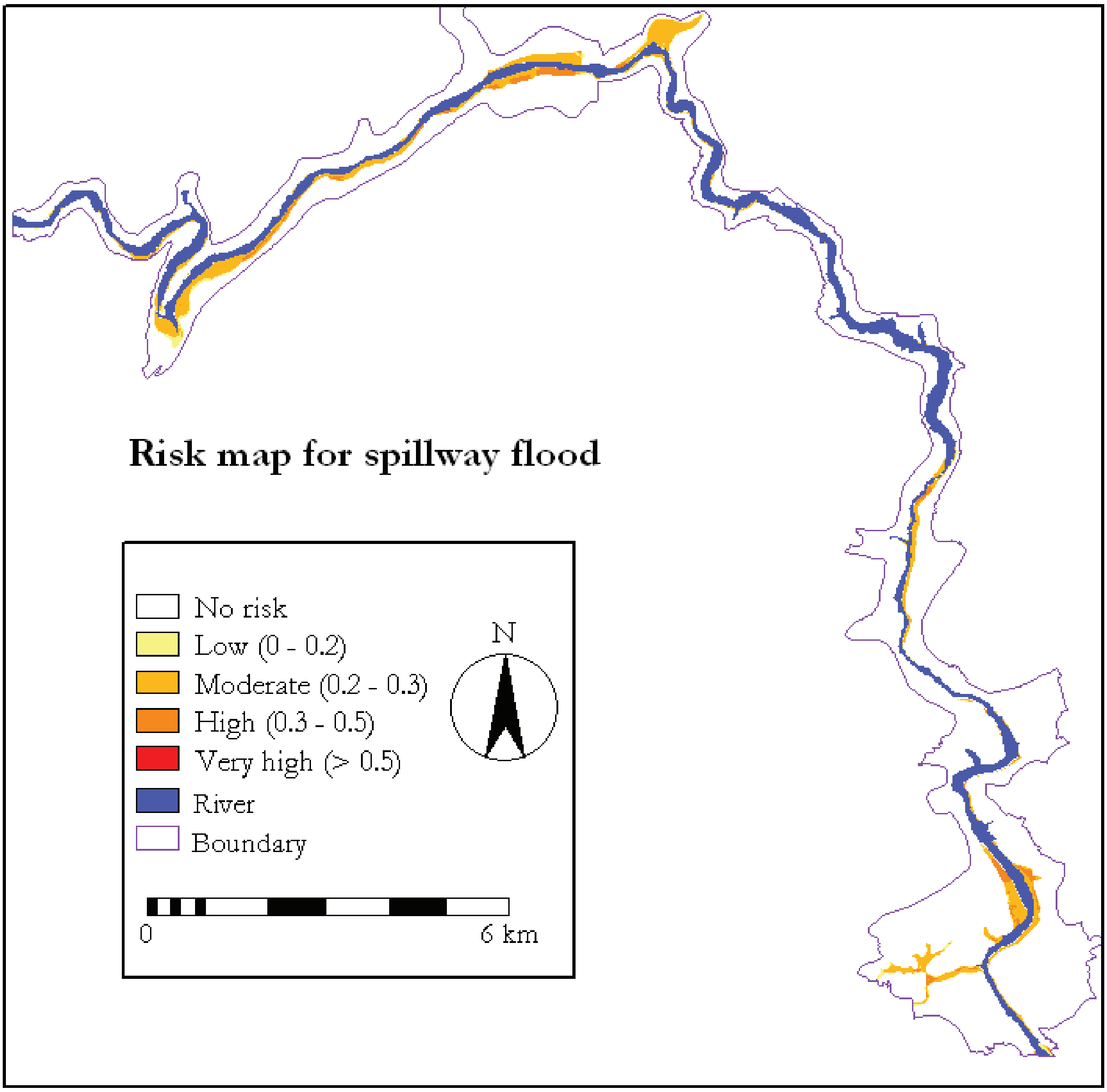


Figure 7-5 Risk map for spillway flood

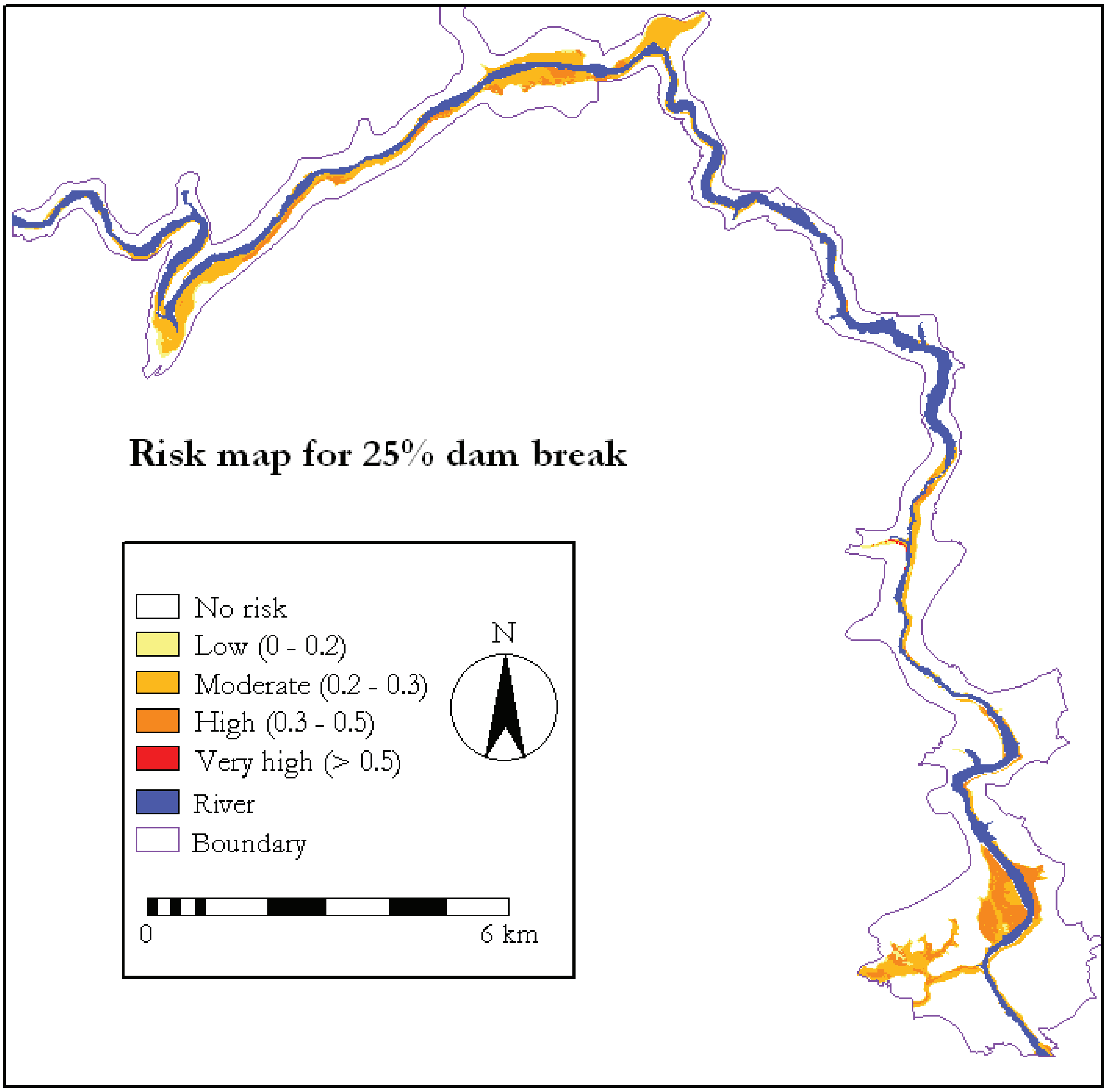


Figure 7-6 Risk map for 25% dam break

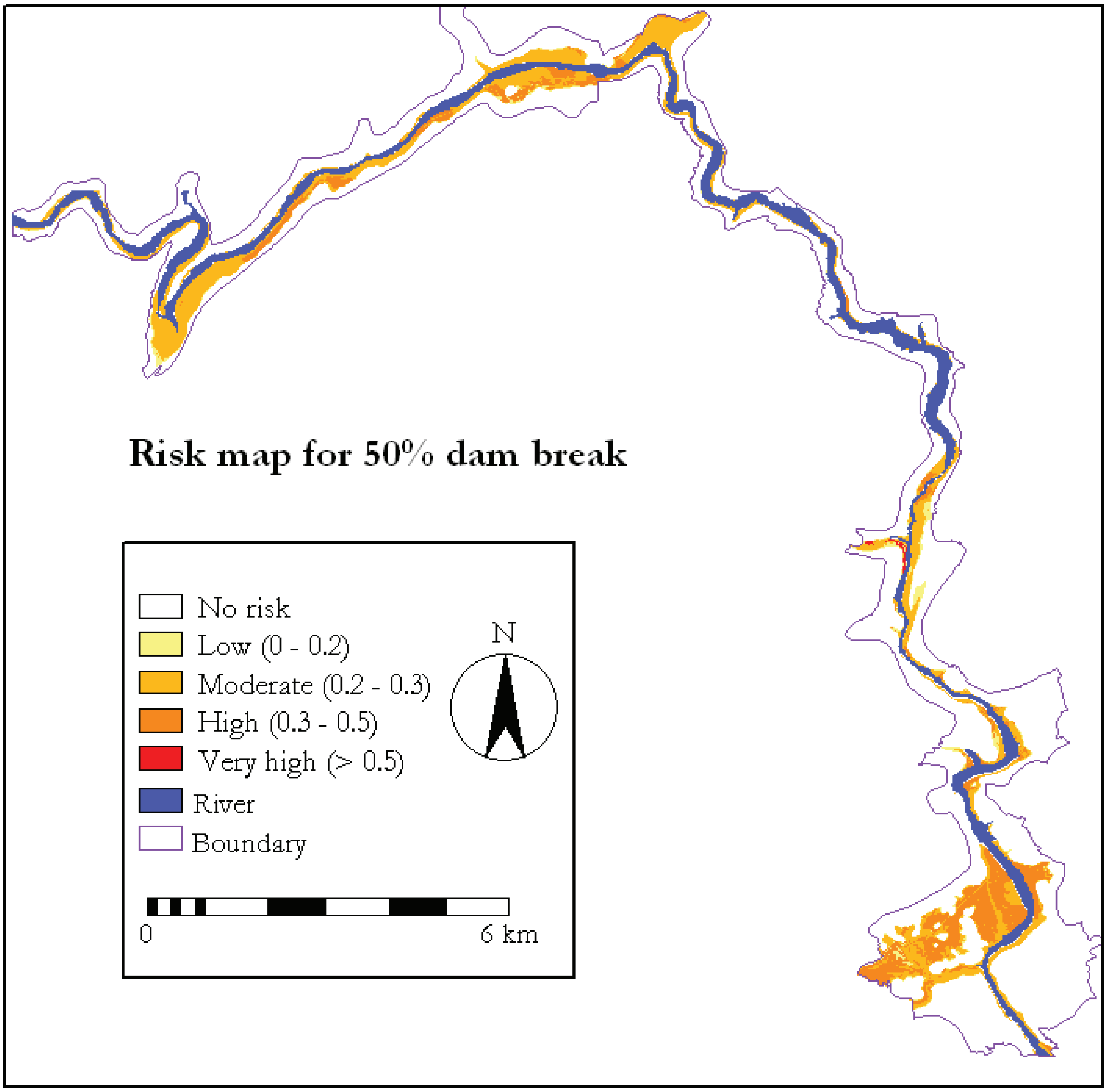


Figure 7-7 Risk map for 50% dam break

The comparison of three different scenarios has revealed that the percentage of high risk level has increased consecutively for spill way, 25% and 50% dam break flooding (see Figure 7-5, Figure 7-6 and Figure 7-7). Those areas which were at no risk or low risk level during the spill way or 25% break were changed into high risk level during 50% dam break. Not only the level of risk has increased according to the different scenarios but also the spatial variation of risk has occurred. Remarkable spatial variation is observed from the map visualization near the Dengia town, Tongkou town and at the southern part of the study area which belongs to Xiangshui town. Comparing spillway and 25% dam break scenario, it is observed that, in case of spillway flood Dengjia and Xiangshui areas are at high risk category while in case of 25% dam break the very high risk areas are located at Tongkou town.

7.4. Evaluation of evacuation rule

During the interview with the officials it is found that there is evacuation rule exists in the study area. From the interview result it is found that, the evacuation plan considered both normal flood and flash flood possibility. There is provision for early warring system in the plan in case of emergency and evacuation timing for different types of flood hazards. Moreover, alternative evacuation rout planning is also included in the plan. Collaboration with the relevant departments like hydrological department, weather office, and neighbouring towns is also incorporated. To execute the process of evacuation a group of government departments are involve i.e. town office, health sector, police station, hygienic guard department, transport department and the other relevant departments.

From field survey and local peoples' experience it is exposes that, there is lack of people's participation in the process of evacuation planning. In addition people are also not conscious of the evacuation plans and possible routes for evacuation. Moreover, people are not aware of flood thread that could be happen as a result of dam failure. Furthermore, lack of regular training for evacuation in a regular basis make the people more unprepared for emergency situations.

Combining the result of the local officials' interview and people's perception, it seems necessary to ensure peoples participation in the evacuation planning process so that people can actively response during the evacuation time. Knowledge sharing with the local people of the area can make them understand the danger that exists in the area. Furthermore, regular practice of evacuation should be ensured to make the people trained for any kind of the emergency situation.

8. SUMMARY, CONCLUSION AND RECOMMENDATION

8.1. Summary

This research has explored the flood risk along the Jian River in a comprehensive manner. In doing so, it has carried out flood modelling, investigation of the elements at risk and their vulnerability, event damage calculation and qualitative risk assessment. As flood is not a regular phenomenon in the study area, which makes the inhabitants as well as the authorities unaware of the potential flood risk that exists due to possible occurrence of dam break floods. The outcome of this research shows that the study area has a huge potential to be affected by dam break flood which will cause severe damage in the downstream area. Working in a data poor environment was one of the major challenges of this study.

8.1.1. Hazard assessment for dam break scenario

Hazard assessment has been carried out by using SOBEK for three different flood scenarios i.e., spillway flood, 25% dam break flood and 50% dam break flood (see subsection 5.3.1). The measured hydrograph was used for spillway scenario but in case of other two scenarios the input hydrographs were assumed to be double and quadruple of the spillway hydrograph (see subsection 5.3.2). The output of the model was used to generate the following flood characteristic maps: maximum depth, maximum velocity, impulse, rising, warning time and deposition (see section 5.6). According to the model, the spatial extent of the flood for spillway, 25% dam break and 50% dam break are 1.78, 4.63 and 9.07 km^2 respectively.

8.1.2. Vulnerability and risk assessment

Firstly, the elements at risk were identified in the study area by overlaying the land use map and flood extent map and the percentage of affected areas were calculated by land use type. In addition, affected road by type, number of people affected, affected essential facilities (such as hospitals, schools, police stations, fire brigade station) by flood were also calculated. Thereafter, the vulnerability of the elements at risk for residential buildings, agriculture and forest was carried out by using stage-damage function of the Netherlands. After having the vulnerability of the elements at risk the event damage was calculated and compared for different flood scenarios. Analysis of the event damage reveals that the 50% dam break flood caused 12 times higher event damage than the spillway flood. As it was not possible to calculate the probability of different dam break flood scenarios due to shortage of data, the level of risk was identified for specific flood scenarios by applying semi quantitative approach for risk assessment.

8.2. Conclusion

The general objective of this study is to estimate the dynamics and impact of a landslide-dam break flood in Jian River, Sichuan China; for disaster preparedness. Tangjiashan landslide dam located in Sichuan, China was selected as a case study for this research: to support the main objective the other three specific objectives were formulated, to prepare flood maps for different dam break scenarios, to investigate the elements at risk and their vulnerability in the downstream area and to evaluate the results for disaster preparedness. This study has come up with a complete step by step risk assessment method. The outcome of this research will help to reduce disaster risk for this type of dam break flooding. The main findings of this study are given below.

- By using interpolated DTM based on 20 m contour line it is possible to model the flood for different scenarios by using SOBEK. This research reconstructed the spillway flood scenario and were able generate another two scenarios which predicts the future flood dynamics of this area.

- The flood scenarios of this study provide the potential danger that exists in the study area in case of failure of the landslide dam.

- According to the model, the spatial extent of the flood for spillway, 25% dam break and 50% dam break are 1.78, 4.63 and 9.07 km^2 respectively.

- Flood parameter maps were generated by using the model output in order to use as input for investigating the elements at risk, vulnerability assessment and risk assessment.

- The poor quality of the DTM was one of the major uncertainties for this research. Modelling with this DTM made the SOBEK flood model crush for several times. Through a series of DTM modification by DEM hydro processing in ILWIS were used to improve the quality of the DTM.

- The elements at risk investigated in the study area are population, buildings, agricultural products, forest, and essential facilities such as schools, hospitals, fire brigades and police station. These elements at risk are distributed throughout the study area. In urban areas population density and resource concentration is higher than other areas.

- For a developing country case study like China, small scale flood scenario could be a very effective way for risk assessment especially concerning the data poor environment as well as data restriction. Therefore this study selected small scale flood scenario to represent the elements at risk.

- Though the study area is located in dam break flood risk zone, it never experienced severe type of dam break flood. The local authority consider flood as a potential threat for the area and also has disaster management plan. But the local people are not aware of the danger of dam break flood as well as of the disaster management policy of the local authority.

- The area was not affected severely by the spillway flood, but in case of other two flood scenarios the level of the vulnerability for different elements at risk are noticeable. A large number people are in threat of dam break flood. In addition, large number of residential buildings, agricultural products and forests are in high level of vulnerability. Most of the essential facilities are also in the flood affected zone and half of the total road network will be disrupted.

- The comparison of three different scenarios has revealed that the percentage of high risk level has increased consecutively for spill way, 25% and 50% dam break flooding. A considerable amount of area is at moderate risk level in case of all scenarios. In case of 50% dam break scenario the percentage of high risk is highest and for spillway the percentage of low risk area is highest. Moreover, spatial variation is also found for different flood scenarios.

- The interview with the officials revealed that, evacuation rule exists in the study area. During field survey it was found that, there is lack of awareness among the people about the policy and potential flood danger. In addition, lack of regular training make the people more susceptible to potential flood hazard.

Finally, it can be concluded that, this study conceptualise risk as combination of hazard assessment, elements at risk assessment, vulnerability assessment and risk assessment.

8.3. Recommendation for future study

The DTM is about 50 years old and it does not represent the present situation correctly as the river changes its course and also several protection measures have been taken to improve the situation in the area. So it is suggested to work on the DTM improvement as well as adding all the hydropower dams in the model to get more precise results. Furthermore, calculating the probability for different scenarios should be carried out to calculate the quantitative risk.

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APPENDIX

Appendix -1

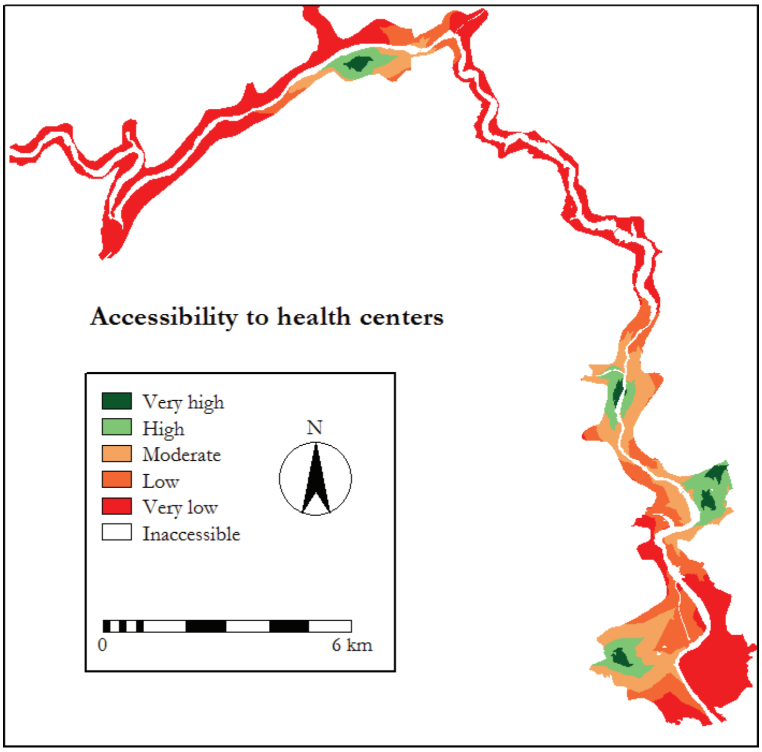

Figure A-1_1 Accessibility of health centre map, used as input for risk assessment

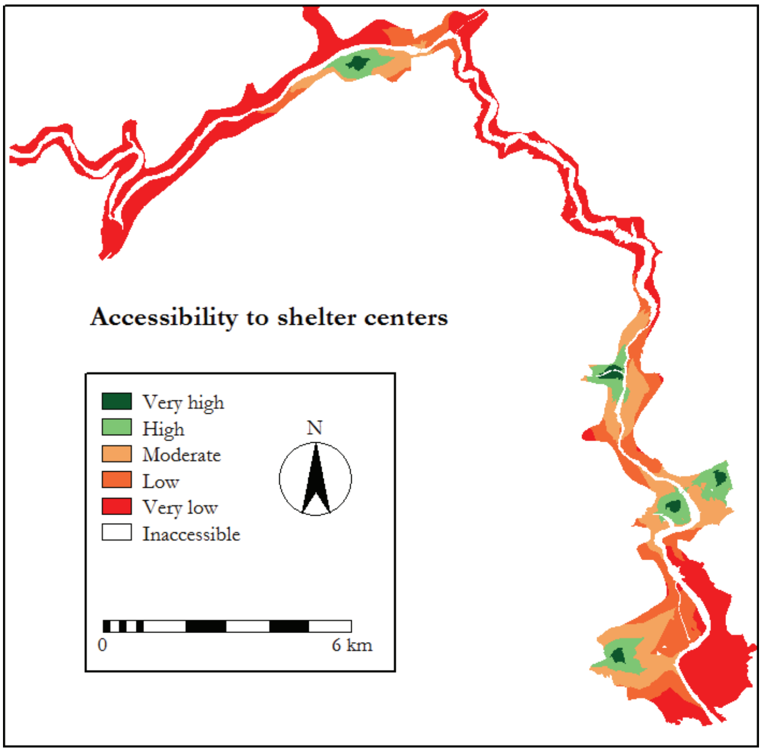

Figure A-1_2 Accessibility to shelter centre map, used as input for risk assessment