# FLOOD VULNERABILITY ASSESSMENT OF THE 2010 EVENT, USING PARTICIPATORY MAPPING TOOLS AND MODELING IN YINGXIU TOWN, CHINA

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February, 2012

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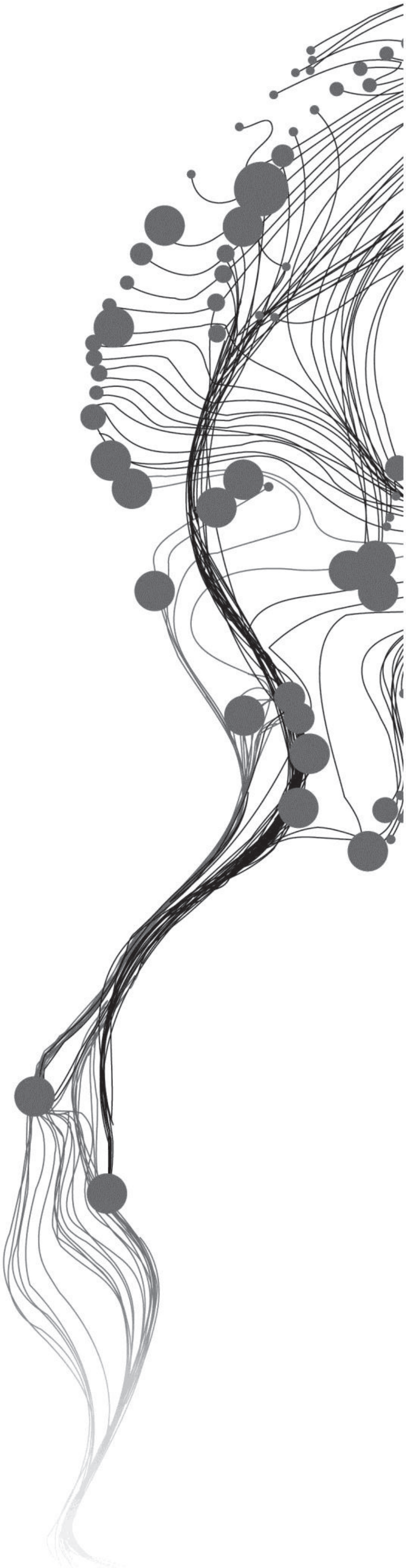

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BEATRIZ LAO RAMOS
Enschede, The Netherlands, February, 2012

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

Flooding has been recognized as one of the most important disasters worldwide by the number of persons killed, the number of victims and economic damages. In China, millions of victims associated to this phenomenon in 1998 places this country as the top of countries affected mostly (Guha Sapir et al., 2011). Also, in 2010 it was the combination of floods and landslides associated to heavy monsoon rains that caused millions of victims in southern China (Guha Sapir, et al., 2011). Yingxiu, a town located in this region was affected as well. However, detailed studies on flooding in this area were not developed. In order to minimize the impacts of future flood, an effective flood risk assessment is required. In this approach, community knowledge is combined with research methods for the assessment of the 2010 flood event, the damage and vulnerability assessment, and the risk reduction option as a stage of flood risk management.

The 2010 flooding is reconstructed using local knowledge and modeling methods. Participatory mapping tools such as participatory GIS, sketch mapping, focus group discussion, and transect mapping were used to capture experiences, perception and coping mechanisms related to this event. Characteristics of the 2010 flood event: extension, water depth on measurements points, and duration were obtained applying this method. Ground height values were obtained through fieldwork measurements and the DEM was improved. Values of water depth for all buildings were calculated. Another characteristic such as velocity was obtained during modeling process applying SOBEK 2D software. Results were combined during the assessment of the 2010 flood event. Community knowledge and fieldwork observation were used in the identification of elements at risk, as well as in the determination of direct and indirect damage. Economic losses values were given on macro scale level. On the other hand, physical and social vulnerability assessments were developed as well. Vulnerability matrices that reflect the flood-vulnerability relationship between water depth, velocity and damage scale (DS) for structural buildings were built based on methods proposed by Kelman (2002). Social vulnerability was based on the integration of social indicators applying Spatial Multi Criteria Evaluation (SMCE). Finally, community perception and coping mechanisms related to the 2010 flood event were analyzed and measures to contribute to the minimization of flood risks are proposed.

The study concluded that the flooded area is located along the right bank of the Minjiang River, occupying an area that around 76.0 $km^2$. Maximum values of water depth (>5.0 m) and velocity (>4.0 m/s) were located in the northern part of the town. The most damaged buildings were building structural type_1 and type_2 located in this area, subjected to high values of water depth and velocity during four flooding days. These buildings correspond to the highest value of physical vulnerability. On the other hand, in the households with high values of the social vulnerability were found children and elderly people, population with low and very low income and two or more persons with the primary educational level. In general, the contribution of this event to the annual risk exceeded 10 million of Yuan (1.3 million of Euros).

Keywords: Flood Event Assessment, Damage Assessment, Vulnerability Assessment, Risk Reduction Option, Participatory Mapping Tools, Yingxiu Town.

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Enschede, February 2012

Beatriz Lao Ramos

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# 1. GENERAL INTRODUCTION OF RESEARCH

This chapter explains the general overview of this research, containing the background information, the history about flood events in China, and the purpose of the research. The purpose of the research consisting: the research problem; research objectives and questions; benefits and limitation of the research.

## 1.1. Background Information

Flood is the most frequent event that causes adverse damage to human being. Every year, economic, social and environmental losses associated to this phenomenon become considerable with upward trend (Prabhakar et al., 2009). Statistics shows an increase in the number of victims by 20% in 2010 compared to 2009. Eighty five percent of victims from total natural disasters were associated with flood events. The most affected countries in 2010 are China, Pakistan and Australia (Guha Sapir, et al., 2011). In southern China 134.0 million victims (killed and total affected) were reported, associated to flood and landslide, with cost US $ 18.0 billion (Guha Sapir, et al., 2011). The large losses of lives due to flooding events in developing countries are related to the less accurate or missing disaster policy and land use planning.

The rise in the number and intensity of flood events as a consequence of climate changes (Prabhakar, et al., 2009), combined with the growth of settlements in flood hazardous zones, have influenced the increase of the number of damages and victims (van Westen et al., 2010). In China, in the middle and lower reaches of major rivers and deltas, where the flooding takes place, there is a wide distribution of the urbanization areas with dense population and economic development (Shi et al., 2002). This has caused China to be one of the countries in the world with the highest frequency of flood occurrences and with great negative impacts.

### 1.1.1. Flood Events in China

Flood events have affected China repeatedly through the history. Luo (1987) reported older flooding events described in 223 A.D., but most of the historical flood events occurred after the eighteenth century. Floodings were identified by him for the year 1583 on the Hanshui River; the 1843 flood in the Huanghe River; and the 1888 flood in the Taizi River. Information related to some of the characteristic of the flooding, such as water depth were inscribed by the people on permanent structures or on rocks on the river bank or gorge walls (Luo, 1987). Other information was qualitatively described linking to calamites of the magnitude of the event, such as the Yellow River where huge numbers of people have lost their lives in floods, including more than 300,000 at Kaifeng in 1642, more than 870,000 in 1887 and between 100,000 and 4 million in 1931(Ni et al., 2010).

Assessment of the flood frequency in China based on historical records indicates that there is an increase in the occurrence of flooding during the last two millennia. Side (2004) provides as example an analysis of the Yangtze River, a major river in the Sichuan province, with a flooding average of once every 18 years during the Tang Dynasty. During the Son Dynasty the average was once every 6 years and during the Ming and the Qing Dynasties flooding took place once every 4 years. Through the 1930s and 1940s, floods occurred once every 2.5 years on average. An increase in the frequency of flood events corresponded to 1980, 1982, 1983, 1989, 1991 and 1998. In the last year, the damage of the flooding "cost more than 2 billion US$ as, about 5 million houses, and 223 million people were affected by this and of whom more than 1320 people died". This event was characterized as being heavier than usual monsoon rains that were possibly associated with the La Nina climate event and impacts accentuated by human activities like deforestation (Sidle et al., 2004).

Flooding related to the Minjiang River reported by Shipeng (1997) between May 1st and 3th in 1994, was described as heavy mountain torrents with a return period of 100 year and a rainfall intensity of around 125.6 mm during 2h. Great damages in this area were caused by this flood event. Another major flood event has been reported on by Li et al., (2006) corresponding to 1998 and is ascribed to the deforestation activities in the main stream and its branches. Details of damages linked to these flood events were not found.

## 1.2. Purpose

### 1.2.1. Research Problem

Yingxiu is a town in the Sichuan province and is located in southwestern China. It is bordered by the Minjiang River along of the east part of the city. Yingxiu is set in Quaternary deposits (Tang et al., 2011), surrounded by mountains with elevations ranging between 1580.0 m to 1913.6 m.

On May 12th 2008, Yingxiu was devastated by the largest seismic event in China in more than 50 years, known as the Wenchuan earthquake. The earthquake originated in Beichuan fault and branched into two segments east of Yingxiu (Zheng Kang et al., 2009). The strong shaking affected the stability of slopes creating and abundance of loose material, which later created landslide debris on the slopes (Tang, et al., 2011). This hazardous event caused 7700 victims and extensive damage in Yingxiu town. Survivors were transferred to other cities closeby such as Dujiangyan and Xinjing city or they were relocated to temporal houses on the left bank of the Minjiang River and the right bank of the Roa River. After that the reconstruction of the town on the river terrace was initiated. But before this process was completed, the town was flooded due to the heavy rainfall that occurred on 14th August 2010. This rainfall triggered a total of 21 debris flows around Yingxiu town. One of these, "the Hongchun gully debris flow transported huge amounts of sediment into the Minjiang River to form a debris dam of 10 m height, 100 m in length across the river, and 150 m in width along the river" (Tang, et al., 2011). The dam blocked the left bank of the river changing its course which caused flooding of the new part of Yingxiu town that was being rebuilt (Figure 1). As a consequence 5500 residents located within the temporal houses and within the temporal hospital had to be evacuated (Tang, et al., 2011) and around 30 deaths were reported. However, a detailed evaluation of damages caused by this flood event is missing.

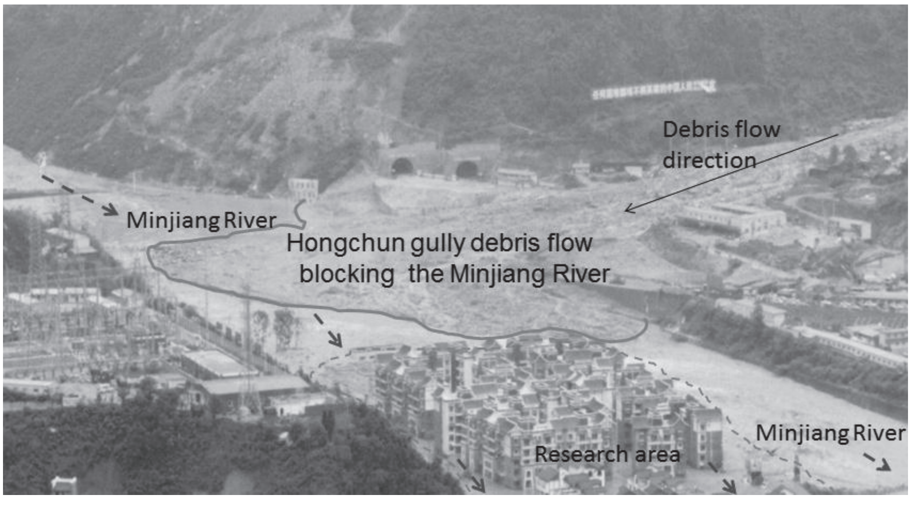



**Figure 1. Debris dam blocking the Minjiang River**

In the study area, after the earthquake the landslide susceptibility was increased (Tang, et al., 2011). Hence, there is a strong relationship between topographic characteristic, loose material from landslide originated by earthquake shaking and heavy rainfall conditions. The combination of these factors could result in future debris flows and new obstructions of the Minjiang River, causing similar flooding in Yingxiu town. Therefore the population of the town is continually threatened by hazardous events. Several studies related to the 2008 earthquake regarding tectonics and geology of the area have been developed; but no detailed research in the field of flood hazard. There is a clear need in the identification and evaluation of the flood in 2010 as well as a definition of the degree of vulnerability of each element exposed together with the identification of causes that originated the fatalities.

This study centers on the flooding problem of the Yingxiu town. The flood event of 2010 is analyzed; the flood damage and the vulnerability of elements exposed at risk were assessed. Also, measures to contribute to mitigate the impact of flood events were suggested. This research provides to local authorities a valuable tool for decisions makers, on policymaking and designing of strategies in view to further flood risk management to reduce losses and to minimize risks.

### 1.2.2. Main Objective

To assess the impact of the Yingxiu flood in 2010; and the construction of flood-vulnerability relationship. It is also aims to analyze the community's response to this flood event

### 1.2.3. Specific objectives and Research Questions

The specific objectives and the research questions to answer the main objective are summarized in Table **1**.

**Table 1. Research Questions**

| No. | Specific Objectives | Research Questions |
|---|---|---|
| 1 | To generate the flood event map of 2010 based on community knowledge (flood extension, water point depth maps and flood duration). | What was the maximum flood extent reached during the 2010 flood event in Yingxiu town based on community knowledge?<br>What is the spatial distribution of water depth point values associated to the 2010 event?<br>What was the duration of this flooding event? |
| 2 | To identify the elements exposed to the flooding and their characterization. | What were elements at risk exposed to the 2010 flood in Yingxiu town?<br>How could elements exposed be categorized? |
| 3 | Create a hydrographical correct DEM using existing data and field data. | What is the best method for the interpolation of ground height values? |
| 4 | To construct a flood depth map of the area based on fieldwork observations. | What method of interpolation was the most appropriated for the water level values? |
| 5 | Reconstruction of the 2010 flood event using SOBEK model 2D and field data. | Which scenario is the best representative of the 2010 flooding?<br>What parameter maps can be generated? |
| 6 | To quantify the damage caused by the 2010 flood event based on field data. | Where is the highest damaged area located?<br><br>What is the damage associated to the 2010 flood event? |
| 7 | To assess the perception of people and coping capacity related to the 2010 flood event. | What is the perception of people and coping capacity for flooding? |
| 8<br><br><br>a) | To assess the vulnerability related to key elements at risk.<br><br>Physical vulnerability | a) What is the relationship between water depth, velocity and damage in order to assess vulnerability for building types?<br>b) What are the main factors that control the social vulnerability? |

| | | |
|---|---|---|
| b) | Social vulnerability | What is the spatial distribution of vulnerability for those elements at risk? |
| 9 | To contribute to the improvement of the strategy to flood risk reduction. | Which measures could contribute to minimize the impact of the flood event based on community knowledge and field research? |

A conceptual framework to relate the main stage of this research to their specific objectives is displayed in Figure 2.

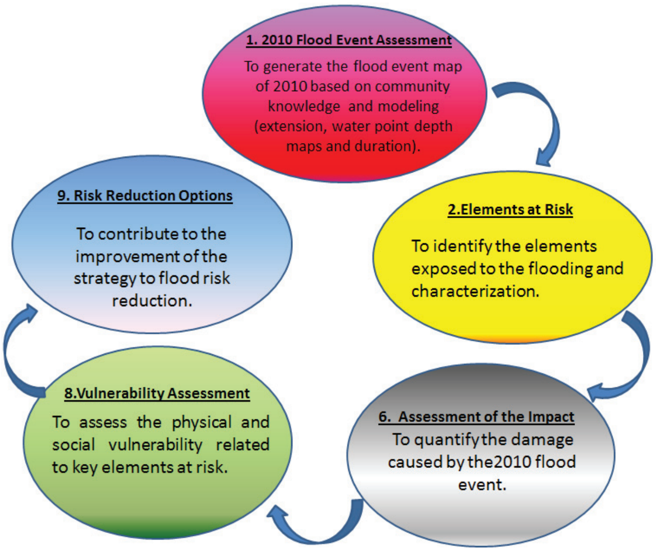



**Figure 2. Research conceptual framework**

#### 1.2.4. Benefit of the research

The research may give several benefits which could be used on flood disaster management in Yingxiu town. Some benefits are related below:

1. Provides valuable information related to community characteristics such as building inventory and road map.
2. Provides information associated to the 2010 flood event based on community knowledge and modeling.
3. Identifies elements at risk related to the 2010 flood event.
4. Provides detailed information related to physical and social vulnerability of elements exposed at risk.
5. Determines the contribution of the 2010 flood event to the annual average risk with the calculation of associated damage.
6. Provides measures to contribute to minimize the impact of flood event based in risk perception and coping mechanisms related to the 2010 flood event. Therefore gives to the local government a tool to generate policy and programs in order to flood risk reduction.

#### 1.2.5. Limitations of the research

In this research, the building footprint was created using the available aerial photo from August 15, 2010. This photo was taken during the flood event. The higher level of water depth (> 5.0 m) towards the northern part of the town made the delineation of the boundary for buildings located inside of the water factory difficult. Because of this the accuracy of the identification of elements at risk could be affected. The absence of information related to building contents and outside property framed the physical vulnerability assessment only to the analysis of vulnerability of the structural type of buildings. Also the lack of data related to costs of buildings damaged does not allow the evaluation of losses in economic values.

## 1.3. Outline of the thesis

This thesis has been divided into seven chapters.

The first chapter introduces the background information related to flooding around the world and in China. Also the research problem, specific objectives, research questions, benefits and limitations for the research are defined.

The second chapter includes a detailed literature review on the definitions related to hazard, vulnerability and damage. Moreover, selected approaches for this research related to participatory mapping tools, flood hazard assessment, elements at risk, vulnerability assessment and damage assessment are described. Approaches used by other authors for the vulnerability and damage assessment are mentioned as well.

The third chapter provides a brief overview on the geographical location of the Yingxiu town, geology, geomorphology, climate and hydrology of the area. Socio-economic conditions before and after the earthquake that influences the social flood vulnerability is described.

The fourth chapter explains the required data to develop the research and their sources. Also research methods used during pre-fieldwork and the fieldwork phase to collect the data are explained. Methods and methodology used to answer the research questions are detailed within the post-fieldwork phase, as a part of this chapter.

The fifth chapter describes the results obtained in the different stages of the research. This chapter is divided on fifth sections. These sections are related to the 2010 flood event assessment, elements at risk, improvement of the DEM, construction of the flood depth map for the 2010 flooding and reconstruction of the event using modelling process (SOBEK 2D).

The sixth chapter contains description of the structural building type, damage assessment, community perception and coping mechanisms related to flooding and vulnerability assessment.

The seventh chapter is related to vulnerability assessment. Several approaches for the physical vulnerability are analyzed. Also social vulnerability analysis applying SMCE is described.

The eighth chapter is related to the risk reduction options. Measures to contribute to the reduction of flood risks are proposed based on weaknesses detected from technical and non-technical measures related to flooding.

The final chapter concludes the research. The discussion of results is reflected in this chapter. Each conclusion is based on answers of the research questions. Also recommendations for further studies are explained.

# 2. LITERATURE REVIEW

This chapter shows a summary of reviewed literature related to the research topic. It contains definitions of hazard, vulnerability and damage provided by experts in the field. It also includes an appraisal of several authors about their selected approaches, and an explanation of the selected methods to be used in this research.

## 2.1. Definition of hazard, vulnerability and damage

Hazard has been defined by several authors in different ways. Burton et al., (1978) described hazard as "those elements of the physical environment, harmful to man and caused by forces extraneous to him". According to Smith (2001) hazard is related to the process occurs naturally or are induced by human activities, associated to loss that generate future damage. Another hazard definition is given by UNDRO (1991) "the probability of occurrence, within a specific period of time in a given area, of a potentially damaging natural phenomenon". In this approach the definition given for United Nations International Strategy for Disaster reduction (UNISDR, 2009) is considered where hazard is defined as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation".

Previous definitions of hazard related natural phenomena to population settlements exposed to these events. The impact suffered by each exposed element depends on their vulnerability. Vulnerability is defined by Etkin et al.,(2010) "the propensity to suffer some degree of loss such as injury, death or damage from a hazardous event". For the purpose of this research the concept of vulnerability to be apply is given by United Nations International Strategy for Disaster Reduction (UNISDR, 2009) as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard".

The occurrence of hazardous events on vulnerable areas leading to the existence of damage of exposed elements. These are classified as direct and indirect. In flood events, direct damage occurs by physical contact of water with elements exposed. However indirect damages are caused by direct flood damage and reflected by disruption of economic and social activities (Dutta et al., 2001). Assessed losses in monetary values, both damages are classified in tangible and intangible (Merz et al., 2011).

## 2.2. Selected approaches for this research

### 2.2.1. Participatory mapping

Historical data and information related to previous flood events remain stored in the memories of people who have outlived inundations such as local knowledge, experiences or community perception can be collected applying participatory mapping.

Participatory mapping is described as "map – making process that attempts to make visible the association between land and local communities by using the commonly understood and recognized language of cartography"(IFAD, 2009). Based on the previous definition, participatory mapping is considered as a process in which local knowledge can be represented spatially and expressed in maps. Therefore they are considered as a source of information and as an alternative method to collect data when the available data is insufficient (Peters Guarin et al., 2004).

The local knowledge considers community's perception of the flood risk, flood experience and coping capacity. Risk perception is defined by several authors in different ways; such as Schelfaut et al., (2011) "is a result of risk communication, and implies how actors or residents perceive the risk". Another definition is given by Krishnamurthy et al., (2011) "visual representation of local risk perceptions during the mapping process". The community's perception is a source of help to identify the risk and its nature (Peters Guarin et al., 2008).

Experience and coping capacity, as part of local knowledge are other important factors that can be considered during the identification of elements at risk and evaluation of its vulnerabilities. Community's experiences related to previous flood events can be used to identify community weaknesses too, which should be strengthened (Schelfaut, et al., 2011). The spatial representation of community weaknesses allows a clear overview of problems (Peters Guarin, et al., 2008) and the identification of direction towards management actions.

Unlike the experiences and perception that are more related to community feelings, coping capacity is more linked to local actions of the community to confront events. van Westen et al., (2010) defined coping capacity as "a combination of all strength and resources available with a community or organization that can reduce the level of risk, or the effect of a disaster". Examples of coping mechanism cited by Tran et al., (2010) are: build of the houses on elevated areas; the adjust of production activities to avoid adverse impacts of flooding and the move of livestock and other properties towards higher places before the flood season. Other like early warning systems are considered as effective in strengthening coping mechanism (Schelfaut, et al., 2011).

The application of local knowledge is considered as important in the reduction of the negative impact of flood hazards (Schelfaut, et al., 2011) and in the elaboration of strategies for the risk reduction at community level (Krishnamurthy, et al., 2011). Information collected from the community allows the defining of characteristic of historical flood events, that are used by the elaboration of flood hazard map and evaluation of vulnerability of exposed element (Peters Guarin, et al., 2004). The local knowledge can be used in the making policy process and risk assessment as tool for planning to consider during evaluation of flood hazard and flood damage (Plate, 2002); and in risk management and disaster reduction (K. Smith, 2001).

### 2.2.2. Flood hazard assessment

Flood hazard assessment describe "the intensity and probability of a flood scenario in a given region and timeframe" (Thieken et al., 2008). In this research the definition of hazard assessment given by van Westen, et al., (2010) was considered, associated with the analysis of physical characteristic of the 2010 flood event with the aim of providing an estimation of its spatial probability of occurrence and magnitude.

The department of Regional Development of American States (1991) identified traditional techniques related to historical flood data that can be used during the hazard assessment. For example, detailed surveys related to topographic information (slopes, cross section and contours maps) and records of peak flows during a period of the year. Also information related to geology, geomorphology and soil can be used. These traditional techniques can be supported by another method such as remote sensing. Modeling using scientific information is another method to flood hazard assessment applied (Bhattacharya, 2010). In this study, the 2010 flood event assessment was carrying out considering historical information from community knowledge and modeling methods.

Flood hazard characteristics such as location, frequency and intensity can be collected from the community perception (Krishnamurthy, et al., 2011). Also, other characteristics like water depth, extension and duration are obtained by applying the same approach or as output of models where maximum impulse and flow velocity are also calculated and represented like parameter maps (Alkema et al., 2007).

The temporal and spatial probability of occurrence of hazardous flood events with a given magnitude is considered as its frequency (van Westen, et al., 2010) and can be used in the calculation of the return period, defined by Smith (2001) as average time elapsed between two events that equal or exceed a determined magnitude. This is considered as an important characteristic in the study of flood hazardous events. "Probabilities are calculated from statistical analyses of yearly discharged maxima or discharges above a threshold" (Schumann, 2011). The lack of data that shows the sequence of discharges does not allow a temporal analysis.

A flood hazard map with the characteristics of the flood event such as: water depth, extension, duration and velocity shows the final result of the flood hazard assessment (Peters Guarin, et al., 2008). This created flood hazard map is used in the vulnerability analysis of the elements exposed.

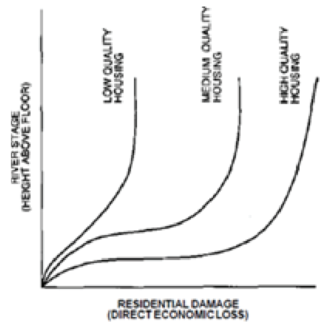
### 2.2.3. Elements at risk and vulnerability assessment

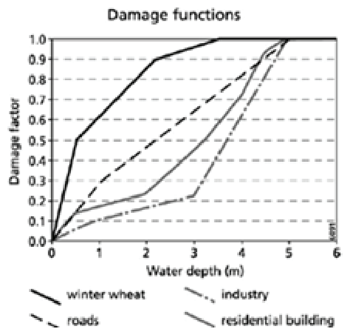
Elements exposed at risk are defined by UNISDR (2009) as "People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses". A detailed definition of these is given by van Westen, et al.,(2010) "all objects, persons, animals, activities and processes that may be adversely affected by hazardous phenomena, in a particular area, either directly or indirectly. This includes buildings, facilities, population, livestock, economic activities, public services, and environment". The degree of exposed elements to flooding events determinates its vulnerability.

According to Etkin, et al., (2010) there are six types of vulnerability: physical, social, structural, cultural, economic and institutional. For the purpose of this research the definitions of physical and social vulnerability shown by van Westen, et al.,(2010) are considered. The physical vulnerability is related to the physical impact of the flood hazard on the built environment and population. On the other hand the social vulnerability is considered as the potential impacts of events on vulnerable groups.

Gungor (2003) defines vulnerability assessment as "the process by which the level of exposure is determined." The vulnerability assessment can be determined using two methods: synthetic data collection related to estimation of potential damage as the expectative result from the flood event with specific magnitude; or the collection of real flood damage stated after the flood event (Maiti, 2007). For this approach the second method is more appropriated. Flood damage information was collected from the community using participatory mapping tools.

Based on the type of vulnerability, several methods of evaluation can be applied. For physical vulnerability assessment buildings exposed are categorized into building type, building content and outside properties (Dutta et al., 2003). Several authors such as Smith (2001) and Dutta, et al., (2001) used vulnerability curves or stage damage curves during the physical vulnerability assessment (Figure 3). Smith (2001) established a relationship between water depth and damage for residential properties. However Dutta, et al., (2001) shows a relationship between water depth and damage for different land covers.



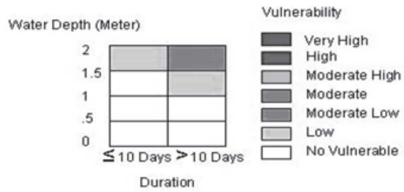

Damage curves by Smith (2001) Damage curves by Dutta, et al., (2001)

**Figure 3. Stage damage curves for physical vulnerability assessment**

An advantage of the stage damage method is that less effort and resource are required; and the flood damage can be estimated in less time. Merz, et al., (2011) describe the stage damage curves as "the essential building blocks upon witch flood damage assessment are based. They are considered as standard approach to assess urban flood damage". The damage curves relate land cover types to water depth and degree damage (Alkema, et al., 2007).

Other authors such as Kelman (2002) and Maiti (2007) built vulnerability matrices as another method of physical vulnerability assessment (Figure 4). Two dimensional vulnerability matrixes created by Kelman (2002) display a relationship between flood depth differential (fdiff), flood velocity (m/s) and the damage scale considering building type. On the other side, Maiti (2007) shows a vulnerability matrix of a relationship between water depth, duration and building structure type built of strong concrete wall, floor and roof material which is not so vulnerable to flood water. In this approach, the method proposed by Kelman (2002) is used during the physical vulnerability assessment.

| V ↓ | 0.0m | Fdiff 1 | Fdiff 2 | Fdiff 3 | [...] |
|---|---|---|---|---|---|
| 0.0 m/s | | | | | |
| V1 | | | | | |
| V2 | | | | | |
| V3 | | | | | |
| [...] | | | | | |




Vulnerability matrix by Kelman (2002) Vulnerability matrix by Maiti (2007)

**Figure 4. Vulnerability matrices for physical vulnerability assessment**

The social vulnerability assessment is related to vulnerable groups including the poor, the women, the disabled, the young, the elderly, single parent families, the less educated, lower income and the unemployed (Etkin, et al., 2010). These indicators proposed by Etkin, et al. (2010) were considered in this research. The socio – economic conditions of a society determines its vulnerability (Schumann, 2011). Flood events affect the environment, producing losses to biodiversity, potential pollution and erodibility (Kubal et al., 2009). In urban areas, environmental vulnerability assessment is associated with the accessibility to public services like the collection system, location of waste disposal and state of sewage system (Peters Guarin, et al., 2004). In this approach, the accessibility to health, education, water, sewage system, transportation and solid waste collection, were considered as important indicators related to the health of population.

Aspects related to the lack of access to the resources and public awareness; the accessibility to the information; disintegration of social patterns; limited access to political power; beliefs and customs influence in the vulnerability of exposed elements (Alcántara Ayala, 2002). Also the contradictions between economic, social and environmental development reduces sustainability and increases flood vulnerabilities (Ni, et al., 2010).

#### 2.2.4. Damage assessment

Merz, et al., (2011) described damage assessment as the quantification of damage spatially distributed, to be considered for the decision process on flood mitigation. Also these authors classified losses into tangible and intangible. According to Vinet (2008), the flood damage is classified into direct and indirect. The direct damage is related to damage on residential properties, infrastructures, agricultures (van der Sande et al., 2003). Indirect damage is associated to loss of live and costs linked to reparation of damage, psychological consequence of flood (Vinet, 2008), losses by disruption of activities, progressive deterioration of buildings, insurance losses and loss of biodiversity (van Westen, et al., 2010).

Dutta, et al., (2001) identifies two methods for the estimation of losses for flood events. The first is using past flood questionnaires that lead to affected people to estimate the damage to properties. The second method is based on the stage damage function, to related damage extension to land cover and flood characteristics like water depth and duration. In this research the first method was applied. The grade of damage can be expressed in percentage or absolute value (van Westen, et al., 2010). To calculate the real financial damage, the economic value of land cover must be known (van der Sande, et al., 2003). Merz, et al., (2011) described three scales for the spatial implementation of flood damage assessment: micro-scale, meso-scale and macro-scale. Micro-scale is related to damage assessment based on single elements exposed at risk, for example building. Meso–scale is associated to spatial aggregation, for instance units of land use such as industrial or residential area. Macro-scale is linked to large scale spatial unit, such as municipality or region. In this approach macro-scale is considered. The macro_scale shows compiled damage in economic values developed for the complete town.

# 3. STUDY AREA

This chapter includes a brief description of the study area and factors related to causes of the 2010 flood event in Yingxiu town.

## 3.1. Geographical location of the study area

Yingxiu is a typical mountainous town, located in Sichuan province, southwestern of China. It lies between latitudes 31º 03' to 31º 04' North and longitudes 103º 28' 30" to 103º 29' 36" East. Administratively Yingxiu belongs to Wenchuan County, with an area around 115 km2. An average altitude of 1012 m above sea level (Wikipedia, 2011). The town is crossed by Minjiang and Roa rivers (Figure 5).

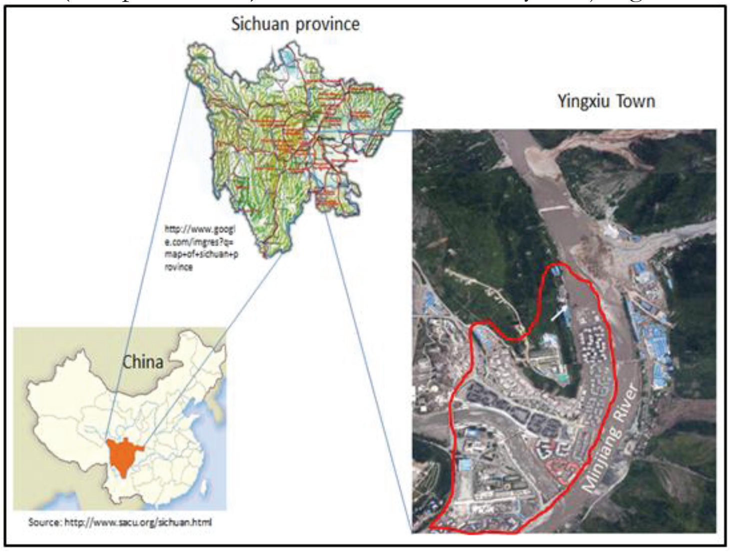



**Figure 5. Location of study area (red colour) in Yingxiu town, China**

## 3.2. Geology and Geomorphology

Yingxiu is located in an area known as the transitional zone between Sichuan Basin and the Western Sichuan Plateau, (Tang, et al., 2011). The town is settled on Quaternary deposits surrounded by mountains with elevations ranging between 1580.0 m to 1913.6 m (Figure 6).

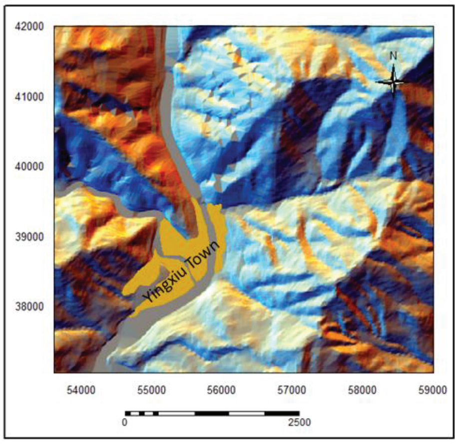



**Figure 6. Hill shade with Yingxiu town**

The lithology around the town is represented by "granitic rocks, Sinian pyroclastic rocks, carboniferous limestone, and Triassic sandstone", the geological main structure and the strike of the rock strata show a

NE–SW orientation (Tang, et al., 2011). The geomorphology of the area is described by the previous author as alluvial terraces and fans in loose Quaternary deposits, near to Yingxiu town. Bedrocks are greatly fractured and weathered.

The tectonic of the area is very active. Along the limit between the basin and plateau, with trend NE-SW runs a fault zone, where Yingxiu – Beichuan fault is considered the main structure, causative of 2008 earthquake. Associated to this event several landslides occurred; the majority were concentrated on the hanging wall part of the Yingxiu–Beichuan fault (Tolga et al., 2008). This faulting is categorized as a thrust with northwestern-dipping (Tang, et al., 2011). The dextral strike-slip rate of the Yingxiu–Beichuan fault since the late Pleistocene is considered less than 1 mm/year, and the thrust rate is about 0.3–6.0 mm/year (Tolga, et al., 2008). Joins are shown in competent lithologies, producing potentials failures surface in the slopes, when are combined with the faulting and bedding (Tang, et al., 2011). The geological map is shows in Figure 7.

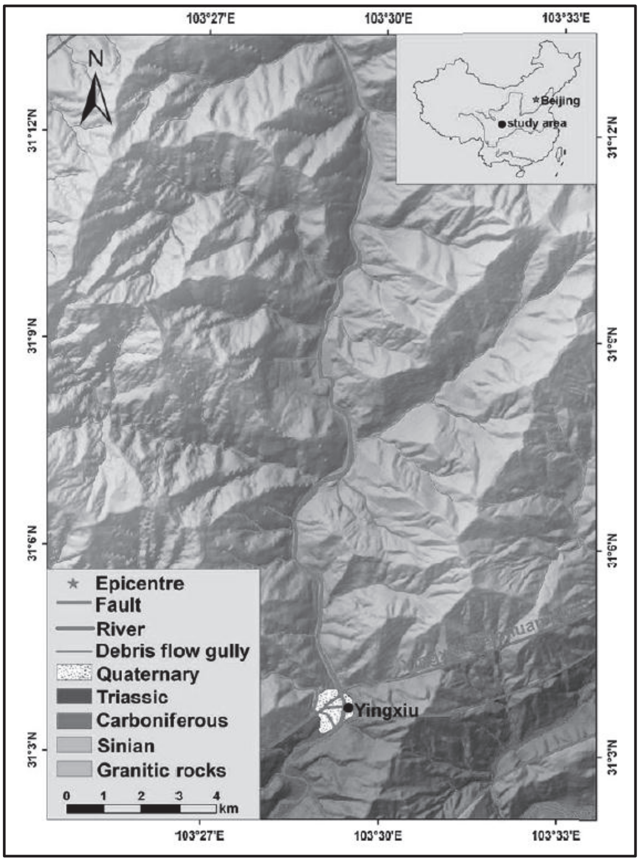



**Figure 7. Geological map of the study area. Source: Tang, et al., (2011)**

## 3.3. Climate

The study area is situated in a humid subtropical zone with a monsoon climate, where the annual average temperature is 12.9°C. The rainfall is concentrated in the months from June to September, with an average 70% of the annual precipitation falls during this period. "The annual average precipitation over a period of 30 years is 1253 mm, with a highest recorded annual precipitation of 1688 mm in 1964". The data from Yingxiu station shows that the maximum recorded rainfall intensity was 269.8 mm/day in 1964 (Tang, et al., 2011). Rainfall data associated to the 2010 flood event recorded by Yingxiu station are displayed in Figure 8.

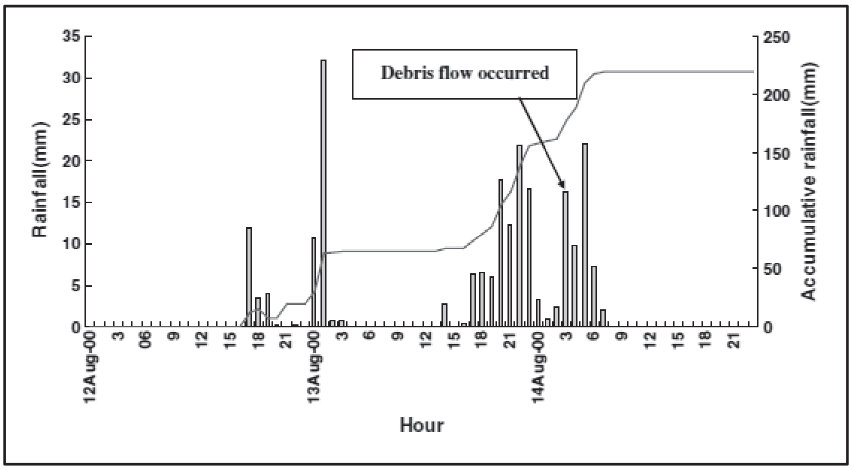



**Figure 8. Distribution of hourly and accumulated precipitation occurred between August 12th and 14th, 2010. Source: Tang, et al., (2011)**

On August 12th, between 17:00 and 24:00 hours; 19.9 mm of rainfall was recorded. The entire day of 13th August a total of 126.8 mm was recorded and 14th August, between 00:00 and 02:00 a.m; 23.4 mm of precipitation was recorded. From 17:00 p.m on 12th August, until 02:00 a.m on 14th August a total of 162.1 mm of accumulated rainfall was reported. The rainfall with an intensity of 4 mm/h originated the debris flow (Tang, et al., 2011). The previous author referred that rainfall occurred between August 13th to 14th is associated to 5 years of return period.

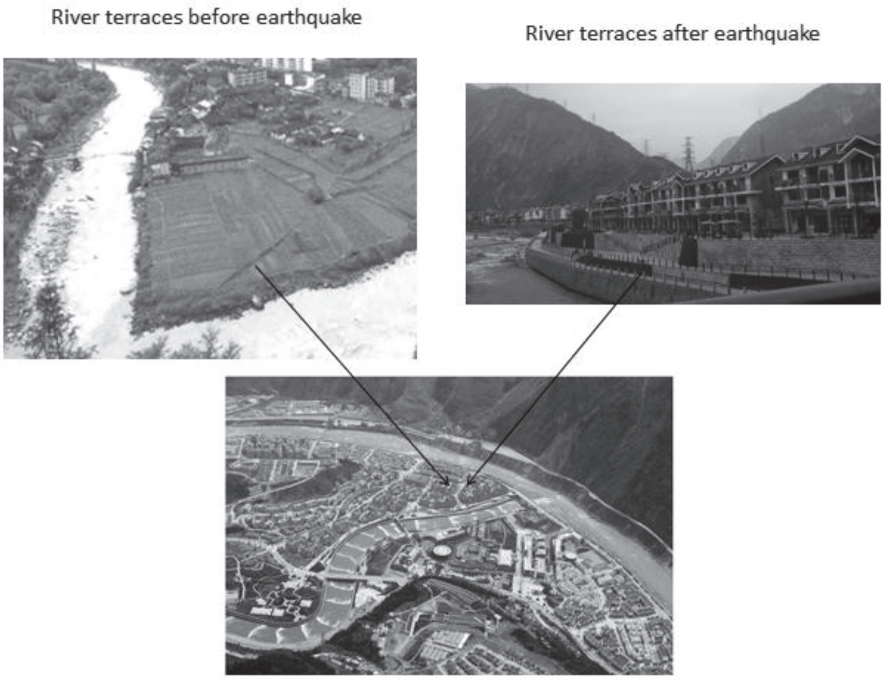
### 3.4. Hidrology

Minjiang River is the main river in the study area. It starts in the northwestern and it is situated an in mountainous area. It is a first-order branch of the Yangtze River and considered as "an ecologically weak transition zone that extends from the Tibetan Plateau to the Sichuan Basin" (Ye et al., 2006). Lies between 31º-33º N and 102º -104º E, with a length of 340 km and area about 23 000 km$^2$ (Li et al., 2006). Its annual mean discharge is 452 m$^3$/s and peak stream discharges averaged 2790 m$^3$/s during 1958 (Tang, et al., 2011). The Minjiang River runs along of the east part of Yingxiu town. One of its tributaries is the Roa River, which crosses the town from the western towards east. At its mouth joins the Minjiang River.

### 3.5. Socio-economic conditions

Yingxiu belongs to Wenchuan County, Ngawa Tibetan and Qiang autonomous prefecture of the Sichuan province. It is located approximately 65 Km away from the provincial capital city of Chengdu. Before the Wenchuan earthquake, the population of the town was around 12 000, with mostly ethnic Qiangs, Tibetans and Hans; "benefiting from its natural resources and location near famous tourist attractions it was once a relatively prosperous township in Ngawa" (Lu, 2010). The main economic activities were related to mineral, forest industries and tourism. Also the local farmers cultivated vegetables, fruits and corn (Lu, 2010) on river terraces (Figure 9).

After the earthquake, socio-economic conditions changed. During the earthquake around 9000 people were killed (Lu, 2010), and the town was devastated. A new town was rebuilt. People from other cities such as Dujiangyan and Xinjing City moved into Yingxiu. Today, the population in the town is around 6000 inhabitants. The main economic activities are associated with tourism. Extensions of agricultural' areas were limited by changes in the land use on river terraces. New buildings were built in this area (Figure 9).




Source: http://dictall.com/news/2011-05/11/0039145.htm

**Figure 9. Change of the land use on river terraces**

# 4. RESEARCH METHODS

This topic describes the process of this research to be carried out in order to reach the objectives explained in Chapter 1. The process has been divided into three phases: pre-fieldwork, fieldwork and post fieldwork. Also, it includes the explanation of research approaches to be used.

A conceptual framework about the overall research processes to each phase is represented in Figure 10.

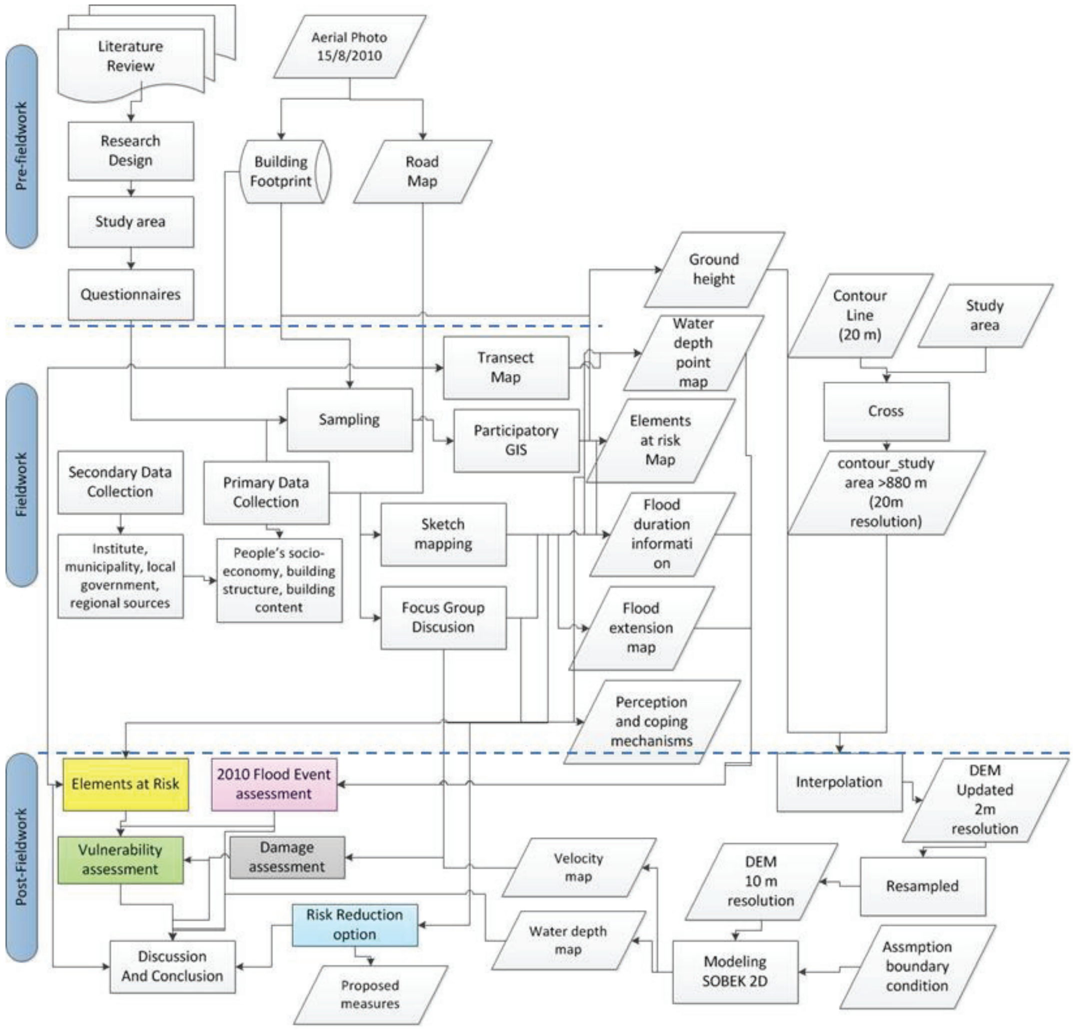



**Figure 10. Framework of the overall research processes**

## 4.1. Pre-fieldwork

The aim of this stage is to prepare all required data for the fieldwork stage. This phase includes a literature review about the study area and selected approaches to apply during the research. Selection, classification and organization of available data took place in this step followed by the identification of the required data. Also, a database for the building footprint information was created. Questionnaires and interviews to fill the created database were elaborated.

### 4.1.1. Selection of study area

Yingxiu was a relatively prosperous township of Wenchuan County. It was a famous town because of its tourist attractions and it's nice landscapes (Lu, 2010). After the earthquake of May 12th 2008 the city was devastated and slopes around the city became unstable (Tang, et al., 2011). Heavy rainfall occurred on 14th

August 2010 triggering Hongchun gully debris flows into the Minjiang River, causing flooding in Yingxiu town (Tang, et al., 2011). There is no detailed evaluation of this event yet. The town lying within an alluvial depositional zone; it is surrounded by the Minjiang River and also dominated by unstable steep slopes. These conditions make the city more vulnerable to flooding that may lead to serious disasters in the near future.

#### 4.1.2. Data requirement

Spatial and non-spatial data are required to carry out this research. Data requirements were divided considering availability of its sources. These are presented in
Table **2** and Table 3.

**Table 2. Required data and available sources**

| No | Data requirement | Data Source |
|---|---|---|
| 1 | Satellite image after earthquake and before flood event. | Google Earth image.<br>Aerial Photo (0.5 m resolution) |
| 2 | Aerial photo during flood event (to create footprint). | Aerial photo August 15, 2010 |
| 3 | Topographic of the area | DEM (20m resolution) obtained from contour line before earthquake and flood event. |

There are two available images related to Yingxiu town taken after the earthquake and before the 2010 flood event. The aerial photo (0.5 m resolution) taken on May 18, 2008 shows tents and temporary sets of plank houses built for the earthquake victims (Han, 2009). The image from Google Earth displays other stage of reconstruction on Yingxiu where tents were used as temporary shelters. The temporal distribution of these houses impedes the use of these images for the creation of the building footprint. After that, new buildings were constructed in Yingxiu town and these are shown on an aerial photo taken on August 15, 2010 during the flood event (Figure 11). Therefore the aerial photo from August 15, 2010 was used to generate the footprint and road map during the digitalization process.


**Figure 11. Temporal sequence of building construction on Yingxiu town**

**Table 3. Required data to be collected during fieldwork**

| No | Data requirement | Data Source |
|---|---|---|
| 1 | Water depth, flood extension and duration | PGIS, sketch mapping, focus group discussion (FGD) and transect mapping |
| 2 | Elements at risk (building type, building contents and socio-economic condition) | Interview, questionnaires and secondary data |
| 3 | Building occupancy type | Transect Mapping |
| 4 | Flood velocity | Using DEM and discharge from the river in modeling (SOBEK 2D) |
| 5 | Damage assessment | From local knowledge (interview and questionnaires) |
| 6 | Vulnerability assessment (physical and social) | Analysis of characteristics of the 210 flood event, elements at risk and damage. |
| 7 | Coping mechanism | Interview and questionnaires |

Information related to building occupancy type was collected during transect mapping. As result an element at risk map for the town was built. Also, elements at risk were obtained from digitalization process and results of questionnaires. Characteristics of the 2010 flood event (water depth, extension and duration), coping mechanism and damage were obtained through questionnaires and interviews. These were applied through PGIS, focus group discussions and transect mapping. Details about the fieldwork time distribution are shown in Appendix 1. Another characteristic such as flood velocity was obtained from modeling applying SOBEK 2D software. The vulnerability assessment was developed during the post-fieldwork stage considering characteristics of elements at risk, and the 2010 flood event and its damages.

All data collected were georeferenced and processed using Geographic Information System (GIS). These were put into the same coordinate system and projection created using ILWIS software. The coordinate system is World Geographical System (WGS) with the projection Universal Transverse Mercator (UTM). The aerial photo and footprint map were stored in the mobile PDA (Personal Digital Assistance) and used during the fieldwork stage.

#### 4.1.3. Questionnaires

Two questionnaires to collect the local knowledge were prepared and translated into Chinese (Appendix 2 and 3). One was applied during participatory Geographic Information System (PGIS) and the other questionnaire was used through the transect mapping and focus group discussions. The first questionnaire is divided into three sections. The first section is related to building information and building content (considering tangibles damage); the second section includes population information (socio-economic aspects and intangible damage); and the last section is concerned with coping mechanisms and risk perception. Characteristics of the 2010 flood event were included in the first and third sections.

The second questionnaire is divided into two sections. The first section is focused on coping mechanisms, risk perception and characteristics of the 2010 flood event. The second section is concerned with flood damages (direct and indirect).

### 4.2. Fieldwork

The aim of this stage is to collect the data related to 2010 flood event. The fieldwork was conducted from 21st of September to 22st of October; in the study area of Yingxiu town. During fieldwork, primary and secondary data were collected. Also, secondary data were obtained during pre-fieldwork stage. Primary data collected were based on local knowledge, expressed as the community's perception of the flood risk, flood experience and coping capacity. These were collected through questionnaires, interviews, focus group discussion and transect mapping. Secondary data were obtained through reports and additional information from national and regional sources, the municipality and an educational Institute.

#### 4.2.1. Sampling method

PGIS questionnaires were developed applying a stratified random sampling method. This method is concentrated on the distribution of a specific variable (Sang et al., 2008). During transect and participatory GIS, the stratified random sampling methods were applied considering structural types of building and building occupancy type. The major number of samples was taken in the more affected area.

Fieldwork observations show the existence of variability of house distribution in vertical and horizontal directions. In buildings with three floors, the change in a new housing occurs in the horizontal direction. However, in buildings with five floors, the change into new apartments is produced in a horizontal and vertical direction. This indicator was considered during the sampling method. In order to define the more representative numbers of floors of sampling, the formula from Snedecor and Cochran used by Lockwood, et.al., (2000) was applied. This formula is shown below.

$n = t^2 (s^2/L^2)$
Where **n** is appropriated sample size; **s** is standard deviation and **L** is error relative to mean.

$L = x^- p$
Where $x^-$ is the mean of number of floors; p is precision (considered as 0.25)
So, **L** was calculated as L= 3.23 * 0.25 = 0.8075

Considering 90 % of confidence level t=1.96
$n= 1.96^2 (0.722^2/0.8075^2) = 1.962* 0.799=3.07$

So, to achieve a precision of ± 25 % of mean with 90 % of confidence level a minimum of 3 floors can be sampled on buildings of five floors. Then buildings were sampled until the third floor. For buildings less than five floors only the first floor was sampled.

Also the number of buildings to sample was calculated. Considering that Yingxiu is a small town and therefore, the number of buildings are few, the formula applied by Glenn (2009) was taken into account. Glenn (2009) considered that a "given the sample size proportionality proves more information for a small population than for a large population". The representative of samples was calculated as follows:

n = no/ 1+(no-1/N)
Where **n** is sample size; **no** is sample size adjusted; **N** is population size

For buildings located inside of the flooded area the application of the formula is:
n= 44(1+(44-1)/75)= 44*1.57=69.08

That means that 69 buildings should be sampled inside of the flooded area. Considering that Yingxiu is a new town that was only rebuilt last year, where the high percentage of population moved out of the town after the 2008 earthquake, without returning; 35 buildings and 257 apartments located inside of study area are empty (without persons), making it difficult for the sample process in some areas (for example, for buildings of five floors). Only 60 buildings were sampled. From these, 44 sampled buildings were located inside of the flooded area. This represents 64 % of the sample size.

The building occupancy type was another important aspect to take into account during the sampling. Samples in residential and commercial-residential building (shops, restaurant and hotel) were also taken as well.

### 4.2.2. Participatory mapping

During data collection in the fieldwork the aerial photo from August 15, 2010 stored in the mobile PDA (Personal Digital Assistance) was used to georeference each building sampled. Primary data was collected from the community through questionnaires. Sixty buildings were sampled using the stratified random method. The information collected was transferred into GIS, and the spatial distribution is shown in Figure 12. A building inventory with data about elements at risk and damage estimation was created. Social aspects and coping mechanisms were collected through questionnaires as well. Also information of water depth and duration were obtained through this method.

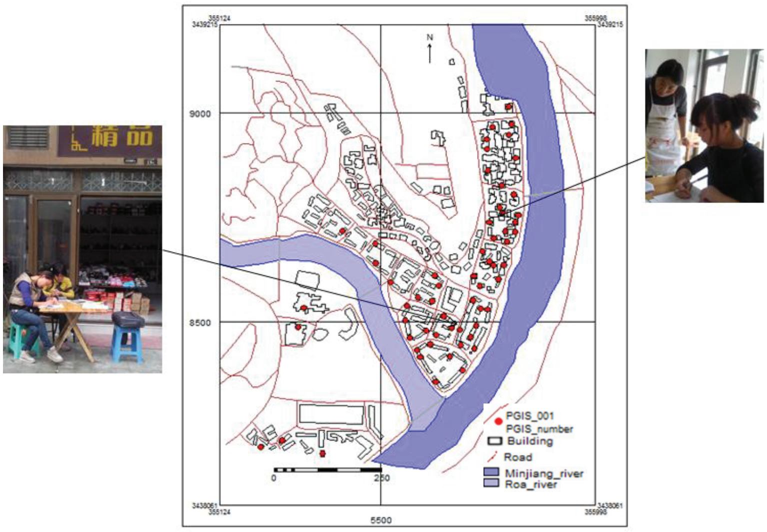



**Figure 12. Spatial distribution of buildings sampled using PGIS**

### 4.2.3. Transect mapping

This method was applied in order to become familiar with the study area. Walking follows routes that were previously defined. Therefore observations of resources distribution and photos were taken. The spatial distribution of measurement' points are shown in **Figure 13**.

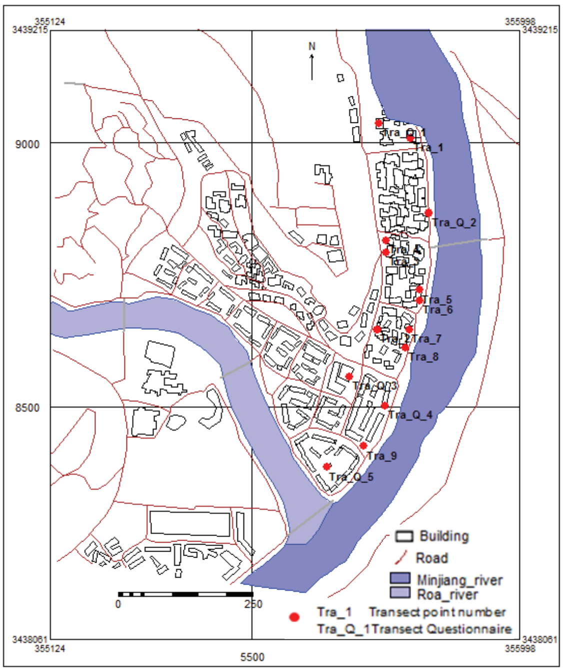


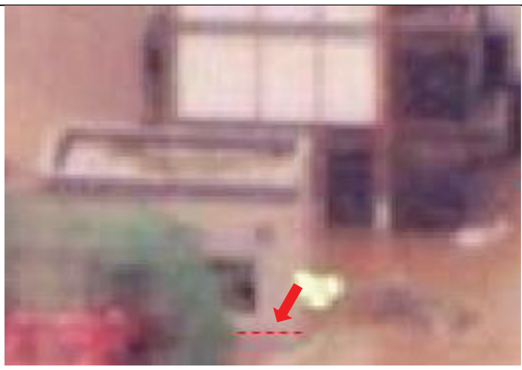

**Figure 13. Spatial distribution of buildings sampled during transect mapping**

During transect mapping the measurements of water depth inside and outside of damaged buildings were taken. Nine buildings were sampled and values of water depth according to the local people were compared with the flood mark existing in the building of the water factory and with photos taken during the flooding of 2010 (Table 4). Also questionnaires and interviews with the people (passers) were undertaken. Questionnaires were related to the damage of the flood event, community perception and actions taken by the community during the 2010 flood event. Measurements of ground height were doing applying this method as well.

**Table 4. Measurements of water depth during transect mapping**

| Point | Photo during Flood event | Photo after flood event |
|---|---|---|
| Tra_1 | <br>Source: http://insidechinatoday.net/2010/08/21 /inside-china-today-saturday-21st-august | <br> |
| Tra_2 |  | <br> |
| Tra_3 and Tra_4 |  | <br> |
| Tra_5 |  | <br> |

**Table 4. Measurements of water depth during transect mapping (cont.)**

| Point | Photo during Flood event | Photo after flood event |
|---|---|---|
| Tra_6 |  |  |
| Tra_7 and Tra_8 |  |  |
| Tra_9 |  |  |

#### 4.2.4. Building Inventory

An inventory on buildings was established in order to obtain building information. The building information is related to building types (wall and roof); number of floors; Building occupancy type; age; state; height of ground floor relative from the street level; existence of underground spaces or retained structure for flooding; building damage; building content and damage to building content. Also, information related to water depth and duration was obtained. This information was verified in the third section of this questionnaire.

#### 4.2.5. Focus group discussions

This method was conducted with the aim to obtain more information from the community about flood risk perception and coping mechanisms used during the 2010 flood event. Also, causes and circumstances that originated the victims were analyzed. Questionnaires with information about community perception, actions from the community, 2010 flood event characteristics (water depth and duration) and damage were applied as an introductory method. Two meetings were organized. In the first meeting, the group discussion using of questionnaires were developed (Figure 14). In the second meeting, results were validated. Memories, opinions, ideas, suggestions resulting from FGD were compiled.

**Figure 14. Focus Group Discussion**

#### 4.2.6. Sketch mapping

Sketch mapping was developed to get information on the 2010 flood extension. An aerial photo from 15th August 2010, printed in large size was used for the participants, who drew the 2010 flood extension based on their experiences and knowledge. Also, information related to water depth, flow direction and location of the most damaged area were noted (Figure 15).

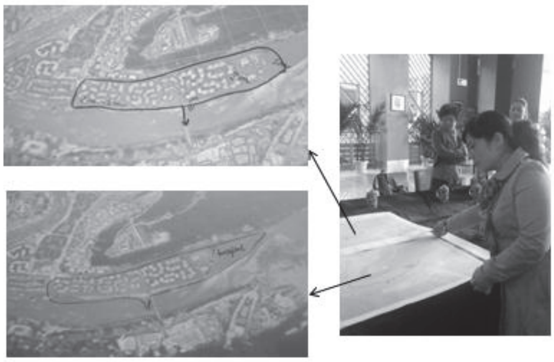


**Figure 15. Sketch mapping of 2010 flood event**

### 4.3. Post-fieldwork

During this stage data collected from the fieldwork were processed and analyzed. Errors were adjusted. Using ILWIS software, the 2010 flood event assessment, flood vulnerability evaluations of elements at risk and damage calculation were done. Details about the methodology applied are explained below.

#### 4.3.1. 2010 Flood Event assessment

The 2010 flood event assessment was carried out taking into account the definition given by van Westen, et al., (2010). Historical data of the flood event of 2010 (flood extension, water depth and duration) were collected using participatory mapping tools. Therefore local knowledge was transformed into input data of the flood event assessment. GIS was used to carry out quantitative and spatial analysis of this information. As results water depth point map and flood extension map were created. Information of flood duration collected was considered adequate. The conceptual framework for the 2010 flood event assessment is shown in Figure 16.

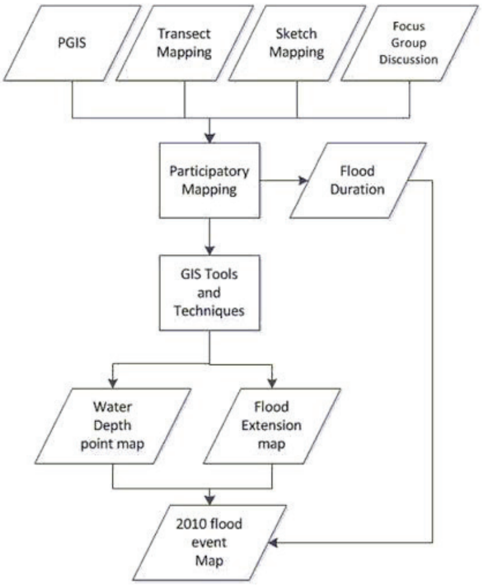



**Figure 16. Conceptual framework of the 2010 flood event assessment**

Finally the flood map of the 2010 event with the characteristics of water depth and extension obtained from the community knowledge, combined with velocity (from modeling) were created.

#### 4.3.2. Elements at risk due to the 2010 flood event

The identification of elements at risk started with the creation of the building footprint during the digitalization process using the aerial photo from August 15, 2010. Data collected related to the characteristics of buildings and population were stored on the building inventory. As sources of data were applied to those identified by Trang (2010), which were adjusted to this research (Figure 17).

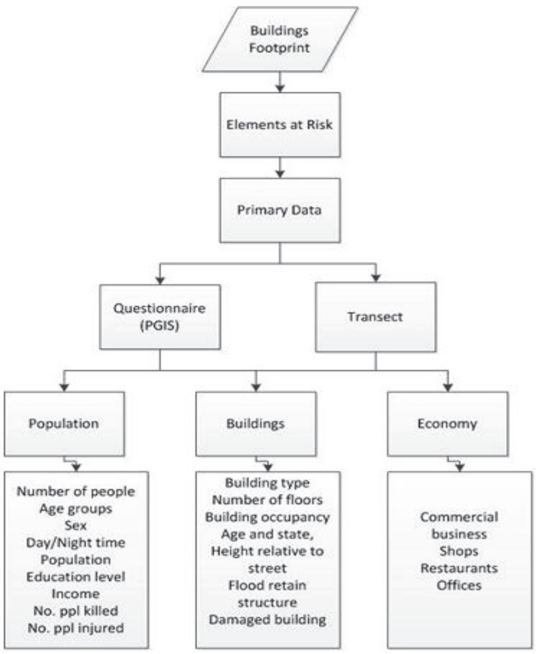



**Figure 17. Conceptual framework of elements at risk. Based on Trang (2010)**

#### 4.3.3. Improvement of the DEM

Measurements of ground height from 53 points were used to update of DEM existing, created from contour map with a contour interval of 20.0 m. Contour lines were transformed into points and ground height measured were added. Using ILWIS 3.3 the elevation values were interpolated. Details about the interpolation process and update of the DEM are given in section 5.3.

#### 4.3.4. Construction of flood depth map for the 2010 Flood Event

Data related to water depths collected from 22 measures points during transect and participatory GIS were reflected as point map. These water depth values were combined to elevation values obtained from DEM updated for the calculation of water level. As result a point map was obtained, which was interpolated. Details about the interpolation methods are given in section 5.4. Finally, values of water depth for all the buildings were calculated as the difference between water level and DEM values.

#### 4.3.5. Modeling applied to the flood assessment

Modeling using scientific information is another method used by several authors during flood assessment. Some authors such as Neuhold, et al., (2009) integrated the river bed dynamic into the flood risk assessment using modeling methods. The model calculates morphological changes in the river bed at the moment of the peak flow. This allows the estimation of variability on the water surface level, flow velocity and possible inundation areas. Other authors such as Arduino, et al., (2005) show the advantage in the use of modeling as mechanisms to represent the run-off generation, which can be used on the flood forecasting for the warning system.

In this approach the modeling is applied with the aim to obtain flood velocity values, which will be used on the flooding of 2010 assessment and damage assessment. Flood velocity values were obtained applying SOBEK software. The application of a 1D model is not successful in urban areas because the calculation of the river flow is limited by obstacles such as roads and buildings (Bhattacharya, 2010); by this reason for this research, a 2D model was applied. A 2D model determines the flow of water in two spatial dimensions (Alkema, et al., 2007). The calibration of model was based on values of the Manning's coefficient given by Alkema, et al., (2007). During the modeling process two scenarios were considered. Details about validation and calibration of the model are given in section 5.5. As results values of velocity, water depth and extension are calculated. Velocity values obtained from the second scenario were adopted. The conceptual framework of the modeling process is show in Figure 18.

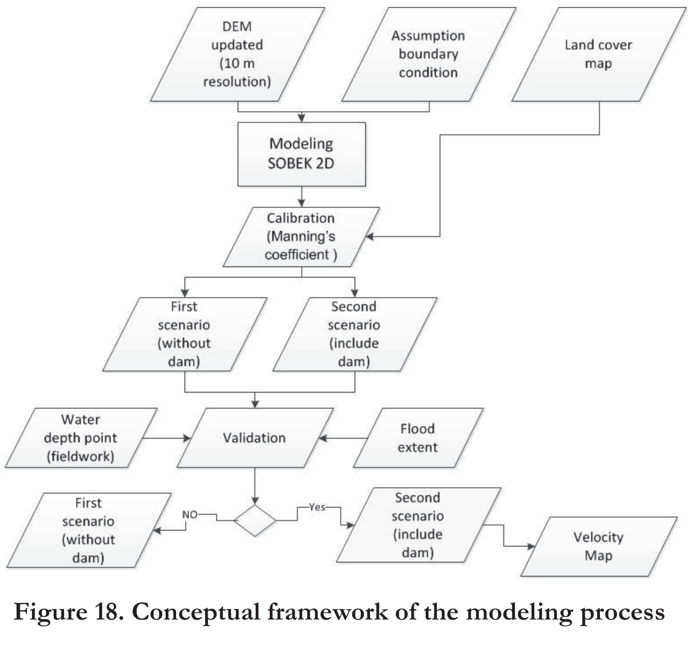



**Figure 18. Conceptual framework of the modeling process**

### 4.3.6. Flood damage assessment

In order to quantify the damage, the 2010 flood event map created was combined with elements at risk. The flood damage assessment was undertaken considering one of methods for the estimation of losses proposed by Dutta, et al., (2001). Questionnaires were held amongst the people affected, with the aim to evaluate the damage to their properties, and to create an inventory of the flood damage. This damage was categorized as direct or indirect and quantified as tangible. Also intangible losses were evaluated using social indicators such as number of fatalities, injures, and psychological impacts. A conceptual framework of damage assessment is shown in Figure 19.

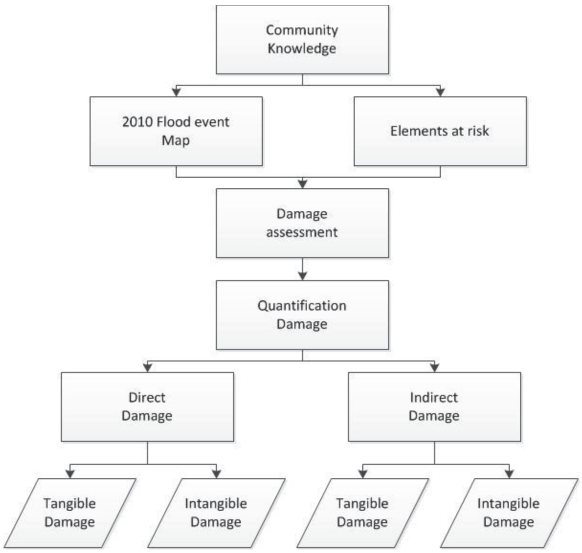



**Figure 19. Conceptual framework of damage assessment**

The final results of the flood damage assessment were a flood damage map with the spatial distribution of direct damages based on damage scale proposed by Kelman (2002), and another map with the indirect damage from psychological impacts.

### 4.3.7. Flood vulnerability assessment

The vulnerability assessment begins with the identification of elements exposed. Building characteristics and socio-economic aspects collected using tools of participatory mapping were combined to the flood event map of 2010 created to evaluate the vulnerability of each element. Physical and social vulnerability were determined based on indicators related to the definition given by van Westen, et al., (2010).

The physical vulnerability evaluation considers the analysis of buildings characteristics, which were detailed in questionnaires, interviews and transect mapping. Two dimensional vulnerability matrices created by Kelman (2002) with the relationship of water depth (m), flood velocity (m/s) and the damage scale for building structural type were applied. The social vulnerability assessment was done considering aspects defined by Etkin, et al., (2010) in the section 2.2.3. These aspects and others were detailed in the questionnaire, section: population information. The conceptual framework of vulnerability assessment is shows in Figure 20.

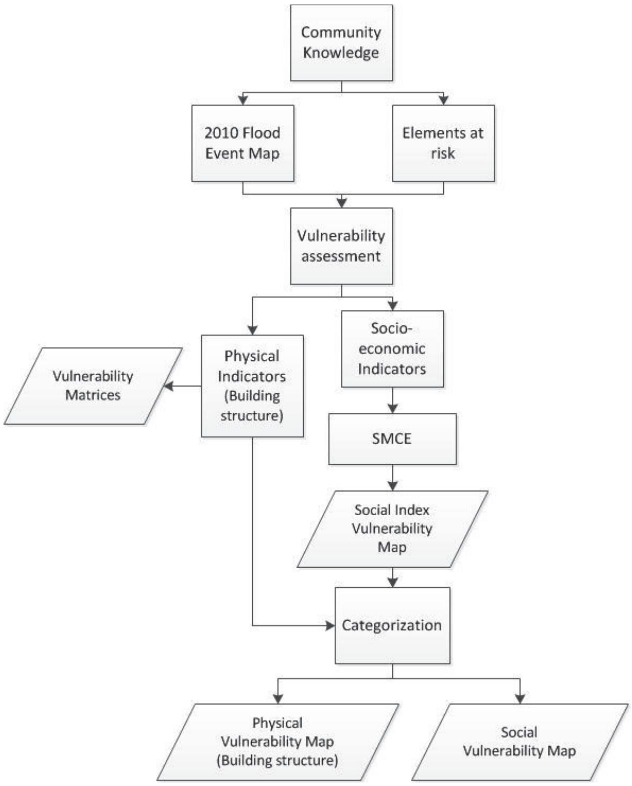



**Figure 20. Conceptual framework of vulnerability assessment**

Also, as part of vulnerability assessment, spatial multi-criteria evaluation (SMCE) method was applied. This has been used by Peters Guarin, et al.,(2008), Alkema et al.,(2007) and Kubal et al.,(2009) during risk assessment, where the vulnerability evaluation has been considered implicitly. Based on this principle; social indicators were combined to determine social vulnerable areas.

### 4.3.8. Community perception, coping mechanisms and risk reduction option

With the aim to fulfill the second objective of this research, community perception and coping mechanism related to the 2010 event flood collected applying questionnaires and interviews were analyzed. Also effectiveness of the early warning system and evaluation process were evaluated. Technical and non-technical measures were considered. Finally, measures to improve the strategy to flood risk reduction and minimize the impact of next flood events were suggested. Details are given in chapter 8.

# 5. RESULTS FROM FLOOD ASSESSMENT AND ELEMENTS AT RISK

In this chapter data collected from the population of the Yingxiu town and secondary sources are analyzed using SIG. As a result, maps with the spatial distribution of these data show the characteristics of the 2010 flood event. Building description from building inventory is details within this chapter. Also methods used to improvement of the DEM and the construction of the flood event map are described. Reconstruction of the 2010 flood event using modeling is included in this chapter as well.

## 5.1. 2010 Flood Event assessment

The reconstruction of the 2010 flood event was centered on results of the application of participatory mapping tools and modeling process. The absence of data related to record of rainfall, historical flood events, and multi temporal image does not allow by the use of methods applied by authors such as Maiti (2007) and Bhattacharya (2010) in order to produce similar results. Therefore, the 2010 flood event assessment was based in the analysis of flood characteristics such as: flood extension, water depth, velocity and duration. Details are given below.

### 5.1.1. Flood extension for the 2010 flood event

The determination of flood extension was based on community participation in terms of their experiences and knowledge related to the 2010 flooding. Participatory mapping tools such as participatory GIS (PGIS) and sketch mapping were used as method to obtain this information from the community. During the PGIS survey, areas that were flooded and unflooded areas were identified. Through sketch mapping boundaries between these areas were drawn on the aerial photo from 15th August, 2010. Details of the flooded area were obtained too, such as, the direction of water flow and the main areas of incorporation of water flow to the Minjiang River were defined. From the boundary for the flooded area the extent map was created. The map of the flood extent is shown in Figure 21.The flooded area is located mainly towards the North and East of the town; and towards the South near to the confluence of two rivers Minjiang and Roa. In general during the 2010 the area flooded was around 76.0 km² along the Minjiang River.

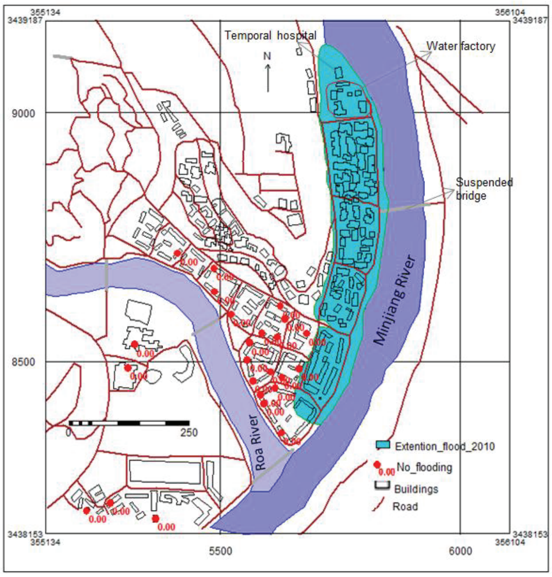



**Figure 21. Flood extension map for the 2010 flooding**

### 5.1.2. Water depth from field observation for the 2010 Flood Event

Water depth values associated to this event were obtained through measurements during the application of participatory GIS and transect mapping. Data of water depth inside and outside of buildings were collected. Figure 22 shows the spatial distribution of 22 measured points of water depth. The highest values of water depth (2.80 m) were measured towards the north part, inside of the water factory (Figure 21), where watermarks are observed (Table 4 Tra_1). Also towards the east of the town, near to the suspended bridge (Figure 21) high values were obtained (2.70 m). However towards the south water depth values were less than 1.0 m. The least value of water depth measured in the southern part was 0.25m, where the water did not enter inside the building.

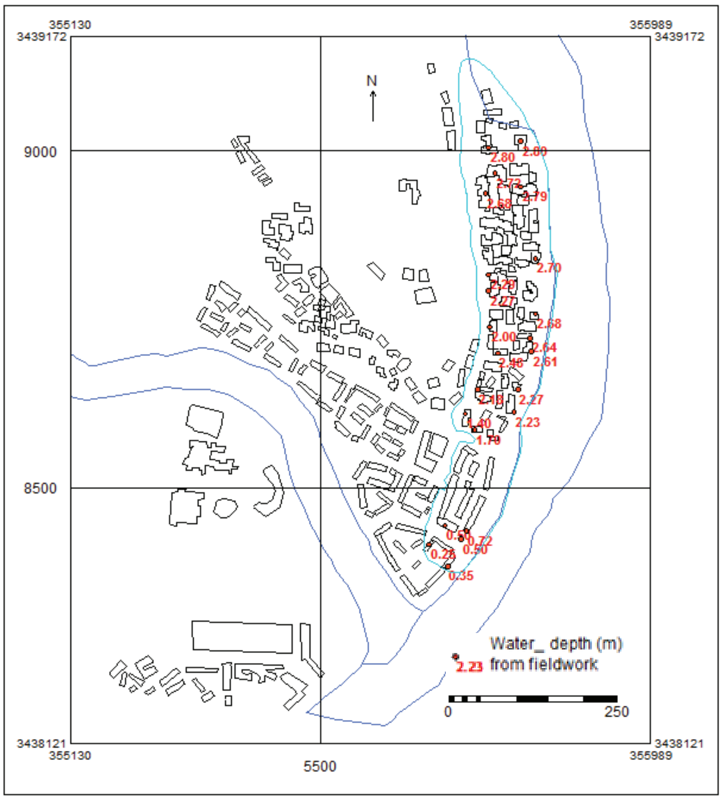



**Figure 22. Flood depth point map from fieldwork observations**

### 5.1.3. Flood duration for the 2010 Flood Event

Information related to the flood duration was also collected. The duration of this event as other flood events was related to the cause that originated the 2010 flood event. This was triggered by dam debris flows from Hongchun gully that blocked the left bank of the Minjiang River. Statements from population and local authorities of the town confirmed that after the debris flow (August 14th) the flooding started and ended four days after, when the dam was breached by an explosion operation. The duration of the flooding was four days.

## 5.2. Elements at risk due to 2010 Flood Event assessment

The identification of elements at risk was divided into two steps. The first step was developed during the pre-fieldwork stage. The aerial photo from August 15, 2010 was used as a base for the digitalization of the building footprint. In the second step characteristics of buildings and population as parts of elements exposed at risk were collected during the fieldwork stage and stored in the database of the building inventory. Details about buildings are described below, and information about social indicators is described in section 7.3.

### 5.2.1. Building description from building inventory

The building description contains physical information about buildings, such as: building types, number of floors, building occupancy type, age, state, height of ground floor, existence of flooding retained structures for buildings and building size.

#### 5.2.1.1. Building types

Two different building types were registered in Yingxiu town during the fieldwork stage. One building type was constructed with concrete (79 %) and other buildings (temporal houses) were built with metal (21%).

Concrete buildings are located on the right bank of the Minjiang River and both sides of Roa River. These buildings, although they have similarity with construction materials, there are differences in their designs (Figure 24), which influence their vulnerability to flooding. Similarity of the buildings is given for floor materials and roof materials. In both cases concrete is the material used. The roof of these buildings is covered by asbestos cement material as a decorative appearance of traditional Chinese buildings (Figure 23).

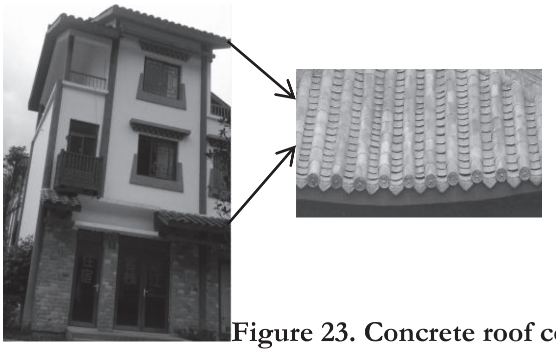


**Figure 23. Concrete roof covered for asbestos cement**

In these building walls are built of concrete and in several cases coated with another material. Bricks and fragments of rocks such as granite are used. Types of coating used depend of building design (Figure 24).

**Figure 24. Types of material coating recovering walls on different buildings designs**

The materials that coats walls act as a protection, avoiding the moisture to penetrate into walls. As a disadvantage in some of the building designs, walls are not completely covered and showing damage from humidity (Figure 24 circle).

Another building type found in the town is represented by temporal houses, constructed with walls of styrofoam, coated by a thin metal layer. Floors and roofs are built with the same material. These buildings are located towards the left bank of the Minjiang River and external part of the town, outside of the area of interest of this research. This building type, however, was represented by the temporal hospital during the 2010 flood event, for this reason its characteristics were considered in the vulnerability analysis. On 2010, 21 % of buildings were temporal houses. The spatial distribution of these temporal houses during 2010 and 2011 are shown in Figure 25 together with the distribution of concrete buildings.

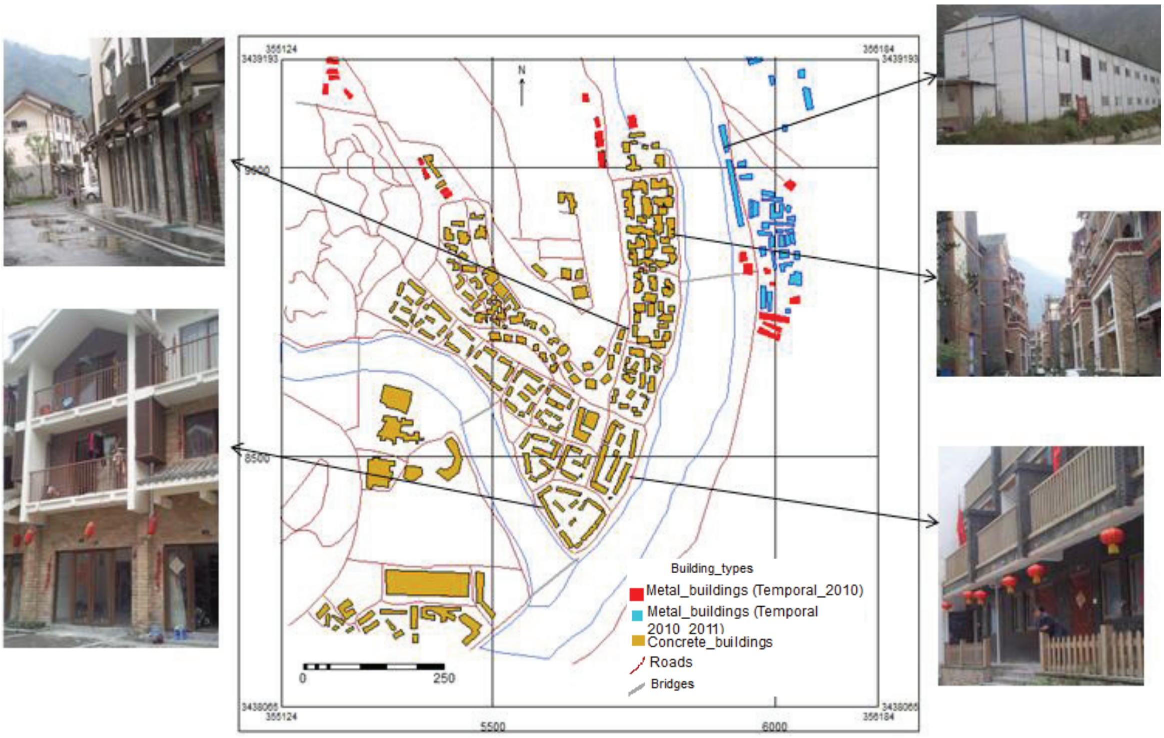



**Figure 25. Spatial distribution of building types**

#### 5.2.1.2. Number of floors

The buildings described in the previous section were classified by the number of floors. Concrete buildings were divided into four groups and metal buildings into two groups. Figure 26 reveals that the largest group of buildings type structures are buildings of concrete with 3 floors, which represents 63 % from the total buildings during 2010. The second largest group are buildings of metal with 1floor (11 %) and 2 floors (9.78 %). On the other side, buildings of concrete with 5 floors (7.61%) and concrete with 2 floors (5.07 %) are less represented on the study area. The smallest representation corresponds to concrete buildings with 1floor.

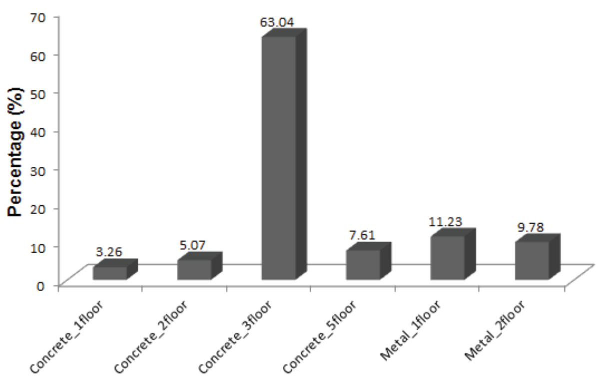



**Figure 26. Frequency of number of floors per building type**

The distribution of buildings considering the number of floors follows distribution patterns showing the differentiation on the ground. As was explained in the previous section, metal buildings represented in temporal houses are concentrated mainly on the left bank of the Minjiang River (outside of study area). Although during 2010 metal houses with one floor were found towards the northern part of the town as well (Figure 27). Close to these buildings, towards the north the highest concentration of concrete buildings can be found with one and two floors located inside of the water factory. In the northern part of the study area buildings were found of five floors close to the buildings of two floors. Following the buildings of five floors there are buildings with three floors. These are extending towards the center, the western and southern part of the town, being located on the right riverbank of the Roa River as well. The spatial distribution of buildings considering the number of floors is shown in Figure 27.

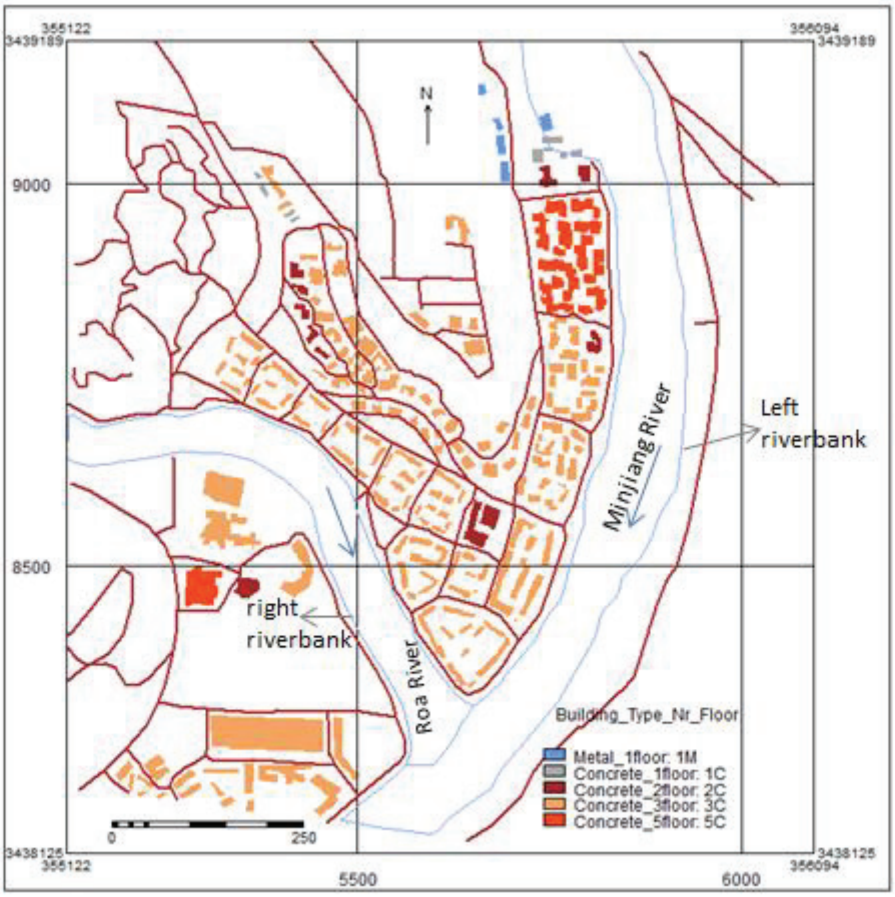



**Figure 27. Spatial distribution of building type considering number of floors**

#### 5.2.1.3. Building occupancy type

The occupancy was another characteristic of buildings considered. Inside of the study area 245 buildings were found. The number of apartments for each building is different, depending on the design of the building. The number of apartments inside the buildings of five floors varies from four to six. Apartments on the first and second floor are occupancies as residences, although more than 70% of these apartments are completely empty. Apartments between third and fifth floor are governmental offices, police stations and residences of the employees. On the other hand, buildings with three floors are multi-family dwelling, where the number of apartments varies from three, four and six apartments. For the longest buildings located towards the southern part, the number of apartments ranges between eight to ten, and in some cases up until 14 apartments were found. The occupancy is represented by mainly residences for families (54.4%). From these 13.9 % of the apartments are commercial locations on the first floor and in other cases restaurants (2.8 %). However, 38% are occupied as residences for families only. The remaining parts of the apartments are represented by public and cultural buildings (Figure 28).

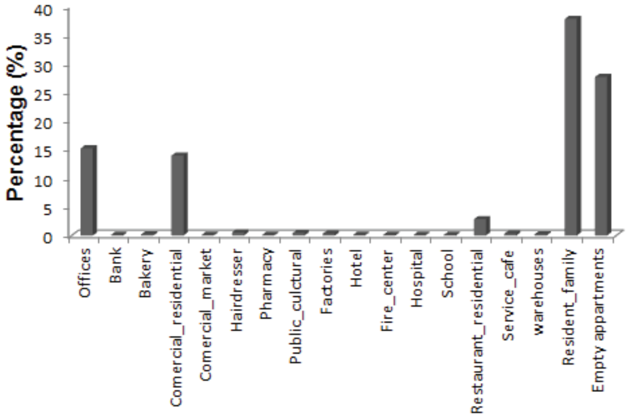



**Figure 28. Frequency of building occupancy type**

These buildings were identified as part of the elements at risk. The spatial distribution is shown in Figure 29. There is a significant representation of empty apartments in the town, which 27.6 % are concentrated mainly towards western, on the first floor of buildings with five floors, but also in buildings of three floors located inside of the flooded area.

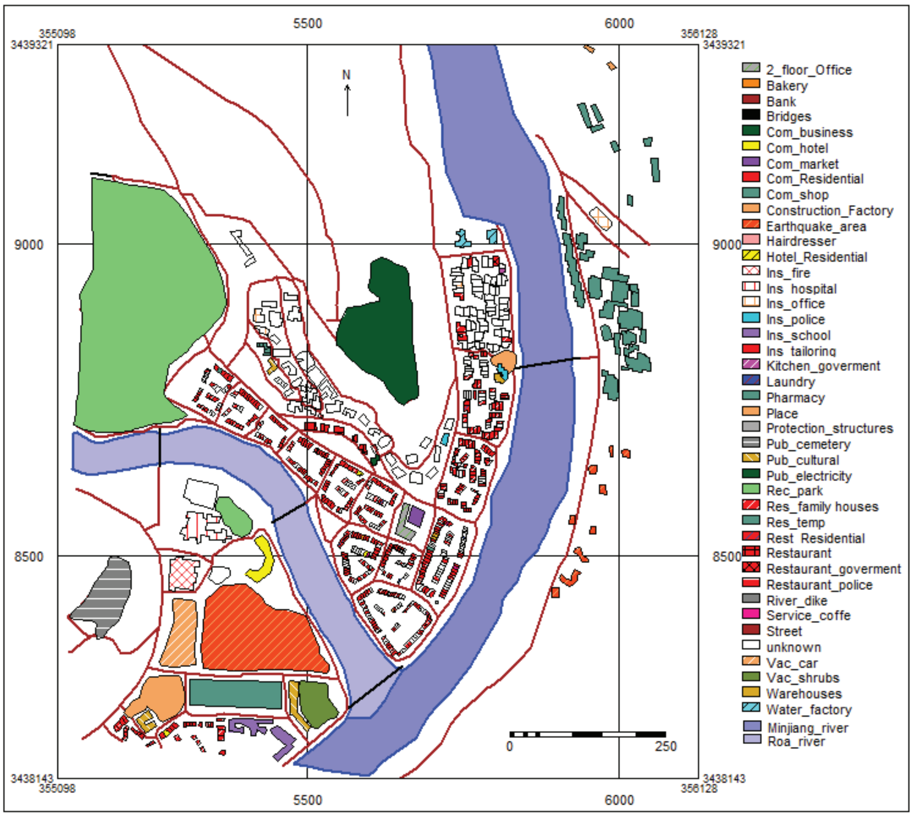



**Figure 29. Elements at risk map of Yingxiu town**

#### 5.2.1.4. Age and State

The Yingxiu town was completely rebuilt after the earthquake of 2008 and on April 23th 2011 the town was officially opened. This means that the average age of the building is around one and half years old. During 2010 flood event, buildings were being built, as explained above, so damaged paint on walls and floors, water marks and moisture on walls were repaired by the Construction Company. Therefore results of questionnaires show a good state of the buildings in all responses.

### 5.2.1.5. Height of ground floor relative to the street level

The height of the floors relative to the street level is an important indicator of the vulnerability of buildings during flooding. The height of the ground floor varies from one building to another and sometime within the same building. Also differences in height values are displayed between the front and back side of buildings. Buildings with five floors and buildings located along the Minjiang River (near to the river) have the highest height values (between 0.55 cm and 1.0 m). Buildings where the ground floor is located below the street level were observed as well (Figure 30). In these buildings height values vary between -0.80m and -0.37 m. These are highly vulnerable to flooding.

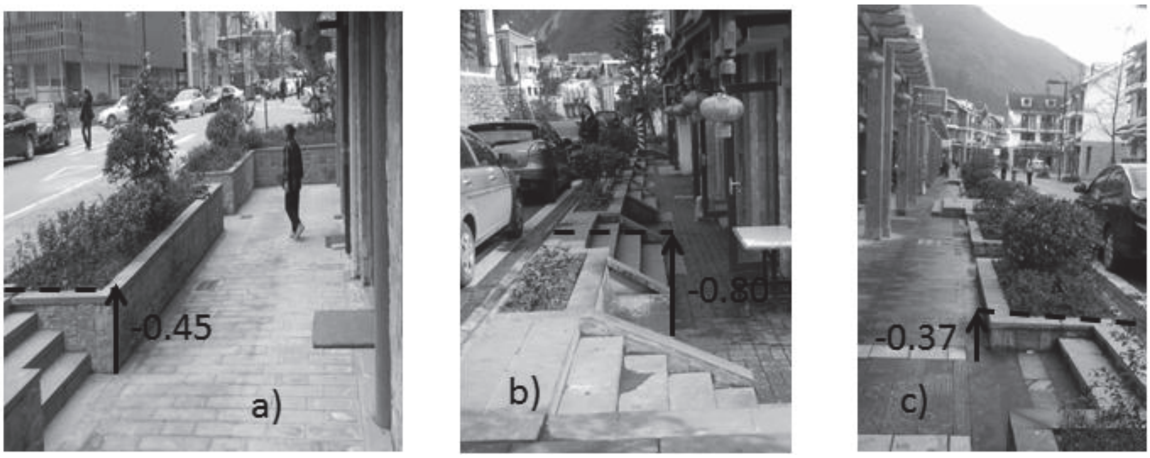



**Figure 30. Ground floor below the street level**

A tape measure was used during the measurement of ground floor. Maps with values of height of ground floor on the front (Appendix 4) and back (Appendix 5) side of the buildings in relation to the street level were created.

Based on the values of the height of the ground floor on front side of buildings in Yingxiu, we can conclude that 38% of buildings have 0.15 cm of height and 31 % have height between 0.27cm and 0.45cm. Also, there is a predominance of buildings where the height of the ground floor on the back side of the buildings is around 0.15 cm, these represent 55 % of the buildings of the town (Figure 31). Buildings with the highest values of height of the ground floor on the front (0.55cm to 1.0m) and on the back side (0.42cm and 0.70cm) of the buildings correspond to concrete buildings with five and three floors located mainly inside of the flooded area near to Minjiang River (Appendix 4 and 5).

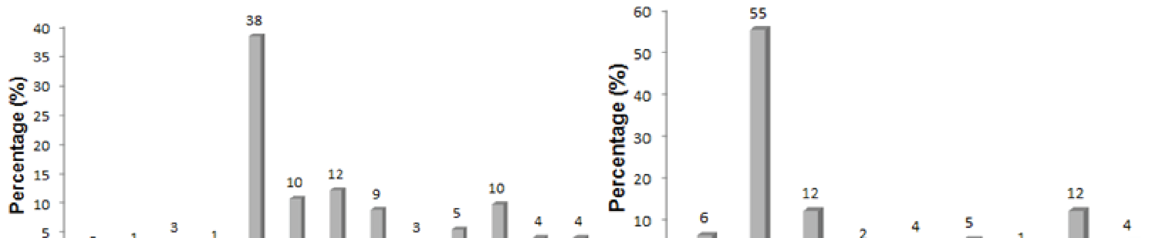



**Figure 31. Frequency of height of ground floor relative to street level**

### 5.2.1.6. The existence of flood retained structures

The height of the ground floor is directly related to the existence of flood retained structures for buildings. These are represented for two types: steps and balconies. Around 57 % of the buildings have more than two steps so that these buildings have around 0.30cm to 1.0m above the street level (Figure 31). Another retained structure observed only on buildings of five floors is balconies. These are completely closed until the height 1.0m, avoiding the water movement towards the inside of the building. The spatial distribution of flood retaining structure types is shown in Figure 32.

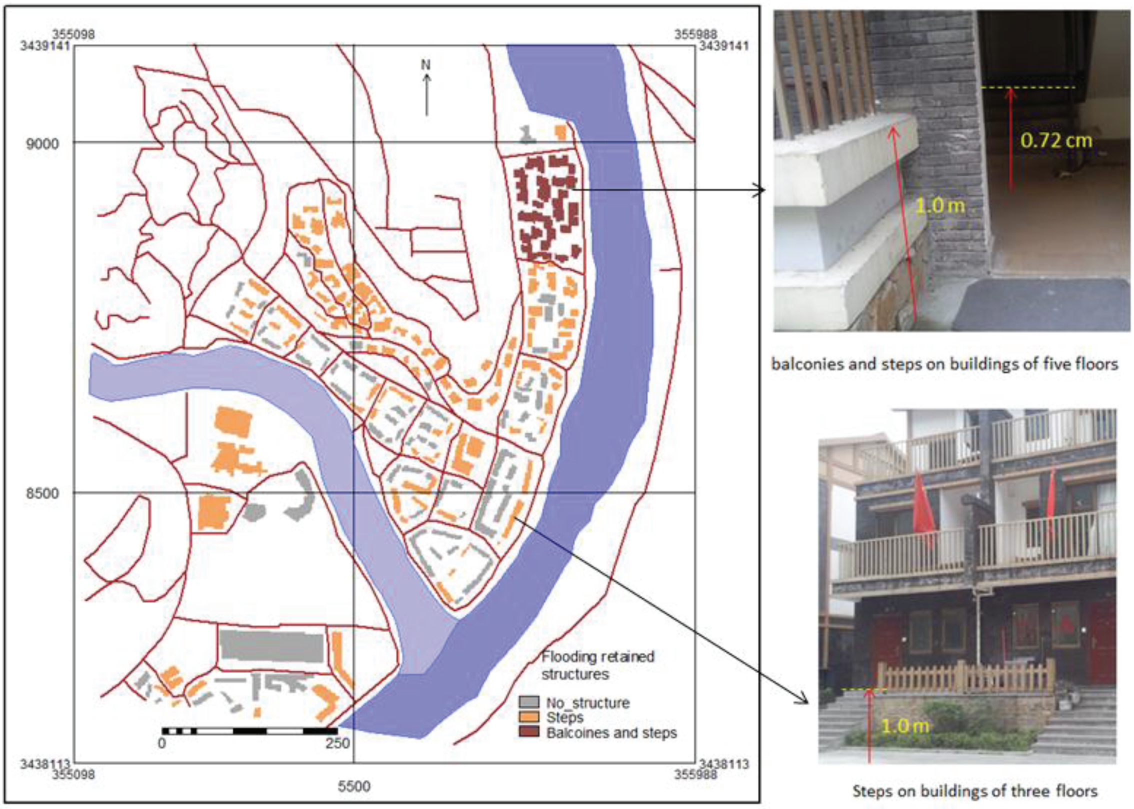



**Figure 32. Spatial distribution of flood retaining structures**

#### 5.2.1.7. Building size

Measurements of height, width and length of the living room for the most common buildings in the flooded area were taking using a digital equipment Bosch (PLR 30) displayed in

Figure 33. shows a comparison of building sizes for these building types. The area and the height for the apartments of buildings with five floors show lower values than apartments with three floors.


**Figure 33. Digital equipment Bosh**

**Table 5. The Comparison of building size for most common apartments inside the flooded area**

| Building size | Apartment Concrete_3 floor (m) | Apartment Concrete_5 floor (m) |
|---|---|---|
| Height_one room | 3.42 | 2.83 |
| Wide_one room | 3.76 | 3.98 |
| Length_one room | 3.69 | 5.54 |
| Area_one room | 13.87 m2 | 22.04 m2 |
| Area_apartment | 120 m2 | 80 m2 |
| Height_building | 10.26 | 14.2 |

### 5.3. Improvement of the DEM

Changes in the land use in the area of river terraces, as was explained in the section 3.5 required an improvement of the existing DEM created from contour lines with 20 m contour intervals. For the update process measurements of elevation from 53 points were made using a GPS Garmin E-trex 12 channel. Then the contour lines where transformed into points at an interval of 50 meters. In total 37 points from the contour map and 53 elevation values from the measurements were combined into one file. For the best optimization of the interpolation process values of elevation were interpolated using two of the most common methods: inverse distance and Kriging.

#### 5.3.1. Inverse distance (ID) and inverse squared distance (ISD) interpolation

The inverse distance methods perform a weighted averaging on point values and return a raster map as output. The weight assigned to given source point in the estimation of a target point depends on the distance between these two points. The greater the distance the smaller the weight. In ID interpolation the weight decreases linearly with the distance ($1/x,$); in ISD the weight decreases with the square of the distance ($1/x^2$) with the distance  Based on these principles the values of elevation where interpolated using these two variants. As a limiting distance 515.0 m (maximum distance between source and target points) were considered in both cases.  The results maps and shadow maps are show in Figure 34.

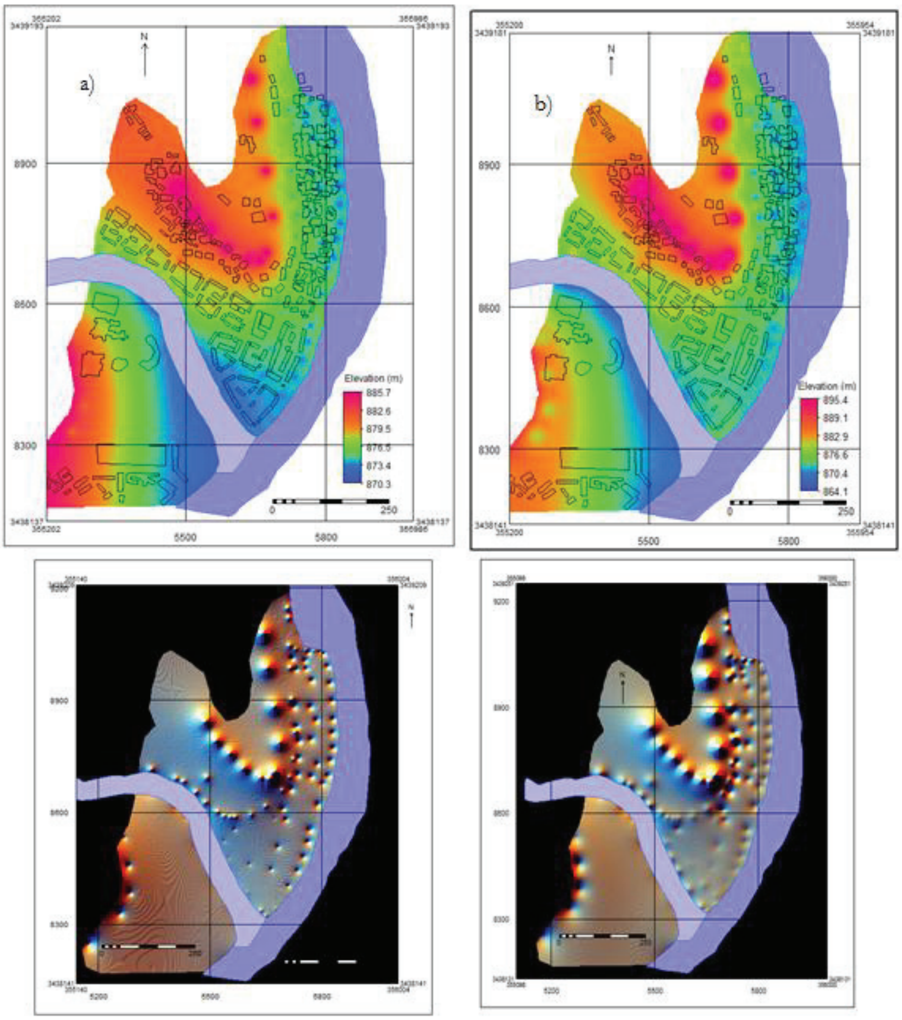



**Figure 34. DEM interpolated using Inverse distance methods. a) Inverse distance (ID) and b) Inverse squared distance (ISD)**

Another method applied for the interpolation was Kriging. "This method calculates each input point values using weighted averages. The weighting factor is determined using a semi-variogram model" (Cornelia, 2008). Two variants of this method: Simple Kriging and Ordinary Kriging were applied. For each variant during the interpolation two options were analyzed. These two methods are described in the next section.

#### 5.3.2. Simple and Ordinary Kriging

The Simple Kriging method assigns weights to all points of the input map, for the estimation of each output pixel value all input point values are used. Ordinary Kriging method uses for the estimation of each output pixel value only values of points that are within limiting distance towards a pixel. The distance is user-specified. This gives the estimation method a more local character (ILWIS help). The first option of analysis for both methods was to assume values given for default Nugget=0, Sill=1 and Range=1000 m. In the Ordinary Kriging method the limited distance of 515.0 m (same than inverse distance method) was set. The error maps were calculated. The resulting raster maps and shadow maps are shown in Figure 35.

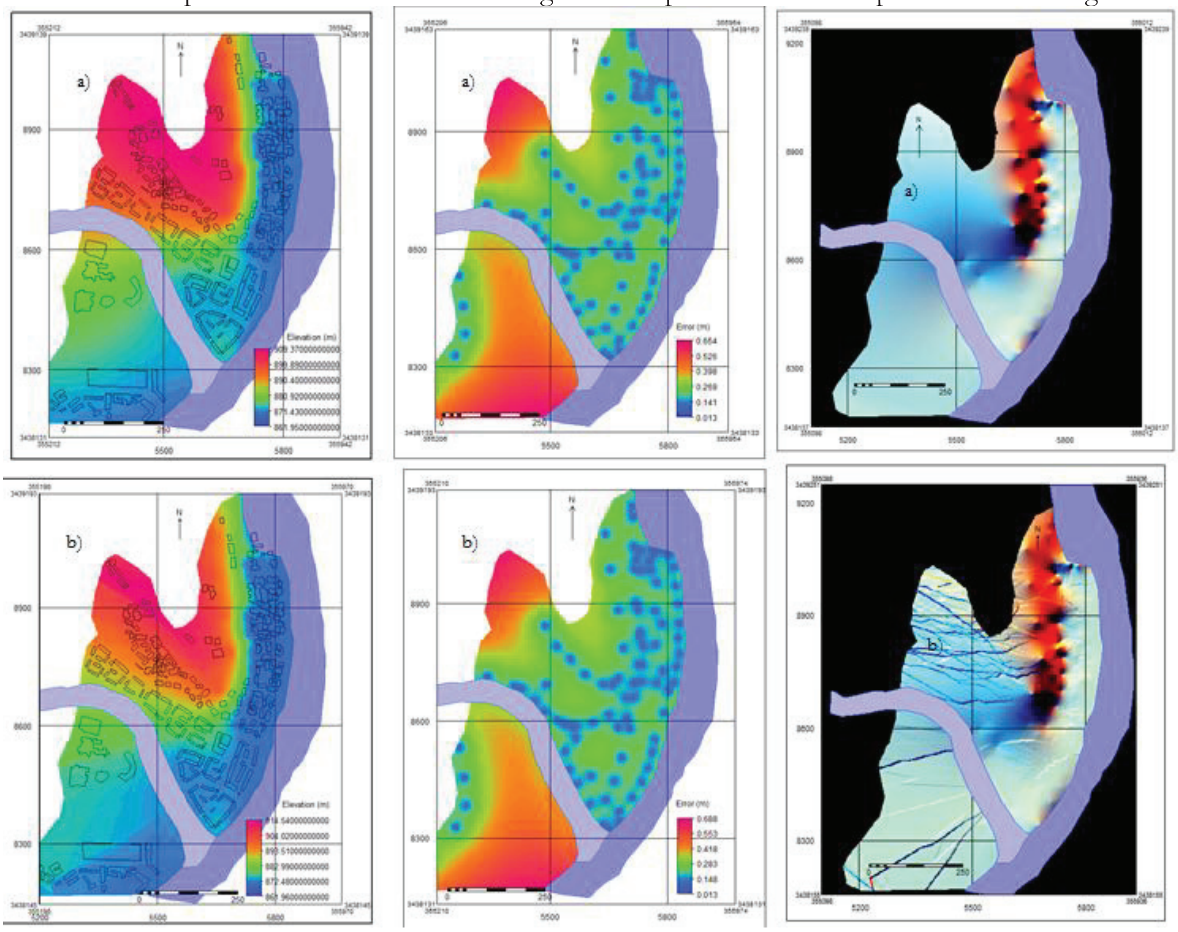


**Figure 35. DEM interpolated using Kriging method (default setting). a) Simple and b) Ordinary**

The second option for the application of Simple Kriging and Ordinary Kriging method the semi-variogram was more closely studied. The lag distance was set 50 m (predominant distance between measurements point). In the Ordinary Kriging method the limit distance value was again set at 515.0 m. The variograms of the elevation point datasets are shown Figure 36. Several variogram models were fitted as shown in Figure 36 and the exponential model was selected as variogram model of choice. It gave the following values for Simple Kriging: Nugget=0.8, Sill=4.0 and Range=300 m, and for Ordinary Kriging Nugget=1.0, Sill=8.0 and Range=350 m.

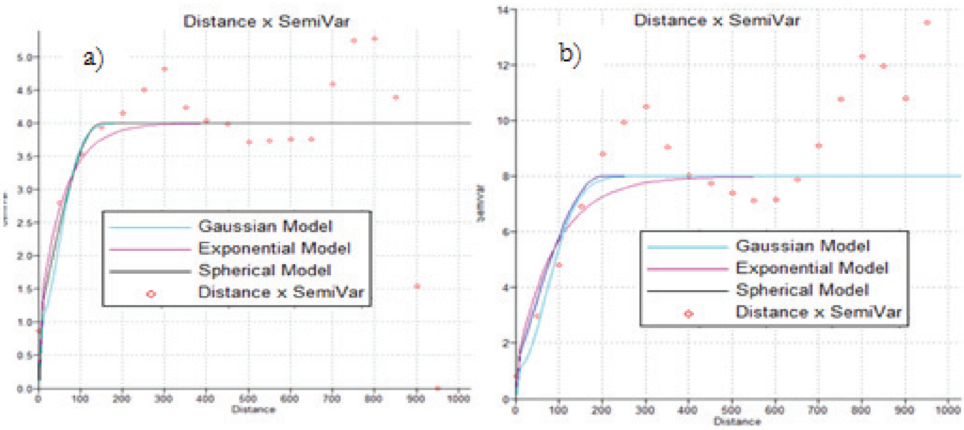



**Figure 36. Variogram with semivariogram models applied for Kriging method (interpolation lag distance 50m). a) Simple and b) Ordinary**

The resulting maps of the interpolation, error maps and the shadow maps for the two variants are shows in Figure 37.

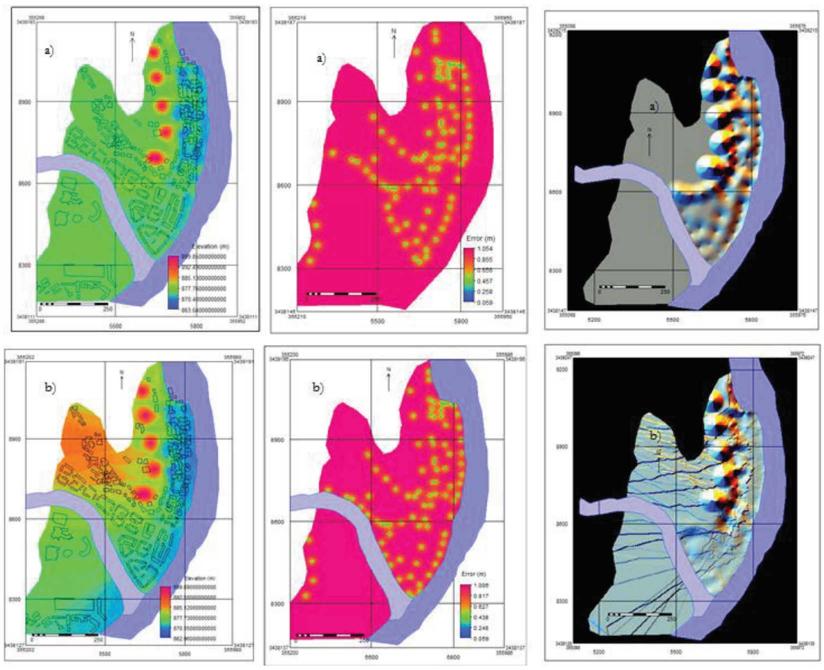


**Figure 37. DEM interpolated using Kriging method (interpolation lag distance 50 m). a) Simple and b) Ordinary**

A compilation of variogram parameters for different Kriging methods applied are shown in Table 6. Lowest values for the Sill (4.0), Nugget (0.8) and Range (300 m) correspond to the variant Simple lag 50m.

**Table 6. Compilation of variogram parameters for interpolation methods applied**

| Method | Variant | Nugget | Sill | Range |
|---|---|---|---|---|
| Kriging (default setting) | Simple | 1.00 | 19.0 | 500 |
| | Ordinary | 1.00 | 21.0 | 510 |
| Kriging (interpolation lag 50m) | Simple | 0.8 | **4.0** | 300 |
| | Ordinary | 1.00 | 8.0 | 350 |

The raster maps of the DEM obtained using the two interpolation methods: inverse distance (ID and ISD) and Kriging (all the variants) did not show good results. The comparison of the DEM maps, error maps and shadow maps created shows discrepancy between the elevation values obtained from measurements during the fieldwork and ground heights values from contour lines in all the interpolation methods applied. Therefore elevation values obtained from contours lines were removed and values obtained from fieldwork measurements (53 points) were interpolated again. As a limiting distance 515.0 m was used. Results from ID and ISD are show in Figure 38.

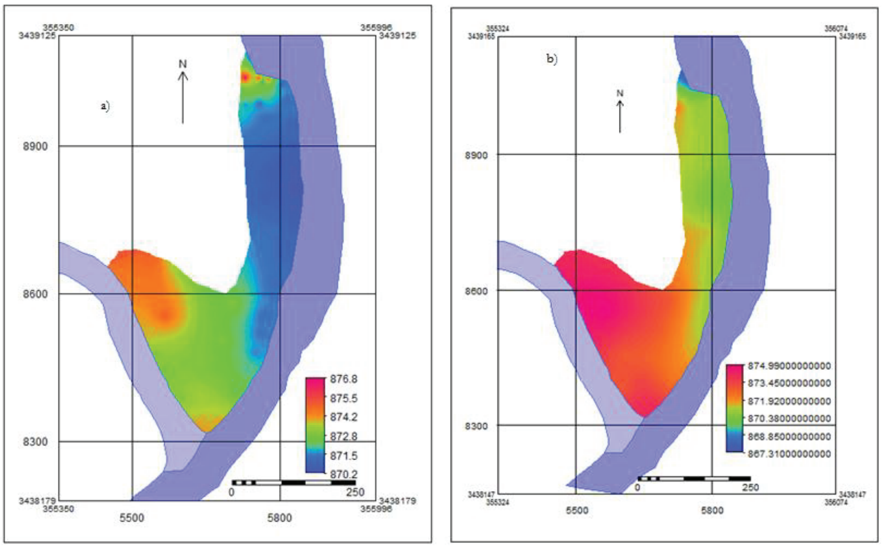



**Figure 38. DEM interpolated using fieldwork data. Inverse distance methods: a) Inverse distance (ID) and b) Inverse squared distance (ISD)**

The Kriging interpolation method with the two variants of this method: Simple Kriging and Ordinary Kriging were applied. The limited distance of 515.0 m for the Ordinary Kriging method was used. Results for the default setting with Nugget=0, Sill=1 and Range=1000 m are show in Figure 39.

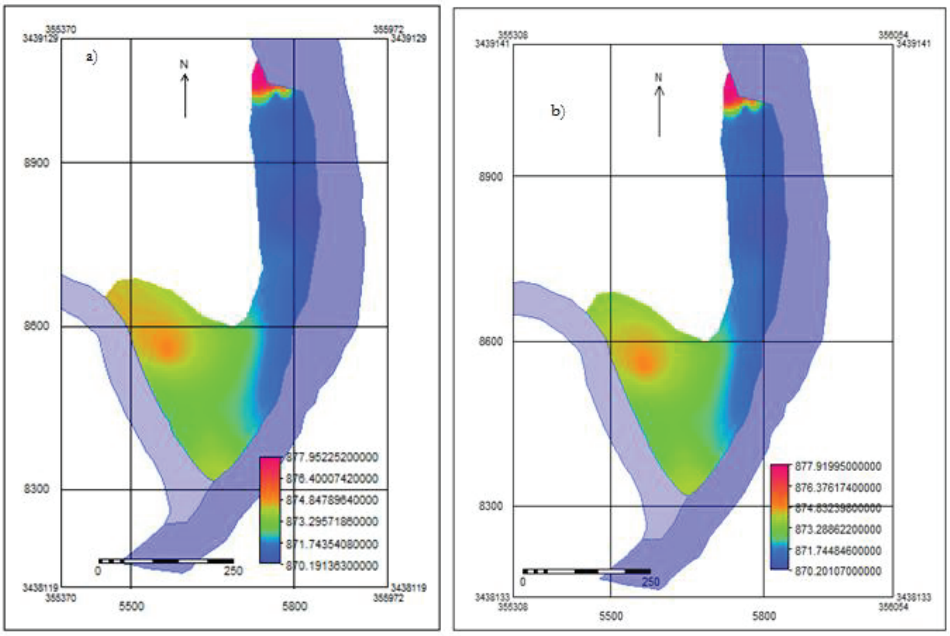



**Figure 39. DEM interpolated using fieldwork data. Kriging method (default setting):a) Simple and b) Ordinary**

Another option for the application of Simple Kriging and Ordinary Kriging method was using as lag distance 50 m. In the Ordinary Kriging method the limit distance value was again set at 515.0 m. The variograms of the elevation point datasets are shown in Figure 40. Variogram models fitted are show in Figure 40. The Gaussian model was selected as variogram model of choice. It gave the following values for Simple Kriging: Nugget=0, Sill=0.30 and Range=40 m, and for Ordinary Kriging Nugget=0, Sill=0.1 and Range=40 m.

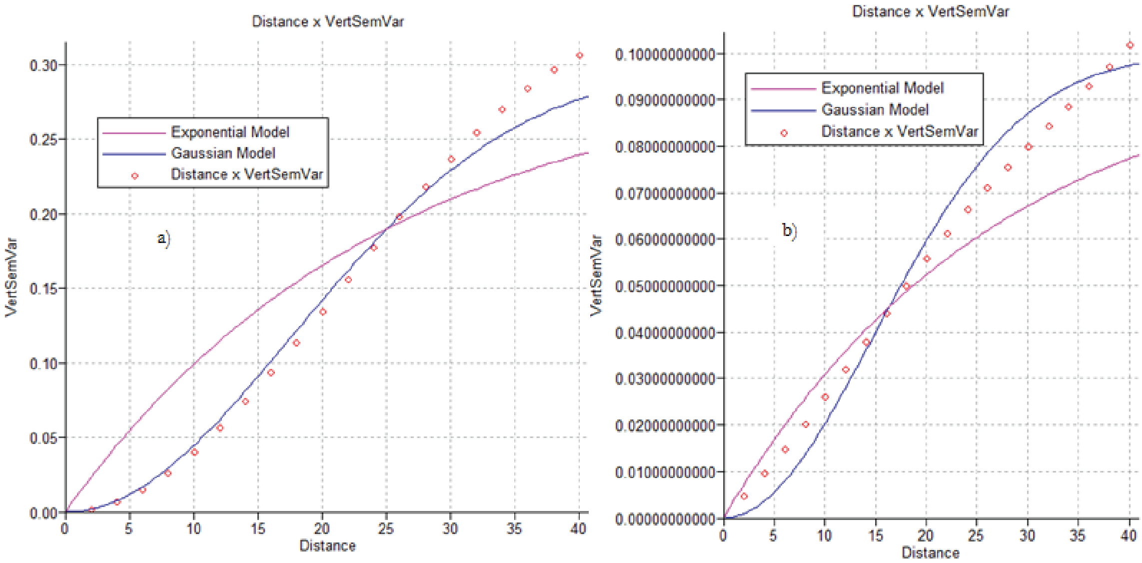



**Figure 40. Variogram with semivariogram models applied for Kriging method (interpolation lag distance 50m) using fieldwork data. a) Simple and b) Ordinary**

The resulting raster maps of the interpolation process for the two variants are shows in Figure 41.

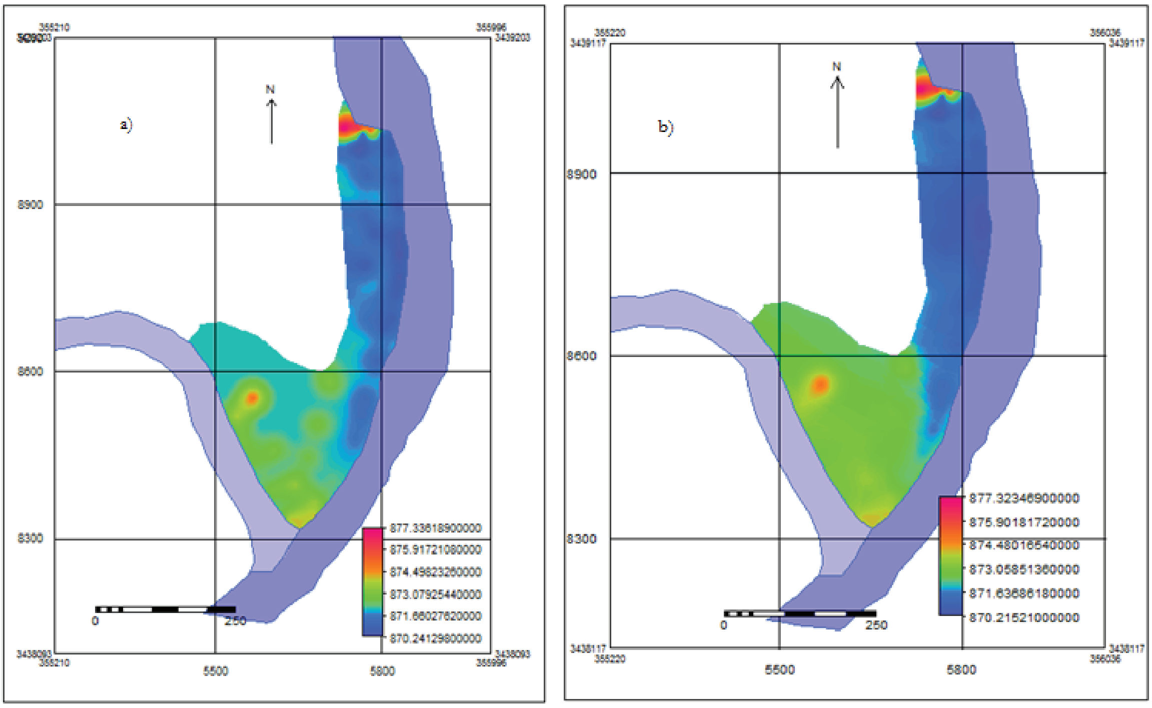



**Figure 41. DEM interpolated using fieldwork data. Kriging method (interpolation lag distance 50 m): a) Simple and b) Ordinary**

A compilation of variogram parameters for different Kriging methods applied are shown in Table 7. Lowest values for the Sill (0.1), Nugget (0) and Range (40 m) correspond to the variant Ordinary lag 50m.

**Table 7.Compilation of variogram parameters for interpolation methods applied**

| Method | Variant | Nugget | Sill | Range |
|---|---|---|---|---|
| Kriging (default setting) | Simple | 0.0 | 0.30 | 40.0 |
| | Ordinary | 0.0 | 0.30 | 40.0 |
| Kriging (interpolation lag 50m) | Simple | 0.0 | 0.30 | 40.0 |
| | Ordinary | 0.0 | **0.10** | 40.0 |

In order to analyze the tendency and dispersion of data distribution, statistical indicators for each interpolation methods were analyzed. Table 8 shows the higher values of standard deviation are associated to Kriging interpolation methods (default setting). This means that the variations of values from mean is larger than other interpolate methods. On the other hand the ordinary Kriging variant (50m) shows the smallest values of dispersion (1.02) for this method. However, the inverse squared distance (ISD) method shows the smallest values (0.76) of dispersion for all interpolation methods applied.

**Table 8.Statistical indicators for interpolation methods applied**

| Method | variant | Mean | Median | STD |
|---|---|---|---|---|
| Moving average (inverse distance) | ID | 872.34 | 872.2 | 1.24 |
| | ISD | 872.01 | 872.0 | **0.76** |
| Kriging (default setting) | Simple | 872.41 | 872.5 | 1.58 |
| | Ordinary | 872.39 | 872.3 | 1.54 |
| Kriging (interpolation lag 50 m) | Simple | 872.27 | 871.9 | 1.53 |
| | Ordinary | 872.11 | 872.4 | **1.02** |

Therefore, taking into account that "Sill represents variability in the absence of spatial dependence" (Kelman, 2007) and the Nugget is the vertical jump from value 0 at the origin to the semivariogram value at extremely small separation distances (ILWIS help) we can conclude that the smallest values of Sill and Nugget correspond with greater precision during the interpolation process. For this reason the Ordinary Kriging (interpolation range 50m) was selected as the best variant for this method. Also this method shows a relative small standard deviation. Also the ISD method gives low values for standard deviation. In the further analysis also this method will be tested.

### 5.3.3. Validation

The validation of interpolated results for these methods was based on the method applied by Falivene, et al., (2009). Variations in the number of neighboring points were applied and later results were compared. Therefore five points with elevation values measured during fieldwork were removed randomly from the original database. After that, ground elevation points were interpolated again. Values of the root mean squared error (RMSE) were calculated. Results are show in Table 9.

**Table 9. RMSE for the interpolation methods used**

| Point | ID (m) | | ISD (m) | | Simp. Kriging 50 m | | Ord. Kriging 50 m | | Simp. Kriging 1000 m | | Ord. Kriging 1000 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | height | diff | height | diff | height | diff | height | diff | height | diff | height | diff |
| 870.40 | 870.40 | 0.00 | 870.39 | 0.01 | 870.48 | -0.08 | 870.41 | -0.01 | 870.38 | 0.02 | 870.41 | -0.01 |
| 871.00 | 871.00 | 0.00 | 871.00 | 0.00 | 871.01 | -0.01 | 871.00 | 0.00 | 870.98 | 0.02 | 870.99 | 0.01 |
| 871.30 | 871.20 | 0.10 | 871.30 | 0.00 | 871.31 | -0.01 | 871.32 | -0.02 | 871.28 | 0.02 | 871.32 | -0.02 |
| 872.00 | 872.20 | -0.20 | 872.00 | 0.00 | 872.07 | -0.07 | 872.07 | -0.07 | 872.08 | -0.08 | 872.09 | -0.09 |
| 873.50 | 873.50 | 0.00 | 873.50 | 0.00 | 873.46 | 0.04 | 873.48 | 0.02 | 873.49 | 0.01 | 873.48 | 0.02 |
| RMSE | 0.22 | | **0.01** | | 0.11 | | 0.08 | | 0.09 | | 0.10 | |

The comparison between interpolation methods shows that Ordinary Kriging (lag 50 m) and ISD methods have the lowest values of RMSE. However the lowest values of RMSE correspond to the ISD

(0.01), being selected this as the most optimal interpolation method. The final DEM obtained with 2.0 m resolution for the study area is shows in Figure 42.

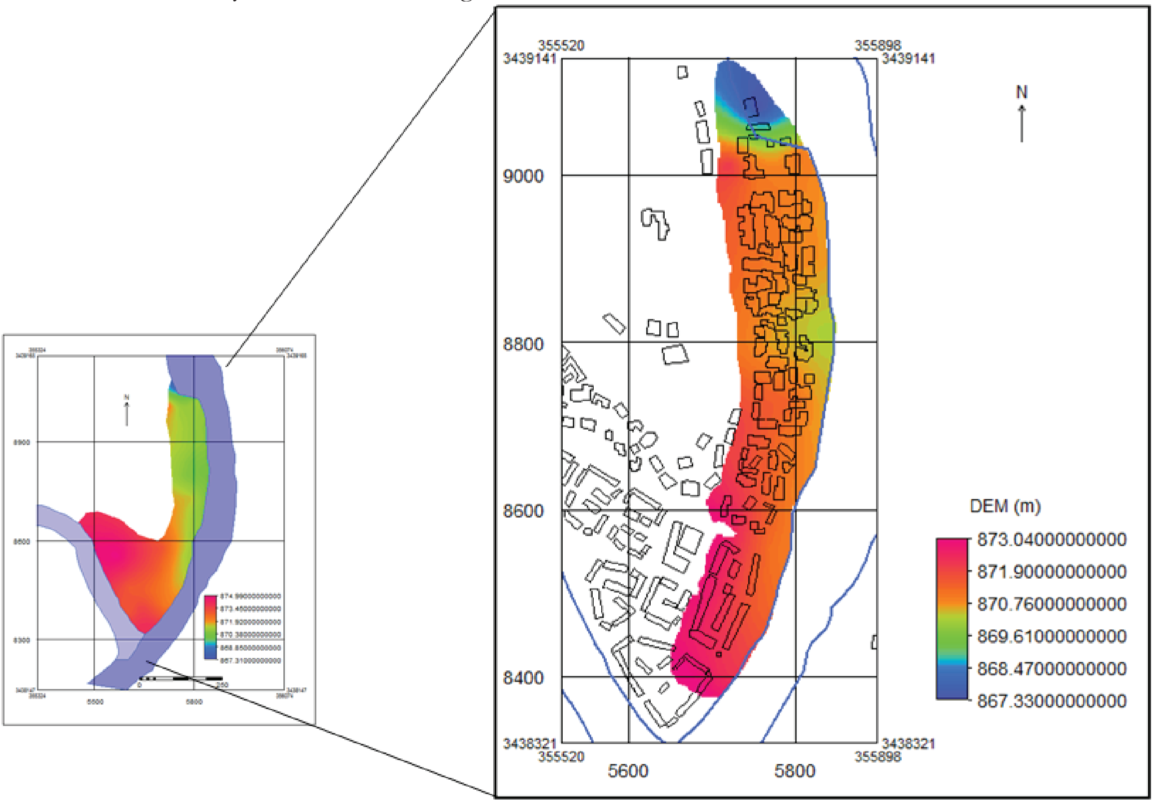



**Figure 42. DTM interpolated using ISD method**

### 5.4. Construction of the flood depth map for the 2010 Flood Event

In order to determine the values of water depth for all the area, measurements of water depth from 22 points taken during fieldwork were combined with the ground height values from DEM into the calculation of the water level. The water level was calculated using the following formula: Water level = Water depth + DEM (interpolated using ISD method). As a result a point map with values of water level was obtained. Statistical analysis of these values was done considering the data distribution on the histogram (Figure 43).

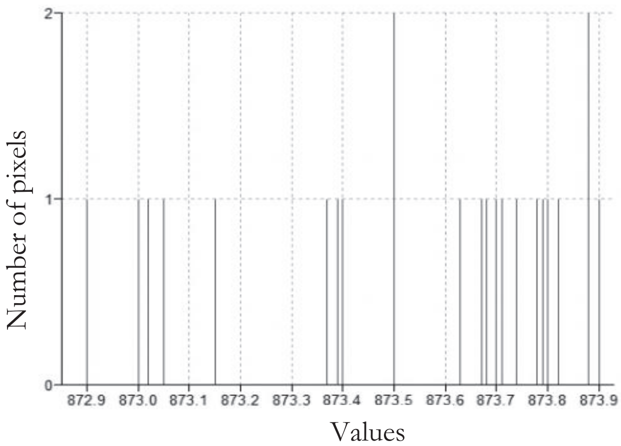



**Figure 43. Histogram of water level values calculated**

The histogram shows a little variation on the frequency of distribution of water level values. The range of values for water level (872.9 m to 873.9 m) is displayed as well. The difference (1.0 m) between the minimum and maximum values of water level can be associated to three causes: errors of GPS positioning; errors during the measurement of water depth due to lack of watermarks on walls; and errors during the interpolation process of ground elevation values used during calculation of water level. On the other hand, the analysis of indicators of central tendency shows similar values for mean (873.43 m) and median (873.57 m). Therefore low value is displayed by the standard deviation (0.32) showing little scatter of data around the mean. The comparison between mean and median values allows us to conclude that data tend to a symmetric distribution.

The values of water level were interpolated. Two methods of interpolation explained before were used, inverse distance (ID and ISD) and Kriging with its variants: simple and ordinary. For the interpolation process using ID and ISD methods the limiting distance considered was 661 m (maximum distance between points). Kriging was another interpolation method applied with its two variants simple and Ordinary Kriging. During the interpolation process values the lag distance assigned was 40m (predominance distance between points). In the Ordinary Kriging method as the limit distance was assigned 661m. To define the appropriated interpolation method similar procedure explained on the section above for the interpolation of elevation values was applied. As more appropriated method for the interpolation was selected the inverse squared distance method with the lowest values of RMSE (0.10) and the standard deviation value is 0.22.

The raster map resulting from the interpolation process using ISD method was used for the calculation of a flood depth map. The final flood depth map was calculated following this formula:

Flood_depth = Water_level – DEM.

For the validation of the flood depth map, values of water depth obtained during measurement of fieldwork stage for 22 points were compared with flood depth values calculated. The comparison is shown in Table 10.

**Table 10. Comparison of values of water depth measured and calculated**

| Point | Water depth measured (m) | Water depth Calculated (m) | Difference (m) | Point | Water depth Measured (m) | Water depth Calculated (m) | Difference (m) |
|---|---|---|---|---|---|---|---|
| 1 | 2.80 | 2.81 | 0.01 | 12 | 2.64 | 2.64 | 0 |
| 2 | 2.80 | 2.80 | 0 | 13 | 2.61 | 2.61 | 0 |
| 3 | 2.72 | 2.72 | 0 | 14 | 2.48 | 2.48 | 0 |
| 4 | 2.68 | 2.68 | 0 | 15 | 2.27 | 2.27 | 0 |
| 5 | 2.79 | 2.79 | 0 | 16 | 2.18 | 2.18 | 0 |
| 6 | 2.70 | 2.70 | 0 | 17 | 1.40 | 1.40 | 0 |
| 7 | 2.29 | 2.29 | 0 | 18 | 1.70 | 1.80 | 0.10 |
| 8 | 2.27 | 2.27 | 0 | 19 | 0.72 | 0.72 | 0 |
| 9 | 2.68 | 2.68 | 0 | 20 | 0.50 | 0.50 | 0 |
| 10 | 2.00 | 2.10 | 0.10 | 21 | 0.25 | 0.25 | 0 |
| 11 | 2.68 | 2.68 | 0 | 22 | 0.35 | 0.35 | 0 |

The above table shows a correspondence between values of water depth measurement during fieldwork and values of flood depth calculated. From 22 checkpoints, 19 points show a total correspondence in values, only in three points there is a small difference in the values of 0.01 cm and 0.10 cm, which represent 1.5% of data analyzed. The percentage of accuracy of data show a high precision (98.5%) of the flood depth map calculated, and is therefore being considered as acceptable. Finally the spatial distribution of water depth values calculated is shown in Figure 44.

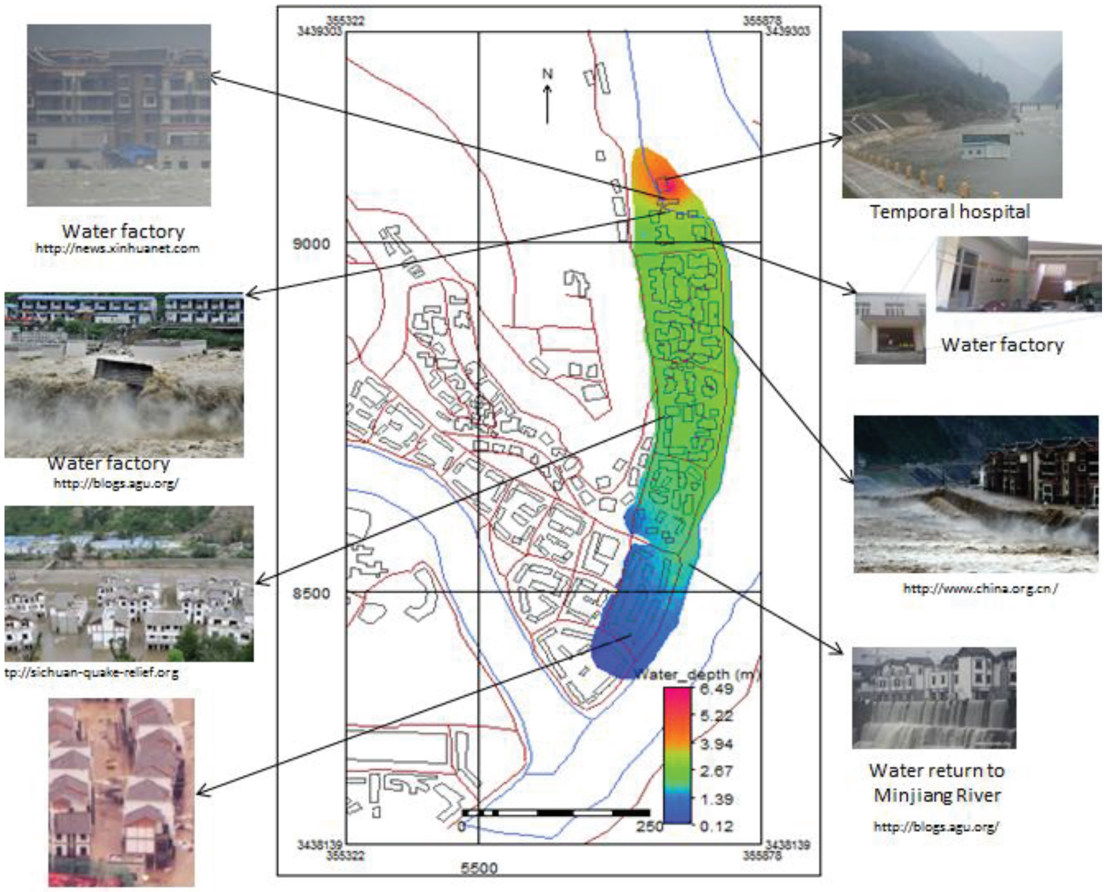



**Figure 44. Water depth map for the 2010 flooding**

The above figure above shows that the highest values of water depth (5.90m) were located towards the north part of the town where the elevation is less (about 867.3 m). In this area the temporal hospital was situated. Around thirty meters of distance from this area five buildings belonging to the water factory were largely impacted by the high volume of water. Values of water depth of between 2.80 m to 4.74 m were obtained for this area. Buildings located in the vicinity of the water factory with five floors show lower values of water depth. In this area the water depth is between 2.21m to 2.88m. Next, the blocks of buildings with three floors show values of water depth range of 1.11m to 2.72m. The difference between these values is related to variance in elevation values, which increase towards the western part of the town (higher than 871.9m) and decrease towards the east part. This elevation difference favored the movement of the water during the 2010 flood event, which used the road as channels to return to the main Minjiang River channel (Figure 44). The lowest values of water depth (0.25 m) was obtained towards the southern part of the town, in buildings of three floors near to the Roa River, where higher values of elevation (874.0m) favored the water move towards Minjiang River.

Although the main objective of this research is related to the 2010 flood event; we also interesting to collect data related to historical flood events in this town. This goal was however not successful because the population of Yingxiu is composed mainly with people from Hongchun gully, Dujiangyan and Xinjing city who moved into Yingxiu town after its official inauguration on April 23th 2011. Only a remaining part of the native population remains in the town. In many cases the inhabitants are too young and have not experience with flooding. Results of the questionnaires applied to elderly people have given valuable information. Two elderly women reported that during 1964 a big flood event occurred in the ancient Yingxiu town, the town was completely flooded. It was not possible to collect information related to the number of damage associated to this event. Another statement from the two elderly women and an older man show the existence of a small flood event in 1998, but the damage was not reported. Also the inhabitants' respondents in the proximity of Roa River claim that in January of 2011 the amount of water in this river increased considerably leading to the breaking of the wall protection (Figure 45).


**Figure 45. The wall protection broken by the Roa River**

## 5.5. Reconstruction of the 2010 Flood Event using modeling

Modeling methods had been used by several authors as an approach to integrate data from the ground height, land cover and river discharge in order to calculate variables such as velocity, water level and extension. Results had been used in studies related to flood risk assessment and flood management. In this research the modeling is applied with the aim to obtain flood velocity values, which are used on the assessment of the 2010 flood event.

For the modeling SOBEK software 2D model is used. This software allows to calculate the flow of water in two spatial dimensions for different time intervals (Alkema, et al., 2007). As input data, the DEM of the outside areas of the town was required. Therefore the DEM created on section 5.3.2 using Simple Kriging method with lag distance 50 m was selected (Table 6). In order to obtain more soothing surface the raster map was resampled to 10.0 m of resolution. Also data of Minjiang and Roa river channels; surface roughness coefficient; and boundary conditions were necessary. The boundary condition is related to the water level in the upstream and downstream boundaries of the study area. The boundary condition values were obtained applying the trial and error method due to the lack of data related to discharge from the Minjiang River.

Before starting the modeling process the DEM existing in ILWIS was exported as ASCII format and imported in SOBEK. River channels were added as a shape file format and another parameter such as boundary condition was fixed after several simulations. Also cross sections were defined in places of modification of river channel. The calibration of the model was based on the selection of Manning's roughness coefficient. It depends of the type of land cover existing in the area. Values of Manning's coefficient proposed by Alkema, et al., (2007), Peter Guarin, et al., (2008) and Bhattacharya (2010) were analyzed. Finally Manning's coefficient values proposed by Alkema, et al., (2007) were used considering that they have more representativeness of land cover of the area. These roughness coefficients values are show in Table 11, where built-up values were assigned to buildings. Values of pasture were given to areas covered by grass and values for flood plain areas were assigned to bare soil land use outside of town, located on river terraces.

**Table 11. Manning's coefficient proposed by Alkema, et al., (2007)**

| Land cover /unit | Manning's coefficient |
|---|---|
| River bed | 0.027 |
| Flood plain | 0.032 |
| Pasture | 0.05 |
| Roads | 0.02 |
| Built-up | 0.25 |

In order to achieve better results, two different scenarios were considered in the modeling process. The first scenario shows the flooding process without regarding the dam created by the debris flow in the northern part. In the second scenario the dam created by the debris flow was taken into account, its dimensions were added into the DEM. Values of Manning's coefficient selected were used on both scenarios. The validation of results for each scenario was based on the comparison with fieldwork measurements.

#### 5.5.1. Parameter maps generated by modeling process

As a result of the modeling process two maps for each scenario were obtained. One map shows the maximum water depth values and another map the maximum velocity values achieved. Both maps obtained as ASCII format were imported to ILWIS to visualization and use in future analysis.

A comparison of water extension and water depth values from the fieldwork and results obtained from modeling were done for each scenario. As a disadvantage for the first scenario, flood extension and water depth values from fieldwork were not obtained from the modeling process. For this reason this scenario was not considered within the analysis. However, the inclusion of the dam in the modeling allowed obtaining more realistic results in the second scenario. Like other researches mentioned above such as Alkema, et al., (2007) and Bhattacharya (2010) in this study the model sensitivity is influenced by changes in the terrain elevation. The comparison for the second scenario is shown in Figure 46 and Table 12.

The Figure 46 shows that there is a correspondence between water extension obtained as result of application of participatory mapping tools (**Figure 21**) and water extension from the modeling process. The Table 12 shows the comparison of water depth values obtained from fieldwork and water depth values simulated. In more than 85% of points the difference between water depth values is less than 0.50m. The average difference between measurements and simulated values is 0.33m which is considered acceptable. Significant difference in the water depth values was observed only in one measurement point located on the proximity to the 880 m (value from the contour line).

**Table 12. Comparison of water depth values obtained from fieldwork and modeling result**

| Water depth (m) fieldwork | Water depth (m) modeling | Diff (m) | Water depth (m) fieldwork | Water depth (m) modeling | Diff (m) |
|---|---|---|---|---|---|
| 2.80 | 2.97 | 0.17 | 2.48 | 2.02 | 0.46 |
| 2.72 | 2.62 | 0.12 | 2.27 | 2.67 | 0.40 |
| 2.79 | 2.56 | 0.23 | 2.18 | 1.32 | 0.86 |
| 2.68 | 2.18 | 0.50 | 2.23 | 2.45 | 0.22 |
| 2.70 | 3.11 | 0.41 | 1.40 | 0.76 | 0.64 |
| 2.29 | 2.61 | 0.32 | 1.70 | 1.17 | 0.53 |
| 2.27 | 2.45 | 0.18 | 0.72 | 0.62 | 0.10 |
| 2.68 | 2.96 | 0.28 | 0.50 | 0.28 | 0.22 |
| 2.64 | 2.73 | 0.09 | 0.50 | 0.22 | 0.28 |
| 2.61 | 2.83 | 0.22 | 0.35 | 0.05 | 0.30 |
| 2.00 | 1.81 | 0.19 | 0.25 | 0.15 | 0.10 |

The velocity map in another result obtained from the modeling. This is a significant parameter to be considered during the 2010 flooding assessment. Velocity values are important indicators of flood damage (Maiti, 2007). Flood velocity values determine if a structure is moving or not, if the structure collapses or no, as well as the percentage of damage in monetary values (Kelman, 2002).

Flood velocity values can be obtained directly from fieldwork measurements; calculated using software for modeling or mathematic formula such as the Manning' equation. In this approach velocity values were obtained as a result of the modeling process as was explained in the section above. The spatial distribution of the maximum velocity values is displayed in Figure 46.

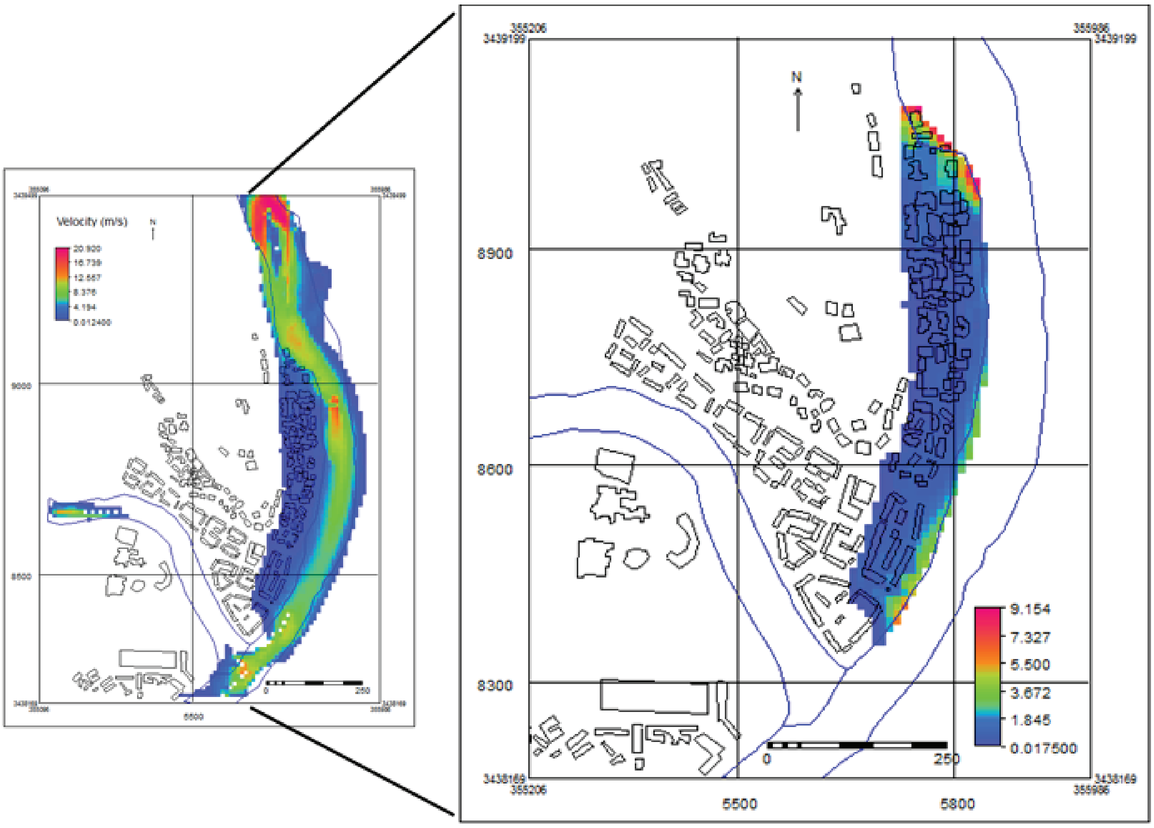


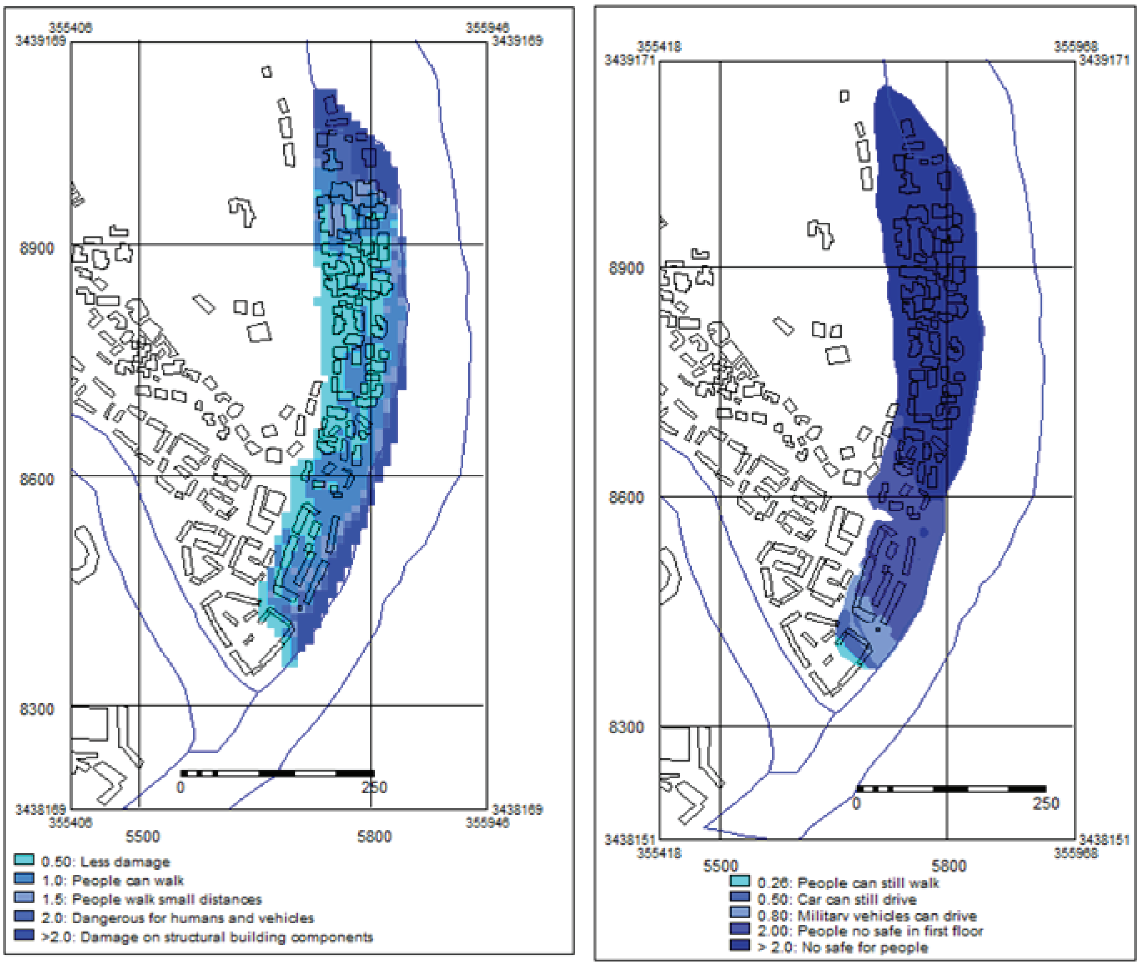
**Figure 46. Velocity map of the 2010 flood event**

The figure above shows that maximum velocity values were obtained toward the northerner part, achieving 5.49 m/s. In this area, buildings with structure type_1 were located. Take into account the structural damage categories created by Clausen (1989) and water depth values in this area is possible to include buildings with structure type_1 in the category of total destruction. Also, buildings with structural type_2 were severely damaged by maximum velocity values between 2.0 m/s to 4.9 m/s.

Outside this area, the velocity values decrease, being less (2.78 m/s) in buildings with structure type_3. Velocity values ranging between 0.34 m/s and 1.38 m/s in buildings with structure type_5 were obtained. Buildings with structure type_4 show predominancy of velocity values between 0.16 m/s and 0.61 m/s. The lowest velocity values were obtained toward the southern part (0.16 m/s). The existence of lesser damage in buildings with structural type_3, type_4 and type_5 correspond to low velocity values obtained for these buildings.

The combination of water depth and velocity values determines the damage potential of floods. Researches related to the determination of maximum values of water depth and velocity that allow people to walk or vehicles to drive through water, were developed by several authors. Some results show that with water depth values of 0.26m and velocity of 1.7m/s it is possible to for the people to walk through the water. However, an increase of the velocity close to 3.0m/s causes the people to fall (S. N. Jonkman et al., 2008). Another research shows that for water depth ranging between 0.3m to 0.8m and velocity values close to 1.0 m/s vehicles to become unstable (WMO, 2007). A more detailed evaluation about damage is given by Smith (2004) where dangerous zones for people, vehicles and buildings were created as a result of the combination of water depth and velocity values. For values of water depth less than 0.5 m and velocity more than 1.5 m/s the area is dangerous to human and vehicles. For values of velocity higher than 2.0m/s and water depth higher than 1.5 m damage on the structural building components are obtained (Clausen, 1989). Also an estimation of damage for people and vehicles considering water depth values were developed by Pieterse, et al., (2009). Results are applied in this research as well (Figure 47 b).

In order to identify dangerous areas for the 2010 flooding in Yingxiu, results from previous authors were combined with the fieldwork and modeling results from this research. Dangerous areas were created. The water depth and velocity maps were classified considering these areas. The spatial distribution of these areas is shown in Figure 47.




a) Dangerous areas by velocity values

b)Dangerous areas by water depth values

**Figure 47. Dangerous areas by the 2010 flooding in Yingxiu**

According to Figure 47 a) maximum values of velocity (>2.0 m/s) located in the northern part caused damage on the structural building components such as doors and windows and erosion on the building foundations. Areas with values of water depth that reaches more than 2.0m are categorized as no safe places for the people (Figure 47 b). Towards the southern part high values of velocity (≥2.0 m/s) were obtained as a result of the modeling process, located on the street and transitional steps between the street and the river. A narrow area with velocity values between 1.5 m/s to 2.0 m/s was found surrounding the area where the velocity was higher than 2.0 m/s. This area was categorized as dangerous for humans and vehicles, as velocity values tend to increase. On the other hand, areas flooded with velocity values ranging from 1.0 m/s and 1.5 m/s were detected mainly towards the northern and southern areas between buildings, and on the street along the Minjiang River. In this area the velocity of the water flow allows to the people to walk small distances only. On the other hand, the largest areas with velocity values between 0.50 m/s to 1.0 m/s and less than 0.50 m/s are represented by 31.3% and 35.9% of the flooded area respectively. Velocity values are indicators for the possibility of people to walk through the water. These areas are located in the center. However areas with less damage are located mainly towards the western part and where buildings are closer to each other, which influence the reduction of velocity values. In general Figure 47 a) shows a tendency to increases in the velocity values from the west (<0.5 m/s) towards the east (≥2.0 m/s). However from the north towards the south the velocity values tend to decrease.

Unlike the velocity values, the water depth values show a tendency to decrease gradually (Figure 47 b) from the north toward the south. As was mentioned before, in the northern part water depth values reached maximum values (higher than 2.0 m). These values combined with velocity values contributed to the damage of buildings, being categorized as no safe for people. Areas with water depths higher than 2.0m were extended toward the center and western part representing around 69.54% of the flooded area. Following this area, another area was observed with a velocity value close to 2.0 m where people living on the first floor are not safe. For the purpose of this research the first floor is considered the floor close to the street level. This area located towards the center and south is represented by 22.51 % of the flooded area. However, areas where cars and vehicles can drive are located in the southern part. For values of water depth close to 0.8m military vehicles can drive in around 5.10% of the flooded area. Areas where cars can still drive during the flooding are associated to water depth values between 0.26m to 0.50m and are represented by 2.17% of the flooded area. A small representation (0.69%) of the area where people can walk was found in the southern area associated to water depth values around 0.26 m.

On the other hand the analysis of the environment of the Minjiang River, characteristics of the 2010 event and following criteria given by van Westen, et al.,(2010) we can conclude that this event is categorized as a flash flood. The 2010 flooding was triggered by debris flows resulting of heavy rainfall produced on 14$^{th}$ August; as a result there was a rapid increase of water level reached values of water depth more than 5.0 m towards the northern part. Also high flow velocity values were obtained in this area (5.49m/s) and a large amount of debris was washed away by the water flow.

# 6. RESULTS FROM THE SURVEY: FLOOD IMPACT ASSESSMENT

This chapter contains a description of the building types existing in the study area. The description of flood characteristics on damage assessment is included as well. Damage to the building structure, as well as other damage reported due to the 2010 flood event are described. Community perception and coping mechanisms related to this event are details.

## 6.1. Structural building types

Results of questionnaires and fieldwork observation allowed identification of five structural building types for the study area, which are described below.

1. Structural Type_1

Represented by the temporal house of one floor, made from the combination of styrofoam, coated by a thin metal layer around 0.15 cm of wide. Walls, roof and floors are formed with the same materials which made these buildings very vulnerable to flooding. During the 2010 flood event in the flooded area this building type was represented by the temporal hospital which was destroyed completely with water depth values over 5.0 m and velocity of 5.49 m/s.

2. Structural Type_2

Buildings made of walls of concrete with one floor. The floor and roof built with the same material. In 2010 these were represented by four buildings located inside of the water factory near to the temporal hospital. These buildings were severely damaged by water values ranging between 2.80m and 4.74m and velocity between 2.0 m/s and 4.9 m/s. Another building representation was located towards the southern part, with the height of the ground floor in respect to the street level around 0.23 m making it vulnerable to flooding. During the last flooding this building had no doors or windows installed being slightly damaged by water values near to 0.60 m and velocity of 0.58 m/s.

3. Structural Type 3

Buildings with walls, floor and roof built of concrete. These building have two floors and are located inside of the water factory. During the 2010 flooding the building components of the first floor were damaged by water values of 2.80 m and velocity of 2.78 m/s. However, the damage on the second floor was not reported.

4. Structural Type_4

Represented by multi-family dwelling of three floors built of concrete, and walls and roofs are of the same material. This structural type is the predominant in the area. In the flooding of 2010 they neither had doors nor windows. So these building walls were only slightly damaged by water depth values ranging from 0.25m to 2.72m and velocity between 0.16 m/s and 0.61 m/s.

5. Structural Type_5

Buildings built of concrete with five floors, located towards the northern part of the town. Results of questionnaires show that similar damages to the structural type_4 were reported for higher values of water depth (2.21m to 2.88m) and velocity (0.34 m/s to 1.38 m/s).

The spatial distribution of the structural building type is shown in Figure 48. In order to indicate a better representation of structural type, the buildings existing during 2010 and 2011 where combined into this figure. Buildings of structural type_1 existing during 2010 only were located towards the northern part of the town. These building represented the 1.79 % of buildings of the area. However, buildings of structural type_2, belonging to 2010 were located inside of the water factory. These building were less typical (1.6%). Buildings with structural type_3 represented 6.75 % of all buildings. These were located inside and outside of flooded area during 2010. During this event buildings with structural type_3 inside of the flooded area were located towards the north inside of the area of the water factory. Figure 48 shows a building type_3 inside of flooded area, which was built after the 2010 flooding. Remaining buildings with structural type_3 are located outside of the flooded area. These buildings remain during 2011 as well. On the other hand buildings with structural type_4 are the most represented in the area, and they are dispersed everywhere, representing 75.69 % of all buildings. However buildings with structural type_5 are concentrated towards the northern part of town, close to the water factory. These represent 14.17 %. Building type_4 and type 5 were built during 2010 and remaining during 2011.


**Figure 48. Spatial distribution of structural building type**

Damage assessment was based on data collected from questionnaires, interviews, FGD and fieldwork observations. Maiti, (2007) described several factors that determinate damage. In this research the influence of flood characteristics such as: water depth, velocity, duration and sediments characteristics in building damage are considered. Building damage collected during the fieldwork are explained in this section as well.

## 6.2. Flood characteristics on damage assessment

The magnitude of flood characteristics is one of the factors that determine the degree of damage of the building. Water depth is related to the submerged volume of a building. This is considered as the characteristic "has strongest influence on damage magnitude" (Maiti, 2007). Kelman, (2002) reflected water depth as the most detailed flood characteristic during a flood analyses. In this research the characteristics of water depth was the respondents remembering more during the interviews and for this reason the collected data is more detailed than other flood characteristics. The increase of water level produces more damage on elements exposed. In buildings with higher values of water depth cause more damage in their components such as walls (moisture), windows, doors, floors, and in many cases roof. Other subcomponents such as: glass, frames and hinges are damaged too. The difference of water level values outside and inside of buildings causes pressure differences that could originate the buildings failure (Kelman, 2002).

During the 2010 flood event water depth values ranged between 0.12 m to 6.49 m (Figure 44). Highest values of water depth were located towards the northern part (around 3.0 m to 5.90 m), where components and subcomponents of buildings from the water factory and the temporal hospital were completely destroyed. The flood waters also deposited large amount of sediments on buildings and roads.

The duration of the flood event is another important characteristic to be considered during the damage analysis. In urban areas this indicator is related to how long a building is inundated. The water depth and duration are two indicators to be analyzed together. Longer durations of flooding cause greater saturation of walls. Therefore buildings being flooded during a long time are more damaged that buildings exposed to flooding for a shorter time. The duration associated to the 2010 flooding was four days, as was explained in section 5.1.3. So buildings located towards the north part were exposed to higher values of water depth during a long time.

The velocity is one of the most important flood characteristics to take into account during a flood damage assessment, especially when it concern a flash flooding (Maiti, 2007). High flow velocity values originate lateral pressures instigating breach zones in walls of buildings or other building structures causing further failures (Begum et al., 2007). Then buildings exposed to higher values of velocity are more damaged than others. High velocity of the water moving around a corner of a building erodes building foundations originating its destabilization (Kelman, 2002). Also a large amount of sediment is generated during the water erosion process, which is transported during flooding. So associated to velocity sediment characteristics such as amount, size of sediments and weight are necessary to analyze. For example debris moving at by high velocity can impact buildings and cause damage to their structure and erosion of its foundation (Kelman, 2002). Also, a high amount of sediments leads to the increase of cleaning works.

During the 2010 flood event, the northern part of the study area experienced a combination of high values for water depth, duration and velocity with high loads of debris. The following was reported: the destruction of the temporal hospital, whose relicts were displaced more than 300 m. Also concrete buildings from the water factory close to the temporal hospital were impacted by a high amount of sediments and high velocities values. So, walls were damaged and building foundations were eroded by debris flood moved through water flow. The amount of sediments reported inside of buildings was higher than 0.5 m in height.

### 6.3. Building characteristics of the damage assessment

Building characteristics are one of the most important indicators to be considered during the identification of damage. The response of buildings to flooding determines the percentage of damage of people and its structure. Data collected from fieldwork using PGIS was used on the identification of damage associated to the buildings structure. Buildings with structure type_1 and building with structure type_2 (from the water factory) were not found in the fieldwork but data was collected using questionnaires. Five categories for the damage to the building structure were created (Table 13).

**Table 13. Categories of the damage to the building structure**

| Class number | Categories of the damage |
|---|---|
| 1 | Total destruction |
| 2 | Doors and windows destroyed, and foundation eroded |
| 3 | Doors and window destroyed |
| 4 | Deterioration of walls |
| 5 | No damage |

Damage to the building structure collected from fieldwork were combined in with the flood characteristics for each structural type. Values of water depth were obtained from the flood map (Figure 44) and velocity values were given based on the velocity map obtained from modeling process (Figure 46). Results are shown in Appendix 6. Information of the damage to the buildings based on the structure type was summarized on Table 14. Categories of damaged class estimation displays in this table were given according the author.

**Table 14.** **Damage to the building components collected during fieldwork**

| Building components | Building Structural Type | | | | |
|---|---|---|---|---|---|
| | Type_1 (metal_1 floor) | Type_2 (concrete_1 floor) | Type_3 (Concrete_2 floors) | Type_4 (Concrete_3 floors) | Type_5 (Concrete_5 floors) |
| Wall Damage | Destroyed | High moisture in walls, wall deteriorated | High moisture in walls | Deterioration of walls painted. | Deterioration of walls painted. |
| Doors Damage | Destroyed | Destroyed | Destroyed | Not installed | Not installed |
| Windows Damage | Destroyed | Destroyed | Destroyed | Not installed | Not installed |
| Floors Damage | Destroyed | Floor covered by more than 0.50 m of sediments. | Floor covered by around 0.5 m of sediments | Sediments less than 0.5 m | Sediments less than 0.5 m |
| Building foundations | Removed | Eroded | No damage | No damage | No damage |

The table above shows buildings with structural type_1 (temporal houses) and type_2 (area of water factory) were the most damaged building during the 2010 flood event. These were subjected to high values of water depth and velocity during four flood days. On the other side, building structure type_3 (first floor) shows a higher damage on components such as doors and windows which were destroyed. However, building structure type_4 and type_5 (first floor in both cases) did not show significantly damage.

The spatial distribution of these damage categories is shows in Figure 49. The highest damage area are located in the northern part were buildings were totally destroyed (structure type_1) and the building structure was severely damaged (structure type_2). In buildings with structure type_2 doors and windows were completely destroyed. Also the building foundations were affected. Other damage such as doors and windows destroyed were observed on buildings with structure type_3 located in the northern part as well. As was explained before the remaining buildings located inside of the flooded area were inundated. Deterioration of walls was the main structure damage reported.

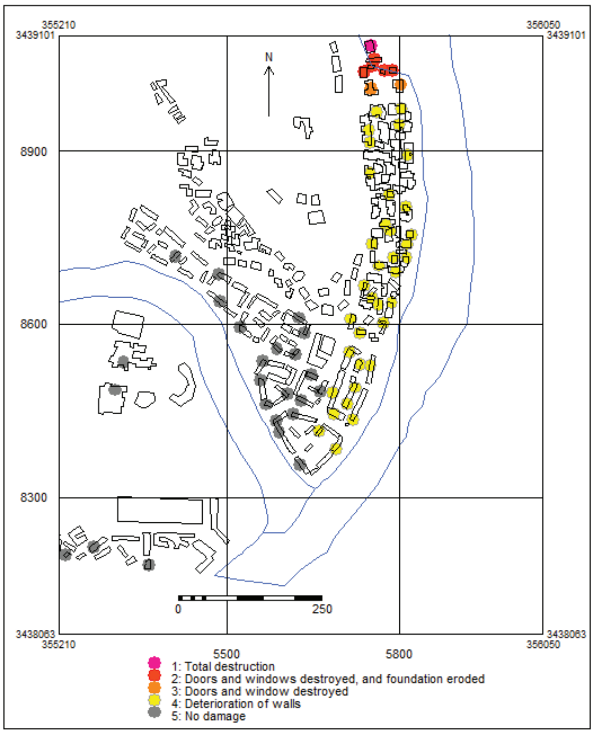



**Figure 49. Damage to the building structure based on fieldwork data**

The lack of information related to the cost of repairs for buildings does not allow the calculation of the percentage damage following the formula applied by Pistrika, et al., (2009).

### 6.4. Other reported damage

Results of questionnaires and interviews show that during the 2010 flood event Yingxiu town was being rebuilt. Therefore, there were no furnishing inside of buildings located in the flooding area that can be accounted for as direct damage or part of the building content for population. Only the water factory had all the required equipment installed, which were completely destroyed. The water factory was built with "about 19 million Yuan (2.5 million Euros) from Dongguan city" (Zhiling, 2010). The damage of the rest of the inundated buildings was lower in comparison to the water factory.

Other direct damages associated to the 2010 flood event were reported. The temporal hospital built by metal and styrofoam was completely destroyed, and swept away by the water to the proximity of the suspended bridge (Figure 21). Ambulance cars and construction trucks were damaged during the flooding as well (Figure 50). In general the total amount of damage reported associated to the 2010 flood event exceeds 10 million of Yuan (1.3 million of Euros)

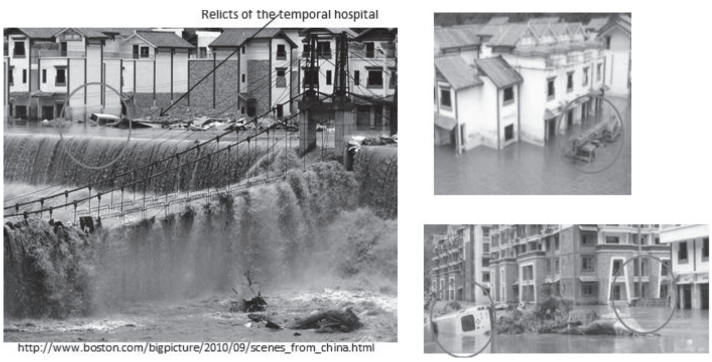



**Figure 50. Damage by 2010 flood event**

Habitants located in Yingxiu town during the 2010 flood event were concentrated mainly in temporal houses on the left bank of Minjiang River and the right bank of Roa River. During this time around 3000 people from Dujiangyan and Xinjing city working on the construction of buildings. In many cases they were people without any experience related to the flooding. Results of interviews show that one hour before the flooding the warning system was activated by the local municipality, but many workers did not evacuate on time. As a result more than 30 persons died inside of the buildings. The identification of these buildings are still missing. This damage was categorized as direct and intangible.

Indirect damage associated to 2010 flood event were compiled as well. As tangible damage the compensation from the government of Macao County and the Construction Company to the people were recorded. In questionnaires the respondents reported that around 40 Yuan/person for one year was given. Also food such as rice and grains (0.5 kg/person x day) were supplied for the duration of two months. In total around 7 million of Yuan (1 million of Euros) were reported as compensation to people in Yingxiu. As intangible damage psychological impacts were reported from people. Results from questionnaires show that around 28.3 % of population surveyed expressed feelings of fear associated to the 2010 flood event. Although several people lived through the experience of the 2010 flood event, they knew the consequences of this flooding through other persons. The spatial distribution of this indirect damage is shown in Figure 51.

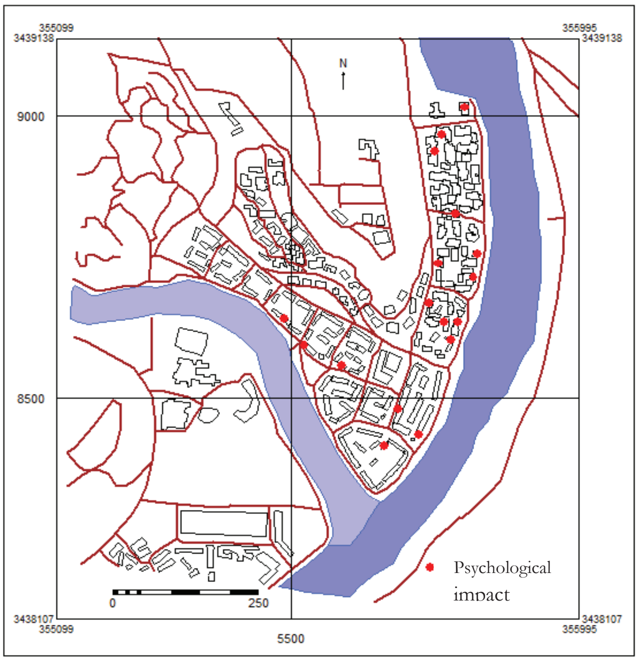



**Figure 51. Spatial distribution of indirect damage (psychological impact)**

Figure 51 show that from 28% of households sampled where the population have psychological impacts 23 % of households are situated inside of the flooded area. Higher concentration of these households is located mainly toward north and center of the flooded area.

Damage related to the disruption of the transportation although they were not directly related to the flooding they were associated to the cause that originated the flooding in the town. As a consequence of debris flows the highway that connecting the city of Chengdu and Yingxiu had around 70 km of damages and the highway between Yingxiu and Dujiangyan around 16 km. As a consequence the transportation was affected for 15 days.

### 6.5. Community perception of the 2010 Flood Event

The perception of the community to flooding is defined by Schelfaut et al., (2011) as the way that residents perceive the flood risk and their local knowledge about flooding. Other authors such as Krishnamurthy, et al., (2011) have a view that is more representative of the concept and defining the flood risk perception as "visual representation of local risk perceptions during the mapping process". In this approach the definition given by Schelfaut et al., (2011) is applied. Local knowledge is linked to the manner in which those inhabitants perceive the flood risk.

Data associated to community perception were collected through questionnaires and interviews. The knowledge captured was related to:

a) Experiences of the peoples related to flooding.
b) Feelings of fear related to the 2010 flood event.
c) Comparison of flooding with another phenomenon such as a landslide and an earthquake.
d) Thoughts of inhabitants about the possibility of their houses being damaged as a result of future flood events.
e) Water level according to inhabitant's perception (ankle, knee, hip, breast, head and higher) and also the number of floors where there is flooding (first, second or third floor).
f) Estimation of velocity values according to the people's perception.
g) Identification of causes of flooding.

As was explained before the perception analysis was based on answers of questionnaires and interviews applied to sixty households sampled and answers of the FGD. Also during the transect mapping questionnaires were supplied to the population on the streets but in many cases the population found on the streets were tourists or persons without any flood experiences; so this method was not considered as effective, therefore the answers were not taken into account.

Results of questionnaires show that 68.8 % of the respondents lived in Yingxiu during the flooding of 2010 and have been, relocated to temporal houses on the left bank of the Minjiang River and the right bank of the Roa River. Therefore they answered that they have knowledge related to flooding. However, the remaining part of respondents (31 %) lived outside of the town during this event. Nevertheless, 100% of the respondents have knowledge about the 2010 flood event, showing the flooding area. As a consequence of flooding, psychological impacts reflected as feelings of fear were found in 28.3% of the population (Figure 51). Another psychological impact reflected by the population of the town is associated to the earthquake of 2008. Although this event happened prior (2008) to the flooding (2010), the population keep the memories of this event. Unlike with the flooding, more than 80 % of the sampled population lived in the town during the earthquake which explains why people have more knowledge related to this event and around 84.3 % of people answered that an earthquake is more dangerous than flooding. The comparison of flooding with other earthquake is shown in Table 15.

**Table 15. Comparison between flood and other phenomena**

| Criteria | Flood compared to landslide (%) | Flood compared to small earthquake (%) | Flood compared to large earthquake (%) |
|---|---|---|---|
| Harmless | 0.00 | 0.00 | 0.00 |
| Less dangerous | 35.21 | 17.39 | 84.28 |
| Equal | 32.39 | 10.14 | 7.14 |
| More dangerous | 22.53 | 43.48 | 5.71 |
| Extremely dangerous | 5.63 | 26.09 | 0.00 |
| I don't know | 4.23 | 2.90 | 2.86 |

The table above shows that a maximum percentage (35.21%) of people considered flood as a phenomenon less dangerous than a landslide, and 32.4 % of respondents considered flooding in the same category of danger than a landslide. This is because they considered landslides a more frequent event that caused damage during 2008 and during 2010. This phenomenon is evident in the mountains that surround the town. Several respondents indicated as an example the destruction of several homes caused by Hongchun gully debris, and others pointed to houses covered by sediment on the left bank of the Minjiang River. However, flooding was reflected as a not common event that happened many years before and is only kept in the minds of elderly people. They associated the occurrence of flooding after the landslide or debris flow. Observations from fieldwork confirmed the existence of several landslides around the town. Some of these are old landslides covered by vegetation and others are new landslides without vegetation. Figure 52 displays some of these landslides.

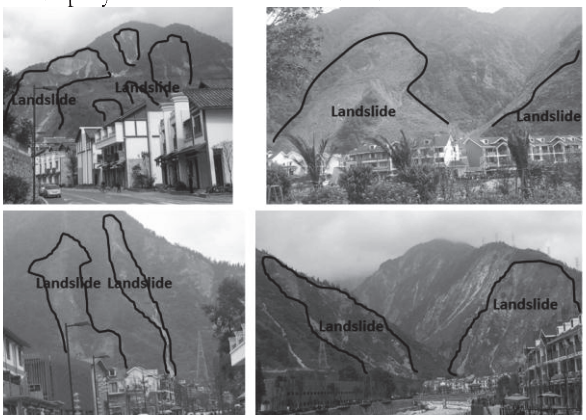



**Figure 52. Landslides around Yingxiu town**

On the other hand 22.53 % of the respondents considered that flooding is more dangerous than landslides because they can affect a larger area and landslides are more local. Around 5.63 % considered that flooding is extremely dangerous and could cause more damage.

The comparison between flooding and small earthquakes display that 43.48% of surveys agree that flooding is more dangerous than small earthquakes, and 26.09% expressed that flooding is extremely dangerous. This is because they considered that small earthquakes cannot cause severe damage to people and the buildings, but severe flooding can cause destruction of strong buildings such as the water factory, as many pointed out as an example. On the other side 17.39 % considered the small earthquakes as more dangerous than flooding because they associated it with the small occurrence or the existence of one large earthquake. However 10.14% considered these two phenomena as equally dangerous, assessing the possible consequences.

As was mentioned before large earthquakes are considered the worst phenomena for the population. Around 84.3 % of the respondents considered flooding as less dangerous compared to large earthquakes because they explained that before or during the flooding you have time to evacuate or go to higher places and some of them said that there is time to take money or something important. During an earthquake there is no time to evacuate, and there are not safe places. Also associated to the earthquakes are the amount of damage and the number of victims is always higher than with flooding. At several moments respondents exemplified the state of their household and loss of family members during the 2008 earthquake. On the other side 7.14 % considered both events as equally dangerous, and 5.71 % considered flooding as more dangerous because they related the probability of the occurrence of flooding greater possibility than the occurrence of another large earthquake. More than 50% of respondent said that information related to earthquake, its causes and damage were obtained through educational programs from television (TV).

Other information obtained from the comparison between these events in Table 15 is associated to the number of persons (10 %) that don't know the difference between these events. In many cases this population comes from other cities or town closeby without any experience related to flooding or earthquake event; making them vulnerable. In general the population sampled was able to perceive three phenomena compared as dangerous. Flooding was categorized as less dangerous than landslides by the probability of its occurrence, its dependence of this event (for 2010 flooding), more dangerous than small earthquake for its consequences and the area affected, and less dangerous than large earthquakes because the damage associated is less and the time for evacuation is different.

Although the population considers that flooding is a dangerous phenomenon that happened during 2010 causing severe damage 23.4 % of respondents think that their houses cannot be affected again as result of future flooding events. Measures taken by the government make them feel protected. Some measurements like the building of dikes and walls protection are detailed in section 6.6. However 14 % of respondents said that similar events can be happen and there is the possibility that houses can be damage again. On the other side 62.6 % doubt whether their houses can be damaged again, because they are not sure about the strength of the protective measures.

As was explained in sections before, during the flooding of 2010 the town was being built, so only people working on the construction were inside of the buildings. The main population remained in temporal houses outside of this area. For this reason the information related to the inhabitant's perception (ankle, knee, hip, breast, head and higher) about water depth was not possible to collect. The identification of water depth was then obtained from the number of floors that had flooded and the signals of water depth made by the population on the walls of buildings.

In order to classify the velocity of the 2010 flood event estimations were done considering the people's perception. Four categories were created: slow, medium, fast or very fast. Results of questionnaires show than 18.75 % of the respondents said that the water flow was very fast. However, 17.18% considered the moving of water flow as fast, and 3.2 % categorize the velocity as medium. The remaining part of respondents had no idea about the water flow velocity.

The identification of causes of the 2010 flooding was based on the three options given to the sampled population: man activities, landslides and heavy rainfall. Around 4.7 % of the population blames the landslides as the main cause for flooding, and 17.18 % identify heavy rainfall as the main source. However, 22 % recognized the combination of heavy rainfall and landslide as the cause of the 2010 flood event. Nevertheless 56 % of the population is not sure about the source of flooding.

The population that lives in Yingxiu have a good understanding in general about flooding although the flooding is not a common phenomenon in this area. The survey results show that 100 % of the population knows about the 2010 flooding event; and are able to point out the flooded area and identify the most damaged area. Over 40 % of the people identified the causes of this flooding event. More than 80 % was able to compare this phenomenon with other phenomena, demonstrating the knowledge about the event. Although the population admits that the 2010 flooding was linked to heavy rainfall that triggered the Hongchun debris flow, causative of flooding, the major percentage of people do not perceive the possibility that the town could be affected by another flooding. They are convinced they are protected by the protective structures built (dikes and walls protection).

## 6.6. Coping capacity related to the 2010 Flood Event

Coping capacity is defined by UNISDR (2009) as "the ability of people, organizations and systems using available skills and resources, to face and management adverse conditions, emergencies or disasters".
In order to identify weaknesses and strength of coping mechanisms used by the community during the 2010 flooding several research questions were added to the questionnaires. These included issue as:

a) Effectiveness of the warning system.
b) Evacuation system.
c) Operation of social ties.
d) Actions to minimize or avoid losses.

The effectiveness of the warning system was evaluated considering the information system used to alarm the population of the occurrence of the flooding. Although several respondents lived outside of the flooding area in temporal houses, they showed to have knowledge about the event. As a result of the questionnaires, 37.5% of the population said that the alarm system was developed by the military, who notified the population about the occurrence of possible flooding and the need to evacuate to safe places. As a way to notify the people, the military knocked on doors and made phone calls. The warning and evacuation system were activated around one hour before the flooding began. So, around 39 % of respondents considered the warning system and evacuation process as effective, which were developed before flooding event. As a method of evacuation people were directed to move towards the highest area of the town located in the western part. Another way to evaluate the perception of the population about the evacuation system was to compare this with the evacuation process during the earthquake. 100 % of respondents said that there were no evacuation systems before the earthquake, unlike with the flooding. Also questions related to the knowledge of people about how to proceed during the flooding situation were applied. About 87.5 % answered positive, exemplifying some actions such as: running towards elevations, removing the more important things to others floor, and stay informed. However, 12.5 % of the respondents said they did not know what to do during the flooding.

The existence and operability of the social ties was evaluated as well. Around 23.43% of the population reported the existence of social ties operating before and after the flooding. Actions before flooding were associated to notices between neighbours (7.8%), who knocked doors and made phone calls. Around 15 % of the respondent said that actions after the flooding were related to people from the closest town that helped with the cleaning activities. Other help related to money and clouds were given to the population by other organization such as the Red Cross, after the flooding.

Coping mechanisms to minimize or avoid losses associated to this 2010 flood event were evaluated from two points of view: from the government and personal views. Both are considered before, during and after the flooding. These mechanisms are shown in Table 16.

**Table 16. Coping mechanisms taking during the 2010 flood event**

| Actions | Before flooding | During flooding | After flooding |
|---|---|---|---|
| Government | -Built strong buildings.<br>-Monitoring of rainfall.<br>-Active the alarm system.<br>-Notice to people.<br>-Evacuation of population<br>-Move things to safe places. | -Open the dam created by the debris sediments.<br>-Provide foods | -Provide foods and money.<br>-Cleaner process.<br>-Placement of lamps on elevations.<br>-Training to people.<br>- Built protective structures on the town (dikes, embankment and walls protection).<br>-Built protective structures on Hongchun gully.<br>- Repair the highway. |
| Personal | -Move towards safe places.<br>-Take money and some food. | Stay in safe places | -Working on the cleaning process.<br>-Participate in training. |

The table above shows that before the 2010 flooding existed, the coping mechanism from the government which was activated during the last flooding. These allowed minimizing the damage from flooding during this event. For example the presence of strong buildings built with concrete, with more than one floor (as predominant), with coated walls and existences of retaining structures to flooding, avoided the occurrence of extensive damage. The monitoring of rainfall allowed the authorities to prevent the occurrence of possible flooding and active the alarm system, notifying people one hour before the flooding started. During interviews a policeman declared to live on the third floor of buildings of five floors during the event. He said before the flooding he worked on notifying the people and in the moving of the most important things towards the fifth floor. Unlike the government, coping mechanism used by population before the flooding show the little preparation and knowledge of people about flooding. These mechanisms were related to the moving towards safe places during the evacuation process, only 3% of respondents said to have taken food and money with them.

During the flooding event the respondents reported staying in evacuation sites and others in temporal houses located on the left bank of the Minjiang River and right bank of the Roa River, where the government provided food on a daily basis, such as rice and noodles. During this time the costs of evacuation were covered by the government. In order to minimize the damage and to reduce the flood duration days, militaries opened the debris dam after four days of flooding.

After the landslide dam was opened the flooding ended. So, new strategies were addressed to the resilience of the town. Amongst actions undertaken by the government that were identified by the respondents, was the provision of food and money as compensation for two months. Other mechanisms were related to the cleaning of streets, sewage system and the interiors of buildings where military, people from Yingxiu and those in town closeby town worked together. The Construction Company repaired the buildings positioned floodlights on elevations with the aim of improving the lighting during the night. In order to prepare the population to deal with flooding; trainings related to evacuation processes are organized by the government two times per year.

Other strategies developed were related to the structural measures such as: construction of embankment, dikes and wall protection. The embankment with two levels, built of concrete (first level) and natural ground (second level) is located in an area close to where temporal hospital was located in 2010. On the other hand, the dike built of concrete with a length of around 101.21m; a width of 3.0 m to 13.0 m and a height between 2.0 m and 7.0 m, is situated in the area were highly damaged buildings of water factories were located. Both protection structures were built on the northern part of the town with the aim to reduce the velocity, water mass and the amount of debris that may arise as a consequence of a similar flooding. Moreover, the protection wall with around 7.0 m of height and 0.37 cm of width was built along the right bank of the Minjiang River. Also around the Roa River there are protection walls with similar characteristics that reach around 10.0 m on the confluence of the two rivers.

Figure **53** shows the location of these structures in the area.

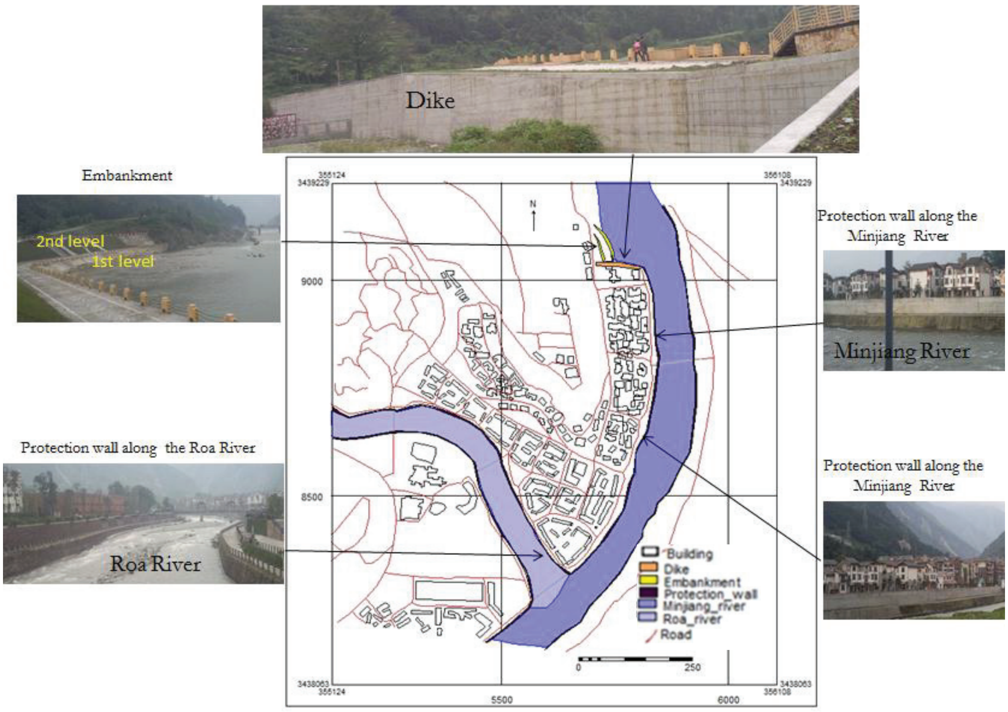



**Figure 53. Flood protection structures built in the town**

Other coping mechanisms aimed to reduce the amount of debris flows to be incorporated into the Minjiang River. Large dams along Hongchun gully were built with this objective. Also, several steps from the first dam until Minjiang River mark different levels for the reduction of velocity and deposition of debris flows. Figure 54 displays examples of dams and steps.

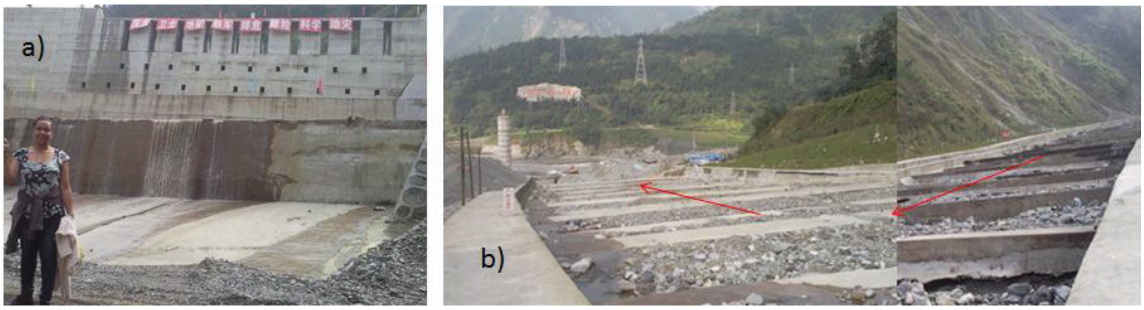



**Figure 54. Protection structures built along Hongchun gully. a) Dam; b) Steps (red arrows indicate the direction of movement of debris flow)**

With the aim to achieve the restoration of transportation, although this was damaged by the Hongchun debris flow, the highway connecting Yingxiu and Dujiangyan city was repaired to have primary means of communication with the town.

# 7. VULNERABILITY ASSESSMENT

The vulnerability assessment was divided into physical and social vulnerability. Details are explained below.

## 7.1. Physical vulnerability assessment

The vulnerability for the building structure was determined based on the damage of the building components (walls, floor, roof, windows and doors) for each building structural type (Appendix 7). This information was collected from respondents and fieldwork observations. Also the magnitude of flooding given by its characteristics such as water depth and velocity were taken into account. Lack of information related to another indicator such as sediment characteristic (size, amount and weight) do not allow these to be considered within this analysis.

In order to evaluate the structural building vulnerability three approaches were taken into account: Clausen (1989), Kelman (2002) and Huizinga, et al., (2004). They will be described and evaluated in the next sections.

### 7.1.1. Method of Clausen

Clausen (1989) is based on empirical data from the dike dam failure create three categories for brick and masonry buildings (K. Pistrika, et al., 2009). The three damage levels are classified: inundation damage, partial damage and total destruction. These categories come from the combination of water depth and velocity values (Figure 55).

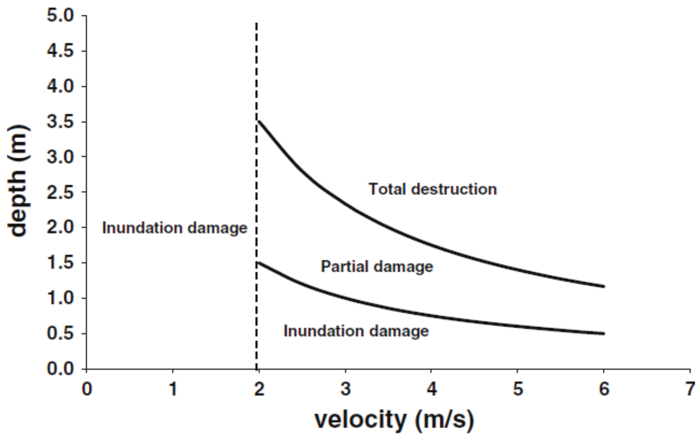



**Figure 55. Structural damage categories created for (Clausen, 1989)**

In order to evaluate the effectiveness of this approach, buildings were categorized based on these classes (Figure 56). Results were compared with the damage information collected from fieldwork. Although there is correspondence between damage collected from the fieldwork and categories created by Clausen (1989), buildings categorized as partial destruction do not reflect details about the structural type of damage produced. The application of this approach has as limitation that the paper is no published; therefore the description of the damage categories is not detailed. Hence this approach was considered as no appropriated for this research. This can be used in studies were general and fast evaluation of damage is required; where water depth values will be less than 5.0 m and velocity less than 6.0m/s.

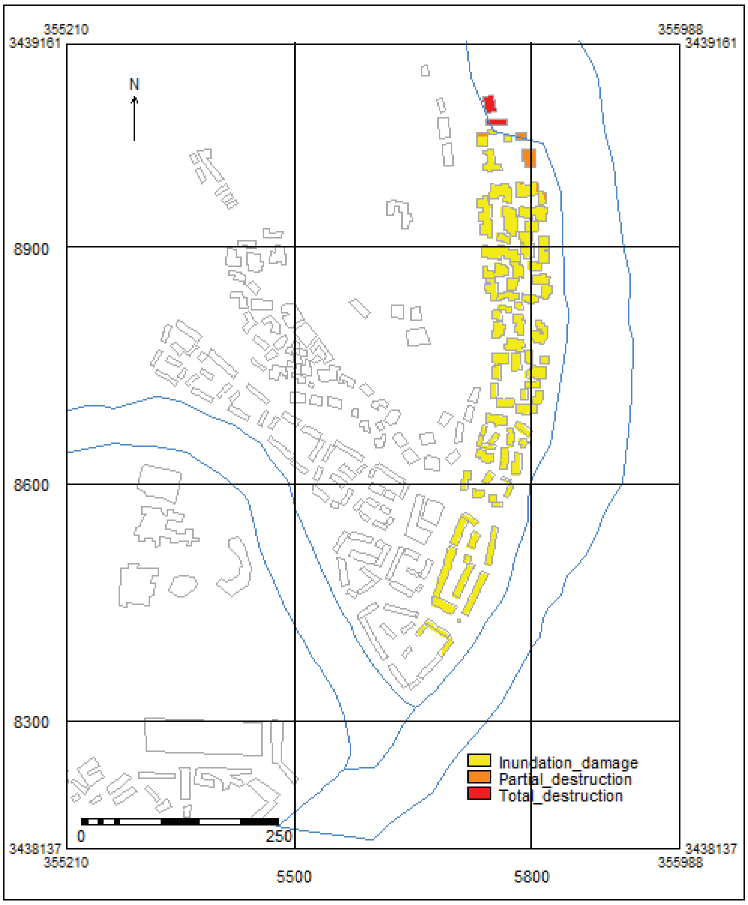



**Figure 56. Damage factor map for structural buildings based on Clausen (1989)**

### 7.1.2. Method of Huizinga

Another approach developed by Huizinga, et al., (2004) was taken into account. The author developed damage factors for Dutch concrete buildings for long polder inundation. The flood duration will probably be much longer than in the present fieldwork situation. Only flood depth is considered in this approach (Figure 57).

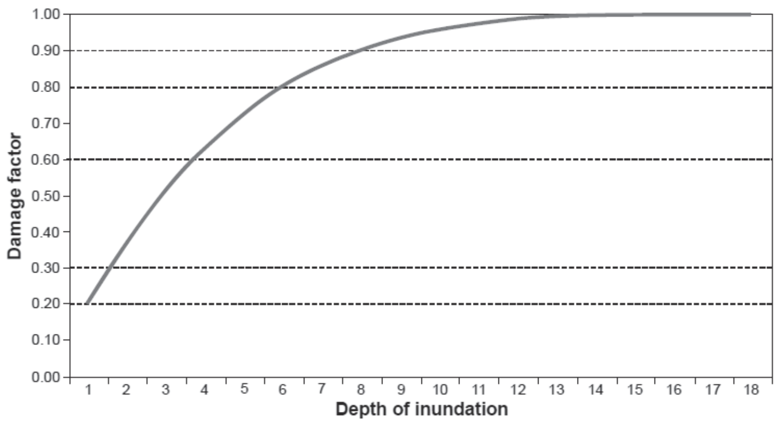



**Figure 57. Depth damage function for high-rise dwellings given by Huizinga, et al., (2004)**

To evaluate the efficiency of this approach for each building a damage factor value was assigned based on the structure type. For buildings with structure type_2 and type_3 this method is not applied because they belong to the water factory and this method is only applicable for dwellings. The spatial distribution of the damage factors is shown in Figure 58. Results were compared with the damage information collected from fieldwork. Results show correspondence between damage collected from the fieldwork and the damage factor created by Huizinga, et al., (2004) by the inundated area. As limitation of this research was identified that was not applicable for all structural type existing in the study area. Also, structural building damage are not described by the author. For these reasons this approach was not considered appropriated for the assessment of the building structure damage.

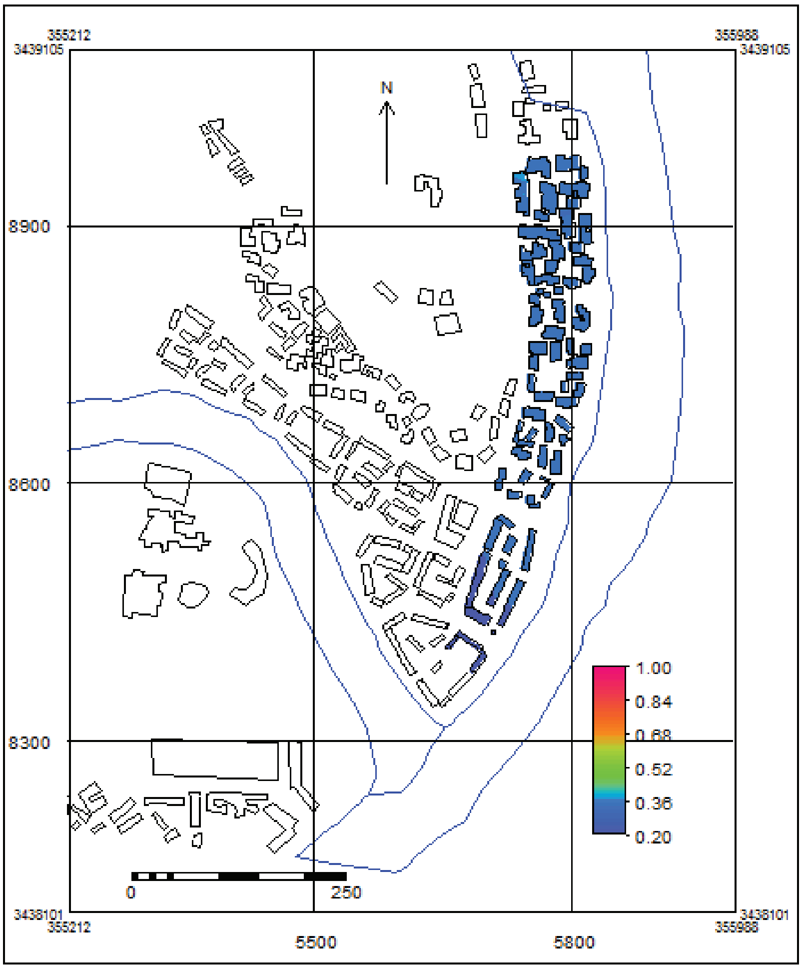



**Figure 58. Damage factor map for structural buildings based on Huizinga, et al., (2004)**

#### 7.1.3. Method of Kelman

The last approach considered in this research was developed by Kelman (2002). In order to clarify the difference between damage and losses, Kelman (2002) established some concepts, which were taken into account in this approach. Kelman (2002) defined damage as "the reduction in value sustained by an item or property" and losses as" the cost incurred to return to the original state". Also he divided damage into two categories: failure (when the restoring of building to its previous state is infeasible) and no failure (when it is feasible to return the building to previous state). To make a difference between these two categories (failure and no failure) the author created a damage scale of floods (Table 17); which is applied in this research. Kelman (2002) considered that "each damage scale level (DS) represents a threshold in which the hazard event affects the building".

**Table 17. Damage scale for buildings flooded (Kelman, 2002)**

| Damage_class | Damage_Scale level (DS) | Water Interaction with Structure |
|---|---|---|
| No damage (No failure) | DS0 | No water contact with structure. |
| Damage (not failure) | DS1 | Water contacts outside of structure but does not enter. |

| | | |
|---|---|---|
| Damage (not failure) | DS2 | Water infiltrates (i.e. seeps or leaks is through small apertures) or external features are damaged or removed by water or debris |
| Transition (from non-failure to failure) | DS3 | Water or debris penetrates through a closed or covered opening (probably by breaking the opening); for example, a window or a door. |
| Structural failure | DS4 | Water or debris penetrates through a route not including an opening (structural integrity is attacked); for example, a wall or roof. |
| Structural failure | DS5 | Structure is damaged beyond repair; for example, walls collapse, the structure moves, or the foundation is undermined. |

In order to minimize the level of uncertainties during the damage assessment, observations from the fieldwork (Table 14) were combined with the damage scale level given by Kelman (2002). As result a relationship between the building structural type and the damage scale (Kelman, 2002) was created taken as criteria values of water depth and velocity in interactions with buildings. The relationship obtained in this research is shows in Table 18.

**Table 18. Relationship between building structure type and damage scale level**

| Building structural type | Water_depth (m) | Velocity (m/s) | Damage_scale level (DS) |
|---|---|---|---|
| Type_1 (metal 1floor) | 5.90 | 5.49 | DS5 |
| Type_2 (concrete 1 floor) | 0.60 | 0.58 | DS3 |
| | 2.80-4.74 | 2.0–4.9 | DS5 |
| Type_3 (concrete 2 floor) | 0.0 | 0.0 | DS0 |
| | 2.80 | 2.78 | DS3 |
| Type_4 (concrete 3 floor) | 0.0 | 0.0 | DS0 |
| | 0.25 | 0.16 | DS1 |
| | 0.26-2.72 | <0.61 | DS3 |
| Type_5 (concrete 5 floor) | 2.21-2.88 | 0.34-1.38 | DS3 |

The table above shows that buildings with damage scale level DS3 (water or debris penetrates through a closed or covered opening) are the most common. These are associated to building type_2 (located outside of the water factory), and the other building types, except by building type_1. This is because at the moment of the flooding the buildings did not have doors and windows installed, which facilitated the movement of water into the building. This reduced the effect of water pressure avoiding major damage (Kelman, 2002). On the other side, buildings with structural type_1 were completed destroyed by water depth values over 5.0 m. Building structure type_2 (located inside of the water factory) although they were not destroyed, they were severely affected by the water depth higher than 2.0 m; the structure was damaged beyond repair. Both building types were categorized as DS5. Building with structure type_4 with low values of water depth (0.25 m) were classified as DS1 because was no water inside of the building, but only outside of the floor level. Buildings with DS0 were considered buildings with structure type_3 and type_4 where was not reported interaction of water within the building.

To create the damage scale level (DS) for buildings it was necessary to assume a single constant water depth value for each building. The water depth map created (Figure 44) was crossed with the elements at risk map. The maximum value of water depth by each building was obtained and considered during DS values categorization.

The spatial distribution of the categorized buildings taken into account within the damage scale level (DS) is shows in Figure 59. Buildings with damage scale level DS3 represent 28.51 % of the total number of buildings, being predominantly inside of the flooded area. On the other side the buildings with damage scale level DS5 are represented by more damage buildings located towards the northern part of the town, where water depth (2.54 m to 5.90 m) and velocity (close to 5.49 m/s) values were higher, and the impact of the water mass was higher as well. These buildings represent 1.54 % of the total number of building (259). However towards the southern part only two buildings were categorized as DS1 because of the height of ground floor level in comparison to the street level (0.35 m) being higher than the water level (0.25 m). These buildings represent 0.18 %. Buildings considered as DS0 are located outside of the flooded area. These represent 69.77 % of the total study area.

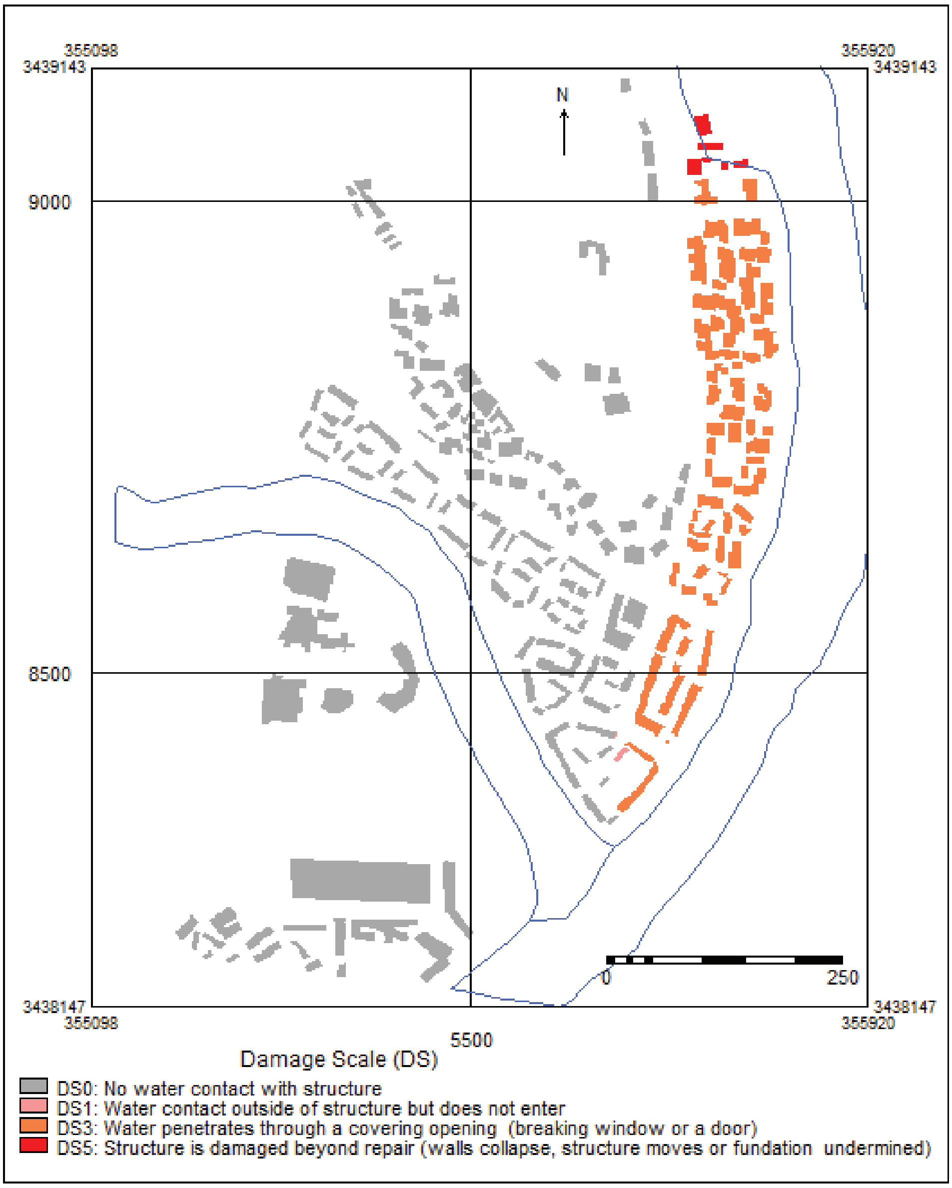



**Figure 59. Damage factor map for structural buildings based on damage scale proposed by Kelman (2002)**

Unlike other approaches, this method describes the structural damage for buildings showing correspondence between damage collected from the fieldwork and categories created by Kelman (2002).

Therefore it was considered as the most representative for the assessment of the structural buildings damage related to the 2010 flooding event.

## 7.2. The modified Kelman method

In this section a relationship between damage scale level (DS) created by Kelman (2002) and flood vulnerability is created based on the previous relationship between building structure type and the damage scale displays on Table 18. For each value of damage scale a vulnerability value is assigned considering structural damage (Table 19). Values for vulnerability ranged from 0 to 1. Where 0 is the value for buildings without damage and 1 is the value for the buildings that were highly damaged.

**Table 19. Relationship between damage scale level (Kelman, 2002) and flood vulnerability**

| Damage Scale Level (DS) | Damage description | Vulnerability values assigned |
|---|---|---|
| DS0 | No damage reported | 0.0 |
| DS1 | Slight damage (water contacts outside of structure but does not enter) | 0.10 |
| DS2 | External features are damaged or removed by water or debris | 0.15 |
| DS3 | Water causes breaking of a window or a door. Transition (from non-failure to failure). | 0.50 |
| DS4 | Buildings structural integrity is attacked; for example, a wall or roof. Structural failure. | 0.90 |
| DS5 | Structure is damaged beyond repair; for example, walls collapse, the structure moves, or the foundation is undermined. Structural failure. | 1.0 |

As was explained before for the damage scale level (DS) a vulnerability value is assigned based on the damage description. Once vulnerability values are assigned to each damage scale (DS), these values can be linked to the building structure type considering the relationship established in Table 18. Therefore for buildings with damage scale DS5 the maximum vulnerability value was assigned. So, building structure type_1 and type_2 with DS5 vulnerability 1 is given. For buildings with DS0 the vulnerability value assigned was 0. Taken into account that for buildings with DS1 the damage was considered as slight, vulnerability value of 0.10 was given. On the other hand for buildings with DS3, transition category for buildings damaged (Table 19) vulnerability value of 0.50 was assigned.

Taken into account that for different values of water depth also the damage is different, a differentiation in the vulnerability values is required. Table 18 shows the same category DS3 for different water depth values making the assignation of the vulnerability values difficult. In order to provide the appropriated vulnerability value for buildings with structure type_4 and type_5 a combination of the three approaches was done. For buildings with DS3 (Kelman, 2002) categorized by Clausen (1989) as inundation damage (velocity less than 2m/s) values of the damage factor proposed by Huizinga, et al., (2004) were given. Taken into account that for building with structure type_2 and type_3 with DS3 the approach given by Huizinga, et al., (2004) is not applicable, vulnerability values were estimated. The relationship established between building structural type and vulnerability values is shows in Table 20.

**Table 20. Relationship between building structure type and vulnerability values assigned**

| Building structural type | Water_depth (m) | Velocity (m/s) | DS (Kelman, 2002) | Vulnerability values assigned |
|---|---|---|---|---|
| Type_1 (metal 1floor) | 5.90 | 5.49 | DS5 | 1 |
| Type_2 (concrete 1 floor) | 0.60 | 0.58 | DS3 | 0.20 |
| | 2.80 - 4.74 | 2.0 – 4.9 | DS5 | 1.0 |

| | | | | |
|---|---|---|---|---|
| Type_3 (concrete 2 floor) | 0.0 | 0.0 | DS0 | 0.0 |
| | 2.80 | 2.78 | DS3 | 0.50 |
| Type_4 (concrete 3 floor) | 0.0 | 0.0 | DS0 | 0.0 |
| | 0.25 | 0.16 | DS1 | 0.10 |
| | 0.26-1.0 | 0.17-0.38 | DS3 | 0.20 (Huizinga, et al., 2004) |
| | 1.0-1.5 | 0.18-0.45 | DS3 | 0.30 (Huizinga, et al., 2004) |
| | 1.5-2.0 | 0.18-0.40 | DS3 | 0.40 (Huizinga, et al., 2004) |
| | 2.0-2.5 | 0.40-0.61 | DS3 | 0.45 (Huizinga, et al., 2004) |
| Type_5 (concrete 5 floor) | 2.21-2.50 | 0.34 | DS3 | 0.45 (Huizinga, et al., 2004) |
| | 2.50-2.88 | 1.38 | DS3 | 0.50 (Huizinga, et al., 2004) |

Based on results of table above for building structural type vulnerability values were assigned and a vulnerability map was generated. Then four vulnerability categories were created: high vulnerability, moderate, low and no vulnerable. The spatial distribution of these vulnerability categories is shows in Figure 60.

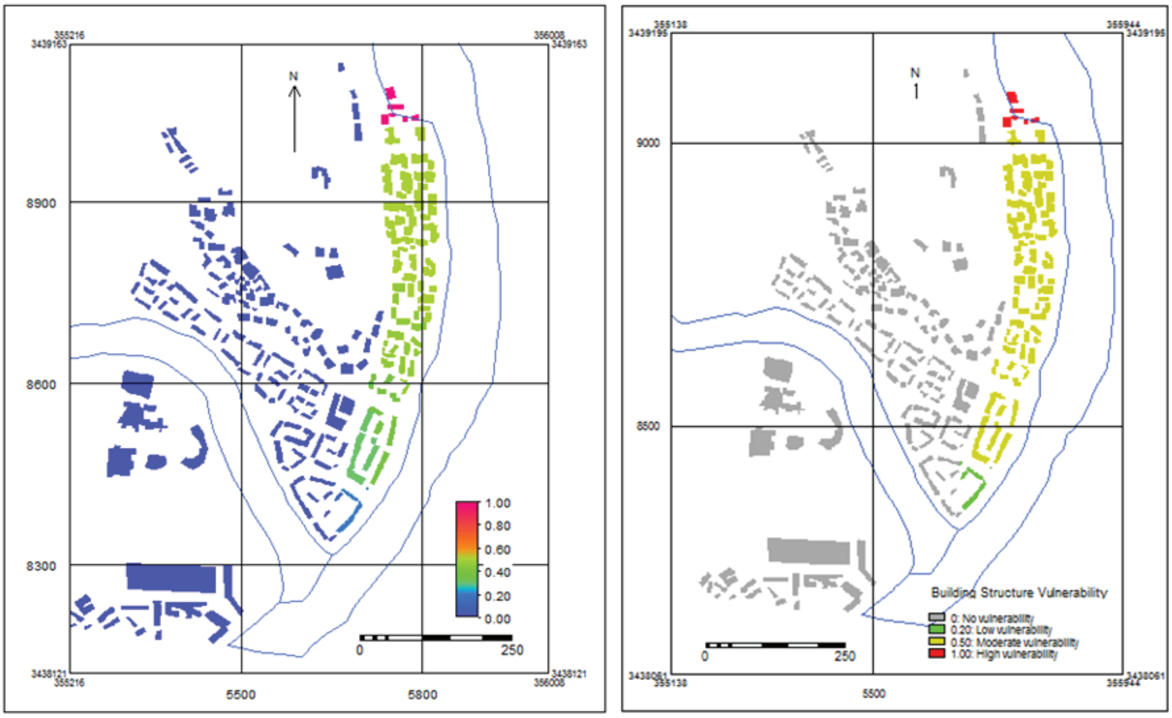



**Figure 60. Building structure vulnerability maps (modified Kelman)**

Buildings with high vulnerability (1.0) are associated to buildings of structural type_1 and type_2, highly damaged or destroyed during the flooding. They were located towards the northern part. On the other hand buildings with moderate vulnerability (0.5) are linked to structural building type_3, type_4 and type_5. These represent 24.61 % of buildings located in the study area and are located along the right bank of the Minjiang River. However, buildings with a low vulnerability are buildings with structure type_4 located towards southern part. The remaining part of the buildings (69.77 %) was categorized as not vulnerable to the 2010 flood event. These are located mainly towards the western part of the town and on the right bank of the Roa River.

In order to assign the damage scale (DS) categories for concrete buildings, the damage levels created by Clausen (1989) were combined with damage scales described by Kelman (2002). The combination displayed on Figure 61 was based on values of water depth, velocity and damage description (Table 17). Taken into account that for values less than 0.25 m the water did no entered on buildings, but outside was inundate DS1 was established. Considering that infiltration of water and external features can be damaged during inundation DS2 was assigned to inundation-damage category. The DS3 was established by Kelman (2002) as a transition from non-failure damage to failure damage (Table 17). For the boundary between inundation and partial damage, and total destruction DS3 was assigned. By definition DS5 was assigned to total destruction. DS4 was established as medial border between DS3 and DS5. On the other hand for building structure type_1 the DS categories were given based on data collected from fieldwork.

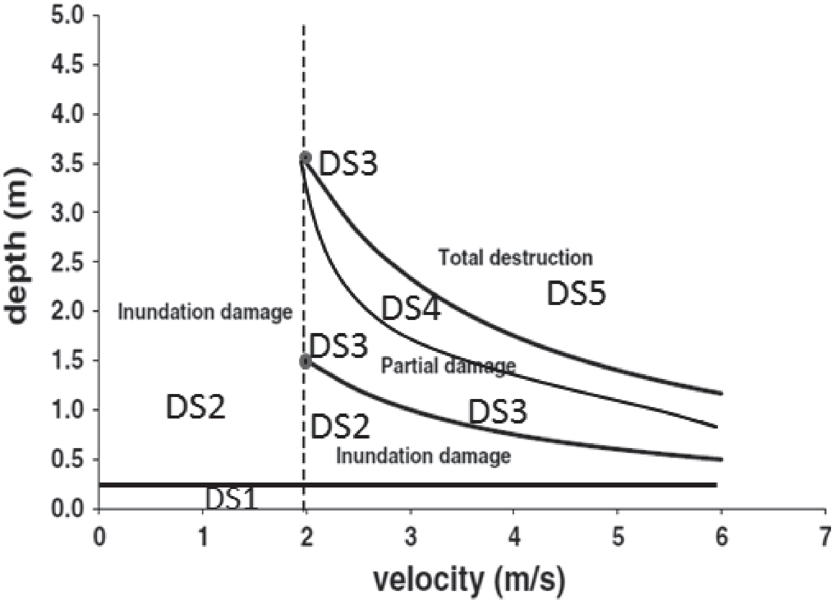



**Figure 61. Combination of damage criteria proposed by Clausen (1989) and damage scale by Kelman (2002)**

According to Figure 61 and data collected from the fieldwork, damages reported by building structural type_3, type_4 and type_5 were considered as similar (DS3). Therefore, a vulnerability matrix for these buildings was created. As a result three matrices with water depth values and velocity were created and related to the damage scale level (DS). These matrices are shown below.

**Table 21. Vulnerability profile for building structure type_1 ($A=240.12\ m^2$, Nr=1) adopted from Kelman (2002)**

| Velocity | Water depth (m) | | | | | |
|---|---|---|---|---|---|---|
| (m/s) | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 | >4.0 |
| 0.0 | DS0 | DS2 | DS4 | DS5 | DS5 | DS5 |
| 1.0 | DS0 | DS3 | DS5 | DS5 | DS5 | DS5 |
| 2.0 | DS0 | DS4 | DS5 | DS5 | DS5 | DS5 |
| 3.0 | DS0 | DS5 | DS5 | DS5 | DS5 | DS5 |
| 4.0 | DS0 | DS5 | DS5 | DS5 | DS5 | DS5 |

**Table 22.Vulnerability profile for building structure type_2 (A=250 m², Nr=1) adopted from Kelman (2002)**

| Velocity (m/s) | Water depth (m) | | | | | |
|---|---|---|---|---|---|---|
| | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 | >4.0 |
| 0.0 | DS0 | DS2 | DS2 | DS5 | DS5 | DS5 |
| 1.0 | DS0 | DS2 | DS2 | DS5 | DS5 | DS5 |
| 2.0 | DS0 | DS2 | DS3 | DS5 | DS5 | DS5 |
| 3.0 | DS0 | DS3 | DS4 | DS5 | DS5 | DS5 |
| 4.0 | DS0 | DS3 | DS5 | DS5 | DS5 | DS5 |

**Table 23. Vulnerability profile for building structure type_3 (A=250m2), type_4 (A=480 m2 and A=1202 m2), and type_5 (A=320m2) and Nr≥2 adopted from Kelman (2002)**

| Velocity (m/s) | Water depth (m) | | | | | |
|---|---|---|---|---|---|---|
| | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 | >4.0 |
| 0.0 | DS0 | DS2 | DS2 | DS2 | DS2 | DS2 |
| 1.0 | DS0 | DS2 | DS2 | DS2 | DS2 | DS2 |
| 2.0 | DS0 | DS2 | DS3 | DS3 | DS3 | DS4 |
| 3.0 | DS0 | DS3 | DS4 | DS5 | DS5 | DS5 |
| 4.0 | DS0 | DS3 | DS5 | DS5 | DS5 | DS5 |

The vulnerability matrix created for building structural type_1 (Table 21) shows these buildings are affected by water depth values of 1.0 m and velocity values close to 1.0 m/s. Its structural integrity is attacked for values of velocity close to 2.0 m/s and water depth of 1.0 m, being completely destroyed when the velocity value is increased to 3.0 m/s. On the other hand, buildings with structure type_2 are affected when the water depth is 1.0 m and velocity 3.0 m/s. For these values, damages to doors and windows are reported. However, for water depth values of 2.0 m and velocity 3.0 m/s are severely damaged; being destroyed for the increase of velocity higher than 3.0 m/s for the same value of water depth (Table 22). For buildings with structure type_3, type_4 and type_5 the structural components are affected equally than building type_2, but with the difference that second floor is severely damaged when the water depth is 3.0 m and the velocity is 3.0 m/s (Table 23).

## 7.3. Social vulnerability assessment

Social vulnerability is considered by van Westen, et al.,(2010) as the potential impact of events on vulnerable groups. Based on the statement made by Schumann (2011) that socio – economic conditions of a society determines its vulnerability, indicators proposed by Etkin, et al., (2010) such as age, gender, family size, and education level were taken into account in this research. Other indicators for example: number of persons during the day and number of persons during the night were detailed as well. As the unit of analysis the household was considered. Other socio-economic indicators as the livelihood and income per household were included as well. Information related to handicapped people was involved in questionnaires, but not any case was reported, and for this reason this indicator was not taken into account. Also indicators associated to accessibility to public services mentioned by Peter Guarin, et al., (2004) were reflected.

It was not possible to collect detailed socio-economic information for each building during the fieldwork stage, and in order to complete a social vulnerability assessment for the whole town it was necessary to establish a relationship between the information collected from social indicators and building type.

Therefore a correlation coefficient between building type and each indicator was calculated and is shown in Table 24.

**Table 24. Correlation coefficient between building type and social indicators**

| Building structural type | Correlation coefficient ($R^2$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total population | Age(≤5 ) | Age(6_18 ) | Age(19_60 ) | Age(>60) | Female | Male |
| | 0.0865 | -0.052 | -0.023 | 0.096 | -0.0007 | -0.034 | 0.151 |
| | Nr_P_Day | Nr_P_N | Nr_Emp | Income | Primary | High_S | Univ |
| | 0.0973 | 0.1993 | 0.1192 | 0.477 | -0.210 | 0.369 | -0.02 |

The table above shows predominancy of the lower and negative values of correlation. Therefore we can conclude that there is a low correlation between building structural type and social indicators. This is because the town was newly built after the earthquake of 2008. Therefore all buildings are concrete with similar conditions, so the building type does not depend on the income of people as in other studies. Also, population with different age, gender and education level are mixed in different building types and sometimes even within the same household. Consequently, it is not possible to establish a relationship between these social indicators and the building structure type. Which is why the socio-economic vulnerability analysis was done based on information collected for sixty buildings sampled.

### 7.3.1. Age distribution

The age of the family members is an important indicator to be considered during the analysis of the flood vulnerability in order to know the distribution of the most vulnerable whom the mobility and accessibility during a flooding is difficult. To collect the population data from the fieldwork four groups were created. The first group includes population aged less than five years old (youngest), followed by the second group of population aged six to eighteen (adolescents), the third group consists of population aged between nineteen to sixty years old (adults); and the last group of population over 60 years old (elder). For the purpose of this research the youngest and the elder groups were considered as most vulnerable. Figure 62 shows predominancy (76.57%) on the number of people aged nineteen to sixty years old of the population sampled. Followed by the group of adolescents represents by 13.64 % of population. However, most vulnerable groups correspond to smaller values of frequency: 6.29% for the youngest and 3.50% for the elder population. This is an indicator of the existence of few children and elder people inside of the sampled households.

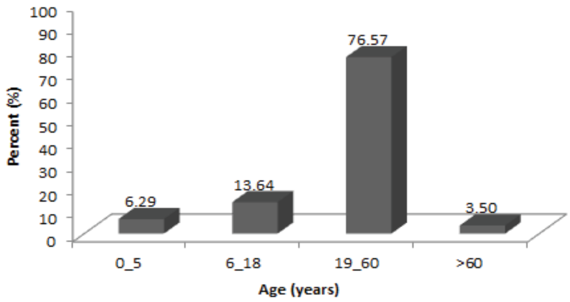



**Figure 62. The age of members per household**

Figure 63 shows the spatial distribution of the most vulnerable groups for this indicator. For the household sampled one is the most common number of children found (in 28.3% of households); this due to the existing rule of family planning in this country. By this reason only in two of household sampled two children were found. Also, in 8 % of the household sampled one elder person is observed and around 5 % of household two elder persons were found. On the other hand, the existence of children and elderly together were observed in few household, which represents 6.7% of the sample. These household are the most flood vulnerable. Although the spatial distribution of these groups do not follow a distribution pattern, Figure 63 shows that the main concentration of children and elderly is located towards center and southern part of study area. Also point maps with the spatial distribution of adolescents and adults were created. These were used as input indicators during the application of SMCE in the section 7.5.

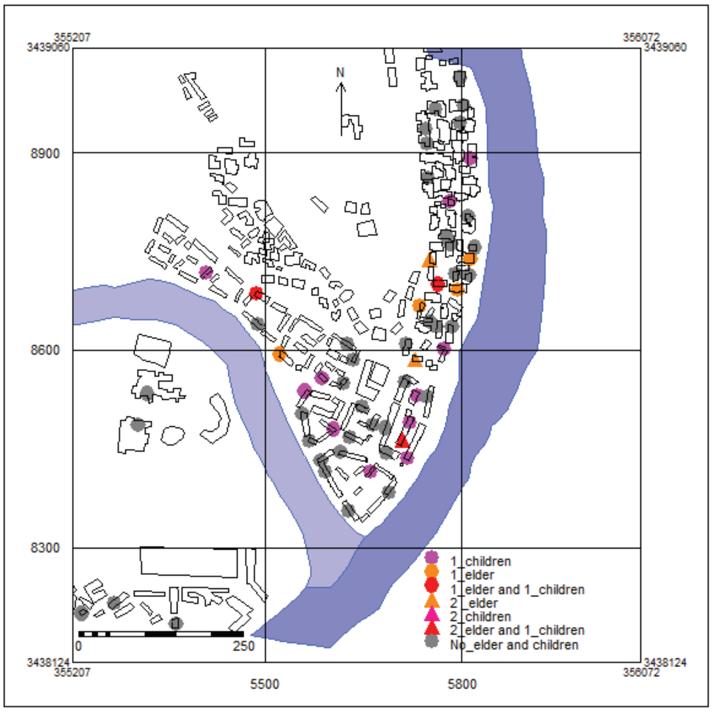



**Figure 63. Number of elder and children per household**

#### 7.3.2. Gender distribution and size of family

Gender is considered as an indicator that can influence in the flooding vulnerability within the household. Women with children and pregnant women are weaker compared to men, by this reason the gender distribution of family member is taken into account in this research. Figure 64 shows similarity in the gender percentage of the population sampled. The number of females (44.4 %) and males are close with a slight predominance in the number of males (55.6 %).

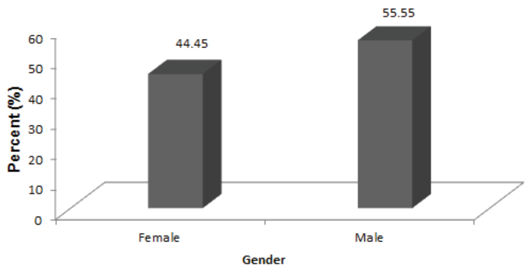



**Figure 64. Gender of members per household**

The spatial distribution of this indicator per household sampled is shown in Figure 65. There is predominance (88 %) of households with two genders. Of around 32% of households only one female representation was found within the family. However one male representation was observed in 37 % of household. On the other hand, 61% of the households have more than one female and 60% have more than two males.

The size of a family is another important indicator to consider during the analysis of household flood vulnerability. Households with three and four members are the predominant in the study area. Households with three members represent 26% and households with four members represent 32 % of the sampled household. However households with members between six and ten were found; but are not common. On the other side households sampled with a single member were found as well; these are the most vulnerable group. Figure 65 displays households with only one family member represented by female (2%) or male (7%). Only males were found in the police station, the water factory, an office and a shop. However, only the female representation was found in a residence; these being the most flood vulnerable places for this indicator.

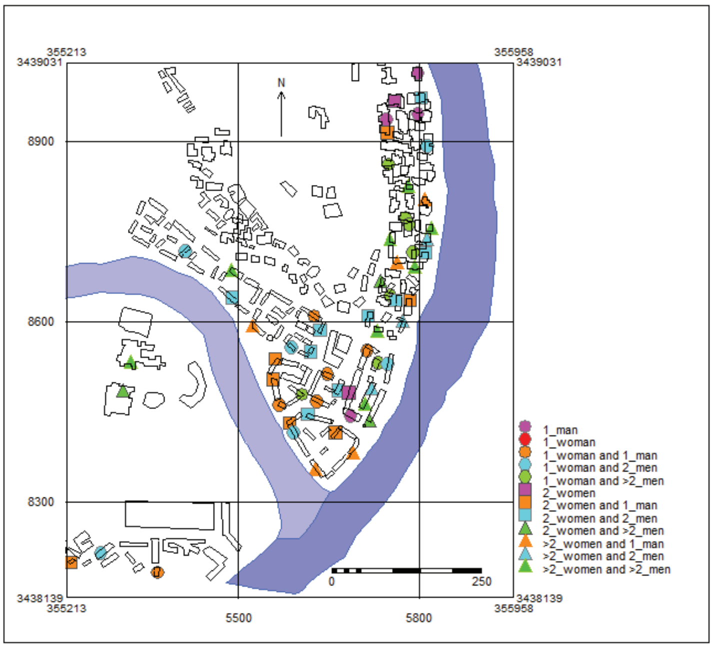



**Figure 65. Number of female and male per household**

#### 7.3.3. Education level

The education level influences the degree of knowledge acquisition. For example people with a higher level of education have a better understanding of the flooding phenomena, causes which originate, mitigation measures from local authorities, as well as information provided during training, flooding or evacuation processes. Therefore the vulnerability degree is reduced with a higher education level. To collect this information from the fieldwork, three groups were created: primary education, high school and university. In the households sampled there were no people found without an education. The frequency distribution of data collected is shown in **Figure 66**. The higher number (53 %) of population sampled has a high school education level. On the other side, around 35 % of population has primary education level, which is the most vulnerable group. Few persons with a university level were found.

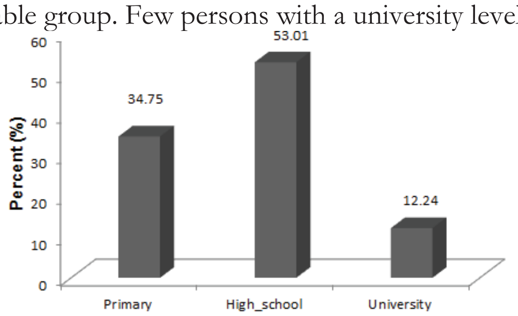



**Figure 66. Distribution of education level per household**

Figure 67 shows the spatial distribution of each group created for this indicator. The comparison between primary education level (a), high school (b) and university (c) maps shows that there is no spatial distribution pattern for this indicator. Populations with different education levels appear dispersed in all areas and sometime mixed in the same household. Although the primary education level map (Figure 67 a) shows the number of household with two or more than two persons with primary education is concentrate mainly towards the center and southern part of the study area, these represent around 15 % of the households sampled. Households with one person with a primary education level (20 %) are located towards the western and southern part. The households with more than two persons with a primary education are the most vulnerable. On the other hand the population that has a high school educational level was found in 77% of households sampled. These households were located everywhere in the town in all building types existing in the area, except for building type_2 (Figure 67 b). There is predominance (52%) of households whit more than one members that have a high school education. However, members with a university level were found manly in the center and northern part of the town (Figure 67 c). These represent 12 % of the households sampled.

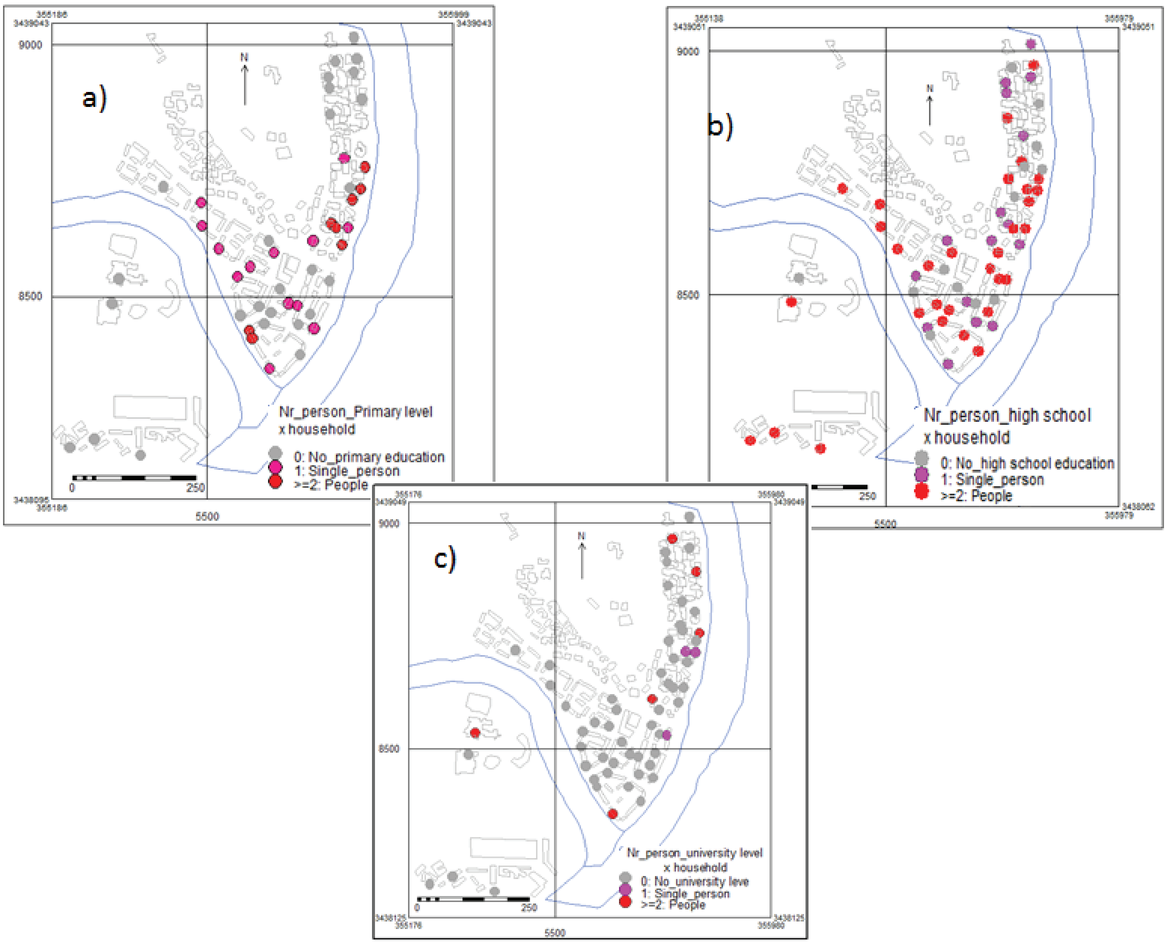



**Figure 67. Number of members with education level per household. a) Primary level, b) High school level, c) University level**

### 7.3.4. Number of household members

The number of members is another important indicator to be considered in the analysis of household flood vulnerability. In order to know the time distribution of the household members, data with the number of members during the day and during the night was collected. Households with a single member during the day are vulnerable to the flood event; however household with single member during the night are the most vulnerable to respond to sudden evacuation. The analysis of causes related to the number of deaths during the 2010 flood event identified this indicator as one of the most important. Figure 68 shows the distribution of the number of members during the day and during the night in respect to the total number of population sampled. In the households sampled, around 19 % of people that remain at their work or school during the day, 5 % of the population work as a farmer outside of the town and 3% work or study in another city close to Yingxiu, such as Dujiangyan and Xinjing City. For this reason only 73.08% of population remains in their household during the day. During the night only 91.26 % of the people remains in their home. Around 6 % of the population that work in the fire brigade and hospital during the evening move to another town close such as Yuzixi; and another part of population (2.74 %) that work during the day in shops and in restaurants during the evening move outside of the town.

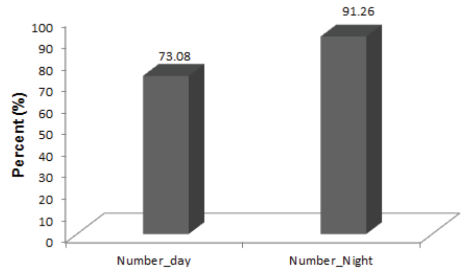



**Figure 68. Time distribution of number of members**

The spatial distribution of the population during the day and during the night is shown in Figure 69. The distribution of the population in the time shows that there is predominance in the household that during the day (41.7%) and during the night (58.3%) have more than two members. Households of a single person during the day represent around 18.3 % and are located towards the northern, southern and western part of the area. However, households with two or more members during the day and during the night are concentrated mostly towards the center and southern part of the study area. On the other side, households with a single person during the night represent 8.3% and are located mainly towards the southern and western part of the town. Toward the northern only a household was found.

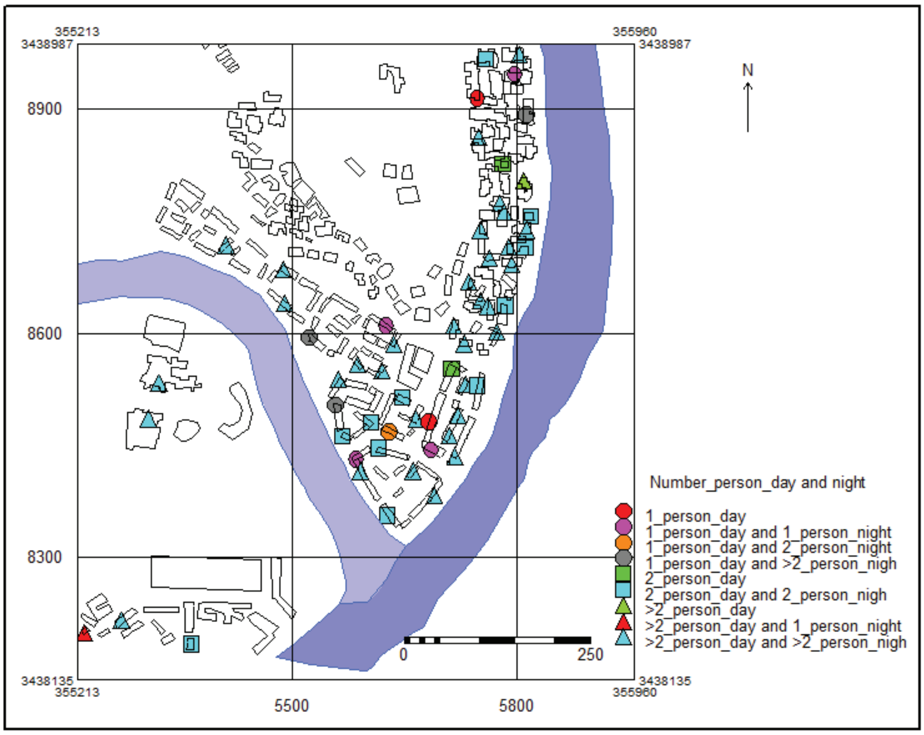



**Figure 69. Number of members during the day and the night per household**

### 7.3.5. The livelihood

Around 46 % of the population from the household sampled work in their own business in restaurants and shops located on the first floors of their houses, in buildings of three floors. Another part uses their house as rooms to rent to tourists. About 23 % of the population works in government offices, pharmacies, the hospital and school. 11% of the men working as policeman, 5 % as farmer and 3% working in factories located in another city close to Yingxiu. On the other hand, around 6 % of women work on cleaning services and tailor shops; and 5% making embroidery in their houses. Only 1 % of the women are housewife and remain at home to take care of children and sometime work as seamstresses (Figure 70).

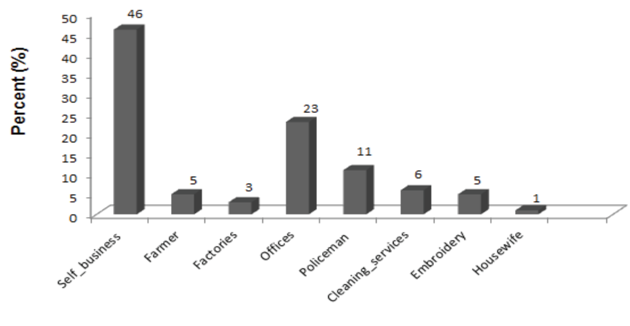



**Figure 70. Distribution of the Livelihood per household**

Figure 71 shows the spatial distribution of the number of employed persons per household. In around 62% of the households sampled there are more than one member employed, however in 33 % of the household one member of the family is employed. On the other hand 5 % of the households are represented as a more vulnerable group for the indicator where the unemployed members were found. These households are located in the center and northern part of the study area.

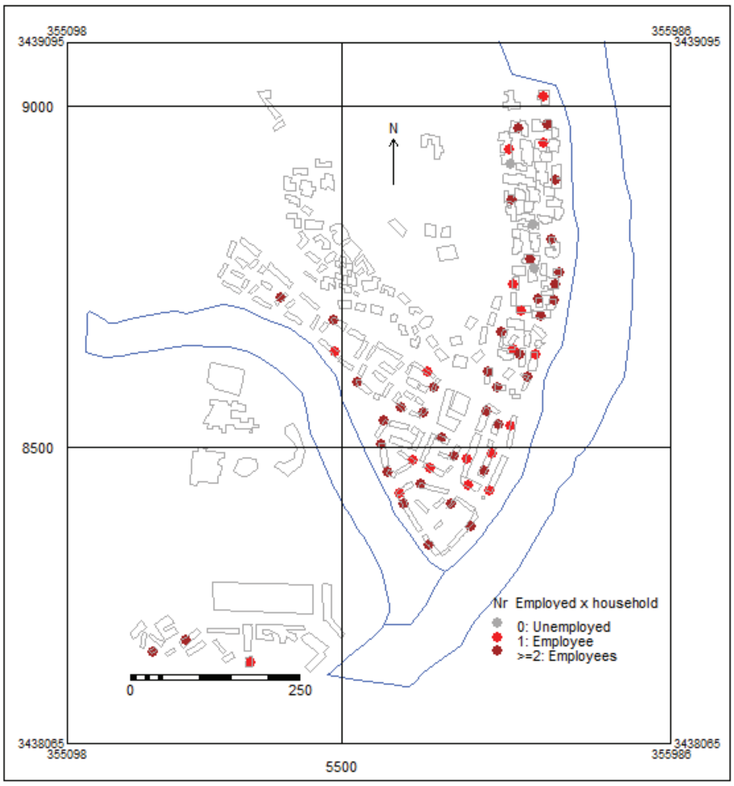



**Figure 71. Number of employed per household**

### 7.3.6. Income

Income is one of the most important indicators to consider during household flood vulnerability. In general people with high incomes can build stronger homes and more than one floor, which make them less vulnerable to flooding. In this approach all the people are located inside of concrete buildings of three and five floors. Therefore the flood vulnerability associated to the income has to be seen from another view. In this research the income is related to the resilience of the household to recover the prior state, achieving rapid economic stability. Household with a high income will be able to recover faster than households with a low income. For the proposal of this research the analysis of this indicator per month was based on five groups created: very low income (<750.0 Yuan), low income (750.0 – 1000.0 Yuan), moderate (1000.0 – 5800.0 Yuan), high (5800.0 – 15000.0 Yuan) and very high (>15000.0 Yuan). In order to get an idea about the income range in Euros, the conversion current was calculated. Table 25 shows the conversion between Yuan to Euros for income groups considered during the fieldwork stage.

**Table 25.Conversion between Yuan to Euros for income groups**

| Income groups | 1 Euro = 7.44 Yuan | |
|---|---|---|
| | Yuan/month | Euros (€)/month |
| Very low | <750.0 | < 100.81 |
| Low | 750.0-1000.0 | 100.81-134.41 |
| Moderate | 1000.0-5800.0 | 134.41-779.57 |
| High | 5800.0-15000.0 | 779.57-2016.13 |
| Very High | >15000.0 | >2016.13 |

Figure **72** shows that the highest value of income for the population of household sampled is 15000.0 Yuan (2016.13 euro per month). Around 46.7 % of the population of these households sampled have moderate income with values ranged from 1000.0 to 5800.0 Yuan. This population in general is represented for people that work in their own business in restaurants, shops or using their house as a hotel, and population that work in offices and the pharmacy. On the other side 15 % have a higher income with values between 5800.0 and 15000.0 Yuan. In these households the population works in offices from government, the hospital and the police station. However the most vulnerable groups with low and very low income are represented by 38.3% of the people. These are related to women work in cleaning services, farmers and people that work in factories outside of the town, in offices where the income is low. Also household where there are older persons (woman> 50 years old and men >60 years old) are found in this group too; because they receive government aid (around 500 Yuan) monthly. Finally women that work in their houses as embroidery and as seamstresses were included in this group with the low income value.

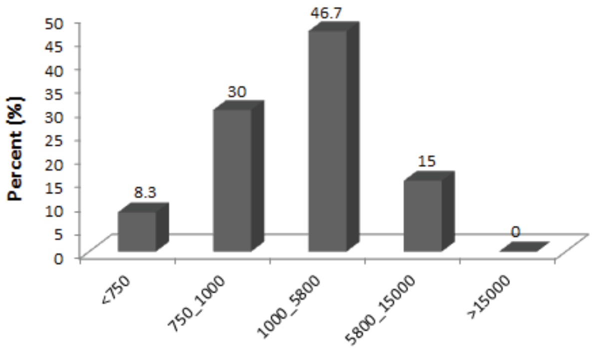



**Figure 72. Income per household**

The spatial distribution of income for the household sampled is displayed in Figure 73. The most vulnerable group of households sampled is located towards the center and southern part of the study area; represented by households with very low (<750) and low (750-100) values of income. Household sampled with moderate values of income are concentrated mainly towards center, southern and western part of the town. Nevertheless, household with the highest values of income were founded towards the north in building with structural type_5, an in small proportion on the center and close to the southern part of the area.

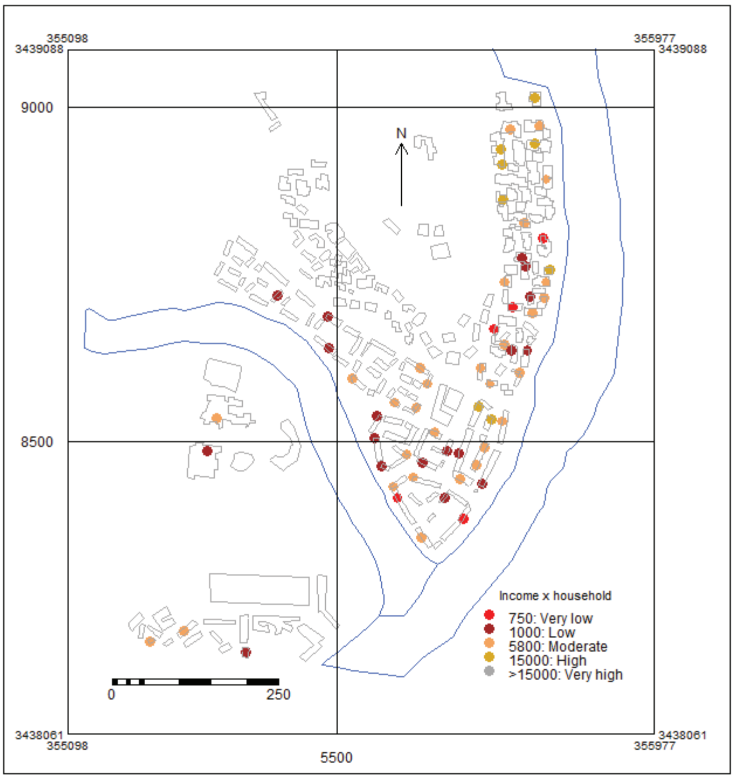



**Figure 73. Income (monthly) per household**

#### 7.3.7. Access to services

The accessibility to public services is considered by some authors such as Peter Guarin, et al., (2004) as an indicator to be considered during a flood vulnerability assessment. Accessibility of the population to health services, education, water, sewage system, and solid waste collection influences in the vulnerability of people to diseases during or after the flooding. Also data related to the transportation was analyzed. This information was collected during the fieldwork stage using questionnaires and fieldwork observations. Results showed that two new schools for primary and high school were built in the town, allowing the population to achieve these educational levels. Universities are located in Chengdu, and around 30 % of the respondents said that the high cost of studying did not allow them to continue their studies. On the other hand, a new hospital was built, which offers services to the population during the day and during the night. The hospital has two ambulance cars to move the population to Dujiangyan or Changu in an emergency situation. Other services such as accessibility to water and the sewage system were established in all buildings during the construction stage. Small cars were assigned to work on the solid waste collection process within the town. Transportation inside and outside of the town has been identified as a problem for the respondents. There is no official public transportation from Yingxiu to another town or to Chengdu. The population has to use official public transportation from another town that is closeby. Inside of the town population uses cars, motorcycles, bicycle or they walk (more than 65%) from one place to another. Only in sectors such as police and tourism services there are (four) small cars used for transportation within the town.

### 7.4. Spatial Multi Criteria Evaluation (SMCE)

Spatial multi criteria evaluation was developed by Saaty in 1980 (Peters Guarin, et al., 2008). The purpose of the SMCE application is integrated in different parameters that are spatially distributed to support decision making (Alkema, et al., 2007). Based on this principle, the identification of social vulnerable areas was defined as the goal of this research for the application of the SMCE technique. Social indicators described above section were integrated into Criteria Trees according to four steps described by Alkema, et al., (2007), where input raster maps were transformed into decisions. These steps are described below.

- Identification of cost and benefits.

In this step social indicators are grouped into cost or benefits considering the manner in which each social indicator analyzed influence on the flood household vulnerability. Definitions of cost and benefits given by Peters Guarin, et al., (2008) are considered. Adjusting definitions to our approach, as benefits, social indicators were taken into account for which higher values contribute the household to become more vulnerable to flooding. On the other side, as costs, social indicators were considered for which higher values contribute to reduce the flood household vulnerability. Table 26 shows the social indicators used in this analysis and their classification into cost or benefit.

**Table 26. Factors, indicators, categories and indication of cost or benefit considered in social vulnerability assessment**

| Factors | Indicators | Category | C or B |
|---|---|---|---|
| Age | Nr_children | Number of children (<5 years) x household | B |
| | Nr_adolescents | Number of adolescents (6-18 years) x household | C |
| | Nr_adults | Number of adults (19-60 years) x household | C |
| | Nr_elderly | Number of elderly (>60 years) x household | B |
| Gender | Nr_Female | Number of female x household | B |
| | Nr_male | Number of male x household | C |
| Population | Total_members | Number of members x household | C |
| | Nr_person_day | Number of members during the day x household | C |
| | Nr_person_night | Number of members during the night x household | C |
| Socio-economic | Nr_employed | Number of employed x household | C |
| | Income | Income x household | C |
| Education | Primary | Number of member with primary level x household | B |
| | High_school | Number of member with high school level x household | C |
| | University | Number of member with university level x household | C |

- Standardization

The standardization is a process performed after identification of cost and benefits. In this step social indicators are standardized at first for comparison later. Each indicator was standardized between 0 (no vulnerable) to 1(vulnerable). As a method of standardization the goal was selected as appropriated, where maximum and minimum values for each social indicator were defined considering an expert knowledge. This method "allows setting a maximum percentage above which the vulnerability will remain at its maximum" (Peters Guarin, et al., 2008). Indicators defined were standardized with range values 0 to 1.

- Prioritization

During this step weights were assigned to each social indicator considering the level of importance of each indicator for flood vulnerability of households. Each indicator is weighed inside of the set of criteria. At first, indicators are weighed inside of the group that is contained and later each group is weighed inside of the set of groups (factors) created. ILWIS has several tools for this process such as: Direct weight, Rank Ordering and Pairwise Comparison. In this research the Pairwise Comparison tool was used. This tool allows to the expert to compare criteria and rank these on a scale from extremely less important to extremely more important. Finally weights to each social indicator and factor are assigned. Weights assigned to indicators and factors were based on extensive literature review and analysis of specific conditions of the town. Some examples of these references are: Dwyer, et al., (Dwyer et al., 2004), Gungor (2003), and Peter Guarin, et al., (2008) where authors assigned weights to indicators and factors based on their importance level. Figure 74 shows the criteria used in this analysis and weight assigned to each criteria.

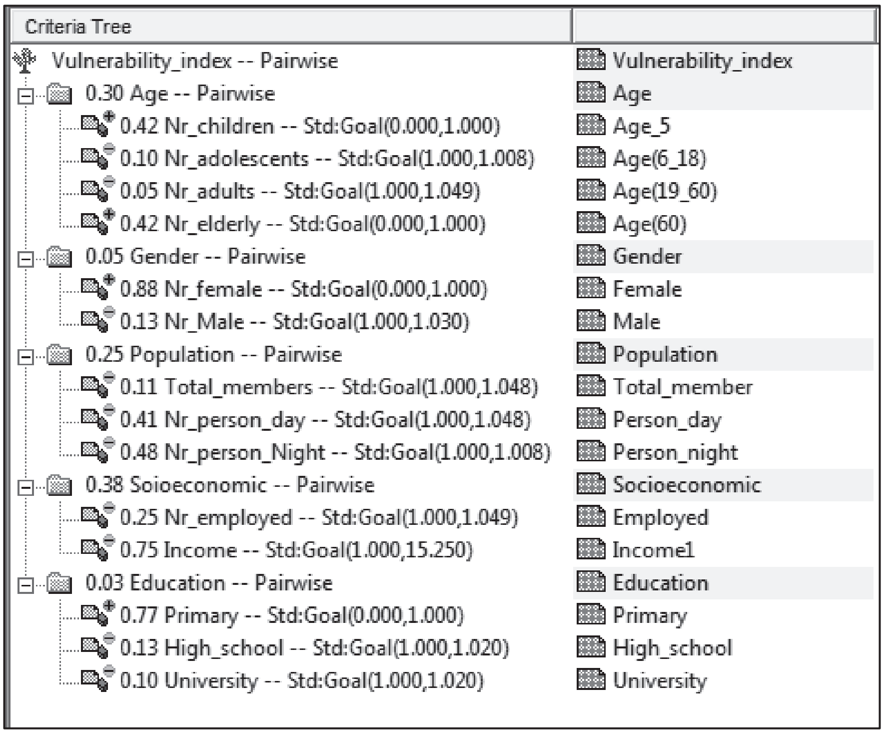



**Figure 74. Weighing for each social indicator**

The figure above shows that higher weights were assigned to benefit criteria, for example the number of children and elderly in the age factor. For the gender indicator, the number of female criteria has higher values, and primary education as an education indicator. Other criteria such as the number of persons during the night and during the day, as well as the number of employed and income, although they are not considered as benefit (according to definition), are important criteria that determine the flood vulnerability of households.

From Figure 74 it is assumed that for the socioeconomic factors, income is the most important indicator to be considered during the analysis of social vulnerability. This is related to the financial preparedness of households for mitigation and recovery before and after flooding. The number of employed persons, although it is an important indicator, does not always determine the income value. For example, in some households where there are more than 3 employed members, the income is moderate and in some households there are only two employed members the income is higher. The second important indicator is age. Residents with children and elderly are the most vulnerable because the physical characteristics impede the rapid movement and their shift to safe places. The next most important factor is the population (number of members during the day and during the night). Households with a single person are more vulnerable because one person has less opportunity to be informed and evacuated during a surprising event. Unlike the household where there are several members so that one person can notify another. When a flooding occurs at night the possibility to notify the single person is more difficult. During the 2010 flooding this was identified as the cause that influenced the number of deaths. Gender (female) was considered as a factor more important than education because associated to the female we can find important indicators for vulnerability such as children or elderly and sometimes pregnant women. The education (primary), although it is important in the process of understanding, has less influence than other indicators considering that they are not related to the income and do not affect the rapid displacement during the evacuation process.

Finally the incoherency among indicators and between factors is determinate by the calculation of the inconsistency ratio, which should be less than 0.1. For this research the value of the inconsistency ratio was 0.07, which is considered adequate.

• Aggregation
In this step the most social vulnerable areas are show in the final vulnerability map. As a result of the application of SMCE an index value map is obtained. After that this index map was categorized based on the histogram values using the option: standard deviation given by ARGIS. Finally the vulnerability map is generated. Four categories were created: very high vulnerability; high; moderate and low vulnerability for households.

The spatial distribution of the social vulnerability categories is shown in Figure 75. Households that are the most vulnerable (value >0.4) to social indicators analyzed are the least (5%). Only one exemplification appears in the center, southern and western part of the study area, associated to multi-dwelling houses with structural type_4. However, the household with a high vulnerability (0.4) is well represented throughout the area. These households are 30 % of households sampled. The population with high vulnerability is located in buildings with structural type_3, type_4 and type_5. On the other hand households categorized as moderate vulnerability (0.3) are located mainly towards center and southern part of the study area; and small proportion towards northern. The households with moderate vulnerability are 23.33 % and are associated to buildings with structural type_4 and type_5. The most common households have a low vulnerable (0.2) to flooding. These represent 41.67% of the households sampled and appear located in the north, the center and the southern part and being mostly concentrated in the southern part. These household are located in buildings with structural type_4 and type_5.

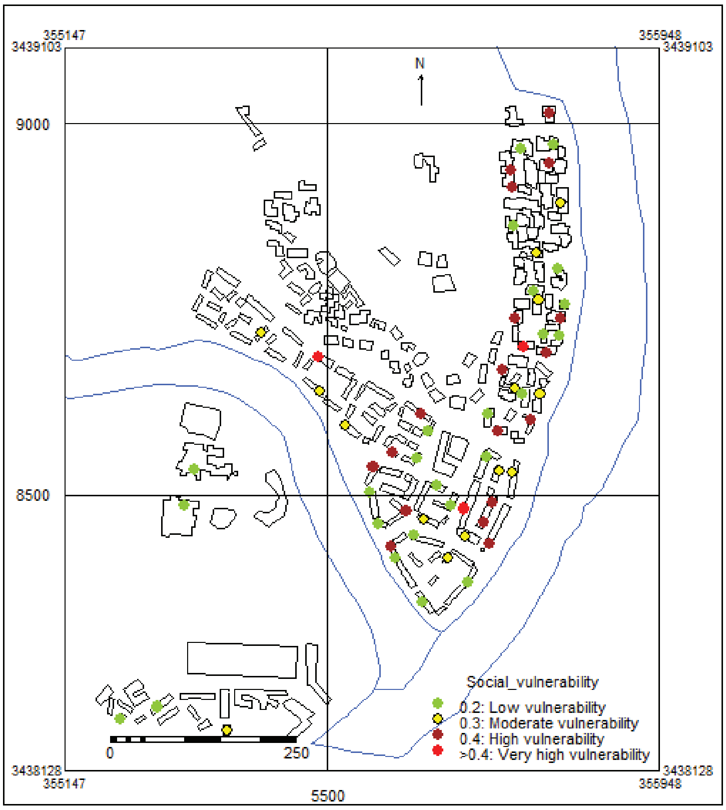



**Figure 75. Social vulnerability map**

Profiles for vulnerability categories created with more important social indicators are shown in Table 27. In order to keep the representativeness of the answers from respondents, predominant values for each indicator were taken into account. The combination of these social indicators allowed the identification of the most flood vulnerable household.

**Table 27. Profiles of social categories for flood household vulnerability**

| Social indicators | Vulnerability categories | | | |
|---|---|---|---|---|
| | Very high | High | Moderate | Low |
| Nr_elderly ( Age>60) | 1 | 0 or 1 | 0 | 0 |
| Nr_children (Age <5) | 1 | 0 or 1 | 0 or 1 | 0 |
| Nr_Female | 1 or >2 | ≥ 2 | 1 or ≥ 2 | 1 or 2 |
| Nr_Male | 0 or 1 | 1 or ≥ 2 | 1 or ≥ 2 | 1 or 2 |
| Nr_person_day | 1 or 2 | >2 | 1 or >2 | ≥ 2 |
| Nr_person_night | ≥ 2 | >2 | > 2 | > 2 |
| Nr_employed | 1 | 0 or ≥ 2 | 1 or ≥ 2 | ≥ 2 |
| Income | <750<br>750-1000 | 750-1000<br>1000-5800 | 1000-5800<br>5800-15000 | 1000-5800<br>5800-15000 |
| Primary_education | 1 or >2 | 0 or ≥ 2 | 0 or 1 | 0 or 1 or ≥ 2 |
| High _school | 0 | 1 or ≥ 2 | 1 or ≥ 2 | 1 or ≥ 2 |
| University | 0 | 0 | 0 or 1 | 1 or ≥ 2 |

The table above shows the correspondence between social indicators and vulnerability categories. For example in households with a very high vulnerability were found an older person and a child, a predominancy of more than two women and more than two persons with primary education were found. This corresponds to the benefit criteria defined above. Persons with a high-school and university education were not found in these households. Other indicators such as income (very low and low), number of persons present during the day, number of employed persons and the number of males also display low values for these household to become vulnerable as was explained above. However, the number of person during the night shows a contradictory value than expected because in the household with more than two persons the presence of children was included as well.

On the other hand in household with high vulnerability, elderly people were found only in 15% of the households; and children only in 37% of the households. Nevertheless, the number of females remains almost constant. Although in 25 % of the households two women were observed. The number of males, the number of people present during the day and during the night, and the number of employed people show an increase. Unemployed residents were found in 5% of these household. These categories show a predominancy of income values considered as moderate (1000-5800), but in lesser proportion (5%) households with a low income (750-1000 Yuan) were found too. Also, changes in the educational level were observed. The number of persons with primary education decreased, around 41 % of the households do not have residents with a primary education. However, more than two persons with a high school level were found in 35% of the households. Persons with an university level were not found in this household category.

In households with a moderate flood vulnerability the presence of older persons is missing. One child was found in 35 % of the households. However the number of females shown tends to decrease, only one woman was observed in 57 % of the households. The number of males and persons during the night remains almost constant. However the number of persons shows variations on the percentage. For the moderate vulnerability class more than two persons during the day were found in around 70% of the households. On the other hand, the number of persons employed shows changes as well. In around 35 % of the households there are more than two persons employed. In 50% of the households an increase in income values were obtained, this being considered as moderate (5800-15000 Yuan). Changes in educational level were observed. The number of households with persons with primary education is less frequent. On the other hand there is an increase in the number of households with more than two persons with a high school educational level (64 %) and an university level (14%).

Households with a low flood vulnerability show a complete absence of elderly and children. Also the number of women and man tends to decrease; only one or two women or men per household were found. In around 68% of the households two women were observed and two men in 80 % of the households. The number of persons during the day increased. As well as the number of employees as more than two employed persons where found in 100% of the households. The number of persons during the night and the income range remains constants. Nevertheless, in 60 % of these households the income was considered as high (5800-15000 Yuan). Notable is the change in educational level. Households with one or two person with a primary education represent 15%. On the other hand persons with a high school education were found in 68 % of these households. The number of university persons has increased to 17% as well.

The comparison between vulnerability categories based on social indicators shows that social vulnerability depends mainly on four indicators, namely: income, presence of elders, children, and on educational level. These indicators define the main differences between households. Households with a very high flood vulnerability class are represented by a population with very low income (<750 Yuan) and low income. However, households with a low flood vulnerability class are associated to a population with a high income. Nevertheless, households categorized as high vulnerability shows predominance in low income values (1000-5800 Yuan). An increase in income values was observed by households with moderate vulnerability, where around 50% of the household population has an income between 5800-15000 Yuan. This percentage has increased in households with low vulnerability reaching 60% of the population.

On the other hand the presence of elders and children show differences between vulnerability categories. The presence of elders and children in households with a very high vulnerability was evident. However, in households with high and moderate vulnerability classes the number of elders and children tend to decrease. For households with moderate vulnerability the presence of elders was not observed, and for households with a low flood vulnerability the outcome was null.

In general the comparison of the educational levels for vulnerability classes displays that in household with the same vulnerability class there are population with different educational level, except for the population inside of households with very high vulnerability that have only a primary education level. The high vulnerability class households with primary education show a decrease (in 41%) on the number of persons with a primary education. Households with more than two persons with a high school level represent around 35%. In household with a moderate vulnerability class and low flood vulnerability although it was possible to find persons with a primary educational level; the number of persons is less than the previous classes. The number of persons with a high school level tends to increase. Around 64% of households with moderate vulnerability have populations with high school level. In 68% of households with low vulnerability class population with high school were found too. A new educational level (university) appears with people from households with moderate vulnerability. An increase in the number of persons with an university level was observed in the low flood vulnerability class.

Other indicators such as the number of females, the number of males and the number of employed persons, show variations although they do not display significant differences between vulnerability classes. In general the number of females tends to decrease from the very high vulnerability class to the low vulnerability class. However, the number of male and the number of employed show increase in the number of person from households with very high vulnerability to low vulnerability. On the other hand other indicators such as number of persons during the day and during the night no show significant variations between vulnerability classes.

The comparison between vulnerability categories based on social indicators show that educational level display a higher difference between vulnerability classes than the number of females per household. For this reason this indicator was considered as more important during the social vulnerability assessment and not as what was thought at the beginning.

In order to reduce the social vulnerability and increase resistance, measures were proposed taking into account the analysis of social indicators and the comparison established in Table 27. These are mentioned below:

- Create new jobs.
- Increase the amount of the economic aid given by the government to elderly persons.
- Seek alternatives sources of employment that allow an increase of the income for the population including the very low (<750 Yuan) and low incomes (750-1000 Yuan).
- Create alternative educational programs that allow reducing the number of persons with a primary education.
- Improve the transportation system inside and outside of the town, facilitating the communication between Yingxiu, Chengdu and other towns.

# 8. RISK REDUCTION OPTIONS

This chapter includes the description of technical and non-technical measures developed in Yingxiu related to the 2010 flood event. The identification of its weaknesses, as well as the plan of measures proposed by this study to reduce the flood risk is discussed.

Flood risk reduction is considered by Schumann, et al., (2011) as an aspect of risk management, that depends on risk evaluation. Risk reduction is defined by UNISDR (2009) as practices and concepts to allow minimize risk through systematic efforts to manage the causal factors of disasters, reducing exposure to hazard and vulnerability of elements, considering improved preparedness for adverse events.

In this approach measures to contribute to minimize the flood risk are suggested. At first an identification of weakness points in the existing flood protection system was done, coupled by the evaluation of effectiveness of protection measures considering some consequences of mechanisms failures. Finally new measures to contribute to the flood risk reductions are proposed.

In order to analyze the existing flood protection system measures were divided into technical and non-technical, considering the classification given by Plate (2002). Technical measures are related to structural measures, its evaluation is based on criteria obtained from fieldwork observation and characteristics of the 2010 flood event. Non-technical were considered measures no related to the construction of the protection structures. Also the early warning system and evaluation process were assessed as part of the preparedness (Plate, 2002) inside of the non-technical measures.

## 8.1. Technical measures

Technical measures taken to reduce the flood risk included the construction of embankments and dikes towards northern part of town. This measure contributes to reduce the flow velocity and amount of debris as was explained in section 6.6. However as a weak point was found the second level of the embankment built of natural ground, located around 3.0 m of height from the river level which will be easily eroded by the water. Taken into account that during the 2010 flooding the highest values of water depth (>5.0 m), velocity and debris flow were obtained in this place. Another protection measure is the brick wall built around Minjiang River; with the objective to avoid that the increase of water in the river channel can penetrate towards the town. Nevertheless we have to consider that the difference of elevation between the western and eastern part of the town facilitated the move of water back into the river using streets as channels. So, considering the occurrence of events with similar characteristics, we can conclude that the movement of water flowing back will be discontinued by the brick wall. Therefore the flood duration could be extended for more days and the damage could be higher.

Another measure taken to reduce the damage from flooding was related to the structure building type and the existence of flooding retained structures. These were considered as positive. Concrete buildings offer greater resistance to flooding events. Buildings with structures type 4 and type 5 enable people to move things to higher floors, contributing to reduce the building content damage. Also helpful was considered the existence of flooding retained structures such as balconies and steps. Although in section 5.2.1.5 it shows that 38 % of buildings have a 0.15 cm of the height of ground floor relative to the street level. Also buildings were found with a height between -0.80 to -0.37 m, and 55 % of the buildings of the town have a height of the ground floor on the back side of buildings around 0.15 cm. These become buildings that are highly vulnerable to flooding. Observations from fieldwork showed that in general the nearest buildings built along the Minjiang River have a higher height of the ground floor than other buildings. These show that a strategy was created for flooding caused of increase of water level from the river bed and not for situation similar to the 2010 flooding. As an example of another measure was observed the walls' coating with other materials with the aim to reduce the moisture, but as a weakness it was identified that still there are some buildings with unprotected walls.

Other large structures built in Hongchun gully such as dam and several steps are displayed in Figure 54 and were categorized as constructive. These play an important role in the reduction of velocity and the amount of debris flow can be incorporated into Minjiang River, taken into account that this was the cause that originated the 2010 flood event. Observations from fieldwork cannot define if the number of dams will be enough for the amount of loose sediment existing in the gully. So, detailed studies will be necessary.

### 8.2. Non-technical measures

Non-technical measures were considered as a sum of actions from the community not related to structural measures. Based on answers of questionnaires, weaknesses related to community perception and coping mechanisms used during the 2010 flooding, effectiveness of the early warning system and evaluation process were identified.

Results of questionnaires show that around 31 % of people living in Yingxiu do not have experience of flooding, and about 68.8 % did not have experience with flooding before the 2010 flooding. Considering that this was one of causes that originated the number of death during 2010, and that the knowledge of people related to flooding, is an important indicator that helps people on how to react with similar events that were identified as a weakness.

Another weakness of the community identified was related to the number of people (28.3 %) claiming to be afraid of flooding. Bearing in mind that the psychological impact might influence how people react to a sudden flood, this was considered as an important indicator.

The comparison established on Table 15 showed that, although more than 80 % was able to compare the flooding with other phenomena based on their experiences, around 10 % of people have no idea about these phenomena becoming more vulnerable to the occurrence of these events.

The certainty that people (23.4%) have that their homes will not be damage again by another flooding, and uncertainties of other people (62.5 %) about this topic, allowed the identification of these points as weaknesses. These aspects negatively influence the way of people to perceive and abide an orientation during preparation or evacuation process.

Weaknesses explained above were associated to the communities perception linked to the flooding. In this part weaknesses identified by the coping mechanisms used during the 2010 flooding will be explained.

During 2010 the warning system was activated around one hour before the flooding began. About 37.5 % of respondents said that the information system used to alarm the population was developed by the military, which knocked on doors and made phone calls. Although 39 % of respondents considered the warning system effective, the number of deaths (around 30 persons) is evidence of failure in the warning system. Based on the analysis of accumulate precipitation (Figure 8) it could be seen that significant peaks between 20:00 to 23:00 hours of the day before had occurred. This should have been used as a signal to activate the warning system in anticipation. On the other side the way to notify the population was not enough, taking into account that the event occurred in the night when people were sleeping. Therefore more effective warning systems are required.

An important weakness identified related to the knowledge of the people about how to proceed during a flooding. Around 12.5 % of respondents said to have no knowledge related to this topic. Although there are actions developed for the government such as trainings two times per year, there are still people that have recently moved (around 5 months) into the town which have not been trained.

The existence and operability of social ties during and after the flooding was evaluated as positive. The weakness that was identified was that only 7.8 % of population reported the existence of social ties between neighbours. This could be used as an alternative to strengthen the warning system. Other coping mechanisms mentioned in Table 16 were evaluated as positive.

## 8.3. Proposed measures

Previous sections identified weaknesses in the flood protection system related to the 2010 flooding event. In this section measures to contribute to the minimization of flooding risks are proposed.

Measures proposed from community knowledge were taken into account in this approach as mode to include community on flood risk reduction. Therefore opinions, ideas, suggestions resulting from application of participatory mapping tools were compiled and included in the measures plan. This plan will contribute to reduce the flood risk at different levels. The measure plan is showed below.

Measure Plan:

- Improve the early warning system based on weather and hydrological forecasts. This measure includes maintaining the monitoring of hourly and accumulative rainfall, incorporating a monitoring of water level with shorter time intervals. This will allow a better estimation for the evacuation time. The improvement of an early warning system was indicated by 12.5 % of respondents.
- Improvement of the existing alarm system. This measure was suggested by 15.6 % of people surveyed. This approach is recommended, in addition to the methods using the incorporating of a moving alarm system such as vehicles with loudspeakers moving through the town informing the population. Also other alarm systems such as bells could be placed in different parts of the town under the responsibility of persons who activates them.
- Reinforcement of the second level of embankment. Cover this level with concrete or another resistant material to reduce the erosive water effect.
- Amplify the drainage system in streets where the water flow back to the river. This will allow more incorporation of water flowing into the river. This process will be limited by the existing of brick walls upon the occurrence of an event with similar characteristics as the flooding of 2010.
- Coat the walls of buildings unprotected by waterproof materials to prevent the penetration of moisture.
- Develop educational programs related to the flooding event in Yingxiu. In order to increase the knowledge level of population on flooding. Suggested is to create educational videos to show the people how to act before and during a flooding. Information related to some actions such as: remaining alert during days of heavy raining; moving things to higher places; characteristics of the early warning system; evacuation routes; concentration places; and other measure taken to contribute to the reducing of damage may be disclosed.
- Promotional of educational flooding programs. Make use of diffuse media available to increase the knowledge. For example the incorporation of this educational program to central TV existing in the parking that offer information on the 2008 earthquake for tourist and inhabitants of the town.
- Create social programs that help to increase the solidarity between neighbours. This allows increasing social ties, which play an important role during the warning system and evacuation process.
- Increase the number of training related to flooding in such a way that spacing in the time allows for people to receive more than one training per year. This measure was suggested by 6.25 % of respondents.
- Monitoring of landslides. This measure was recommended by 28.12 % of the people that answered the survey, especially since this was the cause of the 2010 flooding event.

# 9. DISCUSSION, CONCLUSION AND RECOMMENDATION

This chapter contains the discussion of results, and conclusions of this research. The mains contribution of this study responds to the objectives and research questions proposed for this research. Also recommendations for future research are suggested.

## 9.1. Discussion

In this section observations from results are discussed. The discussion is organised according to the same sequence in this research.

### 9.1.1. 2010 Flood event assessment

The 2010 flood event assessment was based on the construction of the flood extent, water point maps and information on flood duration. Some limitations that could affect the accuracy of the results were identified. For example, during the flooding buildings were under construction, therefore there were no people living inside these buildings except the persons that were working on the construction. Around 31% of the respondents lived outside of the town during this event. After the flooding the water marks were deleted during the completion of buildings. Also the number of empty apartments in the town limited the number of buildings sampled, mainly in buildings with five floors. On the other hand the lack of information such as the records of peak flow related to periods of years do not allow the use of other approaches, as well as a frequency analysis.

### 9.1.2. Elements at risk due to the 2010 flood event

The identification of elements at risk was considered as appropriate due to buildings and socio-economic characteristics were detailed. However, some observations were recognized. For example: the aerial photo from August 15, 2010 (during flooding event) was taken as a basis for the creation of the building footprint. Therefore the accuracy of the delineation of the boundaries for buildings located inside of the water factory was affected by the higher values of water depth. Also the number of buildings sampled, mainly for buildings with five floors was not considered sufficient for a detailed study. Reasons were explained in section 9.1.1.

### 9.1.3. Update of the DEM

Results from the improved DEM, using elevation values from the contour lines and measurements of ground height (53 points), was considered as not good. As was explained on the section 5.3 there is no correspondence between values from the two sources. However satisfactory results were obtained when the elevation values from the contour line were removed and ground height values measured (53 points) on the fieldwork were interpolated. The option to use more than one interpolation method with several variants increased the accuracy of the results. Therefore an increase in the number of sample of ground height points will improve the result.

### 9.1.4. Construction of flood depth map for the 2010 Flood Event

The construction of the flood depth map was recognized as acceptable. Validation of the results shows 98.5% of accuracy of the results. Nevertheless the difference between the minimum and maximum values of water level shows noise in the results. These can be associated to errors occurring during the measurements of water depth due to lack of watermarks on walls, errors of GPS positions, and errors during the interpolation process of ground height and water level values.

### 9.1.5. Reconstruction of the 2010 flood event using modeling

The application of modeling using SOBEK 2D allowed the reconstruction of the 2010 flood event. The validation of results based on the comparison of water depth values shows that in more than 85% the difference is less than 0.50m. Although the precision of the results is considered as acceptable, this could be affected by errors in the DEM related to the interpolation process. Also errors on values of the boundary conditions assumed due to the lack of discharge data from the Minjiang River could influence the accuracy of results. Therefore results can be further improved if values of discharge for the river and measurements of ground height can be incorporated.

### 9.1.6. Flood damage assessment

The flood damage assessment was based on data collected from the community. Results of this stage were considered as not successful. The lack of data related to costs of buildings damage, building content and outside property do not allow an evaluation of losses in economic values. Therefore methods applied by other authors by the evaluation of damage were considered as not appropriated for this research. Damage data collected was too general and as a result the damage assessment was done on macro-scale. The incorporation of data related to the cost of building reparations and economic values of outside property could improve this result.

### 9.1.7. Community perception and coping capacity related to the 2010 Flood Event

Data collected using participatory mapping tools were used for the evaluation of the community perception. Results show that participatory mapping tools used were appropriate and sufficient in order to collect the required information. Therefore the process of evaluation of community perception related to flooding was considered as successful. On the other hand, information relate to coping mechanisms were obtained using participatory mapping tools and fieldwork observations. The evaluation of mechanisms was valued as detailed and critical. This evaluation can be improved considering economic criteria for actions developed to minimize or avoid losses.

### 9.1.8. Vulnerability assessment

The vulnerability assessment shows the vulnerability of buildings and social indicators. Therefore the vulnerability was divided into physical and social vulnerability. The physical vulnerability was centered on the analysis of vulnerability of the structural type of buildings due to the lack of data related to building contents and outside property. The lack of detailed data related to structural building damage does not allow the use of other methods for vulnerability assessment such as stage damage curves. Nevertheless results obtained show correspondence with the field observations. On the other side results of social vulnerability were considered as acceptable. Although these were framed only to households sampled, they were considered as representative of the socio-economic conditions of the study area. The social vulnerability can be improved using data related to population census by buildings or with an increase on the number of households sampled.

### 9.1.9. Risk reduction options

Results from this section were categorized as good. Detailed description of the technical and non-technical measures is provided. Also measures that contribute to reduce the flood risk were proposed. Results from this section could be used by the local government for the designing of strategies in view to improve the flood risk management.

## 9.2. Conclusions

The main objective of this research is to assess the impact of the Yingxiu flood in 2010, and the construction of flood-vulnerability relationships. It is also aims to analyze the community's response to this flood event. The following discussion is based on specific objectives that respond to research questions elaborated in section 1.2.3.

**The first specific objective of this research is to generate the flood event map of 2010 based on community knowledge.** Associated to this objective three research questions were elaborated. The first research question is: What was the maximum flood extent reached during the 2010 flood event in Yingxiu town based on community knowledge In order to answer this question, participatory mapping tools such as participatory GIS (PGIS) and sketch mapping were applied. Results from participatory GIS allowed the identification of the flooded and unflooded areas. However, results of sketch mapping allowed drawing the boundary between these areas based on the aerial photo from 15$^{th}$ August, 2010. The flooded area was located mainly along the right bank of the Minjiang River (Figure 21), occupying an area of around 76.0 km$^2$.

The second research question related to the first specific objective is: What is the spatial distribution of water depth values associated to 2010 event. To obtain this result, information of water depth collected from 22 points during PGIS and transect mapping were combined into the water depth point map (Figure 22). The highest values of water depth (2.80 m) were obtained towards the north part in buildings belonging to the water factory. Also higher values were measured on buildings close to suspended bridge, reaching 2.70 m. On the other hand, lower values were obtained toward southern (close to 1.0 m), where the lowest value 0.25 m was measured.

The third research question associated to this specific objective is: What was the duration of this flooding event? Information collected from PGIS and focus group discussion (FGD) shows that the flooding ended when the landslide dam was breached (with explosives), after four days of flooding.

**The second specific objective of this research was related to the identification of the elements exposed to the flooding and their characterization.** To answer this objective two research questions were formulated. The first research question is: What were elements at risk exposed to the 2010 flood in Yingxiu town? In order to answer this question a building footprint was created during the digitalization process based on the aerial photo from August 15, 2010. A database linked to the building footprint was developed. This contains data from buildings and social indicators collected during the fieldwork stage. Characteristics related to buildings such as: building types, number of floors, building occupancy, age, state, height of ground floor relative to the street level, existence of flooding retained structures and building size are detailed in section 5.2.1. On the other hand data associated to the social indicators such as: age, gender; size of family; educational level; number of members (during the day and during the night), the livelihood, income and access to services are detailed on section 7.3. Considering that in 2010 the town was being built and there was no furniture present inside of buildings, it was not possible to assess the building content.

The second research question of this objective is: How could elements exposed be categorized? The categorization of buildings was based on structural characteristics, considering the results of questionnaires and fieldwork observation. Five structural building types for the study area were identified (section 6.1): Building with structural type_1 (represented by the temporal house of one floor, made from the combination of Styrofoam and metal), building with structural type_2 built of concrete (walls, floor and roof) with one floor; building structural type_3 built by the same material but with two floors, building with structure type_4 represented by multi family dwelling with the same material but with three floors, and buildings with structural type_5 built by concrete as well with five floors. On the other hand, for social data ranges with the number of persons were established considering households as a unit of analysis. For each social indicator different classes were created (section 7.3).

**The third specific objective is to create hydrographical correct DEM using existing data and field data**. The research question elaborated is: What is the best method for the interpolation of ground height values? To answer this question, contour lines with 20 m contour intervals were converted into points and 53 ground height measured points taken during the fieldwork were added. Later these points were interpolated using two methods: Kriging and inverse distance. For the Kriging method two variants of interpolation were applied: simple and ordinary. For the inverse distance method two variants were used ID and ISD (Inverse squared distance). For the Kriging method variograms were built and the best semivariogram model was selected. Variogram parameters were compared for each Kriging variant. Also the shadow maps were built and compared with the DEM interpolated for each variant. Results show discrepancy between elevation values from contour lines and values obtained from fieldwork measurements. Therefore elevation values from contour line were removed. Ground height values measured (53 points) were interpolated again using the same methods and following the same procedure. Sadistic indicators were compared (Table 8). The validation of the interpolation process for all variants was based on method applied by Falivene, et al., (2009). Five points were removed from the measured points and the remaining values were interpolated using these two variants. The root mean squared error (RMSE) was calculated for each variant (Table 9). The comparison of results shows the least values of RMSE and standard deviation are associated to the ISD, selected this as the most optimal interpolation method.

**The fourth specific objective was to construct a flood depth map of the area based on fieldwork observation.** Regarding to this specific objective, the research question elaborated is: What method of interpolation was the most appropriated for the water level values? In order to answer this question community knowledge was combined with scientist methods. Measured of water depth from 22 points obtained from fieldwork were combined to the ground height (from DEM interpolated using ISD method) in the calculation of the water level. The following formula was applied: water level = water depth + DEM. The point map resulting was interpolated using two methods Kriging and inverse distance method. For the Kriging method two variants of interpolation were applied: simple and ordinary. For inverse distance two variants were used ID and ISD. The same procedure for the interpolation of ground height values explained above was followed. Finally the inverse squared distance (ISD) showed the least values of RMSE and standard deviation being selected this as the most appropriated. Then the water depth level map interpolated was used in the calculation of the flood depth map, as follows: flood depth = water level – DEM. The validation of values of flood depth acquired was based on the comparison with the water depth values obtained from fieldwork measurements (Table 10). Results show the correspondence between values. The percentage of the accuracy of data was considered as acceptable with 98.5% of precision.

**The fifth specific objective was related to the reconstruction of the 2010 flood event using SOBEK model 2D and field data.** Regarding to this specific objective, two research questions were elaborated on. The first research question is: Which scenario is the best representative of the 2010 flooding? To obtain this answer two scenarios were considered: the first is related to the flooding considering the lack of dam debris; and the second scenario displays the flooding process taken into account the dimensions of the dam debris. The calibration of the model for the two scenarios was based on the selection of Manning's roughness coefficient. Values of Manning's coefficient proposed by Alkema, et al., (2007) were considered as more representative for the land cover of the area. Results from both scenarios were imported into ILWIS. The validation of results was based on a comparison of flood extension and water depth values from fieldwork measurements and modeling results. Values of water depth modelled for this scenario and obtained from fieldwork are show in Table 12. The comparison shows the second scenario as the most representative of the 2010 flood event. In more than 85% of points the difference between water depth values is less than 0.50m. The average difference between measurements and simulated values is 0.33m which is considered acceptable.

The second research question of this specific objective is: What parameter maps can be generated? To answer this question results from modeling process acquired as ASCII format were imported to ILWIS. Two maps were obtained: one map shows the maximum water depth values, used during the validation of modeling results; and another map displays the maximum velocity values achieved (Figure 46).

**The sixth specific objective was related to the quantification of damage caused by the 2010 flood event based on field data**. Regarding to this specific objective, two research questions were elaborated on. The first research question is: Where is the highest damaged area located? In order to answer this question data collected from population through participatory GIS and transect mapping were analyzed. Based on data from Table 14 the damage map was built (Figure 49). The map shows the highest damage areas were located towards the northern part, represented by building structure type_1 and type_2. These buildings were subjected to high values of water depth (Figure 44) and velocity (Figure 46) during the four flooding days.

The second research question of this objective is: What is the damage associated to the 2010 flood event? To answer this question, data obtained from participatory GIS and FGD tools were used. Damage associated to this event was represented in two forms: direct and indirect damage. Direct damage related to structural buildings are shows Table 14. Another direct damage reported was the number of fatalities for this event (around 30 persons). However, indirect damage was related to compensation given by the government around 7 million of Yuan (1 million of Euros), and psychological impacts (28.3% of respondent) related to this flooding (Figure 51). In general the total amount of damage reported associated to the 2010 flood event exceeds 10 million of Yuan (1.3 million of Euros). These were associated to damage to the temporal hospital, ambulance cars and construction trucks, equipment from the water factory and compensation from the government

**The seventh specific objective is to assess the perception of people and coping capacity related to the 2010 flood event.** The research question elaborated is: What is the perception of people and coping capacity for flooding? Information related to perception and coping capacity was analyzed taken into account answers of questionnaires and interviews applied during participatory GIS and focus group discussion (FGD), and observations from transect mapping. In general the population that lives in Yingxiu has a good the perception about flooding. Answers from respondents show that 100 % of the population know about the 2010 flooding event, and are able to identify the flooded area and the most damaged area. More than 40 % of the people identified causes of this flooding. Also, more than 80 % was able to compare this phenomenon with other phenomena. Information related to the 2010 flood event such as: flood extent, water depth and duration were obtained from the population. Although 44 % of the population associated the cause of the 2010 flooding to heavy rainfall that triggered the Hongchun debris flow, 62.5 % percentage of the people did not consider the possibility that the town could be affected by another flood in future. On the other hand, answers from respondents showed the existence of coping mechanism related to the flooding before the 2010 event. Some mechanisms were used during the flooding, such as: monitoring of rainfall, warning system, the moving of things towards the upper floors. Others were developed before, for example the existence of strong buildings built with concrete with more than one floor, the existence of retained structures and coating of the building walls. Mechanisms developed before and during the flooding allowed minimizing the damage. After the flooding event new mechanisms were established. These include training of the population, and the construction of protective structures such as: dikes, embankment and wall protections around the river. The effectiveness of each mechanism is evaluated in chapter 8.

**The eighth objective is to assess the vulnerability related to the key elements at risk.** Associated to this objective three research questions were elaborated. The first research question is: What is the relationship between water depth, velocity and damage in order to assess vulnerability for building types? To answer this question the proposal of Kelman (2002) to the linked damage scale level (DS) to two variables (area and the number of floors) for each building type was taken into account. Vulnerability matrixes that related to water depth (calculated), velocity (modeling) and damage scale (DS) for each building structural type were created (Table 21 to Table 23). The comparison between these matrices shows that the structural integrity for building type_1 is affected for values of velocity close to 2.0 m/s and water depth of 1.0 m. This building is completely destroyed when the velocity value is increased to 3.0m/s. Buildings with structure type_2 are affected when the water depth is 1.0m and velocity is 3.0m/s. For these values, damage to doors and windows are reported. However, for water depth value of 2.0 m and velocity 3.0m/s, buildings are severely damaged and completely destroyed for the increase of velocity higher than 3.0 m/s. For buildings with structure type_3, type_4 and type_5 the structural components are affected equally than buildings type_2; the structural damage on the second floor is observed when the water depth is 3.0 m and the velocity is 3.0 m/s.

The second research question related to this specific objective is: What are the main factors that control the social vulnerability? The answer of this question was based on the analysis of social indicators. As tool of analysis SMCE was applied. The vulnerability index map resulting was categorized into four class and profiles for each vulnerability category was created (Table 27). The comparison of these profiles shows that social vulnerability depends mainly of four indicators: income, presence of elder, children, and the educational level. These indicators define the main differences between the households sampled. Most vulnerable households in general are represented by the population with low and very low values of income, with two or more persons with a primary educational level, and those with the presence of children and elderly persons.

The third research question for this specific objective is: What is the spatial distribution of vulnerability for those elements at risk? In order to answer this question two maps were created. One map reflects the spatial distribution of building structure vulnerability (Figure 60) and another map displays the spatial distribution of social vulnerability (Figure 75). The building structure vulnerability map was created based on the relationship between building structure type and damage scale (Table 18); and damage scale and flood vulnerability (Table 20) also considering the damage factor values given by Huizinga, et al., (2004). Figure 60 shows buildings with high vulnerability (value 1.0) that are associated to building structural type_1 and type_2, located towards the northern part of the area. These represent 1.54 % of the total buildings of the study area. Buildings categorized with moderate vulnerability (value 0.5) represent 24.61% and are associated to building structure type_3, type_4 and type_5 located on the right bank of the Minjiang River. However, buildings with a low vulnerability (0.2) are located towards the southern part, with a structural type_4. These represent 4.08 % of buildings. Remaining part of buildings are considered as no vulnerable to the 2010 flood event. On the other hand the social vulnerability map was created based on data collected from eight social indicators using participatory GIS tool. These indicators were grouped into five factors (Table 26). As unit of analysis households were considered. As tools of analysis SMCE was applied, where social indicators were integrated into Criteria Trees. The final result shows the social vulnerability map (Figure 75). The household with a very high vulnerability (value>0.4) represent 5%, and are associated to multi-family dwelling with structural type_4. A representation is found on the western, southern and center part of the study area. However, households with a high vulnerability (value 0.4) represent 30% of households sampled. These are located everywhere and are associated to buildings with structural type_3, type_4 and type_5. Households categorized as moderate vulnerability (values 0.3) are located mainly towards center and southern part. These represent 23.33 %; and are associated to buildings with structural type_4. On the other hand, households with low vulnerability (values 0.2) to flooding appear located mainly towards the northern, center and southern part. These are associated to buildings with structural type_4 and type_5, representing 41.67 % of the households sampled.

**The last specific objective of this research is to contribute to the improvement of the strategy to flood risk reduction.** Regarding to this specific objective, the research question elaborated on is: Which measures could contribute to minimize the impact of the flood event based on community knowledge and field research? In order to respond to this question, community perception and coping mechanisms developed in Yingxiu related to the 2010 flood event were analyzed and evaluated (chapter 8). Finally, a list of ten new measures to contribute to the reduction of the flood risk and the impact of the flooding were proposed based on weaknesses identified in technical and non-technical measures related to this event. These measures were mainly aimed to improve the early warning system and the existing alarm system; to strengthen the protection structures such as embankment; to develop of educational programs related to flooding event; the promotional of educational program and the increase of number of training.

## 9.3. Recommendations

Recommendations for future studies are as follows:

- Include results of this research in further studies of flood vulnerability or risk management to develop in the area.
- Implement the list of measures proposed in this research to contribute to minimizing flood risk (section 8.3) and measures proposed in section 7.4 to reduce social vulnerability.
- Modeling new scenarios considering more detailed data about meteorology, hydrology and failure of protection structures (the dike or protection walls).
- A developed study of the damage assessment taken into account the cost of building reparations and economic values of outside property.
- Building of vulnerability curves for all the structural building types existing in the town considering the absolute amount of damage.
- Developed physics vulnerability studies considering new scenarios. For example: population and furniture inside of the buildings, flooding caused by the increase of the water level of the river bed.
- Further studies of social vulnerability could be developed with more details in this area and in another part of the town, for example on the left bank of the Minjiang River and the right bank of the Roa River.

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# APPENDIX

**Appendix 1.** Fieldwork schedule

| Week | Date | Activities |
|---|---|---|
| First week (22/09-28/09) | Thursday | Meeting in University of Chengdu (define interpreter and collecting data) |
| | Friday | University of Chengdu (Collecting data) |
| | Monday | Travel around the study area. Collecting data. |
| | Tuesday | Meeting in the municipality. Organizing FGD. |
| | Wednesday | Meeting with local officers and local leaders to introducing the work to them. Doing FGD and Sketch Mapping. |
| Second week (29/09-5/10) | Thursday | Applying questionnaire, interview and fieldwork measurements. |
| | Friday | Applying questionnaire, interview and fieldwork measurements. |
| | Monday | Applying questionnaire, interview and fieldwork measurements. |
| | Tuesday | Applying questionnaire, interview and fieldwork measurements. |
| | Wednesday | Applying questionnaire, interview and fieldwork measurements. |
| Third week (6/10-12/10) | Thursday | Applying questionnaire, interview and fieldwork measurements. |
| | Friday | Applying questionnaire, interview and fieldwork measurements. |
| | Monday | Applying questionnaire, interview and fieldwork measurements. |
| | Tuesday | Applying transect mapping to see building occupancy type and resources distribution. Applying questionnaire |
| | Wednesday | Applying transect mapping to see building occupancy type and resources distribution. Applying questionnaire |
| Fourth week (13/10-21/10) | Thursday | Applying transect mapping to see building occupancy type and resources distribution. |
| | Friday | Feedback meeting. |
| | Monday_ Wednesday | Working in the database |
| | Thursday | Finalizing fieldwork data. |
| | Friday | Preparing to go back to Enschede. |

**Appendix 2.** QUESTIONNAIRE: VULNERABILITY, COPING MECHANISMS AND RISK PERCEPTION.

Research Institution: University of Twenty. Faculty of ITC, Enschede. Netherland.
Researcher: Beatriz Lao Ramos laoramos07013@itc.nl
Questionnaire No:_______ Interview No:_______ Date:__________
Location Coordinates: X:__________________ Coordinates: Y:___________________
Respondent's name:_______________ Age:_____ Gender: F__ M__

1. Building information:

1.a) Building ☐ Single building ☐

| Building _use | Residential | Commercial | Education | Health | Other |
|---|---|---|---|---|---|
| | | | | | |
| Nr_floors_of building | 1 | 2 | 3 | 4 | More |
| | | | | | |
| State | Very Good | Good | Moderate | Bad | Very Bad |
| | | | | | |
| Age_building | < 1 years | 1-3 years | > 3 years | Was your home damage by 2008 earthquake? Yes__ No___ | |
| | | | | | |
| Height of floor (ground level) | | Floor space | | | |

| Building Type (wall) | Wood | Concrete | Brick | Tents | Combined | Other |
|---|---|---|---|---|---|---|
| | | | | | | |
| Building Type (roof) | Concrete slab | Steel tile | Corrugated Galvanised Iron (GI) | Asbestos cement | Combined | Other |
| | | | | | | |

1.b) Location in building (No_floor_sampled:______)

| Homeowner | | Yes_ No_ | Rented home? | Yes_ No_ | Company name of rent home | | |
|---|---|---|---|---|---|---|---|
| Damaged by 2010 flood event? | % of damage | Water depth inside the house | Duration | Under ground space? | Use of under ground space | Flood retaining structure present? | Type structure |
| Yes_ No_ | | | | Yes_ No_ | | Yes_ No_ | |

1.c) Content damage per sampling floor

| Building _ damage content | Television | Radio | Computer | Refrigerator | Furniture |
|---|---|---|---|---|---|
| | Electric/Gas range | Washing machine | Electromagnetic stove/Oven | Music equipment | Others |
| Price (Yuan) | Television | Radio | Computer | Refrigerator | Furniture |
| | Electric/Gas range | Washing machine | Electromagnetic stove/Oven | Music equipment | Others |
| Other damage | Vehicles damaged? | Yes | No | Value of damage | |

## 2. Population information

| Indicator | | | | |
|---|---|---|---|---|
| Total number of members | | | | |
| Age | 0-5 | 6-18 | 18-60 | >60 |
| Gender | F | | M | |
| Handicapped | F | | M | |
| Number of members present | Day time | | Night time | |
| Number of member with education | (F)Primary | | High school | University |
| | (M)Primary | | High school | University |
| Number of members damaged by 2010 flood event | Fatalities | | Injures | |
| | Psychological impact | | Diseases (polluted water) | |
| Causes of death or injures | Not warned in time_ Handicapped_ Refused to evacuate_ Sleeping_ Other: | | | |

| Indicator | Number |
|---|---|
| Family member employed | |
| Unemployed | |
| Farmer | |
| Self employed | |
| Economic sector | |
| Health sector | |
| Education Sector | |
| Animals for household | |
| Income (Yuan): <750___ 750-1000___ 1000-5800____ 5800-15000____ >15000_____ | |

| Indicator | Education | Health | Water | Transportation | Sanitation | Sewage system | Solid waste collection |
|---|---|---|---|---|---|---|---|
| Accessi-bility | | | | | | | |

## 3. Coping mechanisms and risk perception

| Questions | | | | | |
|---|---|---|---|---|---|
| Did you live in this location before? | How far did you live from the river before? | | | | |
| Do you have any experiences of flood event? | Yes | No | How often do you experience flooding in the year? | | |
| Date of the last one experienced. | Are you affected by other flood before? Y__ N__ | | | | |
| Did you feel afraid by 2010 flood event? Before__ During__ After__ | | | | Yes | No |
| Do you consider that your house can be damaged by flood events? | | | | Yes | No |
| How do you consider that is the flood phenomena compared to other phenomena? | Flood compared to landslide | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| | Flood compared to small earthquake | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| | Flood compared to large earthquake | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| What was the level of water of 2010 flooding? | | Ankle | Knee | | Hip |
| | | Breast | Head | | Higher |
| | | 1 floor | 2 floor | | 3 floor |
| Duration of the 2010 flood event. | | | Days | | Hours |
| How do you classified the water velocity? | | | Slow | | Medium |
| | | | Fast | | Very fast |
| Could you still walk? | | | Yes | | No |

| | | | |
|---|---|---|---|
| Did you know causes of 2010 flood event?<br>Man activities__ Landslide__ Havy rainfall__ | Yes | | No |
| Is your work/income affected by floods? How many days? | Yes | | No |
| Were you affected by road flooding and disruption of transportation services? How many days? | Yes | | No |
| How did you know about the risk of 2010 flood event? | Radio__ Television__ Newspaper__ Neighbours__ Local authorities__ Others__ | | |
| Did you consider that the warning system was effective? | Yes | | No |
| Where you evacuated before or during flooding?How long? | Before | | During |
| The extra costs for th evacuation are pays by | Government__<br>Yourself__<br>Other organization_ | | |
| During the evacuation process who took care of your belongings? | Government__<br>Yourself__Militar__<br>Nobody__<br>Other organization_ | | |
| Evacuation process during the earthquake is different to the evacuation during the flooding? | Yes | | No |
| Could you mention some differences | | | |
| Did you know if there was a evacuation route? | Yes | | No |
| Did you know if there was social ties? | Yes | | No |
| Social ties operated | Before | During | After |
| Did you know what to do during flood event? | Yes | | No |
| Did you take any action to minimize or avoid losses?<br>Before__ During__ After__ | Yes | | No |
| Which actions did you take? | | | |
| Did you know if government or municipality took any action to minimize or avoid losses? | Yes<br>Before | No<br>During | <br>After |
| Which actions did you know? | | | |
| What do you think should be done to reduce the effects of flooding? | | | |
| Does disaster preparedness helps in reduction of flood risk? | Yes | | No |
| Which actions do you consider that is necessary in disaster preparedness? | _Education _Training<br>_Emergency plan<br>_Other<br>Mention | | |

Support / assistance Received

| | Relatives | Neighbours | Community | Municipality | NGO | Military | Rescue team | Emergency |
|---|---|---|---|---|---|---|---|---|
| Before | | | | | | | | |
| Type of support | | | | | | | | |
| During | | | | | | | | |
| After | | | | | | | | |

**Appendix 3**. QUESTIONNAIRE: Focus Group Discussion and Transect Mapping
QUESTIONNAIRE: VULNERABILITY, COPING MECHANISMS AND RISK PERCEPTION.
Research Institution: University of Twenty. Faculty of ITC, Enschede. Netherland.

Researcher: Beatriz Lao Ramos laoramos07013@itc.nl

Questionnaire No:_______ Interview No:_______ Date:__________

1. Coping mechanisms and risk perception.

| Questions | | | | | |
|---|---|---|---|---|---|
| Did you live/work in this location before? Yes__ No__ | How far did you live/work from the river before? | | | | |
| Do you have any experiences of flood event? Yes__ No___ | How often do you experience flooding in the year? | | | | |
| Date of the last one experienced. | Are you affected by other flood before? Y__ N__ | | | | |
| Did you feel afraid by 2010 flood event? Y_ N_ Before__ During__ After__ | Do you consider that your house can be damaged by flood events? Y__ N__ | | | | |
| How do you consider that is the flood phenomena compared to other phenomena? | Flood compared to landslide | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| | Flood compared to small earthquake | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| | Flood compared to large earthquake | | | | |
| | harmless | less dangerous | equal | more dangerous | extremely dangerous |
| What was the level of water? | Ankle | Knee | Hip | | |
| | Breast | Head | Higher | | |
| | 1 floor | 2 floor | 3 floor | | |
| Duration of the 2010 flood event. | Days | Hours | | | |
| How did you classify the water velocity? | Slow | Medium | Did you know what to do during flood event? Yes__ No__ | | |
| | Fast | Very fast | | | |
| Could you still walk? Yes__ No__ | Did you know causes of 2010 flood event? Y__ N__ Man activities__ Landslide__ Heavy rainfall__ | | | | |
| How did you know about the risk of 2010 flood event? | Radio_ Television_ Newspaper_ Neighbours_ Local authorities_ Others_ | | | | |
| Did you consider that the warning system was effective? Yes__ No__ | Where you evacuated before or during flooding? Before__ After__ How long? | | | | |
| Did you know if there was a evacuation route? Yes__ No__ | Did you know if there was social ties? Yes__ No__ Social ties operated: before__ during__ after__ | | | | |
| Did you take any action to minimize or avoid losses? | Yes | No | | | |
| | Before | During | After | | |
| Which actions did you take? | | | | | |
| Did you know if government or municipality took any action to minimize or avoid losses? | Yes | No | | | |
| | Before | During | After | | |
| Which actions did you know? | | | | | |
| Does disaster preparedness helps in reduction of flood risk? | Yes | No | | | |
| Which actions do you consider that is necessary in disaster preparedness? | _Education _Training _Emergency plan _Other Mention | | | | |

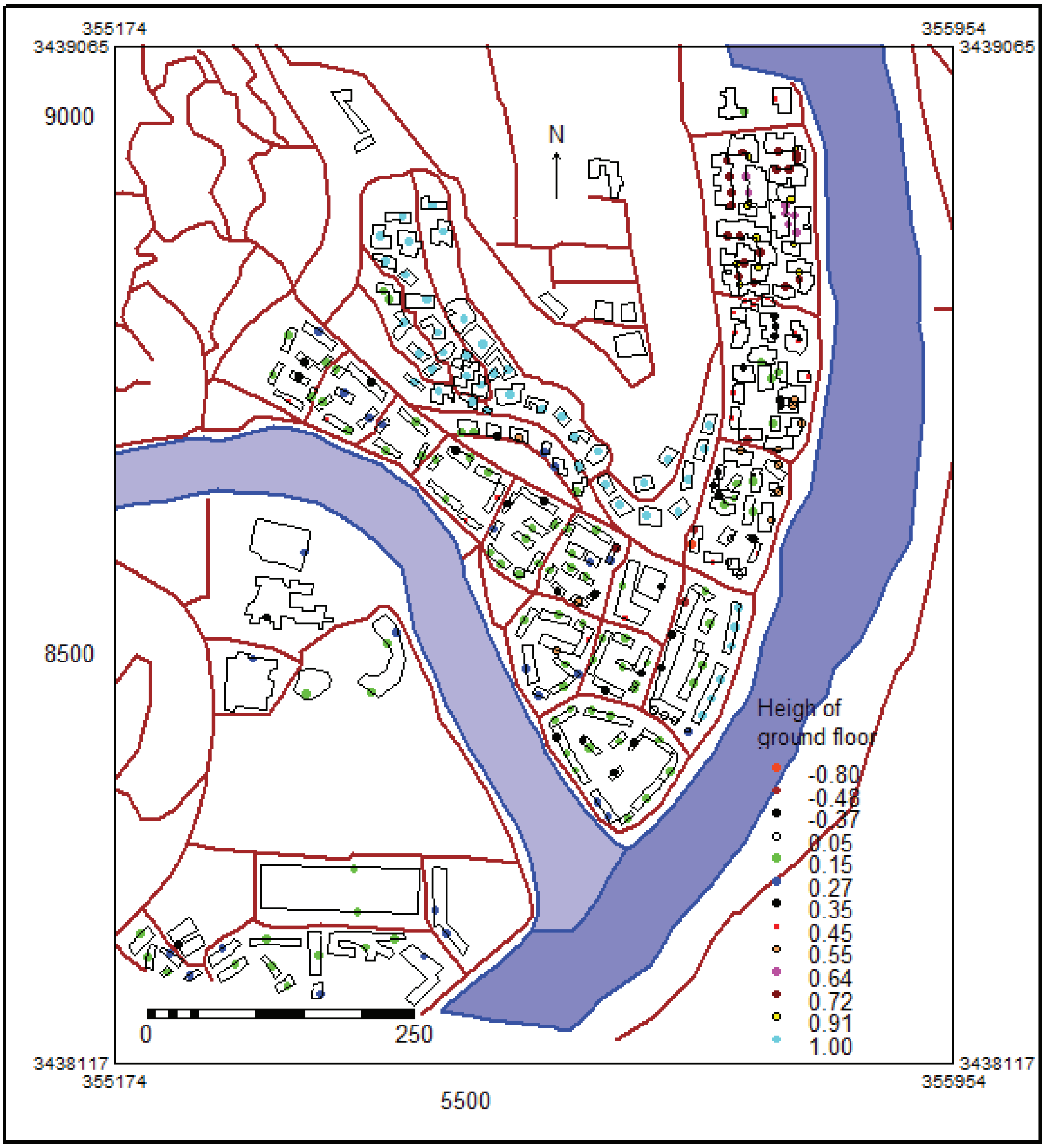
2. Damage information

<table>
<tr><td colspan="5">Questions</td></tr>
<tr><td>Did you can to report any material damage?</td><td>Yes</td><td>No</td><td colspan="2">Value(Yuan)</td></tr>
<tr><td colspan="5">Mention:</td></tr>
<tr><td>Did you or your family suffered any disease by the flood event?</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td>How many persons were diseased?</td><td>(0-5)</td><td>(5-18)</td><td>(18-60)</td><td>(>60)</td></tr>
<tr><td rowspan="2">What kind of disease?</td><td colspan="2">Fatalities</td><td colspan="2">Injures</td></tr>
<tr><td colspan="2">Psychological impact</td><td colspan="2">Diseases (polluted water)</td></tr>
<tr><td>Causes of death or injures</td><td colspan="4">Not warned in time__ Handicapped__<br>Refused to evacuate__ Sleeping__<br>Other:</td></tr>
<tr><td>Was your work/income affected by flooding?</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td>How many days?</td><td colspan="4"></td></tr>
<tr><td>Were you affected by road flooding and disruption of transportation services?</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="5">How many days?</td></tr>
<tr><td colspan="5">What do you think should be done to reduce the damage of flooding?</td></tr>
</table>

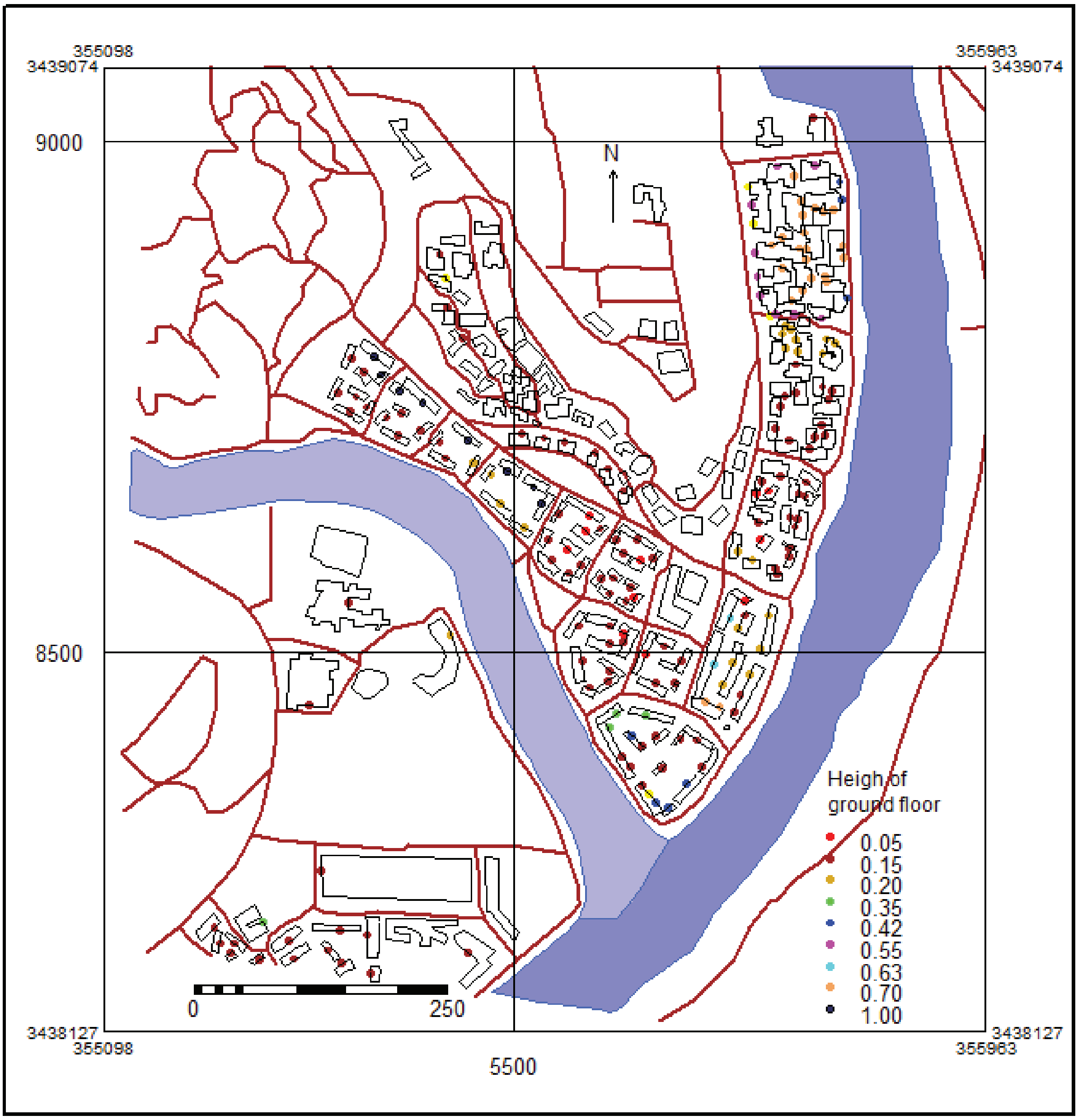
Support / assistance Received

| | Relatives | Neighbours | Community | Municipality | NGO | Military | Rescue team | Emergency |
|---|---|---|---|---|---|---|---|---|
| Before | | | | | | | | |
| Type of support | | | | | | | | |
| During | | | | | | | | |
| Type of support | | | | | | | | |
| After | | | | | | | | |
| Type of support | | | | | | | | |

**Appendix 4**. Height of ground floor relative to street level (front side of buildings)



**Appendix 5.** Height of ground floor relative to street level (back side of buildings)



**Appendix 6.** Damage of building components collected during fieldwork with water depth values calculated and velocity obtained from modeling

| PGIS | Damage fieldwork | Structure type | Water Depth(m) | Velocity (m/s) | PGIS | Damage fieldwork | Structure type | Water Depth(m) | Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| P_1 | 4 | Type_5 | 2.63 | 1.14 | P_32 | 5 | Type_4 | 0.00 | 0.00 |
| P_2 | 3 | Type_3 | 2.80 | 2.78 | P_33 | 5 | Type_4 | 0.00 | 0.00 |
| P_3 | 4 | Type_5 | 2.79 | 0.69 | P_34 | 5 | Type_4 | 0.00 | 0.00 |
| P_4 | 4 | Type_5 | 2.68 | 0.23 | P_35 | 5 | Type_4 | 0.00 | 0.00 |
| P_5 | 4 | Type_4 | 2.58 | 0.20 | P_36 | 5 | Type_4 | 0.00 | 0.00 |
| P_6 | 4 | Type_4 | 2.72 | 0.23 | P_37 | 5 | Type_4 | 0.00 | 0.00 |
| P_7 | 4 | Type_4 | 2.66 | 0.48 | P_38 | 4 | Type_4 | 0.35 | 0.17 |
| P_8 | 4 | Type_4 | 2.18 | 0.61 | P_39 | 4 | Type_4 | 0.50 | 0.22 |
| P_9 | 4 | Type_4 | 2.48 | 0.29 | P_40 | 4 | Type_4 | 0.88 | 0.59 |
| P_10 | 4 | Type_4 | 2.59 | 0.29 | P_41 | 5 | Type_4 | 0.00 | 0.00 |
| P_11 | 4 | Type_4 | 2.24 | 0.59 | P_42 | 4 | Type_5 | 2.77 | 1.38 |
| P_12 | 4 | Type_4 | 1.68 | 0.60 | P_43 | 4 | Type_5 | 2.72 | 0.78 |
| P_13 | 4 | Type_4 | 1.43 | 0.16 | P_44 | 4 | Type_5 | 2.88 | 0.34 |
| P_14 | 4 | Type_4 | 2.04 | 0.40 | P_45 | 4 | Type_5 | 2.53 | 0.34 |
| P_15 | 4 | Type_4 | 1.68 | 0.25 | P_46 | 4 | Type_4 | 2.48 | 0.31 |
| P_16 | 4 | Type_4 | 1.21 | 0.45 | P_47 | 4 | Type_4 | 2.56 | 0.56 |
| P_17 | 4 | Type_4 | 0.72 | 0.38 | P_48 | 4 | Type_4 | 2.50 | 0.51 |
| P_18 | 4 | Type_4 | 0.25 | 0.16 | P_49 | 4 | Type_4 | 2.36 | 0.44 |
| P_19 | 4 | Type_4 | 0.60 | 0.58 | P_50 | 4 | Type_4 | 2.37 | 0.42 |
| P_20 | 4 | Type_4 | 1.40 | 0.18 | P_51 | 4 | Type_4 | 1.97 | 0.18 |
| P_21 | 5 | Type_4 | 0.00 | 0.00 | P_52 | 4 | Type_4 | 2.07 | 0.16 |
| P_22 | 5 | Type_4 | 0.00 | 0.00 | P_53 | 4 | Type_4 | 2.01 | 0.61 |
| P_23 | 5 | Type_4 | 0.00 | 0.00 | P_54 | 4 | Type_4 | 1.74 | 0.49 |
| P_24 | 5 | Type_4 | 0.00 | 0.00 | P_55 | 5 | Type_4 | 0.00 | 0.00 |
| P_25 | 5 | Type_4 | 0.00 | 0.00 | P_56 | 5 | Type_4 | 0.00 | 0.00 |
| P_26 | 5 | Type_4 | 0.00 | 0.00 | P_57 | 5 | Type_4 | 0.00 | 0.00 |
| P_27 | 5 | Type_4 | 0.00 | 0.00 | P_58 | 5 | Type_4 | 0.00 | 0.00 |
| P_28 | 5 | Type_4 | 0.00 | 0.00 | P_59 | 5 | Type_4 | 0.00 | 0.00 |
| P_29 | 5 | Type_4 | 0.00 | 0.00 | P_60 | 5 | Type_5 | 0.00 | 0.00 |
| P_30 | 5 | Type_4 | 0.00 | 0.00 | | 2 | Type_2 | 4.74 | 4.91 |
| P_31 | 5 | Type_4 | 0.00 | 0.00 | | 1 | Type_1 | 5.90 | 5.49 |

## Appendix 7. Building information from fieldwork

Table "PGIS_Questionnaires" - ILWIS

File Edit Columns Records View Help

| | Buildin | Build | Landuse | Building_t | Landuse_bui | Building_roof_typ | Nr_floors | Floor_sam | Area_apar | Retain_w | Building_st | retain | Height | Water_depth | water_depth_to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PGIS_004 | B_7 | Building | Ins_office | Concrete | ins_C | Concrete slab | 5_Floors | 1_Floor | 80.0 | Yes | Very Good | Steps | 0.72 | ? | ? |
| PGIS_043 | B_2 | Building | Res_family | Concrete | res_2C | Concrete slab | 5_Floors | 1_Floor | 80.0 | Yes | Very Good | Steps | 0.72 | 2.00 | 2.72 |
| PGIS_044 | B_11 | Building | Res_family | Concrete | res_2C | Concrete slab | 5_Floors | 2_Floors | 80.0 | Yes | Very Good | Steps | 0.66 | ? | ? |
| PGIS_060 | B_153 | Single build | Ins_fire | Concrete | ins_C | Concrete slab | 5_Floors | 1_Floor | 1202.0 | Yes | Very Good | Steps | 0.22 | 0.00 | 0.00 |
| PGIS_025 | B_121 | Multi Family | Rest_Reside | Concrete | Comres_2C | Concrete slab | 5_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.33 | 0.00 | 0.00 |
| PGIS_003 | B_5 | Building | Ins_police | Concrete | ins_C | Concrete slab | 5_Floors | 3_Floors | 80.0 | Yes | Very Good | Steps | 0.72 | 2.07 | 2.79 |
| PGIS_042 | B_3 | Building | Rest_Reside | Concrete | Restres_C | Concrete slab | 5_Floors | 1_Floor | 80.0 | Yes | Very Good | Steps | 0.72 | ? | ? |
| PGIS_045 | B_20 | Building | Res_family | Concrete | res_2C | Concrete slab | 5_Floors | 1_Floor | 80.0 | Yes | Very Good | Steps | 0.91 | ? | ? |
| PGIS_001 | B_7 | Building | Res_family | Concrete | res_2C | Concrete slab | 5_Floors | 1_Floor | 250.0 | Yes | Very Good | Steps | 0.72 | ? | ? |
| PGIS_049 | B_38 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.15 | ? | ? |
| PGIS_050 | B_37 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 97.0 | Yes | Good | Steps | 0.65 | ? | ? |
| PGIS_047 | B_32 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 140.0 | Yes | Good | Steps | 0.56 | ? | ? |
| PGIS_048 | B_30 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 112.0 | Yes | Good | Steps | 0.12 | ? | ? |
| PGIS_046 | B_28 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 110.0 | Yes | Good | Steps | 0.20 | ? | ? |
| PGIS_036 | B_73 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.35 | 0.00 | 0.00 |
| PGIS_037 | B_72 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.30 | 0.00 | 0.00 |
| PGIS_034 | B_82 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.31 | 0.00 | 0.00 |
| PGIS_035 | B_74 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.12 | 0.00 | 0.00 |
| PGIS_040 | B_64 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.10 | ? | ? |
| PGIS_041 | B_92 | Multi Family | Com_Residen | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.28 | 0.00 | 0.00 |
| PGIS_038 | B_76 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.15 | 0.20 | 0.35 |
| PGIS_039 | B_66 | Multi Family | Com_Residen | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.05 | 0.45 | 0.50 |
| Tra_005 | B_35 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 116.5 | Yes | Good | Steps | 0.48 | 2.16 | 2.64 |
| Tra_006 | B_36 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 116.5 | Yes | Good | Steps | 0.55 | 2.06 | 2.61 |
| Tra_003 | B_27 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 110.0 | Yes | Good | Steps | 0.35 | 1.92 | 2.27 |
| Tra_004 | B_26 | Multi Family | unknown | Concrete | unknown | Concrete slab | 3_Floors | 1_Floor | 110.0 | Yes | Good | Steps | 0.35 | 1.94 | 2.29 |
| Tra_Q_004 | B_62 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 108.0 | Yes | Good | Steps | 1.00 | ? | ? |
| Tra_Q_005 | B_78 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.34 | ? | ? |
| Tra_007 | B_45 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 110.0 | Yes | Good | Steps | 0.36 | 1.91 | 2.27 |
| Tra_008 | B_47 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.27 | 1.96 | 2.23 |
| Tra_002 | B_34 | Multi Family | unknown | Concrete | unknown | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.28 | 1.90 | 2.18 |
| PGIS_054 | B_54 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | -0.45 | 1.74 | 1.74 |
| PGIS_055 | B_79 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.20 | ? | 0.00 |
| PGIS_052 | B_49 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.11 | ? | ? |
| PGIS_053 | B_52 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 117.0 | Yes | Good | Steps | 0.34 | ? | ? |
| PGIS_058 | B_160 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.22 | 0.00 | 0.00 |
| PGIS_059 | B_152 | Single build | Ins_hospita | Concrete | ins_C | Concrete slab | 3_Floors | 1_Floor | 1195.0 | Yes | Very Good | Steps | 0.32 | 0.00 | 0.00 |
| PGIS_056 | B_164 | Multi Family | Hotel_Resid | Concrete | Hotres_C | Concrete slab | 3_Floors | 1_Floor | 112.0 | Yes | Good | Steps | 0.25 | 0.00 | 0.00 |
| PGIS_057 | B_169 | Multi Family | Rest_Reside | Concrete | Restres_C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.20 | 0.00 | 0.00 |
| PGIS_015 | B_61 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.10 | ? | ? |
| PGIS_016 | B_64 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.10 | ? | ? |
| PGIS_013 | B_57 | Multi Family | Rest_Reside | Concrete | Restres_C | Concrete slab | 3_Floors | 1_Floor | 110.0 | No | Good | ? | -0.48 | 1.43 | 1.43 |

Show record PGIS_044 in record view

Table "PGIS_Questionnaires" - ILWIS

File Edit Columns Records View Help

| | Buildin | Build | Landuse | Building_t | Landuse_bui | Building_roof_typ | Nr_floors | Floor_sam | Area_apar | Retain_w | Building_st | retain | Height | Water_depth | water_depth_to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PGIS_018 | B_68 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.35 | 0.00 | 0.25 |
| PGIS_019 | B_63 | Multi Family | Com_busines | Concrete | com_C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | -0.37 | ? | ? |
| PGIS_014 | B_46 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 117.0 | Yes | Good | Steps | 0.13 | ? | ? |
| PGIS_017 | B_65 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 106.8 | Yes | Good | Steps | 0.12 | 0.60 | 0.72 |
| PGIS_008 | B_41 | Multi Family | Rest_Reside | Concrete | Restres_C | Concrete slab | 3_Floors | 1_Floor | 260.0 | Yes | Good | Steps | 0.45 | 1.73 | 2.18 |
| PGIS_009 | B_39 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 110.0 | Yes | Good | Steps | 0.48 | 2.00 | 2.48 |
| PGIS_005 | B_24 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 140.0 | Yes | Good | Steps | 0.45 | ? | ? |
| PGIS_011 | B_47 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 97.3 | Yes | Good | Steps | 0.50 | ? | ? |
| PGIS_012 | B_62 | Multi Family | Rest_Reside | Concrete | Restres_C | Concrete slab | 3_Floors | 1_Floor | 108.0 | Yes | Good | Steps | 1.00 | ? | ? |
| PGIS_007 | B_33 | Multi Family | Res_family | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 90.0 | Yes | Good | Steps | 0.45 | ? | ? |
| PGIS_010 | B_36 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 116.5 | Yes | Good | Steps | 0.55 | ? | ? |
| PGIS_030 | B_90 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.27 | ? | 0.00 |
| PGIS_031 | B_88 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.28 | ? | 0.00 |
| PGIS_028 | B_91 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.22 | 0.00 | 0.00 |
| PGIS_033 | B_75 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.15 | 0.00 | 0.00 |
| PGIS_051 | B_51 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.31 | ? | ? |
| PGIS_029 | B_114 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 140.0 | No | Good | ? | -0.17 | 0.00 | 0.00 |
| PGIS_032 | B_84 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.15 | ? | ? |
| PGIS_022 | B_97 | Multi Family | Ins_tailori | Concrete | ins_C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.32 | 0.00 | 0.00 |
| PGIS_023 | B_96 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.25 | 0.00 | 0.00 |
| PGIS_020 | B_60 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | -0.45 | ? | ? |
| PGIS_026 | B_119 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.15 | 0.00 | 0.00 |
| PGIS_027 | B_127 | Multi Family | Res_family | Concrete | res_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | Good | Steps | 0.25 | 0.00 | 0.00 |
| PGIS_021 | B_103 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 120.0 | Yes | Good | Steps | 0.32 | 0.00 | 0.00 |
| PGIS_024 | B_105 | Multi Family | Com_Residen | Concrete | Comres_2C | Concrete slab | 3_Floors | 1_Floor | 100.0 | Yes | ? | Steps | 0.15 | ? | ? |
| Tra_Q_003 | B_94 | Single build | Com_market | Concrete | com_C | Concrete slab | 2_Floors | 1_Floor | 500.0 | Yes | Very Good | Steps | 0.38 | 0.00 | 0.00 |
| PGIS_006 | B_22 | Multi Family | Ins_police | Concrete | ins_C | Concrete slab | 2_Floors | 1_Floor | 235.0 | Yes | Very Good | Steps | 0.55 | ? | ? |
| PGIS_002 | B_1 | Building | Water_facto | Concrete | factw_C | Concrete slab | 2_Floors | 1_Floor | 250.0 | Yes | Bad | Steps | 0.40 | 2.40 | 2.80 |
| Tra_001 | B_1 | Single build | Water_facto | Concrete | factw_C | Concrete slab | 2_Floors | 1_Floor | 250.0 | Yes | Very Good | Dike | 0.40 | 2.40 | 2.80 |
| Tra_009 | B_67 | Single build | unknown | Concrete | unknown | Concrete slab | 1_Floor | 1_Floor | 16.2 | Yes | Good | Steps | 0.23 | 0.27 | 0.50 |

Table "PGIS_Questionnaires" - ILWIS

File Edit Columns Records View Help

| | Wall | doors | windows | Floor | Foundation | Foto |
|---|---|---|---|---|---|---|
| PGIS_004 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_043 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 986,993,967 |
| PGIS_044 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 988 |
| PGIS_060 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 977 |
| PGIS_025 | no_damage | no_damage | no_damage | no_damage | no_damage | 1011 |
| PGIS_003 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_042 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 990,993,967 |
| PGIS_045 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 997 |
| PGIS_001 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_049 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 972 |
| PGIS_050 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1005,1006,10 |
| PGIS_047 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1001,1004 |
| PGIS_048 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1000 |
| PGIS_046 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 999,969 |
| PGIS_036 | no_damage | no_damage | no_damage | no_damage | no_damage | 953 |
| PGIS_037 | no_damage | no_damage | no_damage | no_damage | no_damage | 1054,953 |
| PGIS_034 | no_damage | no_damage | no_damage | no_damage | no_damage | 952 |
| PGIS_035 | no_damage | no_damage | no_damage | no_damage | no_damage | ? |
| PGIS_040 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 900,903 |
| PGIS_041 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 963,1095 |
| PGIS_038 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 957,1051 |
| PGIS_039 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 958 |
| Tra_005 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1112 |
| Tra_006 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1085 |
| Tra_003 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1099,1100 |
| Tra_004 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 971,1100 |
| Tra_Q_004 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1092,1093,10 |
| Tra_Q_005 | no_damage | no_damage | no_damage | no_damage | no_damage | ? |
| Tra_007 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1083,1084 |
| Tra_008 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1084 |
| Tra_002 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1073,1075,12 |
| PGIS_054 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1098 |
| PGIS_055 | no_damage | no_damage | no_damage | no_damage | no_damage | 1050 |
| PGIS_052 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_053 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_058 | no_damage | no_damage | no_damage | no_damage | no_damage | 978 |
| PGIS_059 | no_damage | no_damage | no_damage | no_damage | no_damage | 976 |
| PGIS_056 | no_damage | no_damage | no_damage | no_damage | no_damage | 1064 |
| PGIS_057 | no_damage | no_damage | no_damage | no_damage | no_damage | ? |
| PGIS_015 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 900,903 |
| PGIS_016 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 900,903 |
| PGIS_013 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 898 |

Table "PGIS_Questionnaires" - ILWIS

File Edit Columns Records View Help

| | Wall | doors | windows | Floor | Foundation | Foto |
|---|---|---|---|---|---|---|
| PGIS_018 | no_damage | no_damage | no_damage | no_damage | no_damage | 904,905 |
| PGIS_019 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 907,908,909, |
| PGIS_014 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 896 |
| PGIS_017 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 900,903 |
| PGIS_008 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 882 |
| PGIS_009 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1005,1006,10 |
| PGIS_005 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_011 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 887 |
| PGIS_012 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 889,903 |
| PGIS_007 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 880 |
| PGIS_010 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1085,1111 |
| PGIS_030 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | ? |
| PGIS_031 | no_damage | no_damage | no_damage | no_damage | no_damage | 950 |
| PGIS_028 | no_damage | no_damage | no_damage | no_damage | no_damage | 963,1095 |
| PGIS_033 | no_damage | no_damage | no_damage | no_damage | no_damage | 951 |
| PGIS_051 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1036 |
| PGIS_029 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 948,949 |
| PGIS_032 | no_damage | no_damage | no_damage | cover_sediments | no_damage | 1097 |
| PGIS_022 | no_damage | no_damage | no_damage | cover_sediments | no_damage | 938,939 |
| PGIS_023 | no_damage | no_damage | no_damage | cover_sediments | no_damage | ? |
| PGIS_020 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 913,915 |
| PGIS_026 | no_damage | no_damage | no_damage | no_damage | no_damage | 942 |
| PGIS_027 | no_damage | no_damage | no_damage | no_damage | no_damage | 944,945 |
| PGIS_021 | no_damage | no_damage | no_damage | no_damage | no_damage | ? |
| PGIS_024 | no_damage | no_damage | no_damage | no_damage | no_damage | ? |
| Tra_Q_003 | no_damage | no_damage | no_damage | no_damage | no_damage | 1110 |
| PGIS_006 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1080,887,889 |
| PGIS_002 | high moisture | destroyed | destroyed | cover_sediments | no_damage | 1085,1111 |
| Tra_001 | high moisture | destroyed | destroyed | cover_sediments | no_damage | 1085,1111 |
| Tra_009 | deterioration_wall | no_installed | no_installed | cover_sediments | no_damage | 1115 |