EXPRESSING UNCERTAINTIES IN BUILDING VULNERABILITY TO HYDRO-METEOROLOGICAL HAZARDS

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April, 2013

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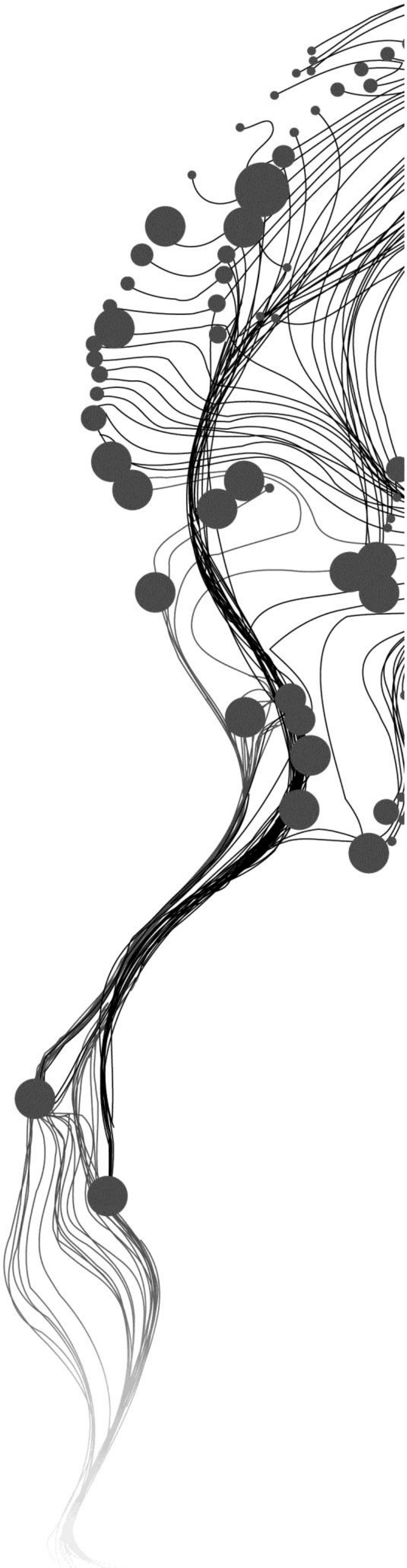

EXPRESSING UNCERTAINTIES IN BUILDING VULNERABILITY TO HYDRO-METEOROLOGICAL HAZARDS

AROSHALINY GODFREY
Enschede, The Netherlands, April, 2013

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- Natural Hazards and Disaster Risk Management

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ABSTRACT

Vulnerability as we know is a complex component within the risk management framework, and it comprises of components such susceptibility, exposure and lack of resilience. These components play a significant role in assessing the vulnerability, however there exists uncertainty within vulnerability in the risk management framework due to its multi -dimensional, dynamic and scale dependent characteristics. It is vital to identify these uncertainties and quantify them to achieve accurate results. This research is aimed at expressing these uncertainties to hydro-meteorological hazards such as floods (river flood, flash flood) and landslides (slow moving and rapid landslides) in Nehoiu, Buzau County, Romania. Inorder to analyse the range of uncertainty, existing vulnerability curves for the Reinforced Cement Concrete (RCC) and wooden buildings were collected and evaluated for the suitable curves. Using the selected curves an averaged vulnerability curve was made and the range of uncertainty expressed as the standard deviation. Field work was carried out to map and characterise the buildings in the study area, 689 buildings were mapped for their structural type, occupancy type and the state of their structural and non-structural components. Interviews were conducted for 60 houses, wherein the information on the detailed building characteristics was obtained. Questionnaires were collected from experts and ESR's to develop a weighting method and weights were assigned using Spatial-Multi Criteria Evaluation (SMCE). The weights from experts along with the weights of the building characteristics from the fieldwork were used to calculate the vulnerability uncertainty index. This vulnerability uncertainty index was then plotted on to the averaged vulnerability curve to identify the range of uncertainty. The vulnerability values along with the assumed hazard information due to the lack of previous hazard information were used to indicate how the risk assessment could be carried out using these values. The research concluded with expressing the complex nature of the existing vulnerability curve and their variation. The predominant building type in the study area consists of wooden buildings. Based on the weighting, the building characteristics significant for river flood: presence of basement and height of the building with respect to river, flash flood: the structural characteristics such as wall material, quality and maintenance of the building. For landslides: It can be concluded that the characteristics such as building close to slope and cracks in the structure were significant for both slow moving and rapid landslides. Lastly risk assessment can be carried out using this method provided that there is more detailed information on the hazard intensity and the damage information.

Keywords: Physical Vulnerability, Building Characteristics, Hydro-meteorological hazards, Uncertainty, Risk Assessment

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1. INTRODUCTION

1.1. Introduction

According to United Nations Office for Disaster Risk Reduction (UNISDR), Natural hazards are defined as *"phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage."* The concept of vulnerability plays a significant role in assessing and reducing the risk in the context of hazards. Vulnerability is a broad term and involves various factors as physical, social, economic and environmental (UNISDR, 2007).

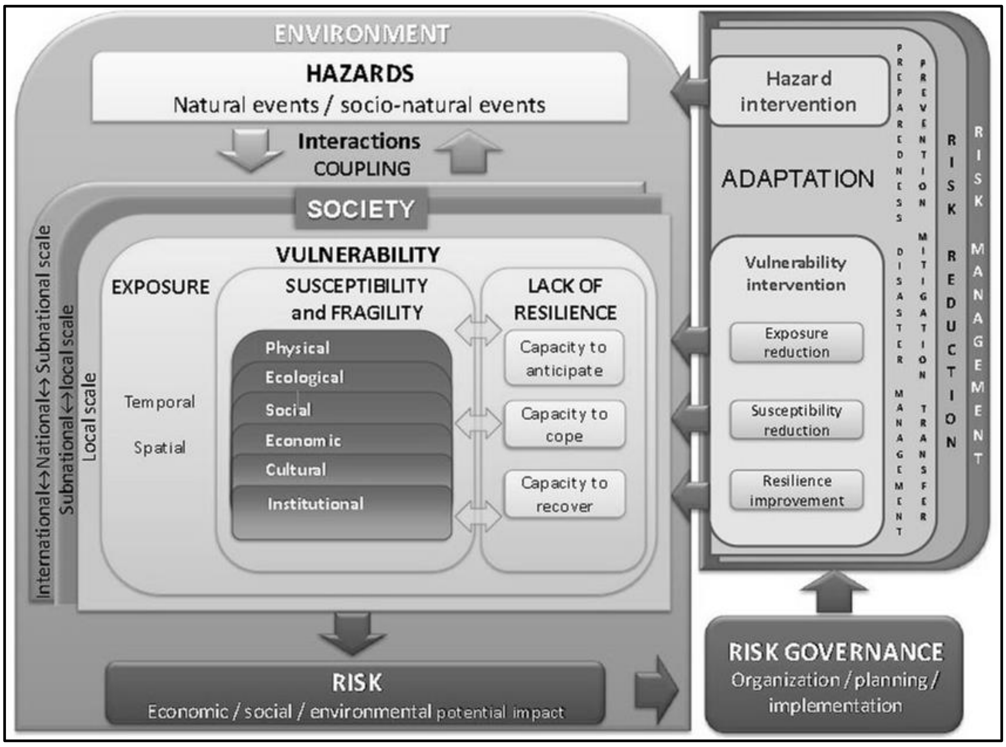


Figure 1. 1: The latest framework developed by the EU FP7 project MOVE

Source: (MOVE, 2011)

The concept of vulnerability is complex and is perceived differently and many authors have proposed different frameworks. The recent framework that discusses vulnerability is by the EU FP7 project MOVE (Methods for Improvement of Vulnerability Assessment in Europe (MOVE, 2011), the framework is an holistic approach towards risk management which encompasses vulnerability, risk and adaptation. According to this framework vulnerability is a combination of exposure, susceptibility and lack of resilience and vulnerability is the crucial aspect in the risk management framework. Each aspect encompassed in the vulnerability module play a significant role in assessing the vulnerability. The exposure reflects the presence of people and property in the hazard prone areas. Susceptibility literally means the lack of ability to resist some external agent, and this consists of physical, ecological, social, cultural and institutional factors. The third component of vulnerability is the lack of resilience, which is characterized by the capacity to anticipate an hazardous event, to cope with it and to recover from it (MOVE, 2011).

The definitions of vulnerability differ slightly depending on the perception and the factors that are emphasized on. One of the comprehensive ways to express vulnerability is the definition, *"the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard"* (Blaikie et al., 1994) De Sherbinin et al. (2007) defines vulnerability as *"Vulnerability is the degree to which a system or unit is likely to experience harm due to exposure to perturbations or stresses."*

Physical vulnerability deals with the vulnerability of the built environment and one of the definitions for vulnerability by Pelling (2003) that describes vulnerability and physical vulnerability are that it *"denotes exposure to risk and an inability to avoid or absorb potential harm."*

The International Strategy for Disaster Reduction (ISDR) defines vulnerability as *"the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards"* (ISDR, 2004). Although in the context of the research the definition of physical vulnerability that seems most appropriate is the *"the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from (no damage) to 1 (total loss)"(UNDRO, 1979).*

The term vulnerability implicates knowledge on the nature of the elements at risk, such as buildings, transportation, infrastructures, lifelines and essential features that are liable to be affected or damaged by an event. The extent of damage depends on the characteristics of the elements at risk (e.g. strength to withstand the impact of the hazard) and on the nature of the hazardous process, represented as the intensity e.g. flood height, impact pressure, acceleration), frequency of the hazardous and on the exposure of the elements at risk (ENSURE, 2009). The factors such as the type of construction, use of the structure and the contents in the structure also play a part in the degree of damage. Uncertainty exists in the risk management framework and is an inherent component of the vulnerability due to its multi-dimensional, dynamic and scale dependent characteristics and the inaccurate damage information of the elements-at-risk (MOVE, 2009). Uncertainty in vulnerability assessment could be either due to the change and the variation in the surrounding environment (e.g. change in rainfall pattern, different construction styles in different countries) in or due lack of reliable information (e.g., historic data). It is therefore necessary to identify the uncertainty and quantify it, inorder to produce a fairly representative and accurate results.

1.2. Research Objective

The overall aim of the research is to analyze the uncertainty related to the physical vulnerability of buildings in terms of their structure, for hydro-meteorological hazards (floods and landslides). The research will be conducted in the study area Nehoiu, Buzau County, Romania

1.2.1. Sub-Objectives and Research Questions

1. To collect existing vulnerability curves for two building types and use these to analyse the level of uncertainty for different building types and hazard types.

2. To map and characterize the elements at risk and their significant factors that can be used to represent the differences in vulnerability of structures.

3. To develop a weighting method based on the expert opinion for building characteristics to determine vulnerability in the uncertainty range expressed by existing vulnerability curves.

4. To indicate how the vulnerability values can be used in the risk assessment

1.2.1.1. Research questions related to objective 1

1. What are the different existing vulnerability curves for floods and landslides that could be used?
2. What are the parameters that are considered in these existing vulnerability curves?
3. How is the uncertainty expressed in these curves and what is the difference in the level of uncertainty expressed?
4. How to use the set of curves to express the uncertainty of vulnerability?
5. How large is the variation for the same elements-at-risk and what causes this variation?

1.2.1.2. Research questions related to objective 2

1. What are the significant characteristics of buildings that determine its vulnerability for river flood, flash flood and landslides?
2. How to collect information on these characteristics using a sample survey?

1.2.1.3. Research questions related to objective 3

1. How to determine the relative importance of the factors considered for the vulnerability assessment for river flood, flash flood and landslide?
2. How do experts analyze the important factors and weight these in a vulnerability assessment?
3. What is the variation in judgment between different experts and what causes this difference?

1.2.1.4. Research questions related to objective 4

1. How is the flood risk assessment carried out using the vulnerability values that are obtained?
2. How is the landslide risk assessment carried out using the vulnerability values that are obtained?

1.3. Methodology

The study is carried out in three different phases: the preparation, data collection phase and post-fieldwork phase. Initially various existing vulnerability curves for flood physical vulnerability for Reinforced Concrete Structures (RCC) and wooden structures were collected. The collected vulnerability curves were evaluated and the representative curves were selected. The curves were also brought back to the same measurement levels: intensity expressed as water height in meters and damage degree between 0 and 1. The vulnerability values from the resulting vulnerability curves were then taken together for the same level of intensity, and the average and standard deviation vulnerability values were calculated curves for the two specific building types present in the area (RCC and wooden). Image interpretation was done for building footprint mapping and landslide mapping.

In the fieldwork phase, a field survey was carried out for checking the building footprint map and data was collected on the building characteristics by conducting interviews and questionnaires. The buildings were then classified based on their occupancy type and their building characteristics. Interviews were carried out to get detailed information on the building characteristics along with information the previous hazard events and the preventive measures. Fieldwork was also carried out to reconstruct past flood events and characterize the landslides in the study area.

In the post-fieldwork stage, the analysis of the uncertainty of the vulnerability was carried out by developing a weighting method based on expert opinion for the building characteristics. This was done due to the lack of sufficient damage data and previous hazard information. This weighting method determines the vulnerability uncertainty index of a building solely based on its building characteristics regardless of the hazard information. The vulnerability of a particular building is then determined by plotting this index on the existing vulnerability curves which were collected in the pre-fieldwork stage. The vulnerability values were then used in combination with specific scenarios to generate flood risk maps. For landslides only exposure maps could be generated due to the lack of landslide intensity information. The procedure is shown in the figure 1.2.

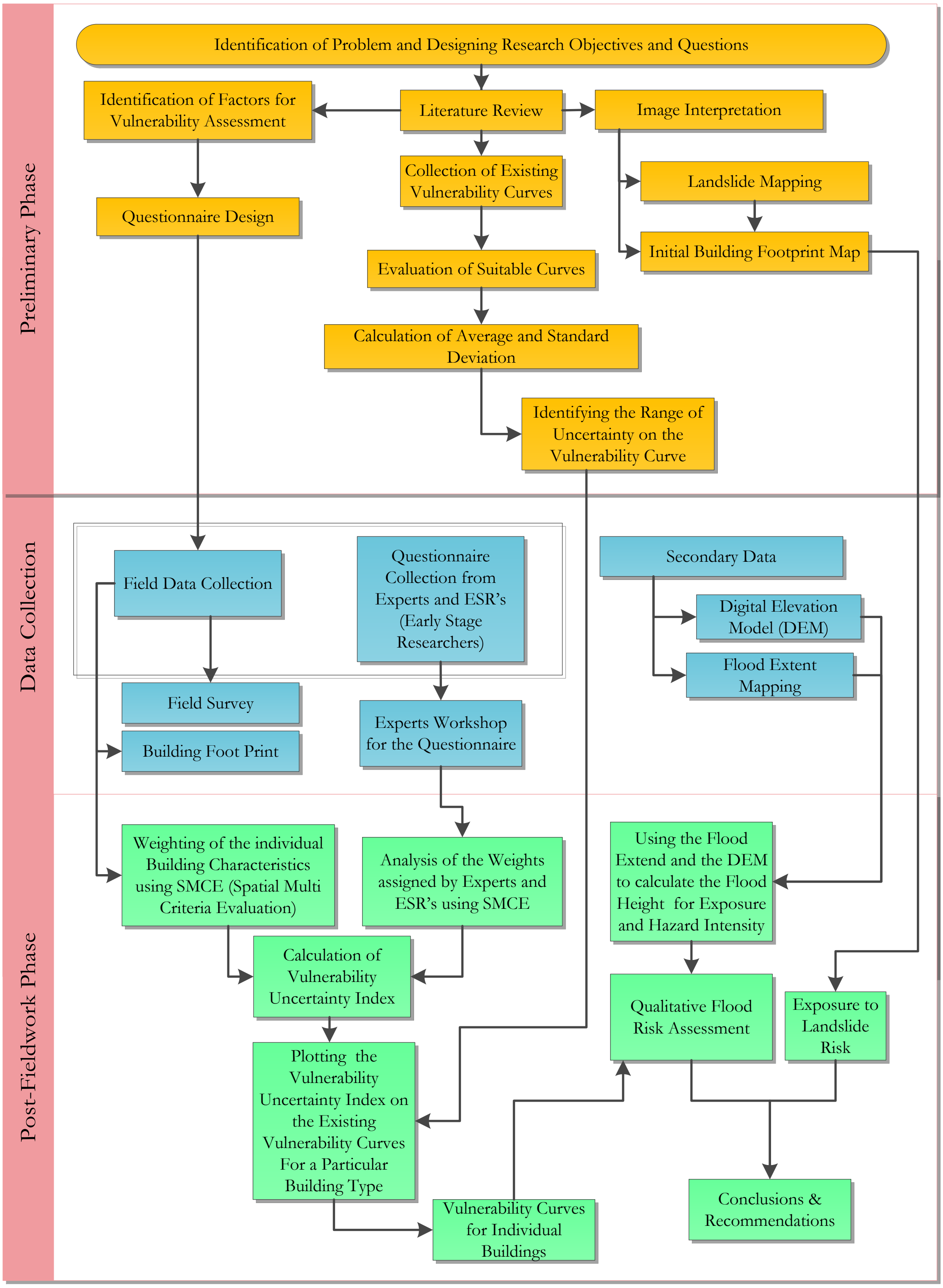


Figure 1. 2: Methodology Flow Chart

1.4. Study Area

Romania is one of the countries in Europe, which is highly vulnerable to natural hazards such as earthquake, floods and landslides. Disaster statistics from EM-DAT database show that floods (including river floods and flash floods) have the highest frequency of occurrence as compared to earthquakes and landslides (EM-DAT, 2012). According to the studies conducted Balteanu et al. (2007), Buzău County is located in one of the hotspots for natural hazards: both in an earthquake prone zone as well as the flood prone area as it is located in between the river valley of Buzău and the Carpathian Mountains (Balteanu *et al.*, 2007).

Geographically the study area lies between latitude 45°8’53.02”N to longitude 26°49’24.02”E, with an area of about 6103 km^2 and a population density of about 80 inhabitants per km^2 (Law, 2012). The climate is temperate-continental and the minimum and the maximum ranges from -3° C to 29° C with an average of 12°-14° C (Weather Online, 2012).

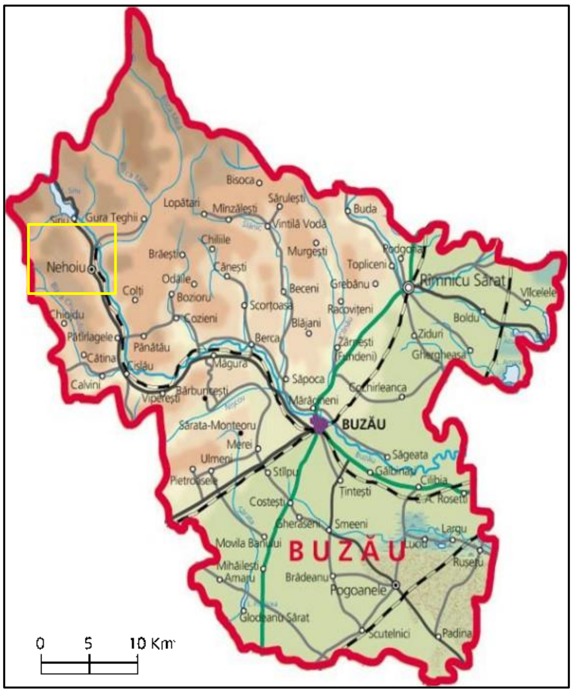


Figure 1. 3: Administrative Map of Buzau

(Source: Consiliul Judeţean Buzău (2012))

Figure 1. 4: Romania 2004 Flood Map

Source: ReliefWeb (2004)

The natural resources from the mountains are a source of economy; this area lies in the Buzău river valley and this river encompasses two hydro-energetic stations and also provides water for irrigation purpose. Since the study area is a mountainous region, it experiences hazards like flash floods and landslides.

Buzau County is one of the most affected counties in Romania during the 2004 floods between 27th to 30th July. The main area of interest for the research is Nehoiu Valley, which lies along the Buzau River. Being situated between the Carpathians, the valley is subjected to hazards such as river floods, flash floods due to the torrential rainfall, debris flows and slow moving landslides. The study area was exposed to a number of flood events, the 1975 floods was the biggest flood recorded over the past 40 years during the period of May-June (Neagu, 2012). The 2004 and 2005 flood events were the main flood events that affected the main area of interest Nehoiu. The 2004 floods destroyed a great deal of infrastructure as the bridges, electric poles and roads along with damage to around 126 households in the Buzau County. The overall damage due to this flood event in 2004 is approximately 145 Billion Lei which is approximately 32.5 billion euros (Dinulescu, 2004). The torrential rain during this period also caused landslides in many areas of Buzau County due to the mountain slopes. The July 2005 flood event also caused similar damage to the buildings as well as the infrastructure in the Nehoiului Valley. During the same period several landslides due to the heavy torrential rainfall were also recorded causing damage to the built-up area (Lebedencu, 2005). Previous studies in this area also show that there are large numbers of landslides being recorded during the period between May and September (Micu, 2011).

Event	**Recorded Date/Month/Year/**
Flood	July 1975
Flood	27th to 30th July 2004
Flood	July 2005
Landslide	May and July 2005
Landslide	April and June 2006

Table 1. 1: List of Recorded/ Reported Hazard Events

(Source: (Amos News Agency, 2011))

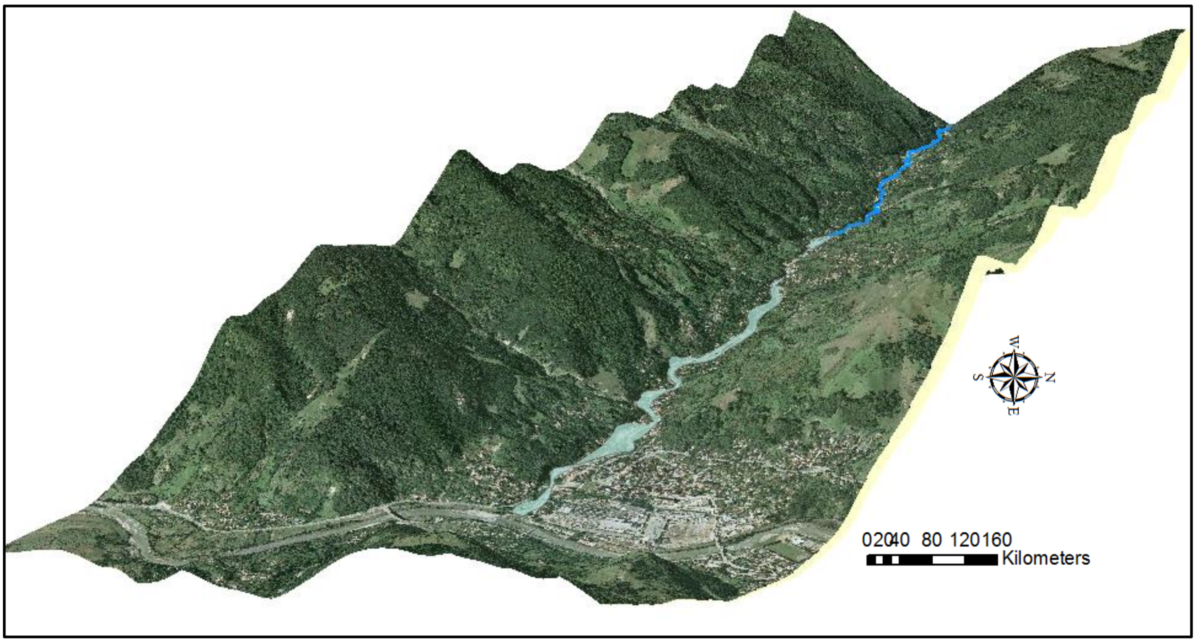


Figure 1. 5: Three Dimensional Impression of Nehoiu Valley

1.4.1. Project framework or cooperation with other groups

The research was carried out in collaboration with Ms. Roxana Liliana Ciurean, PhD Student in the University of Vienna related to the CHANGES Project. The CHANGES network (Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientist) is a Marie Curie Initial Training Network aiming to study how global changes, related to the environment and climate change affect the spatio-temporal patterns of the hydro-meteorological hazards and its risks in Europe (CHANGES, 2011). The project has several test sites including the Buzau region, Romania. Ms. Roxana Liliana Ciurean is currently working on her research in the topic "Expressing uncertainties in vulnerability and value of infrastructure, buildings and land use to hydro-meteorological hazards."

1.5. Outline of the Thesis

The research consisted of three phases pre-field work phase (literature review), field-work stage (data collection) and Post-field work stage (methodology and analysis). These phases are organized across the research in different chapters.

Chapter 1: This chapter deals with the overall overview of the research. This chapter includes the research objectives, research questions, methodology and the study area information.

Chapter 2: This chapter discusses the background literature regarding the research. The chapter explains the different types of vulnerability assessment methods. The literature on the existing vulnerability curves for Reinforced Cement Concrete (RCC) and wooden structures are elaborated and discussed.

Chapter 3: This chapter comprises of the "field-work phase" and explains the data collection methods and the data that was collected during the fieldwork.

Chapter 4: The weighting method will be discussed and the vulnerability analysis for building vulnerability. The analysis for both the experts and the ESR's is explained. This chapter also explains the uncertainty analysis by using the existing vulnerability curves which collected and explained in the literature.

Chapter 5: explains the use of the vulnerability values in the risk assessment for flood and landslides.

Chapter 6: provides the conclusions according to the proposed research questions. This chapter also discusses the recommendations for future work.

2. PHYSICAL VULNERABILITY OF BUILDINGS AND ITS UNCERTAINTY

This chapter introduces the topic of physical vulnerability assessment. This chapter also discusses the existing vulnerability curves from different countries and their differences. It continues with an explanation of the existing vulnerability curves and its variation. Finally how these curves can be used in the research.

Vulnerability assessment is an essential component in quantitative risk assessment, as is illustrated in Figure 2.1. In this figure the schematic procedure for risk assessment is shown. Several hazard scenarios with different return periods and with intensity maps are required. Elements at risk information are needed with a valuation of the amount (e.g. as costs). Elements at risk maps and hazard maps are overlain to produce exposure maps. Intensity values from the hazard maps are used for the exposed elements at risk to represent their degree of damage using vulnerability curves. The vulnerability value is than multiplied with the costs and plotted as loss, against the temporal probability of the hazard scenario. This is done for all scenarios and all elements at risk, resulting in a risk curve. The area below the curve represents the average annual loss, and forms the basis for quantitative cost-benefit analysis of risk reduction measures (van Westen, 2013)

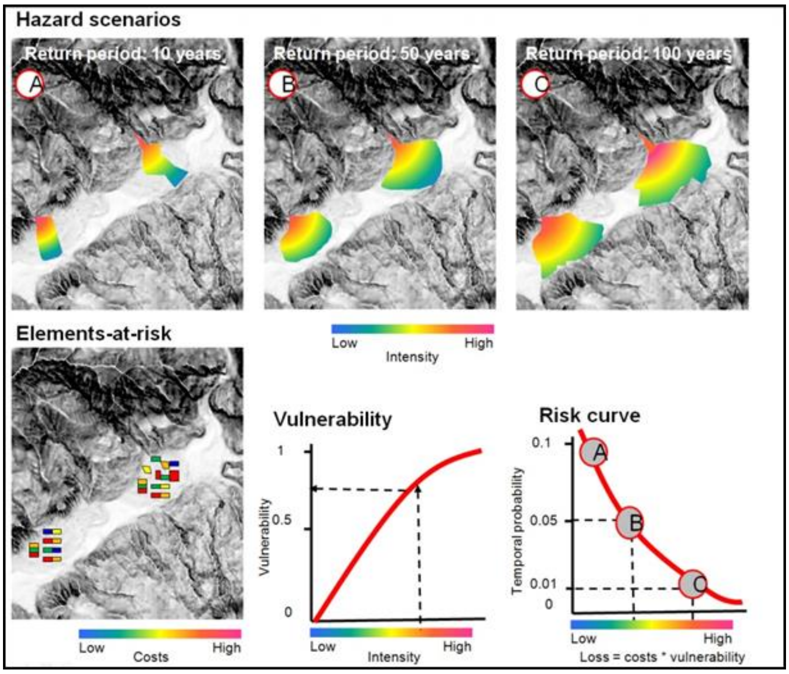


Figure 2. 1: Schematic representation of the procedure for Risk Assessment and the role of Vulnerability

(Source: (van Westen, 2013))

2.1. Vulnerability Assessment

It is crucial to assess the vulnerability as it is a significant part in the risk assessment. The assessment methods vary for different hazards especially for physical vulnerability of buildings as the assessment for each hazard is depends on parameters like building characteristics and the hazard characteristics and also the availability of data. The parameters considered for the building vulnerability are hazard specific. For physical vulnerability to flooding water depth, flow velocity and the impact pressure can be considered as the crucial factors that determine the vulnerability. Whereas for seismic vulnerability the Peak Ground Acceleration (PGA), Peak Ground Displacement (PGD) and Modified Mercalli Intensity (MMI) are considered (ENSURE, 2009).

However for landslides this is not the case, as landslides are more complex as they form a large group of processes (fall, slide, flow, mixed) and have a wide variation in characteristics. This makes it much more difficult to represent magnitude, intensity of flow, duration, exact location, distance travelled by the debris and speed of flow (Glade, 2003). The parameters that were considered for landslide vulnerability assessment are deposition height and flow depth which is also the intensity of the debris flow, this was developed by Akbas et al. (2009) and Fuchs et al. (2007)

Physical vulnerability of a structure can be assessed qualitatively, semi-quantitatively and quantitatively using vulnerability indices, vulnerability curves, fragility curves and vulnerability matrices.

2.2. Vulnerability Index

Vulnerability indices are used in a quantitative vulnerability assessment using a defined set of indicators that indicate the vulnerability of an area (ICRISAT, 2009). The indicators are generally assigned weights based on their importance; the sum of these indicators with their assigned weights with respect to their importance gives the vulnerability index (Plate, 2006). León (2006) developed a method to assess the physical vulnerability of a structure based on its building characteristics, this method involved a vulnerability scale (low, medium and high) to the building characteristics with respect to its material. Weights are assigned to both the vulnerability scale (low, medium and high) and the building characteristics in a matrix; this gives a value expressing its vulnerability. The numerical range of values gives the degree of vulnerability. This method needs an extensive database for the accurate assessment and this is very effective for a hazard of very high magnitude.

The indicator method that is used to express the vulnerability with indicators is mostly based on the concept of Analytical Hierarchy Process (AHP). AHP is a tool for Multi Criteria Decision Making and Multi Criteria Analysis (MCA); it was developed by Prof. Thomas L. Saaty in the early 1970's. This MCA technique uses the relative weights and incorporates the concept of using these weights to carry out a pairwise comparison (Armas, 2012). Papathoma et al. (2003) carried out vulnerability assessment (The Papathoma Tsunami Vulnerability Assessment (PVTA)) for built environment due to Tsunami, considering the worst case scenario and the parameters which would contribute to the vulnerability of the built environment. The assessment was carried out based on different vulnerability classes ranging from low to very high; these classes are based on the impact of the hazard on the built environment using historic data. This PVTA model method was then revised by Dall'Osso et al. (2009), by incorporating the concept of AHP in the building vulnerability assessment and by assigning weights to the factors that contribute to the vulnerability. The assigned weights are based on expert judgement and are then evaluated pair-wise. Müller et al. (2011) also used an indicator based methodology, based on expert judgement to assess urban vulnerability due to flood hazard, similar to Rondon and Chio (2011) who used indicators and weights to assess the structural vulnerability of masonry buildings to landslide hazard.

This indicator based method can be used in area with limited data availability issue also the selection of the indicators for the assessment is local conditions of the study area. The parameters or indicators chosen are based on the general information of the building in the study area. The main advantage is that since it is based on expert judgement, it gives the perspectives based on the experts and the results of the assessment delivered will be subjective to the stakeholders for decision making. However the disadvantage of this method being that it does not provide damage in relation to intensity, and does not lead to quantitative risk.

2.3. Fragility Curves

Fragility curves are one another method to assess vulnerability and are most commonly used in seismic vulnerability assessment. Fragility cures are used to determine the damage probability of a structure with respect to various pre-defined damage states (slightly damaged, moderately damaged, completely damaged) (Kerstin Lang, 2002). The intensity of the ground motion is measured with different parameters as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Peak Ground Displacement (PGD), spectral Acceleration (S_a), Spectral Displacement (S_d), Modified Mercalli Intensity (MMI) and Parameterless Scale Intensity (PSI). The PSI is based on building damage and it relates to the damage grade of D1 to D5 of the MMK, the PSI is also an alternative to the distinct intensity scales. Based on the type of damage data available, fragility curves cam be categorised as empirical, judgement, analytical and hybrid curve (Molina Palacios, 2004).

Empirical curves are used when the damage data of the past earthquake events are available; the representation of the curve depends on the parameter of the hazard intensity that is considered. Damage Probability Matrices (DPM) is expressed graphically as a histogram; this expresses the damage level and its distribution for the scale of intensity which is generally a Parameterless Scale of Intensity (PSI). Empirical curves can also be represented using the ground shaking parameters as PGA, PGV, PGD, S_a and S_d. The significant aspect of this method is that since they are based on the data from the past events, this would represent the most accurate building response and its damage. This method is suitable only for the buildings in a region with similar building population. However the disadvantage being that it requires extremely large amount of data and the fact this method does not consider the modification in the structure since the last event (Kerstin Lang, 2002).

Judgement curves are based on expert opinion, based on their judgement on the probability and the extent of damage for a particular intensity of the earthquake. Analytical curves are based on structural damage of a model of any building type, which is subjected to an earthquake simulation by varying its parameters. This method is carried when there is a lack of available damage data for the analysis. Hybrid curve are generally a combination of empirical, judgement and the analytical curves (Molina Palacios, 2004).

Fragility curves are also used in assessing the seismic vulnerability of lifeline structures like bridges and pipelines (ASCE, 2003).

2.4. Vulnerability Curves

Vulnerability curves are the most commonly used method of assessing the physical vulnerability. These curves express the physical vulnerability as a relationship between the hazard intensity and the expected damage. The vulnerability curves also indicate the degree of damage and loss due to the damage, which can be incorporated in the risk assessment. The main advantage of the vulnerability curves is that it can be used in a large scale for earthquake, flood and landslide hazard (Kappes et al., 2012).

2.4.1. Floods

Physical vulnerability deals with the vulnerability of the built environment, emphasizing on the structural integrity of a building to withstand the flood. The impact of the flood on the structure is based on various parameters like inundation depth, velocity of the flow, duration of the flood, water, and pressure of the water, sediments and toxic substances that are present in the water. Vulnerability assessment of buildings to floods focuses on how vulnerable a structure is to a flood based on its characteristics such as the structural type, number of floors etc., and estimates the degree of damage to the building. The degree of damage of a structure whether actual or expected is expressed as a loss as a percentage or in monetary value (Merz et al., 2010).

Vulnerability curves are one of the most common methods to assess flood physical vulnerability. Stage-Damage/ Depth-Damage curves are used to assess the damage to a structure due to flood hazard as they give the relationship between the hazard intensity and the damage due to it. In flooding, the common idea being the higher the water height is the greater the loss would be. These curves are categorised into actual damage survey curves and synthetic curves. Actual damage survey curves are based on the information of previous hazard events and these can be used to predict the impact of future events for similar types of constructions. Since these available data are for a set of specified elements at risk (e.g., building types) it would be difficult to extrapolate these to other areas with building that have other characteristics. Inorder to overcome these difficulties, synthetic stage-damage curves were developed and these were based on hypothetical analysis by choosing the types of houses and extrapolating the losses due to floods instead of using the existing damage information from previous flood event (D. Smith, 1994). The main advantage of this method is that it could be used for different building types and occupancy types.

Synthetic stage-damage curves can be categorised as two types, existing database and valuation survey method. However both these methods require the elements-at-risk; that is the building type and its contents to be divided into different classes to carry out the analysis. The existing database method requires the building and occupancy type to be divided into different classes and the existing information on the impact of flood on the building material gives the estimation of damage to the building fabric and also its contents. The main concern regarding this method is that it considers the market price of the content and not considering the social class of the owners. Moreover this method requires a large database making it difficult to use it in all the countries due to the availability of data. Valuation survey method as the name suggests it is based on data collected by conducting surveys. The information regarding the building types, contents and other characteristics as height above the ground level and quality of the structure in the flood hazard prone area are collected using checklists for a selected area of interest. The overall information is then taken as an average and the stage-damage curves are plotted based on this information. This method provides the potential damage and loss due to the damage due to the flood hazard (Badilla-Coto, 2002).

The existing stage-damage curves for both the Reinforced Cement Concrete (RCC) and wooden structures that were used for the analysis are briefly described. The parameters used for creating the stage-damage curves vary in each research and each country and it is described briefly in the following section.

Penning-Rowsell and Chatterton (1977) used absolute damage value to determine the economic loss due to floods in the UK, the stage-damage curves used the flood height and damage value in Great Britain Pounds for each type of building. The data used was collected by surveying the affected areas post-flood. The maximum loss value for semi-detached house is "1" for total collapse and the curve is reconstructed as shown in Figure 2.2

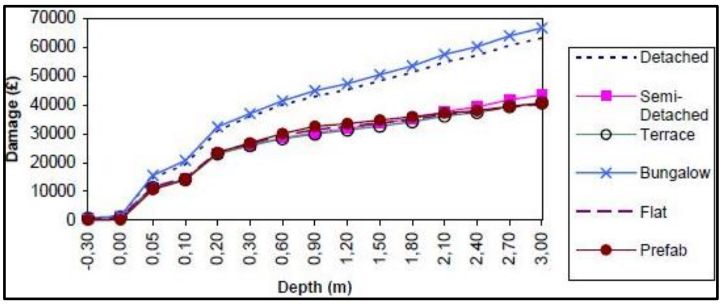


Figure 2. 2: Existing Stage-Damage Curve – UK

(Source: Penning-Rowsell E C et al. (2003))

Dutta et al. (2003) developed a set of vulnerability curves for Japan for estimating the loss due to floods, using stage-damage curves. The relationship between the flood depth and the damage for buildings accounts for the vulnerability. The damage data used for creating this curve is based on the historic data that has been collected by site survey. The vulnerability curves are as shown in the Figure 2.3.

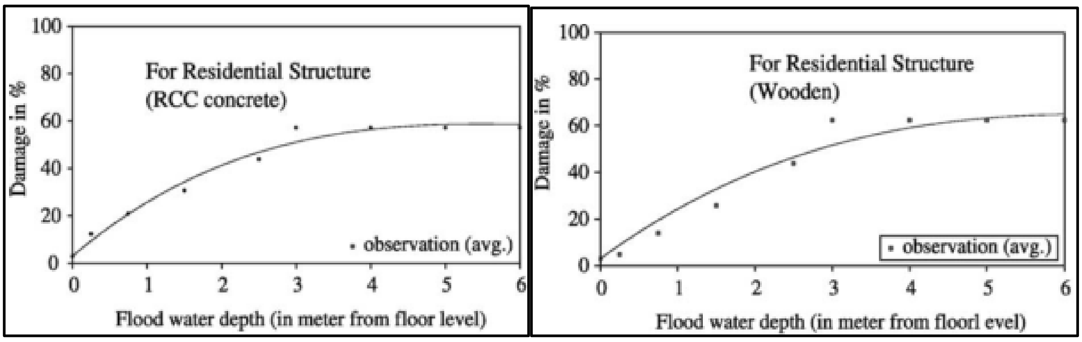


Figure 2. 3: Stage-Damage Curve in Japan for RCC and Wooden Structure

(Source: Dutta *et al.* (2003))

Huizinga et al. (2004) developed a model for evaluating the direct loss due to flood using stage-damage curves in Netherlands for residential buildings. The flood depth and the damage factor were considered for evaluating the loss. The damage factor is based on the historic damage data and expert judgement and takes into account the depth of the water, velocity and building material for the type of building. Jonkman et al. (2008) also developed a model for estimating the damage to flood hazard in the Netherlands, using the stage-damage curves. The estimation of economic loss due to floods is estimated using the relationship between the inundation depths to that of the damage to the structure. The damage factor is calculated using the historical data of the extreme events which were catastrophic, available literature and expert judgement. It can be seen that at a depth of 4.5 m there is a complete damage to the structure.

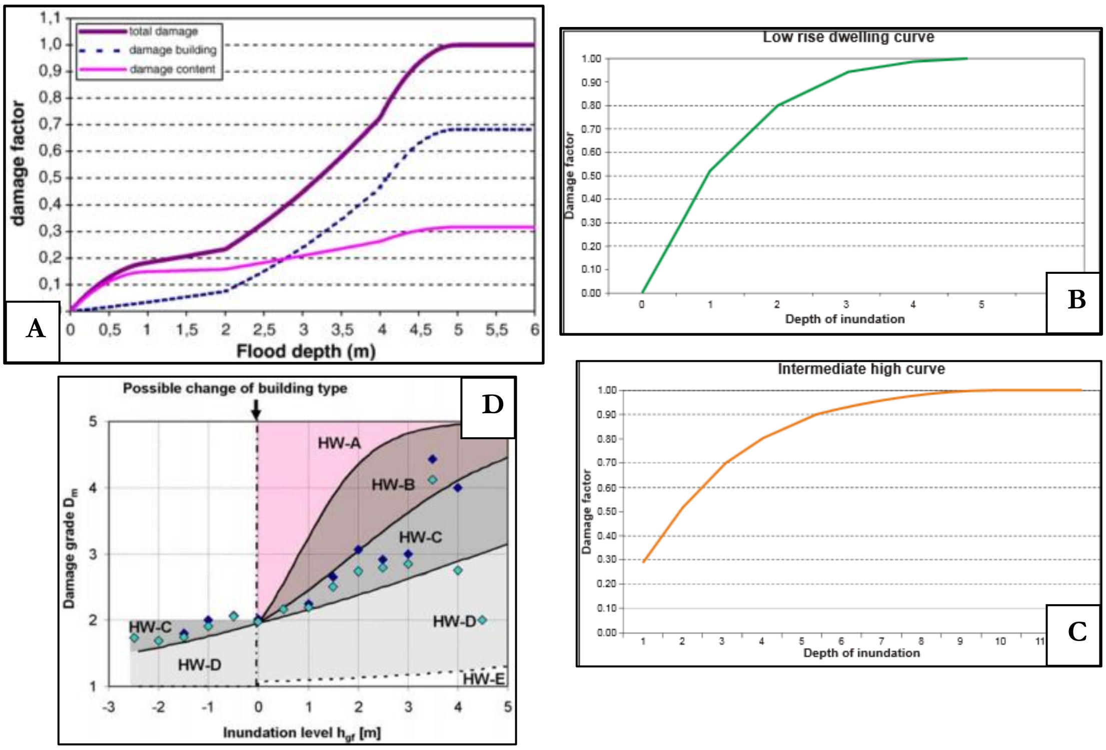


Figure 2. 4: Stage- Damage Curves from the Netherlands (A, B and C) and Germany (D)

(Source: A- Jonkman *et al.* (2008), B & C - Huizinga *et al.* (2004), D - Schwarz and Maiwald (2008))

Schwarz and Maiwald (2008) developed a loss prediction model for Germany to different building types based on the vulnerability of building types for flood hazard. The stage-damage curves were created using the damage grade and the inundation depth, the damage grade for the different types of buildings is categorised from D1 to D5 no damage to heavy damage of the structure. The damage grade is accounted for both structural and non-structural damage. The building types are based and modified from the

Earthquake and damage loss model EMS-98, wherein the building type and the vulnerability is assigned to it.

Reese and Ramsay (2010) developed a tool RiskScape to determine the damage to infrastructure, buildings, people and property and also the impact in New Zealand due to flood hazard. Stage-damage curves in RiskScape are based on the Damage ratio and the flood depth for different types of buildings. The damage ratio is based on the damage state including both structural and non-structural elements ranging from DS0 (insignificant) to DS4 (total collapse) and the damage ratio is categorised as 0-0.2 for the damage state DS0 to >0.95 for DS4. The Maximum flood depth is considered as 5m (Refer Table 2.1).

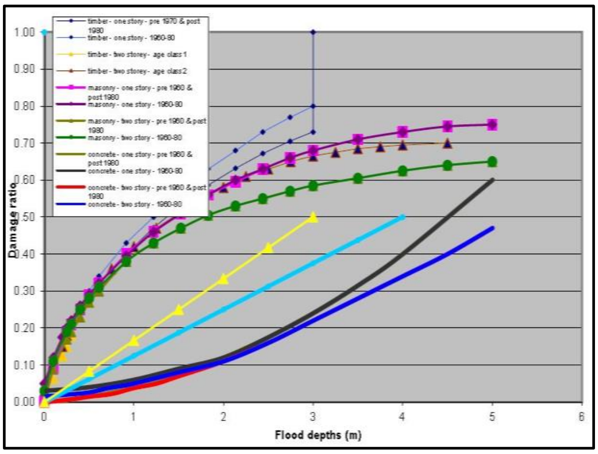


Figure 2. 5: Stage-Damage Curves New Zealand

(Source: Reese and Ramsay (2010))

Vulnerability is expressed as	Country	Description	Advantages and Disadvantages	Source
Absolute Damage	UK	Damage in GB Pounds	The main problem with this method is that due to inflation these values change every year, and also that different buildings of the same type can differ a lot in their total value.	Penning-Rowsell and Chatterton (1977)
Damage %	Japan	Using the historic data collected by the Ministry of Japan	The model requires only few parameters (floor area, type of building etc.,) to calculate the flood loss. Also needs detailed water depth for accurate loss estimation.	Dutta *et al.* (2003)
Damage Factor	Netherlands	It is calculated using the factors that represent the geographical location, water depth, velocity and the material factor for the respective building type.	The tool should be manipulated to be used in other countries, as the building types are different in different countries. Used mainly for floods of high magnitude.	Huizinga *et al.* (2004)
Damage Factor	Netherlands	Calculated based on historical data of the extreme events which were catastrophic, available literature and expert judgement	This curve needs detail damage information.	Jonkman *et al.* (2008)
Damage Grade	Germany	D1-D5, structural and non-structural damage as an indicator collected using questionnaires and interview.	Converting the questionnaires and interviews to damage grade has to be carried out by experienced engineers for assigning the vulnerability using the damage grade.	(Schwarz & Maiwald, 2008)
Damage Ratio	New Zealand	Damage State (DS0 to DS4) of both structural and non-structural elements in terms of Damage Ratio	The maximum level of flooding is considered to be 5m upper limit.	Reese and Ramsay (2010)

Damage Percentage	U.S.A	Damage data collected is based on the actual loss from the previous flood events.	Even though the curves were for structures with no basement, there was still a damage value for the negative flood depth inferring to a basement.	U.S. Army Corps of Engineers (2000)

Table 2. 1: Description and Evaluation of the Existing Vulnerability Curves (RCC)

The existing vulnerability curves for RCC structures are as shown in the Figure 2.6. Even though existing curves collected were for RCC residential structures; there is a large variation between them. One of the main reasons could be that different countries have different construction styles. Also the fact that the social factor comes into play as most of the curves are also based on interviews and questionnaires, and the damage may be based on the perception factor which varies between individuals. One another reason is that some of the curves also consider the velocity parameter while assessing the vulnerability. The individual curves were evaluated before the average and standard deviation curve was plotted. The Schwarz and Maiwald (2008) was however not taken into consideration as there is a large variation in the representation of vulnerability. The damage grade even after being reconstructed on a scale of 0-1 falls as an outlier compared to the other existing vulnerability curves.

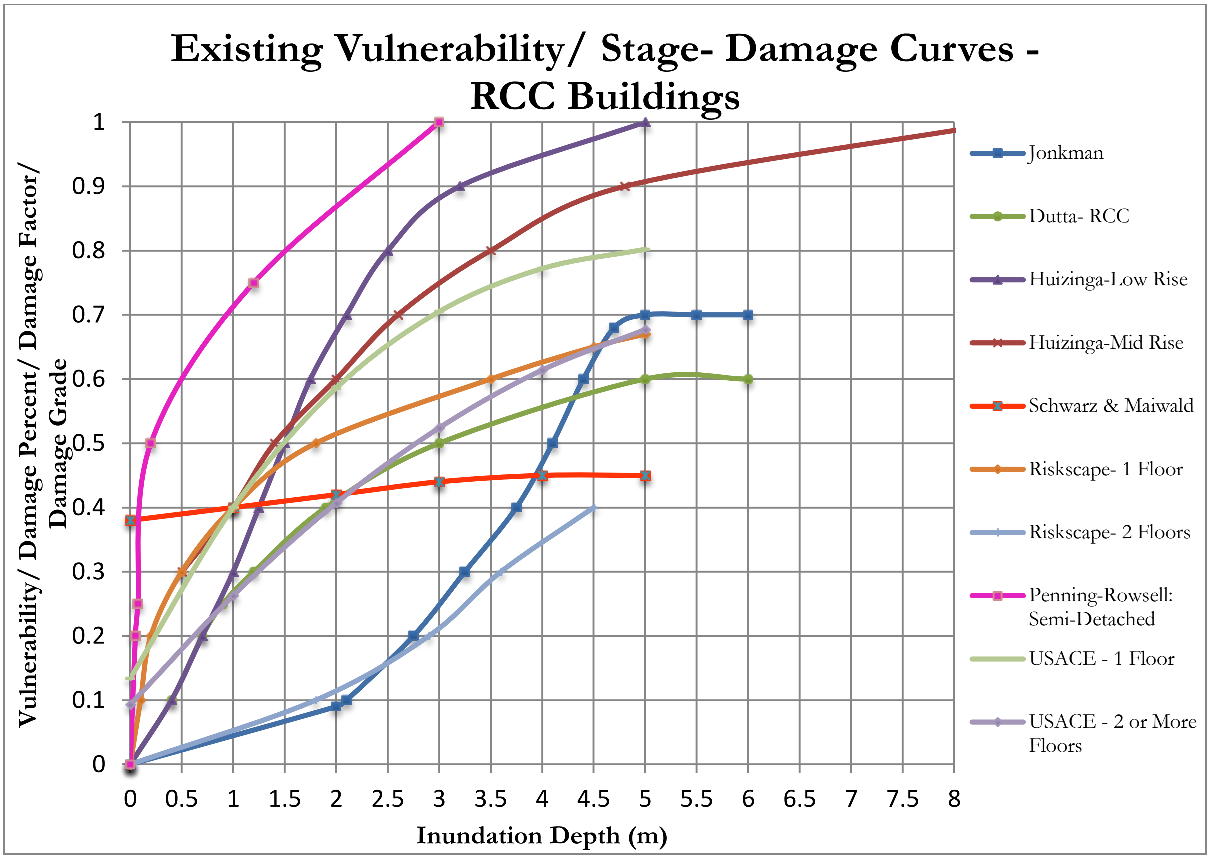


Figure 2. 6: Existing Vulnerability Curve Reconstructed – RCC Buildings

The available vulnerability curves for wooden structures were collected from literature and some of the existing vulnerability curves are described briefly below. Sagala (2006) classified vulnerability as damage of the structures to flood inundation on a scale of 0 to1 for the building type which was classified based on interviews carried out in the Philippines. Guarín et al. (2004) carried out flood risk assessment in San Sebastián, Guatemala, an area with limited available data. The analysis was carried out based on the 1998 flood event from the Samalá River in Guatemala and data was collected using detailed house to house survey. Based on the data collected a vulnerability curve was created using the inundation depth to the damage value ranging from 0 (no damage) to 5 (destroyed structure). The damage value corresponds to the vulnerability value for the wooden buildings ranging from 0.00 (no damage) to 1.00 (total destruction of the structure).

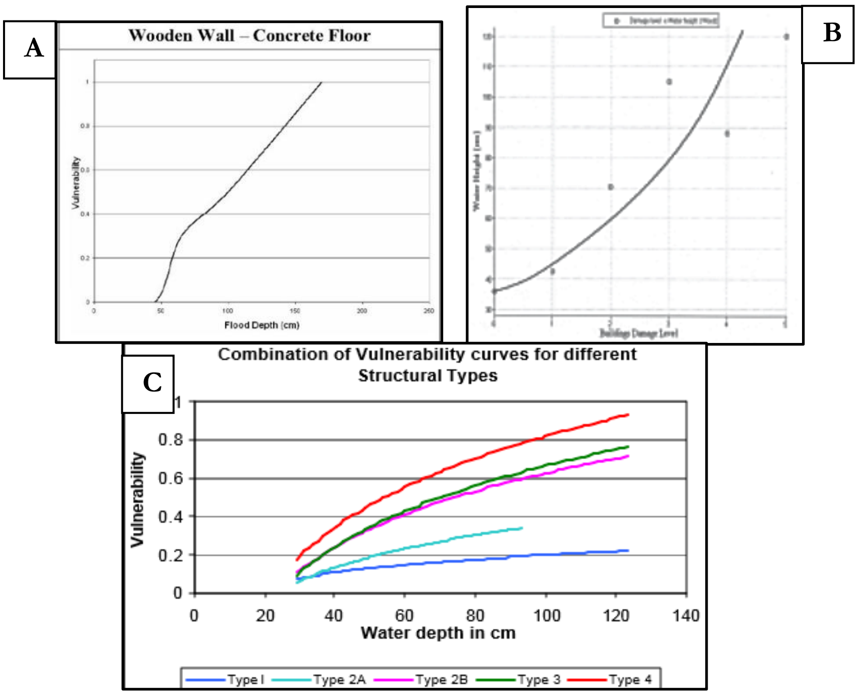


Figure 2. 7: Stage-Damage Curves for Wooden Structures in (A) Philippines (B) Guatemala and (C) India (Curve Type 3 – Wooden structure)

(Source: A- (Dhillon, 2008); Sagala (2006), B- Guarín *et al.* (2004), C- Dhillon (2008))

Dhillon (2008) carried out a micro level damage assessment in Orissa, India. The data was calculated based on fieldwork and house to house interviews. The results show that with a flood depth of 1.2 m there is a total collapse of the wooden structure. The collected existing stage-damage curves for wooden structures that have been collected for the analysis and is as shown in the Figure 2.8

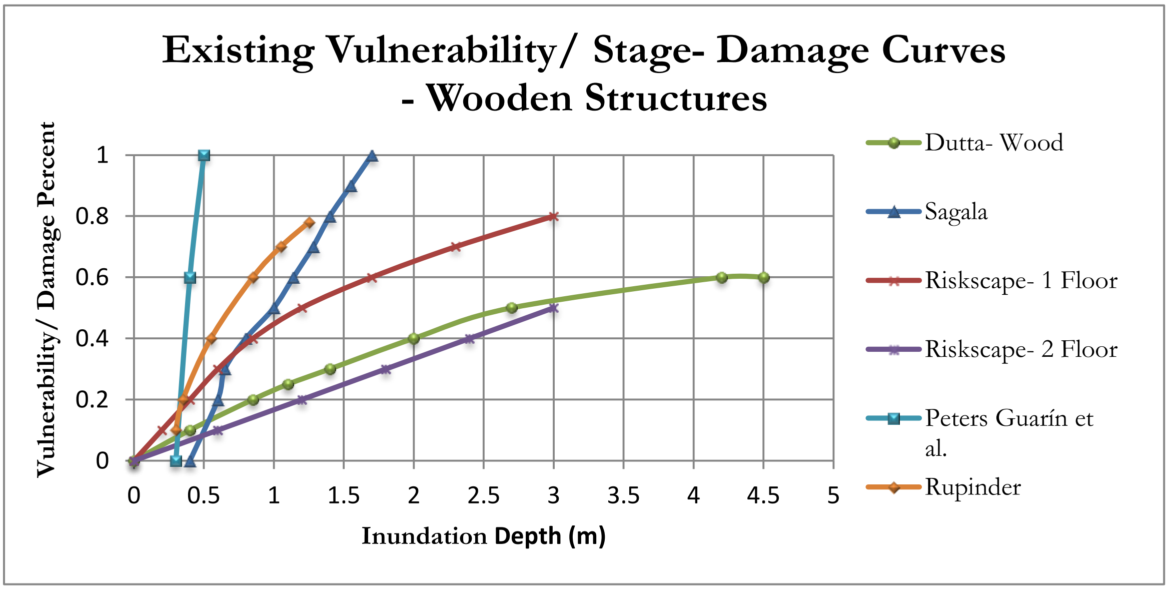


Figure 2. 8: Existing Vulnerability Curve Reconstructed – Wooden Buildings

2.4.2. Landslides

Physical vulnerability assessment to landslides has been one of the areas that are being studied extensively. To assess the vulnerability to landslides, it is necessary to know the characteristics such as the type of landslide, magnitude and intensity that are significant (Dai et al., 2002). However there are limitations in assessing the vulnerabilities to landslides such as the availability of the data and also the fact that the damage is relative. The damage to a structure could vary depending on the type of landslide, the impact and the damage caused by a debris flow is different to that of a rockfall. This variation is due to the velocity of the landslides that vary from speed class 1, with a velocity of 16mm/year to of speed class 7, with a velocity 5m/s (Glade & Crozier, 2004).

Considering all the factors and its significance, studies were carried out on vulnerability assessment to landslides. Galli and Guzzetti (2007) carried out a quantitative landslide vulnerability assessment using the damage and cataloguing it as light (aesthetic), severe (functional) and total damage (structural) and plotting it against the landslide area assuming that there relationship between vulnerability and landslide area. Akbas *et al.* (2009) developed an empirical model for debris flow for Selvetta in the Italian Alps, vulnerability to buildings was assessed considering the vulnerability as a ratio of loss to reconstruction value of each building to the deposition height due to debris flows. The analysis was based on 13 buildings which were affected due to debris flows, the deposition height is considered as the hazard intensity and it is seen that the vulnerability is increases proportionally to the deposition height.

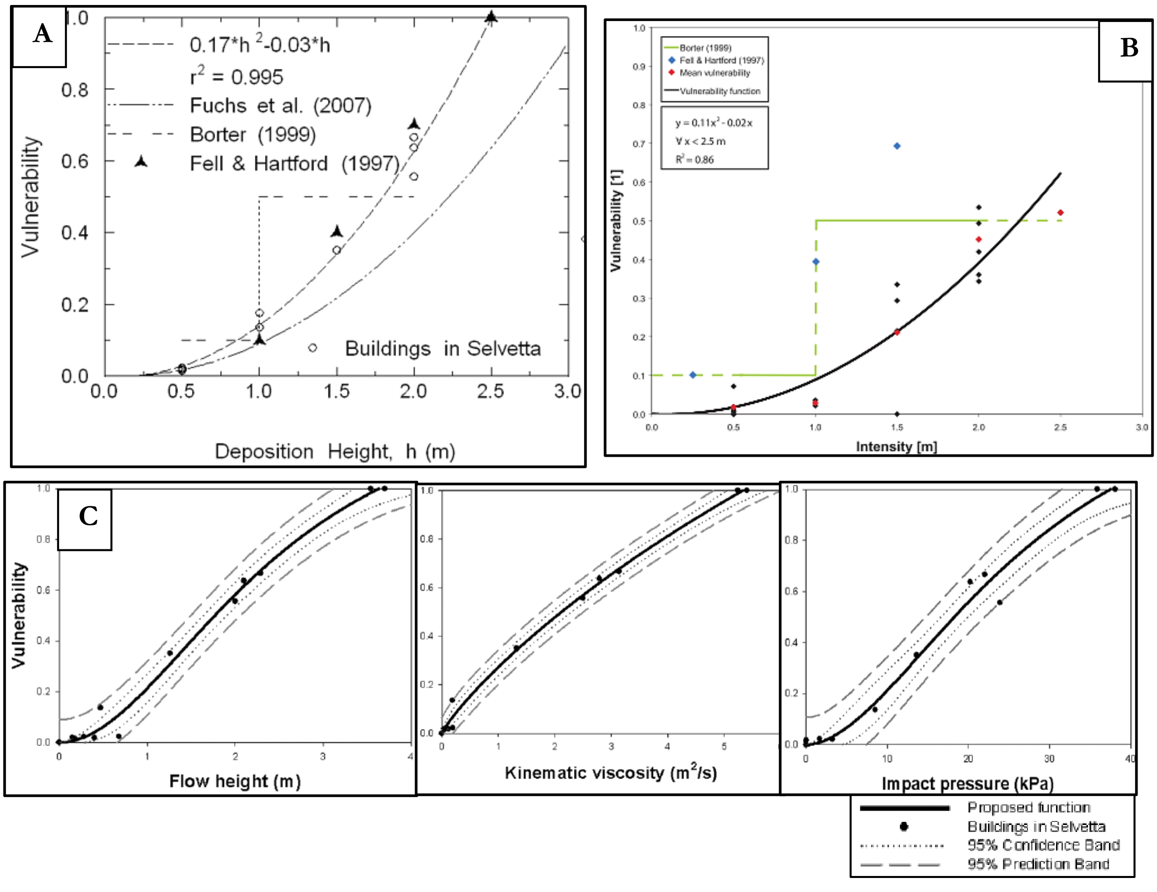


Figure 2. 9: Existing Vulnerability Curves for Landslides (A) and (C) Italy, (B) Austria

(Source: (A)- Akbas *et al.* (2009), (B)- Fuchs *et al.* (2007) and (C)- Luna et al. (2011))

This is similar to Fuchs *et al.* (2007) who also conducted a vulnerability assessment in Austria for debris flow, based on actual damage reports. A vulnerability curve was also created using depositional height in meters to the damage ratio i.e., the ratio of loss to the reconstruction value of the building of 37 damaged buildings. However these methods require sufficient historical damage and intensity information and are site specific which hinders the use of the curves as a standard vulnerability curve in different locations. Luna *et al.* (2011) modelled a debris flow in order to assess the physical vulnerability in Italy, the damage information related to 13 buildings were used for the analysis. Three different vulnerability curves were created based on three different measures of intensity of debris flow such as height of accumulation/ deposition height, impact pressure and kinetic viscosity.

Qualitative approaches like using the degree of damage to a structure are mostly used to assess the vulnerability due to landslides. Glade (2003) carried out a vulnerability assessment method, based on the damage intensity taking into account the type of damage a structure encountered. A completely structure was assigned damage intensity values "I to V," where "V" represents partial or total destruction to a structure will have a vulnerability value of "1." Jaiswal et al. (2011) assessed the vulnerability of buildings to landslides in a similar method as Galli and Guzzetti (2007), in this method a vulnerability value is given from 0 to 1. The vulnerability value is based on the landslide magnitude class (M-I, M-II and M-III), which is based on the run-out distance of the landslide and the volume of the landslide.

Physical vulnerability to landslides can be assessed using another method that is based on indices and indicators. León (2006) developed a vulnerability assessment method using a vulnerability matrix. This method considers different elements of a structure and its construction material. The materials are classified into classes as low, medium and high based on their strength and resistance to the impact of the hazard and weights are assigned to the elements of the building resulting in a vulnerability index of a structure. This method can be customised to a particular region emphasizing on its construction materials, however it requires a large amount of building data and fails at handling the hazard of different intensities. Papathoma-Köhle et al. (2007) developed an indicator based vulnerability assessment, this method collects the building characteristics including the surrounding components that would cause an impact on the structure, weights are assigned to the building characteristics based on its category using multi –criteria analysis. The factors to the categories are also assigned weights and these are then standardized, the product of these two results in a vulnerability value of a building. This method can not only be used for physical vulnerability but also social and economic vulnerability. However this method also requires a large amount of data with respect to buildings, its characteristic, its surroundings and their factors. Figure 2.10 shows the different physical vulnerability curves to debris flow.

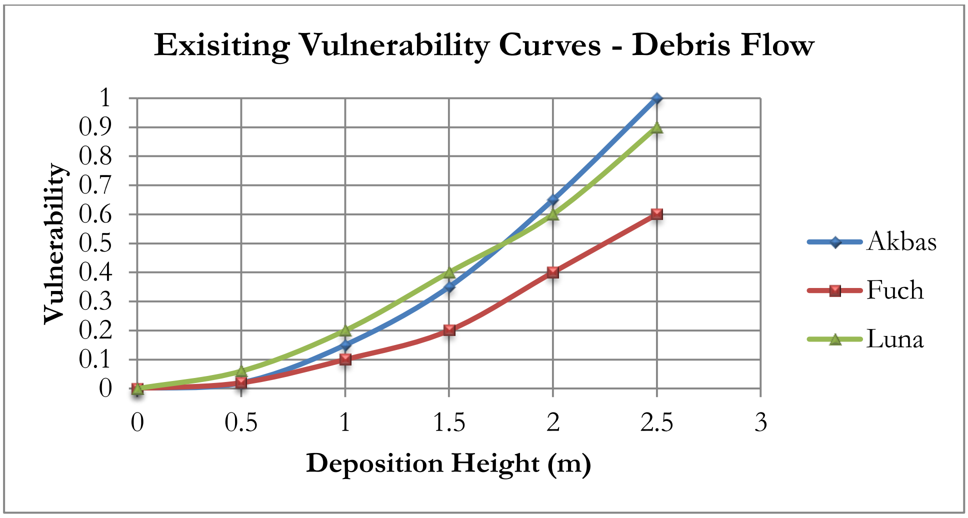


Figure 2. 10: Existing Vulnerability Curves – Debris Flow

2.5. Building Characteristic important for Vulnerability Assessment

To assess the vulnerability of a structure based on its building characteristics, it is necessary to identify the indicators and their importance. It is also important to identify the relationship and dependency of the indicators towards different hazards (Kappes *et al.*, 2012). The building characteristics define the vulnerability of a structure towards any damage to the structure from different hazards. Each building characteristics or building components has a distinctive response to each hazard, emphasizing on the hydro-meteorological hazards (Floods and Landslides).

2.5.1. Building Characteristics for Landslides

A landslide is defined as *"the downslope movement of soil, rock, or debris due to gravitational forces that can be triggered by heavy rainfall, rapid snow melting, slope undercutting, etc."* (Crozier, 1999). Landslides are categorised into different types: flow, fall, topple, spread or slide. Considering only the slow moving and rapid debris flow landslide, the rapid landslides are the most damaging to the structure, as the velocity of the flow is usually very high and these often occur without a warning. Slow moving landslides not any less damaging, this however can be mitigated if identified early (Highland & Bobrowsky, 2008).

The impact of mass is often considered for the building vulnerability. The damage depends on the distance, volume, velocity and the intensity of the flow. Landslide vulnerability is generally assessed as a degree of loss, as the vulnerability analysis is different for different landslide and there is no standard method of assessment.

Some of the factors to be considered are construction type, material of construction (including walls, windows and floors), height of the structure, structural type, building shape and maintenance (Papathoma-Köhle et al., 2011). Some of the important characteristics to be considered are as follows

- **Height of the building**

The higher the building the lower is its resistance to withstand an impact in case of a landslide, as the height of the building determines the flexibility of the structure. Hence tall buildings and higher number of floors are considered more vulnerable than the short buildings during a landslide. However in regards to damage the low rise buildings have more damage.

- **Openings in the structure**

The openings in the building are generally perceived as the weakest point in a structure and the impact of the mass movement on the structure depend on the direction of the openings and its size. The amount of debris flow that enters the house depends also depends on the height at which it is situated. A building is in highly vulnerable and more prone to damage of the structure and losses if there are a higher number of openings in the direction of flow (Papathoma-Köhle et al., 2012).

- **Location of the Building**

The location of the building and its proximity to an existing landslide or a steep slope which is prone to landslides is another significant factor to be considered. Although this is considered more of an exposure factor than a vulnerability factor, it still is quite significant with respect to the damage of a structure. The steepness of slope and the proximity are considered important as this decides the impact of the mass movement in the area (Dai *et al.*, 2002).

- **Structural Type and Construction Materials**

The structural type of a building expresses its vulnerability and the degree of damage during a landslide. It is seen that for rapid landslides the most vulnerable structures are the small wooden buildings followed by masonry buildings and reinforced concrete structures. The steel braced framed structure with aseismic building design is considered as the least vulnerable structural type (SAFELAND, 2011). This is similar to that of the wall material, where wood panels and steel sheets are considered as the highly vulnerable as compared to the Terra- bricks and the concrete bricks.

- **Type of Foundation**

The type of foundation is an important characteristic to be considered for buildings in landslide prone area. The foundation can be shallow or deep based on the type of soil and the amount of soil movement in the area. The type of foundation along with the depth at which it is constructed reduces the impact of the soil movement and stabilizes the structure. The building codes also play a major role in this as the structures without using proper building codes, lack structural strength and is more prone to damage during the landslide.

- **Maintenance of the Structure**

One of the factors that have been considered important for assessing the physical vulnerability to landslides is the maintenance of the structure along with the structural integrity. One of the parameters Rondon and Chio (2011) considers for the vulnerability assessment is the building preservation conditions as in the cracks in the structure from minor non-visible/ visible cracks on the wall to the wide cracks. The parameters cracks in the structure and the maintenance of the building also is also an indicator for the damage intensity in the vulnerability assessment by Glade (2003).

2.5.2. Building Characteristics for Floods

Flash floods are defined by World Meteorological Organization (WMO) as *"flood of short duration with a relatively high peak discharge in which the time interval between the observable causative event and the flood is less than four to six hours"* (WMO, 2006).

The impact of the flood can be drastic on buildings; this however can be mitigated and reduced. The impact on a structure depends on velocity of the floods, flood water depth, duration of the flood event and the content of the flood water including the debris. Some of the building characteristics that were considered important for assessing the vulnerability of a structure to flood hazard are as follows

- **Structural Type and Construction Material**

The capacity of a building to withstand the flood with a minimal damage depends on the materials used for construction and the method of construction. Structurally, Schwarz and Maiwald (2008) considers clay building to be the least resistant and most vulnerable to flood followed by masonry, reinforced concrete and buildings designed for flood resistance. The wall material can be considered one of the most important characteristics as it the first element in a structure that comes in contact with the flood externally. The material of the wall plays an important role with the whole of the structure.

- **Height of the Building from Ground Level**

One another factor that is significant for the flood vulnerability is the height of the building from ground level. The buildings in flood prone areas should be higher from the ground level, the higher the building less is the chance of the flood water to enter the building and less vulnerable to damage.

- **Number of Floors**

Number of floors is considered as an important factor in terms of damage for flood vulnerability, it is logical to think that the higher the number of floors in a building, the lesser would be the damage both in terms of structure and the contents. The damage is more for a low rise than a high rise structure.

- **Presence of Basement**

Penning-Rowsell and Chatterton (1977) describe basement as a structure, which partially above and partially below the street level in a building and is used predominantly for storage. Basements may have multiple openings that allow the water to flow inside the structure; they weaken the structure from the base as they are partially below the ground level. Therefore the presence of basement in a structure increases the vulnerability of a building towards flood hazard.

- **Quality of Construction and Maintenance of the Structure**

Structures lose their structural integrity and stability if not maintained properly. Buildings poorly constructed and poorly maintained tend to be damaged more than the buildings which are constructed with properly. The state of the structural and non-structural elements in a building forms the integrity of a structure.

- **Wall around the Building**

The wall around the building could be considered as a part of the flood proofing, although it might not be able to withstand the high velocity flash floods, it would still protect the building from being completely flooded. Reinforced walls provide higher protection for the building from being inundated.

The above mentioned characteristics were taken into account when designing the questionnaires for the building survey and fieldwork was carried out based on these characteristics that were considered important to the building vulnerability through literature for both landslides and floods.

2.6. Uncertainty Analysis

Over the last few decades, there has been considerable importance given to the uncertainty in vulnerability assessment, and the need to integrate this in the risk assessment framework as many of the factors that determine vulnerability are difficult to assess. Uncertainty exists in the risk management framework within vulnerability, it is an essential part in the vulnerability assessment (MOVE 2009). This is due to the fact that vulnerability involves various factors (social, physical, economic and environmental), which also change over time making this a complicated process (Birkmann, 2006). Uncertainty in vulnerability assessment aids in estimating the variation of losses and damage with respect to a hazard, this is then associated with risk analysis and decision making for effective risk management (E. Smith, 2002).

Figure 2.11 illustrates the importance of uncertainty in the risk assessment approach, which is based on the procedure described in the beginning of this chapter, and illustrated in figure 2.1. Each of the components in Figure 2.1 can have a substantial degree of uncertainty. Return periods of hazard scenarios might have a range of values, as well as the modelled intensity. The elements at risk might have a large variation on the costs. But one of the most important aspects is the uncertainty in the representation of vulnerability, which could be better represented as a polygon, with a minimum and maximum curve then as a single average line. Taking these uncertainties into account the points in the risk curve are no longer represented as single points but as rectangles, where the Y-axis represents the variation in temporal probability and the X-axis the variation in losses (vulnerability * costs). This way minimum, average and maximum loss curves could be made which give a clear indication of the uncertainty involved (van Westen, 2013).

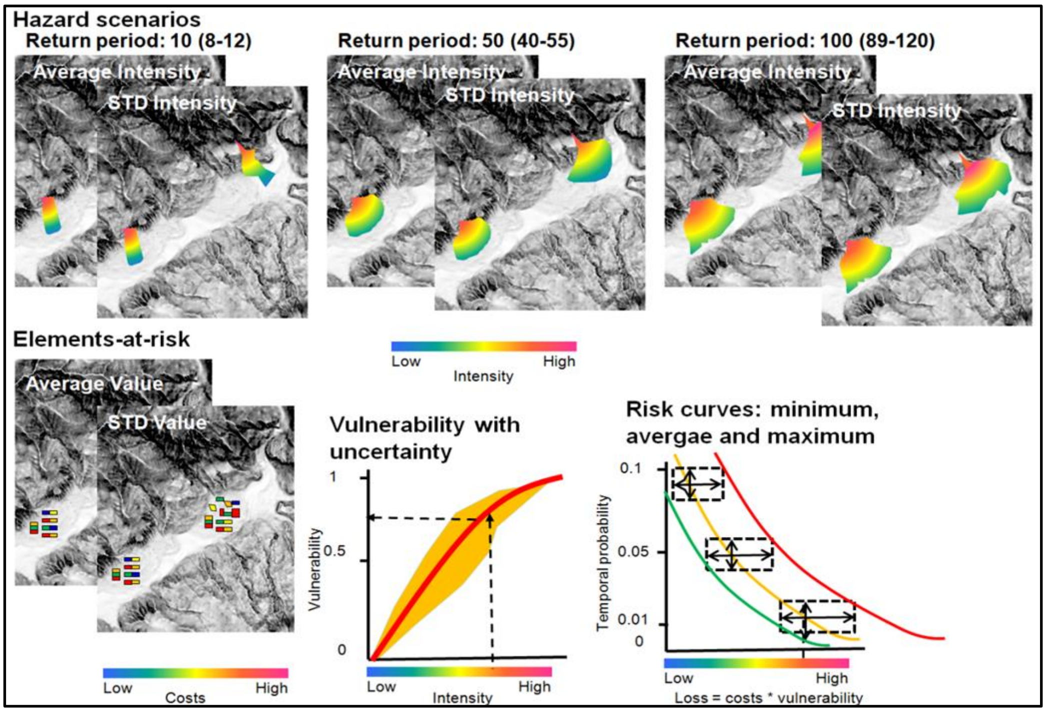


Figure 2. 11: Schematic representation of the procedure for the inclusion of uncertainty in the Risk Assessment.

(Source: (van Westen, 2013))

Generically uncertainty is categorized as aleatory and epistemic uncertainty. The former one is due to variations over time and the natural variability, while the later due to insufficient data or knowledge of the process(Apel et al., 2004). Aleatory uncertainty is the "actual" variability of the physical environment; it is due to the spatio-temporal variation of the physical environment and the inability to predict the nature of the future events. Aleatory uncertainty cannot be reduced and for vulnerability, the aleatory uncertainty is intrinsic (Wong et al., 2000). Whereas epistemic uncertainty as explained earlier is based on lack of knowledge about the behaviour of the system, this however can be reduced with data collection and increasing the sample size. Uncertainty can further be differentiated into parameter uncertainty and modelling uncertainty (MOVE, 2011). Parameter uncertainty is generally related to the input parameters and it is both aleatory and epistemic uncertainty, which in terms of building vulnerability the relates to the characteristics of a structure like the type of the structure, age, occupancy type and the height of the structure play an significant role in vulnerability assessment (Grossi, 2004).

There are various methods to conduct an uncertainty analysis; these methods are qualitative, quantitative and semi-quantitative. Based on the level of information available, the following methods could be considered for uncertainty analysis fuzzy logic, use of expert opinion, probability analysis, Monte Carlo Simulation (MCS), measures of random variability and First Order Second Moment (FOSM) method (MOVE, 2011).

Uncertainty associated with the quantification of physical vulnerability can be incorporated into the risk management framework. However uncertainty is not always taken into consideration in the physical vulnerability assessment due to reasons like data availability, lack of knowledge and the inability to represent it. Uncertainty with respect to building vulnerability deals with the evaluation of building loss and its replacement cost (Durukal et al., 2006). There is no standard way to define uncertainty with respect to vulnerability, as it is difficult to estimate the hazard intensity levels as well as to understand the behaviour of buildings (Rahnama et al., 2004). The buildings of the same class behave differently when exposed to the same hazard intensity due to the differences in their characteristics both in terms of its

structure and its contents. Vulnerability curves are generally used to assess building vulnerability based on their characteristics involved in the construction and are specific to each building type (Eleuterio, 2009). There exists damage uncertainty in vulnerability curves and stage-damage curves due to the lack of historic damage data, lack of information on hazard intensity, structure value and content to structure value and these uncertainties can be evaluated as a measure of error due to its variability (Briant, 2001).
To analyse uncertainty in building vulnerability on a large scale can be tedious and would need a detailed inventory, in such cases the building characteristics play an important role. The uncertainty of existing building can be expressed using the standard deviation; this can be carried out by taking into account the variability of the building characteristics to the vulnerability function (K. Lang, 2002). Since uncertainty is the variation between estimated values to the actual value, it can be measured using standard deviation which can be calculated using variance. Standard deviation is the square root of the variance and higher the standard deviation, higher is the uncertainty (Thomas & Maurice, 2010).

2.6.1. Uncertainty Analysis Methodology

The uncertainty analysis for the building vulnerability was carried out using the following approach:

- Based on the literature study the available vulnerability curves for the two specific building types present in the area (RCC and wood) were collected and curves that were not representative were removed from the dataset. The curves were also brought back to the same measurement levels: intensity expressed as water height in meters and damage degree between 0 and 1.
- The vulnerability values from the resulting vulnerability curves were then taken together for the same level of intensity, and the average and standard deviation vulnerability values were calculated.
- The curve was then presented as an average curve together with the two curves showing the standard deviation. The results for floods are shown in Figure 2.12 and 2.13 and for landslides (debris flow) in the Figure 2.14.

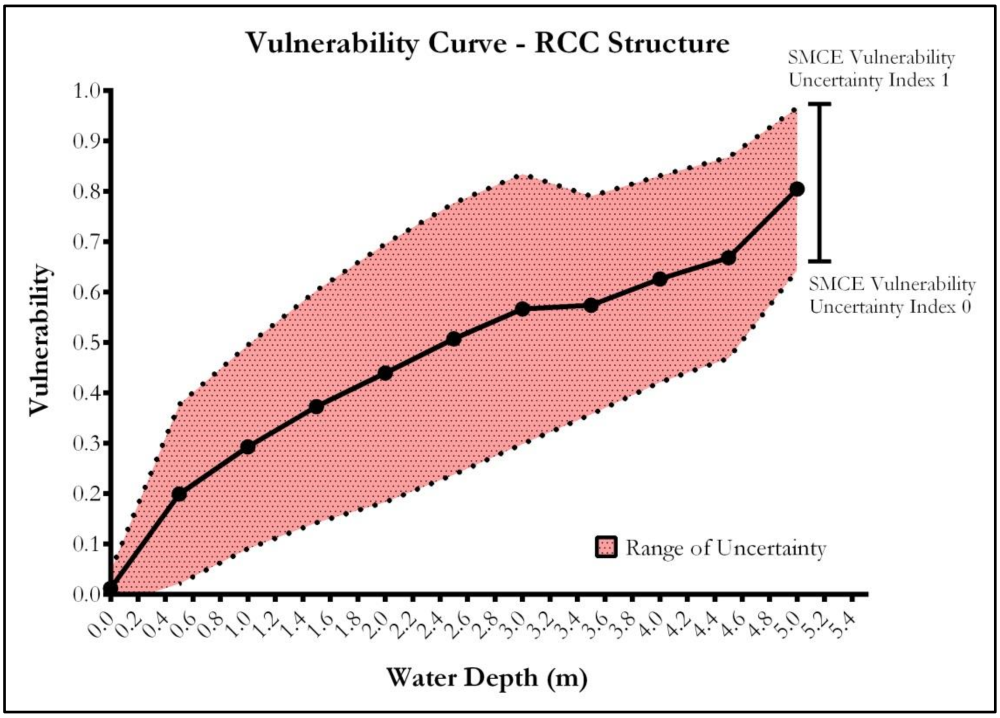


Figure 2. 12: Averaged Vulnerability Curves of RCC Structures

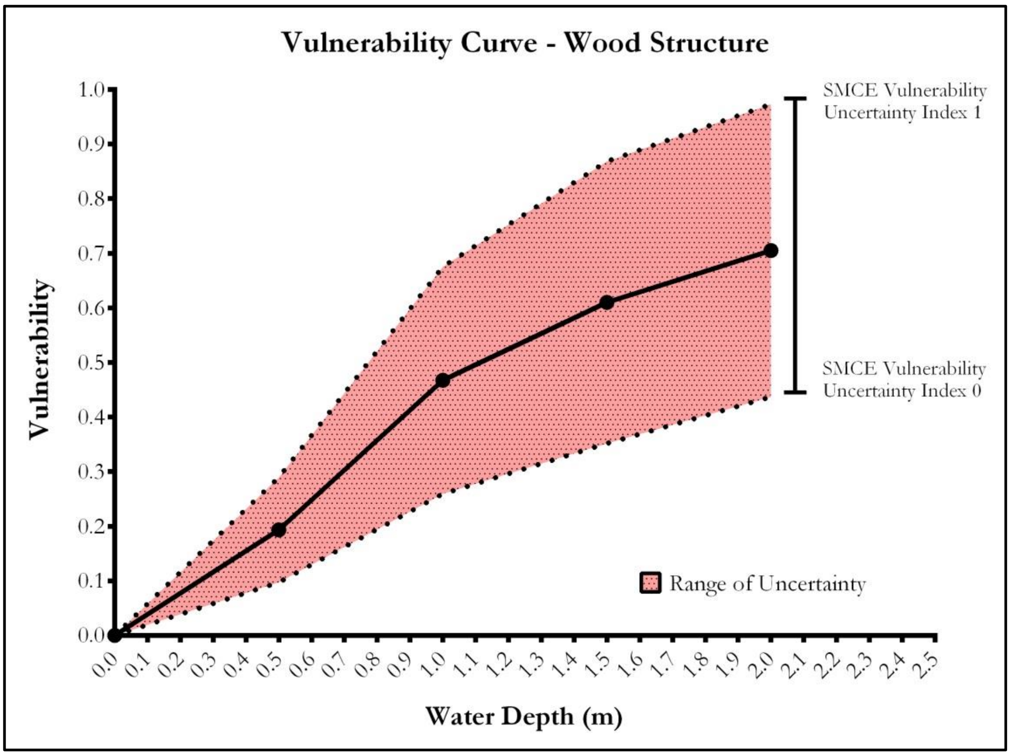


Figure 2. 13: Averaged Vulnerability Curves of Wooden Structures

- ➢ The black line in the centre represents the average vulnerability value of the collected existing vulnerability curves. The calculated standard deviation is plotted on the graph and is represented as the shaded pink area.

The averaged vulnerability curve for debris flow from the existing vulnerability curves was plotted considering the vulnerability versus deposition height in meters is as shown in the Figure 2.14.

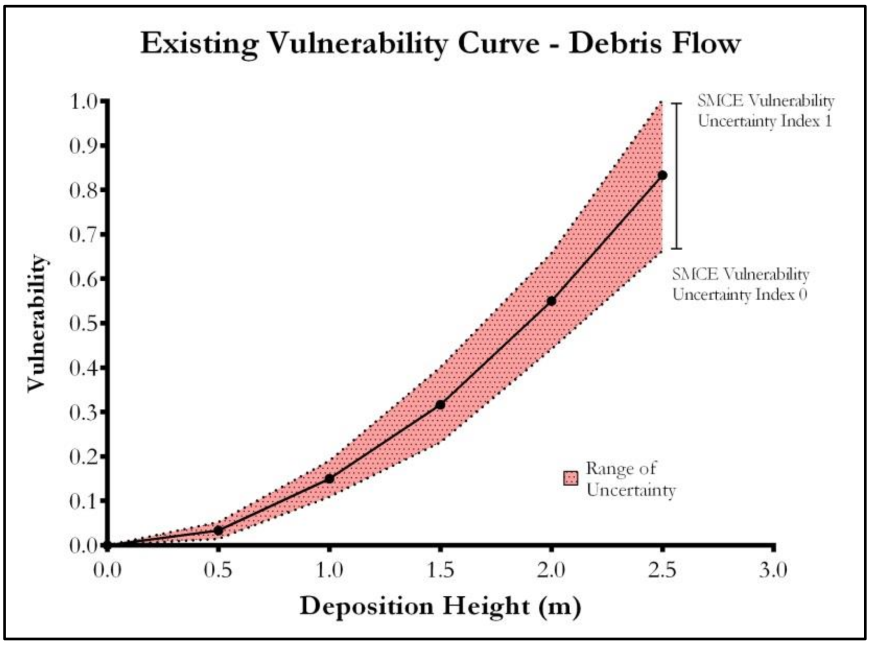


Figure 2. 14: Averaged Vulnerability Curve for Debris Flow

- ➢ For individual buildings the vulnerability uncertainty index method which is based on expert based weights and the characteristics of a building, was then used to represent the specific vulnerability curve of a building. The index value of 0 was used to show the lowest vulnerability curve in the coloured part of the graph. A vulnerability uncertainty index value of 1 means that the particular building is at the maximum level of the coloured vulnerability area within the graphs.

The main reasoning behind this methodology is that the range of vulnerability uncertainty index calculated (0-1) lies in the shaded area of the average and the standard deviation. The vulnerability curves for single buildings are plotted in the graph with respect to their vulnerability uncertainty index value, which relates to the relative importance of the contributing factors related to this building, and the actual classes of these indicators for the specific building. In this way each building could be represented by a specific vulnerability curve that falls within the shaded uncertainty range for all the buildings of the same construction type. Given certain intensity for the hazard (e.g. a certain flood height) for that specific building would then give a specific vulnerability value that can be used in the risk assessment. Figure 2.15 represents the methodology of vulnerability uncertainty index plotted on to the vulnerability curve and the vulnerability for a specific building.

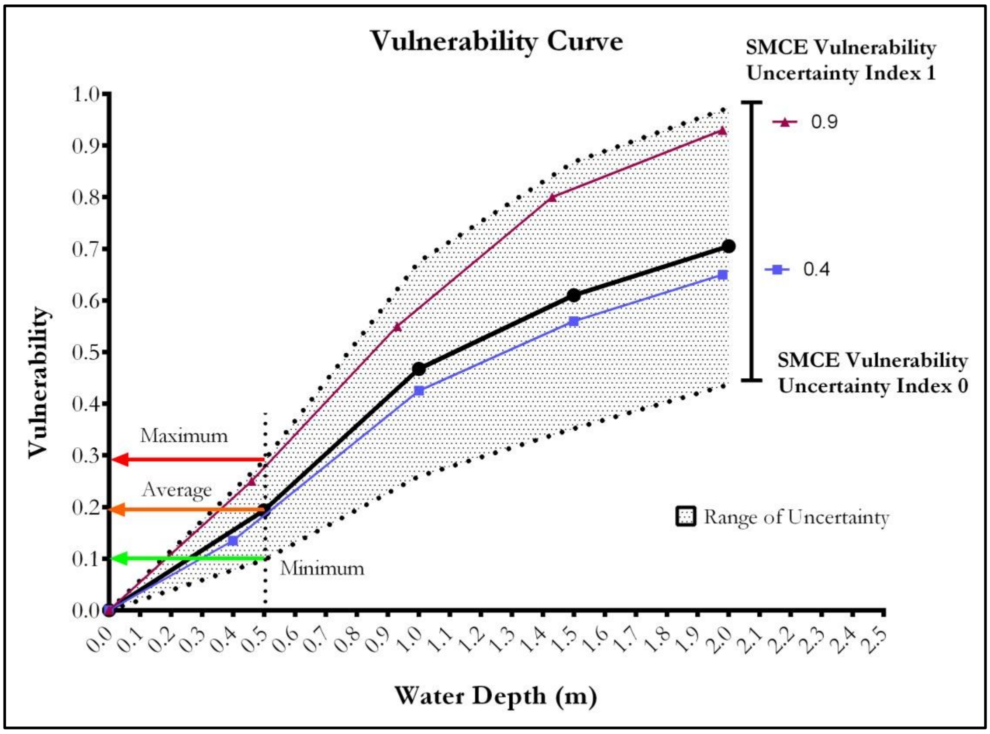


Figure 2. 15: Description of the Plotting Methodology

3. FIELD DATA COLLECTION AND GENERATION OF A DATABASE

This chapter deals with the "pre-fieldwork" and "fieldwork" phase of the thesis and it explains the fieldwork data collection process and the generation of the input maps used in the analysis.

3.1. Pre-fieldwork Data Collection

3.1.1. Existing Data Collection

The available data and the obtained data are as shown in the Table 3.1

Available Data			Obtained Data
Data Type	**Format**	**Extent**	
Landslide Inventory (Location –Point Map)	Vector (Shape file)	Buzau County	Yes
DEM	Raster	Nehoiu	Obtained from Mr. Rodrigo Lopez (the process is explained in the following section
Elements at Risk	Vector	Buzau County	No
Damage Values	Vector	Buzau County	No
Economic Losses due to previous events	Vector	Buzau County	No
Buzau Boundary Limit	Vector	Buzau	Yes
Flood Hazard Information (Intensity)	Raster	Buzau	No
Landslide Hazard Information (Intensity)	Raster	Buzau	No
Damage to Infrastructure (Roads and Bridges – point Map)	Vector	Nehoiu	Yes

Table 3. 1: Existing and Available Data

The data regards the previous hazard information and damage data were not obtained as promised due to the following reasons

- Information was not provided by the involved institutions
- Poor or no data availability regarding the hazard and damage to landslides

Due to the lack of available data on the hazard intensity and the damage information, the vulnerability of the buildings could not be checked using the damage information. Also for the analysis of the uncertainty using the vulnerability curves, the flood height had to be calculated using the available reconstructed flood boundaries and the available DEM. Due to the unavailability of hazard intensity and the damage information, there were difficulties faced during the qualitative risk assessment.

3.1.2. Preparation of Initial Building Footprint Map

Before the initial fieldwork, building mapping for a part of the study area was carried using a Google Earth image. The Google Earth image is geo-referenced using the topographic map of Nehoiu as a reference and using the option "control points." The buildings were digitized on the geo-referenced image, 209 buildings were mapped based on their occupancy type. The buildings that were mapped were along the valley as the valley is prone to potential and actual landslides and flood affected areas. The field survey was carried to get an overall idea about the location on the buildings that are in the study area.

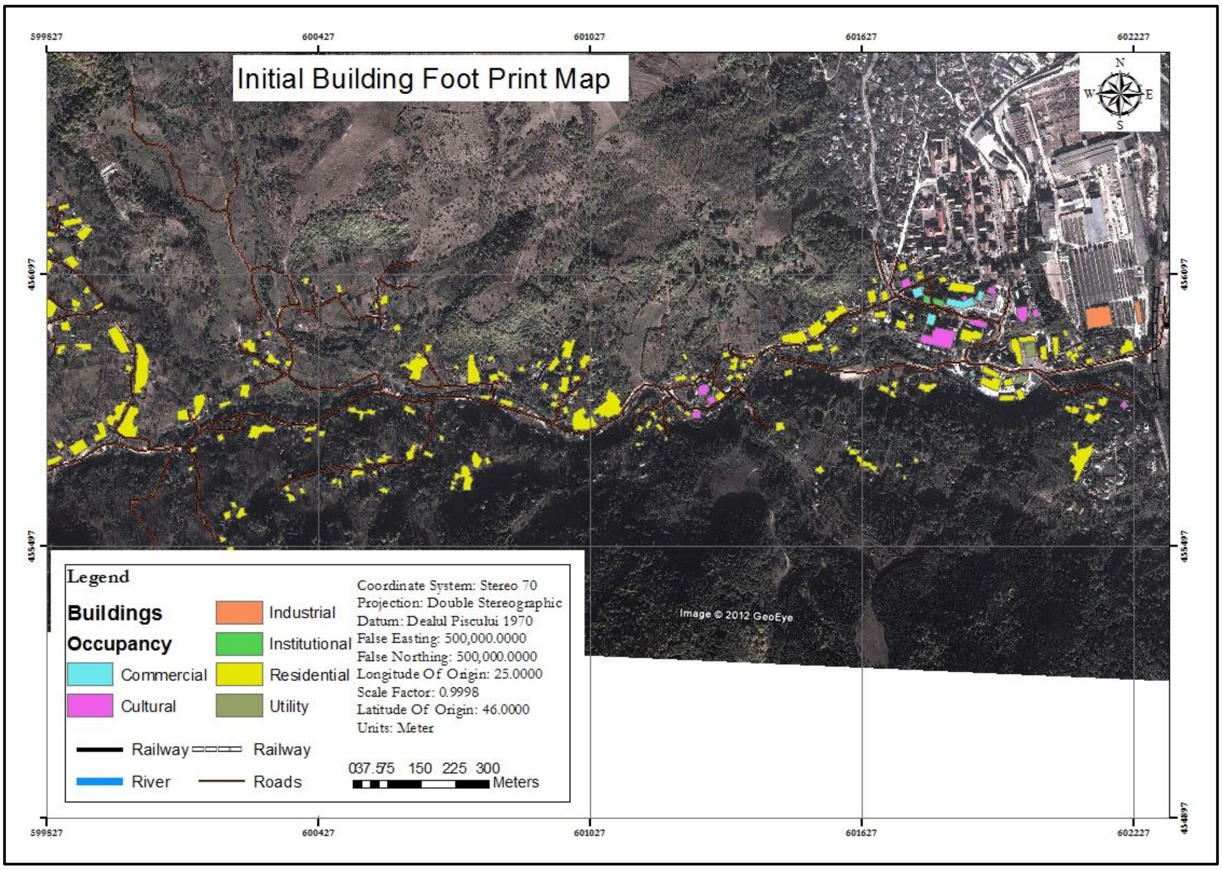


Figure 3. 1: Initial Building Footprint Map of a part of the Study Area

3.1.3. Preparation of Digital Elevation Model (DEM)

The Digital Elevation Model used in the research was prepared by Mr. Rodrigo Lopez and the steps followed are explained briefly as follows

- Several methods were tried to digitize the topographic map both by semi-automatic and automatic processes. One of the semi-automatic methods that were used was by converting the map into duo tone raster, ArcScan was attempted but it resulted in forming many segmented and overlapping lines. A fully automated process using Illustrator tracing was also tried.
- The semi-automatic method that was finally used was by using the tool "Raster Design" in AutoCAD 2013, this method requests the input from the user when the digitizing of the contours become uncertain due to noise. This method also allows the user to include more vertices at the point of curvature in a contour for better accuracy.
- The elevation values were also added in AutoCAD based on 2 different topographic maps (1 in 5000, 1 in 10000) as there were some missing values. Thereby the contour map of Buzau has a scale 1 in 5000 on the left side and 1 in 1000 on the left side. However the study area lies completely in the 1 in 10000 side of the Contour map.
- The resulting vector file ids then exported through AutoCAD Map 2013 to an ArcGIS shape file.
- The raster design identifies the geo-referenced image as well as the AutoCAD map.

The resultant contour map of the Buzau County is as shown in the Figure 3.2.

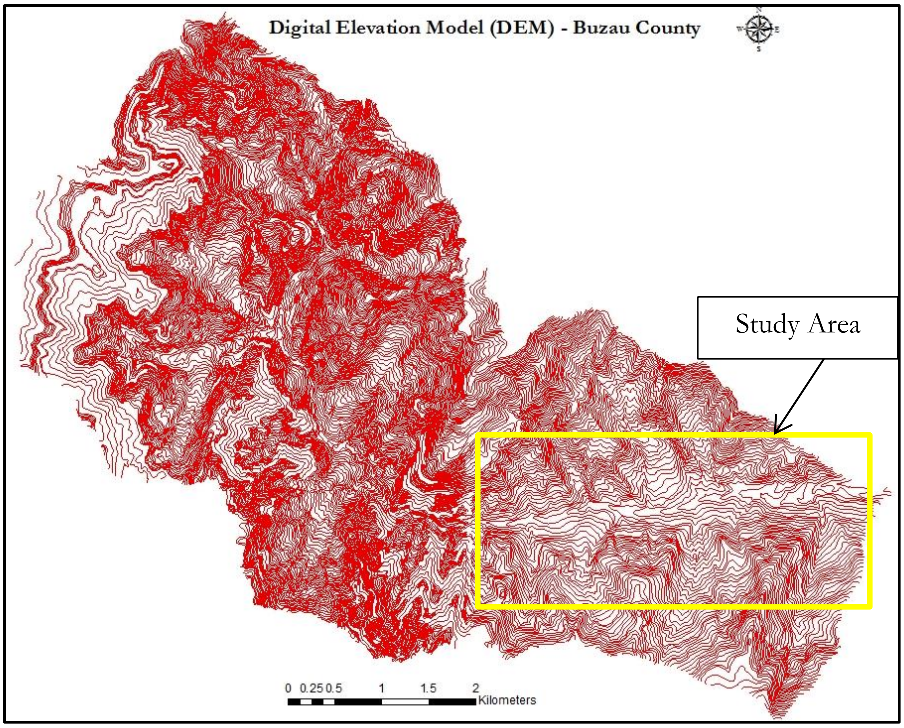


Figure 3. 2: Digital Elevation Model (DEM) of Buzau County

3.1.4. Landslide Interpretation

The landslide map was created by following the below steps
Initially a stereo-pair was created for the study area using the Orthophoto of the study area. To create the stereo-pair, the image was imported into ILWIS and a "Colour Composite" was made. Using the colour composite map of the study area as the raster map and the DEM, a stereo-pair was created. Segment map is created for landslide boundary and a point map "landslideID" for landslide inventory. The landslide inventory landslideID consists of the attributes as shown in the Table 3.2

Landslide Number	Landslide Part	Landslide Type	Slide ID	Certainty	Activity
Nr00x	Scarp	Deep - Slow	Slide0x	Certain confirmed (from the previous landslide point map)	Bare Surface
	Accumulation	Shallow - Slow		Probable from Interpretation	Partly Vegetated
	Transport	Shallow - Rapid		uncertain	Completely Vegetated

Table 3. 2: Attributes in the Landslide Inventory

The boundaries of the landslides were digitized on the stereo-pair and the attributes are assigned to the landslides based on the interpretation. The boundaries are then checked for errors and the segment map was converted to polygon map. This final landslide map was exported to a shapefile in ArcGIS.

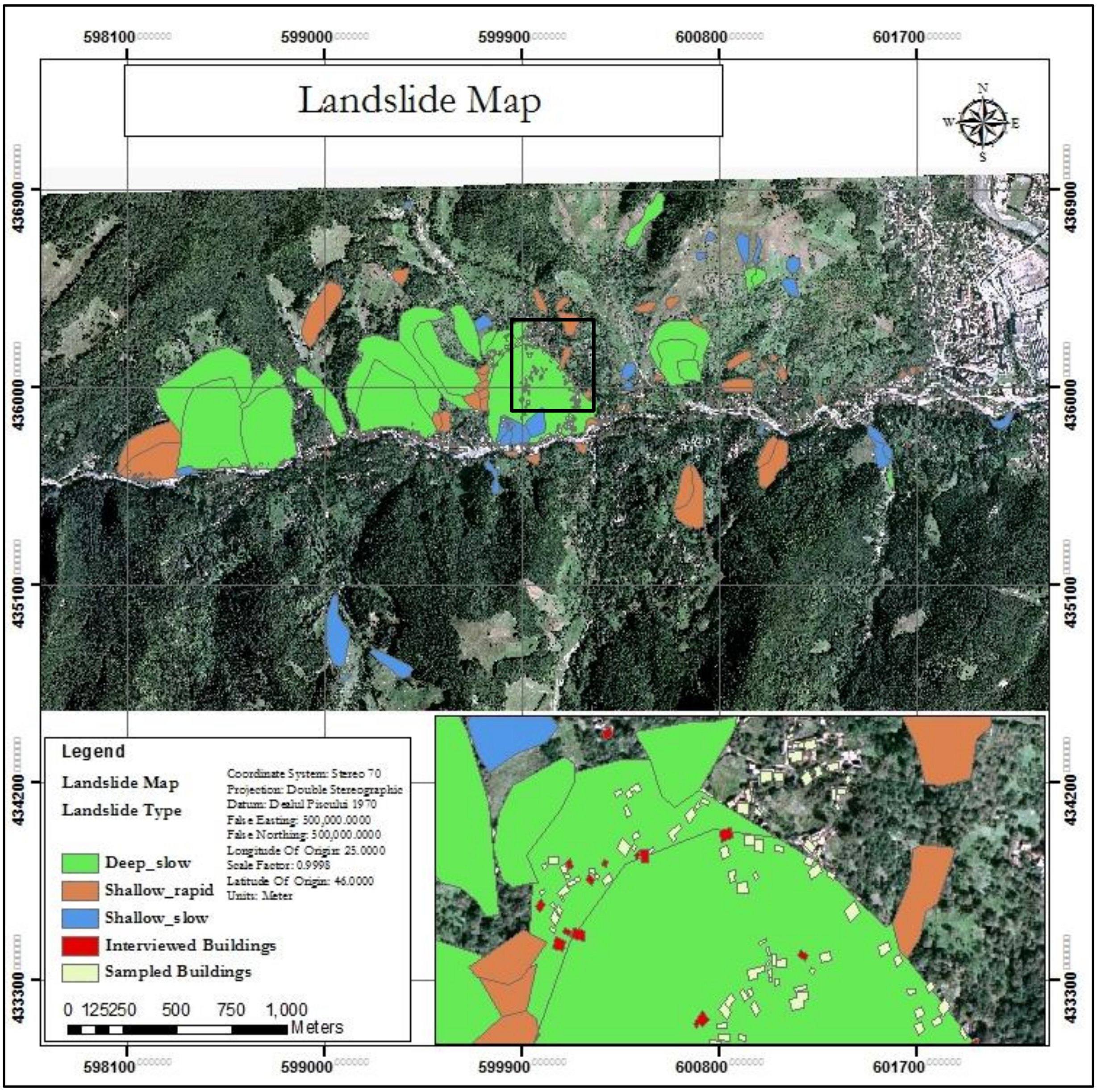


Figure 3. 3: Landslide Map

3.2. Fieldwork

3.2.1. Reconnaissance fieldwork

The reconnaissance fieldwork in the study area was carried out as a part of the EU FP7 Marie Curie Initial Training Network CHANGES (http://changes-itn.eu), "11th edition of the Summer School Environmental Hazards and Sustainable Development in Mountain Regions." Initial fieldwork was carried out to get an overall idea of the area and the problems related with natural hazards such as floods and landslides. An initial reconnaissance was carried out by different teams on various issues such as the hazards, potential trends of hazards, consequences analysis and the aspects related to spatial planning and emergency management. The teams also worked on building footprint mapping of a part of the study area and also mapped the flood extent of the 27th to 30th July 2004 and August 2005 flood event that took place in the Nehoiu based on the assistance of a member of the Nehoiu Town Hall in the field. A scarce amount of data was collected regarding the damage caused to the infrastructure as bridges, light poles and the roads. The flood extent for 2004 flood was reconstructed during this fieldwork by participatory GIS with the help of a member of the municipality; the flood extent is shown in the Appendix A.

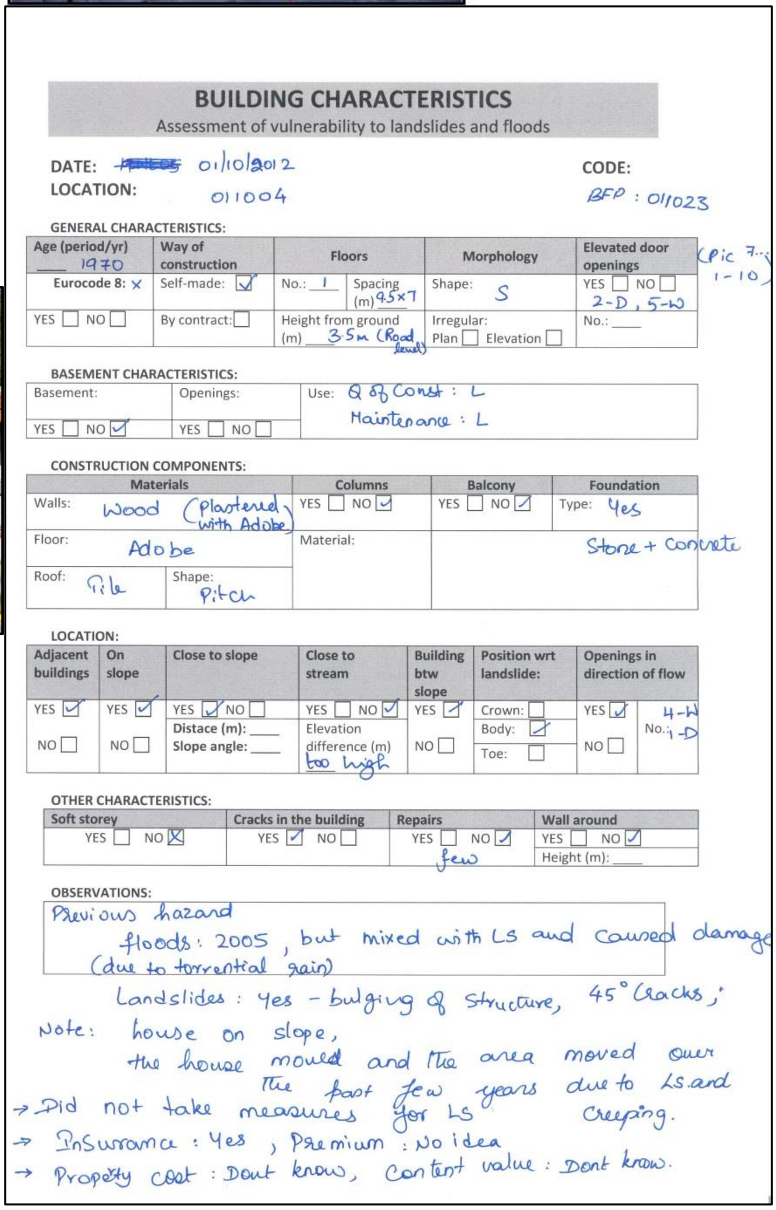
3.3. Field Survey of Buildings

The next phase of the fieldwork was the building mapping of the whole study area, within the accessible limit and without trespassing into local resident's property. The duration of the fieldwork was 3 weeks, with the assistance of a Romanian PhD student to help to communicate and translate with the locals. The interviews with the local people were carried out with the combination of "stratified random sampling" and "convenience sampling." The use of stratified sampling is incorporated in the interview process by emphasizing on the areas prone to both floods and landslides; this was done by focussing on the structures that were near the river and the area with a very high steep and are prone to landslides. However the selection of households to be interviewed for the building characteristics was solely convenience sampling. This method is a non-probability sampling method and involves in sampling people who are willing, interested and are available to take part in the research (Kitchenham & Pfleeger, 2002). In this research this was method was incorporated due to the fact that most of the people in the study area are work far from the study area and are not present through-out the day and the information obtained was based on interviewing people who are available and were willing to participate.

During the building foot print mappings, questionnaires were used in interviews with the local people to obtain information on the building and their characteristics. A total number of 689 buildings were mapped and the details are recorded on occupancy type, structural type, state of structural and non-structural elements, number of floors, number of household and any noticeable observations with regards to the state of the building. A total number of 60 houses were sampled using the questionnaire regarding the information on building characteristics.

The characteristics related to the buildings were collected based on different categories such as general characteristics, basement characteristics, construction components and location with respect to slopes, river, landslides and other buildings (See checklist in Figure 3.5). The general characteristics that were collected consist of the age, method of construction, floor height, and shape of the building and the details of the openings of the building. One of the most important sections of the questionnaire was related to the construction components. This consisted of the material of the wall, roof, floor, column and the foundation. The location characteristics were collected to identify the exposure of the sampled building to potential and actual landslides and flood affected areas. Other characteristics that were collected include quality of construction, maintenance of the building, presence of cracks in the building and flood proofing. The questionnaire was also used to gather information from the residents of the area regarding the previous hazard information with regards to the floods such as in the height of the water during the flood and also the damage caused to the structure due to landslides. The details received from the residents also include information regarding insurance and the approximate replacement cost.

Figure 3. 4: Damages to the structures in the Study area due to landslides and Floods



BUILDING CHARACTERISTICS

Assessment of vulnerability to landslides and floods

DATE: 01/10/2012 CODE: BFP : 011023

LOCATION: 011004

GENERAL CHARACTERISTICS:

Age (period/yr)	Way of construction	Floors		Morphology	Elevated door openings
1970					
Eurocode 8: X	Self-made: ☑	No.: 1	Spacing (m) 45x7	Shape: S	YES ☐ NO ☐ 2-D, 5-W
YES ☐ NO ☐	By contract: ☐	Height from ground (m) 3.5m (Road level)		Irregular: Plan ☐ Elevation ☐	No.: ____

(Pic 7... 1-10)

BASEMENT CHARACTERISTICS:

Basement:	Openings:	Use: Q of Const : L, Maintenance : L
YES ☐ NO ☑	YES ☐ NO ☐	

CONSTRUCTION COMPONENTS:

Materials		Columns	Balcony	Foundation
Walls: Wood (Plastered with Adobe)		YES ☐ NO ☑	YES ☐ NO ☑	Type: Yes
Floor: Adobe		Material:		Stone + Concrete
Roof: Tile	Shape: Pitch			

LOCATION:

Adjacent buildings	On slope	Close to slope	Close to stream	Building btw slope	Position wrt landslide:	Openings in direction of flow
YES ☑	YES ☑	YES ☑ NO ☐	YES ☐ NO ☑	YES ☑	Crown: ☐	YES ☑ 4-W
		Distace (m): ____	Elevation		Body: ☑	No.: 1-D
NO ☐	NO ☐	Slope angle: ____	difference (m) too high	NO ☐	Toe: ☐	NO ☐

OTHER CHARACTERISTICS:

Soft storey	Cracks in the building	Repairs	Wall around
YES ☐ NO ☒	YES ☑ NO ☐	YES ☐ NO ☑ few	YES ☐ NO ☑ Height (m): ____

OBSERVATIONS:

Previous hazard
floods: 2005, but mixed with LS and caused damage (due to torrential rain)
Landslides: Yes - bulging of structure, 45° Cracks;
Note: house on slope,
the house moved and the area moved over the past few years due to LS and Creeping.
→ Did not take measures for LS
→ Insurance : Yes , Premium : No idea
→ Property cost : Dont know, Content value : Dont know.

Figure 3. 5: Questionnaire Used to collect the Information on Building Characteristics of the Interviewed House and the Interviewed House

3.4. Database Generation

A database is created from the data collected from the building footprint mapping and the data collected from the questionnaires. The database is included in the Appendices B and C.

3.5. Description of Elements-at-Risk

The building foot print mapping was carried out using the Urban regulations zoning map of the Nehoiu Valley from the municipality. The following types of building information were recorded: information regarding the occupancy type, structural type and the state of the structural and non-structural elements of the building. Codes were assigned to each of the factors. The codes for occupancy type, structural type and state of construction are presented in the Table 3.3.

Occupancy Type				Number of Buildings
Type	Code	Sub	Description	
Residential	1	SRL	Single Residential Low	92
		SRM	Single Residential Medium	193
		SRH	Single Residential High	75
		MRL	Multiple Residential Low	1
		MRM	Multiple Residential Medium	1
		MRH	Multiple Residential High	2
		RWSH	Residential w/animal shed	36
		RWSS	Residential w/ storage shed	1
		HH	Holiday House	1
		MWSH	Mixed w/ shop	3
		MWOF	Mixed w/ office	2
		MSAB	Multi-storey apartment building	1
Commercial	2	MA	Market	2
		SU	Supermarket	1
		CS	Convenience Store	2
		S	Store	4
		R/C	Restaurant/Café	3
		P	Pharmacy	1
Industry	3	WW	Woodworks	4
		GS	Garage Shop (mechanic service)	1
Cultural	4	CH	Church	1
		CC	Cultural Center	1
Education	5	SCH	School	1
		KDG	Kindergarten	1

Utility	6	GH	Greenhouse	1
		GA	Garage (private)	59
		BA	Barn	71
		STO	Storage	122
		A	Abandoned	8

Structural Type				Number of Buildings
Type	**Code**	**Sub**	**Description**	
Adobe	2	A	Adobe	19
Wood	1	W	Wood	462
		WA	Wood + Adobe	142
		WBR	Wood + Brick	4
		WBL	Wood + Block	16
		WST	Wood + Stone	1
Masonry	4	BR	Brick	-
		BL	Block	7
		ST	Stone	6
Steel	3	S	Steel	2
		SC	Steel + Concrete	-
Reinforced Concrete	5	C	Concrete	1
		CW	Concrete + Wood	-
		CBR	Concrete + Brick	-
		CBL	Concrete + Block	5
		CST	Concrete + Stone	-
Mixed (1st floor concrete)	6	MBRW	Brick + Wood	5
		MBLW	Block + Wood	20
		MSTW	Stone +Wood	1

State of Construction			
Type	**Code**	**Sub**	**Description**
Structural	1	G	Good
		M	Medium
		L	Low
Non-Structural	2	G	Good
		M	Medium
		L	Low

Table 3. 3: Codes and Description of the Occupancy Type, Structural Type and State of Construction in Field

3.6. The Building Foot Print Map

The building foot print is mapped using an existing Urban regulations zoning map of the Nehoiu Valley and a large scale orthophoto photo. The building foot print map of Nehoiu valley is as shown in the Figure 3.6

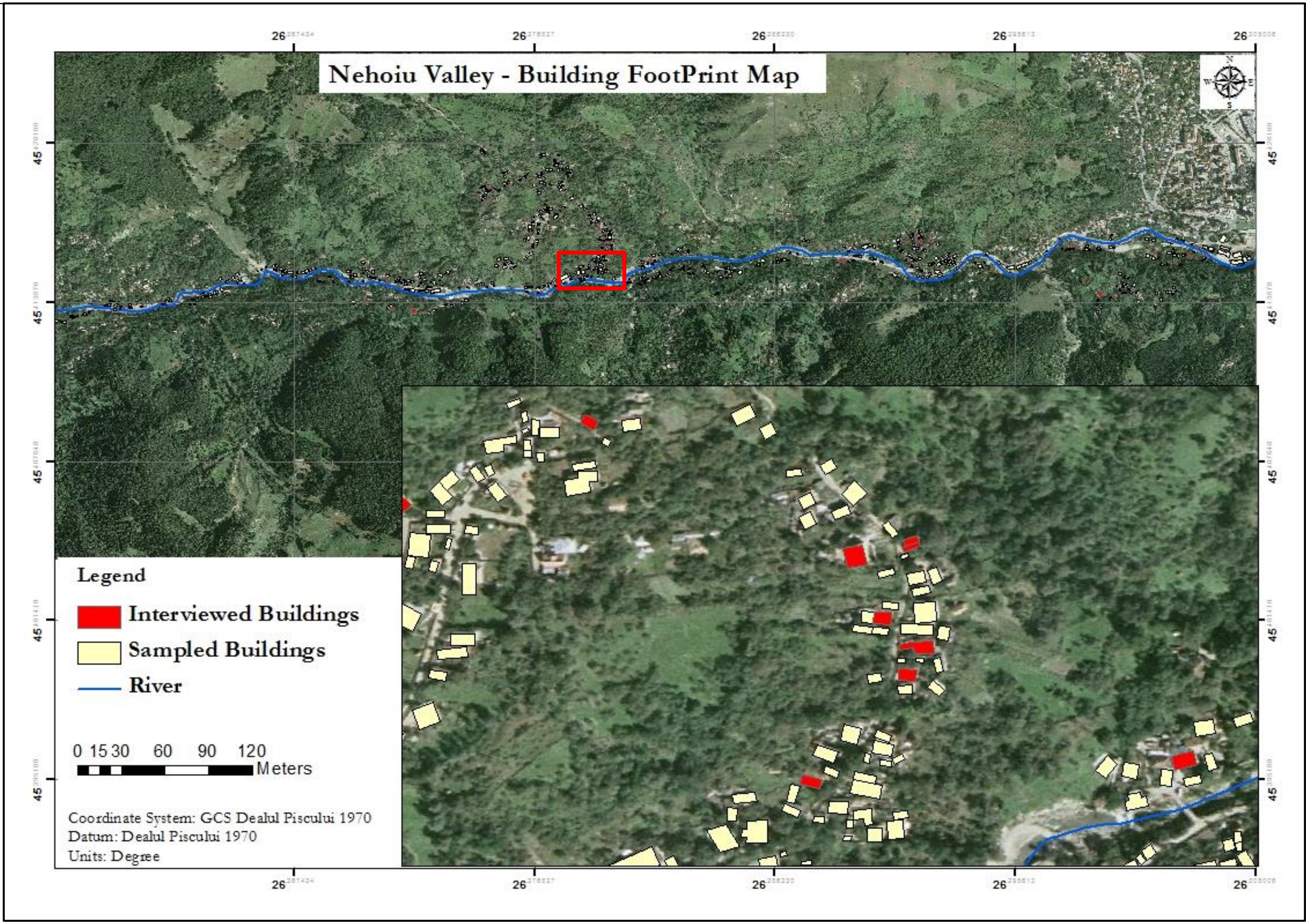


Figure 3. 6: Building Foot Print Map – Nehoiu Valley

3.7. Reconstructing Flood Height

Since accurate flood height information was unavailable, an alternative method to calculate the flood height was been carried out using the available data which is the flood extent polygon, which is the extent to which the flood water has reached the land surface.

Using the ILWIS software, flood height contours were digitized perpendicular over the channel which crosses the point where the flood boundary is at the surface, and the same altitude was selected for the flood height contour line. The flood height contour lines were then interpolated and the flood level was reconstructed. The areas where the flood level was lower than the topography were masked out. The last step was to calculate the flood height, which was calculated by subtracting the "flood surface" map to that of the "DEM." The flood height map was then exported to ArcGIS as ASCII file to overlay it on the building footprint to identify the interviewed house, which lies on the flood area and to identify the flood height at that location. The flood height map is as shown in the Figure 3.7

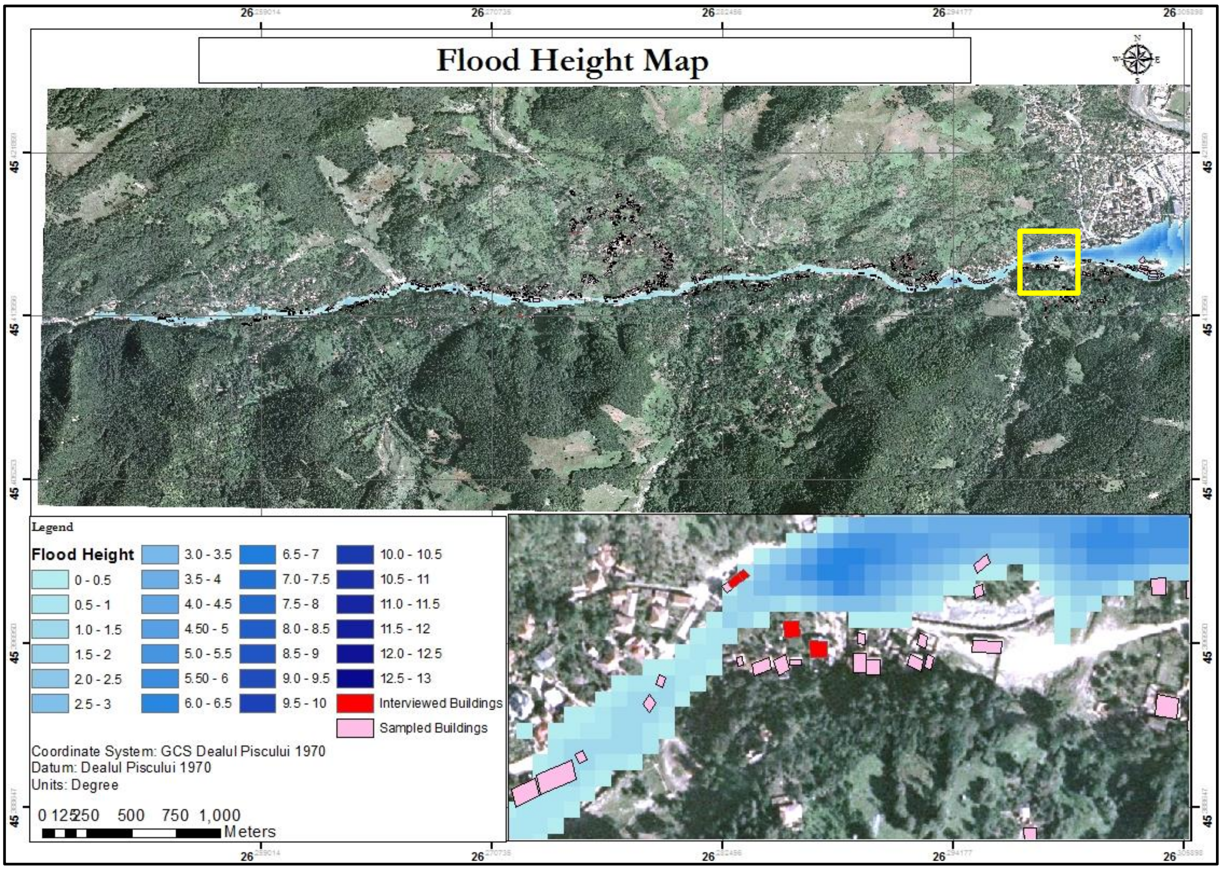


Figure 3. 7: Flood Height Map

4. WEIGHTING METHOD TO DEFINE LOCAL VULNERABILITY OF BUILDINGS

This chapter deals with the "post-fieldwork" phase, which is the analysis phase of the research. The chapter describes the weighting method that was developed based on the expert opinion for building vulnerability to river flood, flash flood, slow moving and rapid landslides. Subsequently continuing to the uncertainty analysis based on the combination of existing vulnerability curves for both RCC and wooden buildings and weight based information.

4.1. Weighting method for assessing the vulnerability of Buildings

To assess the vulnerability of the buildings based on the building characteristic, a weighting method was developed using expert opinion. The weighting method is initially described in brief and then explained step by step as the process. The building characteristics that are considered important for the hazards that were considered are first identified and these factors are expressed as a questionnaire, which was then filled in by the experts. The weights that were given by the experts were then normalized and standardized in ILWIS. These weights are then used to calculate the vulnerability uncertainty index, which assess the vulnerability of buildings based on their building characteristics. This method is explained in detail step by step in the section 4.3

4.2. Classification of Experts

The weighting method was based on expert opinion by group of 20 people who are aware of the hazard situation in the study area in the Nehoiu valley. The persons involved in the expert rating experts who are involved in landslide and flood susceptibility, vulnerability, hazard and risk assessment. The participants also include a number of ESR's (Early Stage Researchers) from the CHANGES project (Changing Hydro-meteorological Risks as Analysed by a New Generation of European Scientists), who work on the analysis of the impact of changes globally on environmental and climate change including socio-economical change that affects the temporal and spatial patterns of hydro-meteorological hazards and associated risks in Europe (CHANGES, 2011). The experts and the ESR's are familiar with the study area and are aware of the hazard situation in the study area Nehoiu valley. Inorder to get a thorough idea and a hands-on experience with the hazard situation present, the participants have visited the study area in an earlier occasion. The participants have carried out a field exercise to identify the hazard affected areas and its consequences, the participants have also mapped the buildings in the study area. During the CHANGES Midterm meeting that was held in Dortmund during the period November 27th -29th 2012, the weighting method was explained to the experts inorder for them to fill in the questionnaire that was given.

The weights are calculated considering two groups of people, with different levels of expertise and possibly different views and understanding the importance of the factors and their indicators. The first group being the senior experts, this group comprises of professors and researchers from 11 European Universities and research centers that focus on hydro-meteorological hazards. Whereas the second group of people are PhD researchers (ESR's) who have started their research a year ago and are also involved with the hydro-meteorological hazards (floods and landslides) and their changes.

4.3. Matrix to Express Vulnerability

The vulnerability assessment was carried out using the Analytic Hierarchy Process (AHP). AHP is a tool for the Multi Criteria Decision Making and Multi Criteria Analysis (MCA). It was developed by Prof. Thomas L. Saaty in the early 1970's. This MCA technique uses the relative weights and incorporates the concept of using these weights to carry out a pairwise comparison (Armas, 2012).

The Multi Criteria Analysis based on the expert opinion for vulnerability of buildings was carried out as follows

Step 1:

Initially the building characteristics that are considered significant for the vulnerability assessment are chosen based on the type of the hazard. In this study four different hazards were considered: river flooding, flash flooding, slow moving landslides and rapid landslides. These hazards are considered due to the fact that the study area is susceptible of exposure to potential and actual hazards as mentioned above. The building characteristics which were considered significant for these hazards are shown in the Table 4.1

Building Characteristics	**River Floods**	**Flash Floods**	**Slow Moving Landslides**	**Rapid Landslides**	**Indicator for**	
					Vulnerability	**Risk**
Height of the Building from Ground Level	✓	✓	✓	✓	✓	✓
Number of Floors	✓	✓	✓	✓	✓	✓
Structural Type	✓	✓			✓	✓
Size of the Building	✓	✓	✓	✓	✓	✓
Wall Material	✓	✓	✓	✓	✓	✓
Presence of Basement	✓	✓			✓	✓
Height of the Door and Windows	✓	✓	✓	✓	✓	✓
Quality of Construction	✓	✓	✓	✓		✓
Maintenance of the Building	✓	✓	✓	✓	✓	✓
Wall around the Building	✓	✓	✓	✓	✓	✓
Openings in the direction of flow			✓	✓	✓	✓
Cracks in the Structure			✓	✓	✓	✓
Building built on Slope			✓	✓	✓	✓
Building close to Slope			✓	✓	✓	✓
Type of Foundation			✓	✓	✓	✓
Depth of Foundation			✓	✓	✓	✓
Size of the Building	✓	✓	✓	✓	✓	✓
Presence of other Building between the Buildings and slopes			✓	✓	✓	✓
Buildings on Slow moving Landslides			✓	✓		✓
Buildings on Rapid Landslides			✓	✓		✓

Table 4. 1: Building Characteristics significant for the considered Hazards

Step 2:

A questionnaire with a vulnerability matrix was developed based on these building characteristics with a given method of rating that ranged from "very less important" to "very much more important." The rating is given in the Table 4.2

Rating	Description	In ILWIS
1	Very much less important	Is extremely more important than
2	Less important	Is strongly more important than
3	Equally important	Is equally important as
4	More important	Is strongly less important than
5	Very much more important	Is extremely less important than

Table 4. 2: Rating for Vulnerability Matrix

Vulnerability for River Flood	Height of building from ground level	Number of Floors	Structural Type	Size of the Building	Wall Material	Presence of Basement	Height of the Door and Windows	Quality of construction	Maintenance of the building	Wall around the building
Height of Building from Ground level										
Number of Floors	4									
Structural Type	2	4								
Size of the Building	2	2	2							
Wall Material	5	4	3	4						
Presence of Basement	4	3	4	4	2					
Height of the Door and Windows	4	4	4	4	4	3				
Quality of construction	2	4	2	4	3	2	1			
Maintenance of the building	2	3	2	4	2	2	1	1		
Wall around the building	3	4	3	4	4	4	3	4	5	

Figure 4. 1 Vulnerability Matrix for River Flood

The characteristics in the vulnerability matrix for both river and flash flood are considered to be same, although there would be a difference with respect to the importance that is given to these characteristics with respect to the hazard.
The matrix for river flood is filled in such a way that the factors of the column (the red arrow) to that of the rows (the green arrow), for instance the importance of "the number of floors" with respect to "height of the building from ground level."
For Slow moving Landslides and the Rapid Landslides, also a similar set of characteristics was considered as shown in Table 4.1. The matrix for slow moving landslide and rapid landslide is also filled in the similar way as it is for the river and flash floods.

Landslide vulnerability for a slow moving landslide	Height of building from ground level	No. of floors	Wall Material	Wall around the building	Openings in the direction of flow	Quality of construction	Maintenance of the building	Cracks in the structure	Building built on slope	Building close to slope	Type of Foundation	Depth of Foundation	Size of the Building	Presence of other Building between the buildings and slopes
Height of building from ground level														
Number of floors	2													
Wall Material	3	1												
Wall around the building	1	1	1											
Openings in the direction of flow	5	1	3	5										
Quality of construction	5	2	4	4	5									
Maintenance of the building	4	3	4	4	4	5								
Cracks in the structure	5	5	5	5	5	5	5							
Building built on slope	5	5	3	3	4	4	5	5						
Building close to slope	2	1	1	1	1	1	1	1	1					
Type of Foundation	5	3	1	1	1	5	4	5	5	1				
Depth of Foundation	5	4	1	1	1	5	4	5	5	1	5			
Size of the Building	4	2	1	1	1	5	4	5	5	1	5	5		
Presence of other Building between the buildings and slopes	5	3	1	1	5	1	1	1	1	1	1	1	1	

Figure 4. 2 Vulnerability Matrix for Landslide Vulnerability for a Slow Moving Landslide

Step 3:

The vulnerability matrix was analysed separately for the group of experts with different levels of expertise as in the experts. Analytical Hierarchy Process (AHP) Software's for decision making such as the "Spatial

Multi Criteria Analysis (SMCE)" module in ILWIS- GIS software, "Expert Choice" and "Definite" can be used to determine the normalised weights of each factor based on their importance. SMCE module is helps in carrying out a multi criteria evaluation in a spatial aspect and also in non-spatial aspect to calculate the normalized weights of the factors. Expert Choice is analytical decision making software that allows you to carry out multi criteria evaluation and also advanced risk analysis (Expert Choice, 2012). Although being open source and user friendly, it was more appropriate to choose the SMCE module in ILWIS for normalization of weights.

Each questionnaire was characterised as an individual criteria tree with a "Goal" and "Sub Goals". The criteria tree is built based on the building characteristics that are considered and these factors are "non-spatial," as these multi-criteria analysis is carried out to calculate the "normalized weights" for each characteristic.

The weighting was done by "pairwise comparison," based on the relative importance one factor compared to another for a particular hazard, for instance for river flood "number of floors" is "equally important" as "structural type" but "structural type" is "much more important than "height of the building from ground level" (Figure 4.3). This analytical hierarchical process gives the weights to each factor based on its importance based on the expert opinion. The mean weights of the normalized weights from each participant are used in assessing the vulnerability.

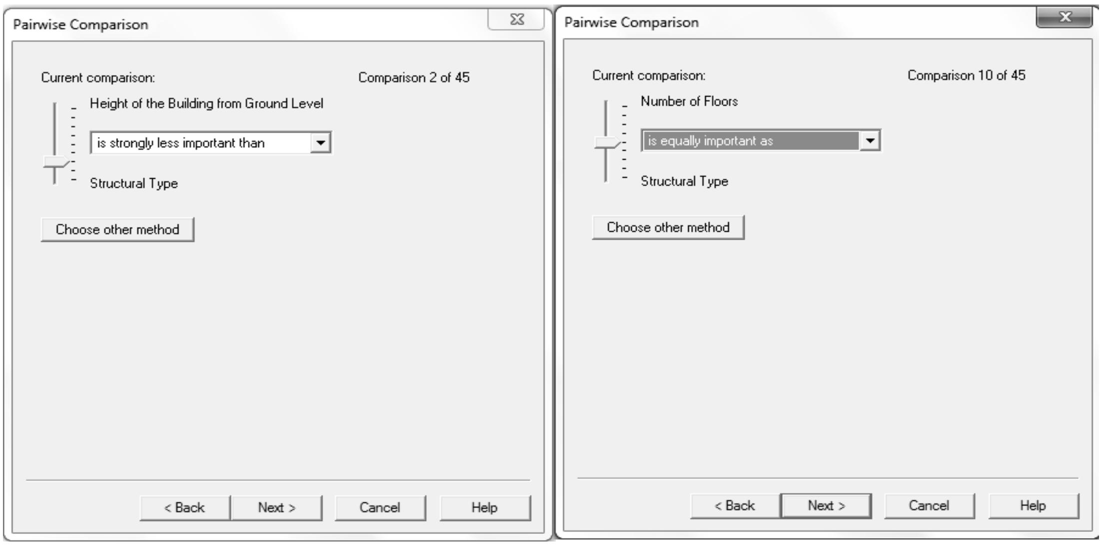


Figure 4. 3: Pairwise Comparison in SMCE Module –ILWIS
(Source: Screenshot from ILWIS 3.3)

4.4. Vulnerability to Floods

The multi-criteria evaluation is carried out for both the river and the flash floods and the normalized weights are obtained after giving them the weights based on the experts for the building characteristics that were considered important. The sum of these normalized weights summed up to "1" and these are used for calculating the vulnerability uncertainty index. The inconsistency ratio identifies the logical inconsistencies of the rating given by the expert judgement and this ratio should be 0.1 to be logical and consistent (Dalalah et al., 2010). However the inconsistency ratio for the river and flash floods is not indicated as ILWIS only calculates the consistency if the number of factors is in the range of 3-9 (ILWIS, 2007). The resulting normalised weights for the building characteristics by the experts and the ESR's are as shown in the Table 4.3.

Building Characteristics	Experts			ESR's		
	Min.	Average	Max.	Min	Average	Max.
RIVER FLOOD						
Height of Building from Ground level	0.043	0.142	0.316	0.023	0.079	0.193
Number of Floors	0.046	0.135	0.244	0.021	0.098	0.229
Structural Type	0.032	0.085	0.149	0.027	0.095	0.147
Size of the Building	0.021	0.093	0.264	0.014	0.064	0.237
Wall Material	0.037	0.121	0.190	0.035	0.100	0.166
Presence of Basement	0.011	0.074	0.206	0.014	0.169	0.381
Height of the Door and Windows	0.017	0.105	0.270	0.032	0.105	0.200
Quality of construction	0.019	0.088	0.220	0.04	0.107	0.176
Maintenance of the building	0.022	0.082	0.174	0.016	0.080	0.294
Wall around the building	0.015	0.075	0.192	0.011	0.078	0.163
FLASH FLOOD						
Height of Building from Ground level	0.026	0.081	0.141	0.021	0.050	0.124
Number of Floors	0.024	0.099	0.194	0.02	0.081	0.410
Structural Type	0.03	0.112	0.179	0.013	0.116	0.200
Size of the Building	0.013	0.069	0.159	0.013	0.057	0.186
Wall Material	0.062	0.134	0.231	0.088	0.131	0.159
Presence of Basement	0.02	0.094	0.202	0.018	0.126	0.231
Height of the Door and Windows	0.024	0.099	0.175	0.017	0.099	0.270
Quality of construction	0.059	0.121	0.221	0.066	0.143	0.268
Maintenance of the building	0.014	0.076	0.126	0.012	0.116	0.294
Wall around the building	0.012	0.116	0.320	0.009	0.120	0.280

Table 4. 3: Normalized Weights for River and Flash Floods

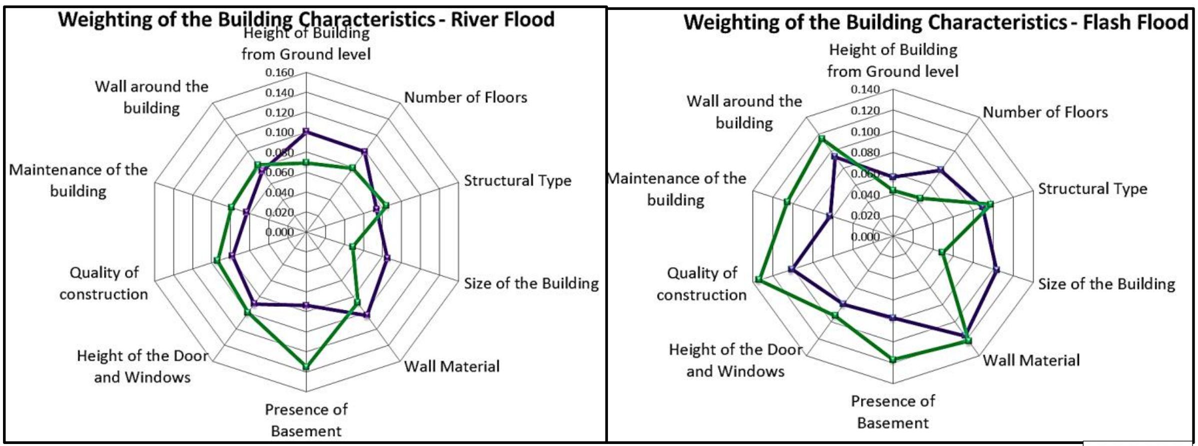


Figure 4. 4: Weights of the Building Characteristics by Experts and ESR's – River Flood and Flash Flood

It was observed that the height of the building was considered the most significant to both river flood and flash floods by both Experts and ESR's, assuming that the flash flood was considered as the excessive flooding due to sudden heavy rainfall and not as torrential rain on an area with steep slopes. It can be seen from Figure 4.4 that there is quite some variation between the Experts and ESR's on how they view the building characteristics. This variation is mainly due to the perception of the building characteristics based on the area of expertise, level of expertise and the knowledge of the structural components of a building and how significant they are and how they respond to each of the hazards.

4.5. Vulnerability to Mass Movement

The process was similar for the mass movements, as it was for flooding. Factors considered were slightly different and the factors considered are shown in the Table 4.1. The resultant normalised weights for the building characteristics by the experts and the ESR's are as shown in the Table 4.4

Building Characteristics	Experts			ESR's		
	Min.	Average	Max.	Min.	Average	Max
SLOW MOVING LANDSLIDES						
Height of building from ground level	0.011	0.036	0.084	0.011	0.043	0.198
Number of floors	0.015	0.053	0.105	0.01	0.045	0.166
Wall Material	0.01	0.069	0.120	0.017	0.065	0.130
Wall around the building	0.014	0.075	0.166	0.015	0.071	0.233
Openings in the direction of flow	0.01	0.054	0.101	0.014	0.050	0.114
Quality of construction	0.027	0.086	0.152	0.024	0.069	0.129
Maintenance of the building	0.021	0.072	0.152	0.018	0.052	0.091
Cracks in the structure	0.044	0.087	0.139	0.026	0.065	0.118
Building built on slope	0.021	0.103	0.172	0.021	0.159	0.291
Building close to slope	0.042	0.079	0.175	0.029	0.107	0.226
Type of Foundation	0.037	0.083	0.178	0.009	0.089	0.239
Depth of Foundation	0.014	0.084	0.185	0.012	0.088	0.185
Size of the Building	0.015	0.061	0.123	0.008	0.042	0.093
Presence of other Building between the buildings and slopes	0.017	0.049	0.101	0.005	0.052	0.167
RAPID LANDSLIDES						
Height of building from ground level	0.009	0.021	0.031	0.01	0.030	0.061
Number of floors	0.009	0.049	0.086	0.011	0.042	0.084
Wall Material	0.048	0.091	0.128	0.014	0.069	0.132
Wall around the building	0.013	0.065	0.161	0.014	0.069	0.172
Openings in the direction of flow	0.011	0.034	0.075	0.011	0.066	0.192
Quality of construction	0.02	0.70	0.112	0.029	0.073	0.137
Maintenance of the building	0.01	0.055	0.112	0.019	0.054	0.132
Cracks in the structure	0.027	0.090	0.171	0.018	0.071	0.132
Building built on slope	0.045	0.111	0.217	0.029	0.125	0.281
Building close to slope	0.05	0.079	0.174	0.029	0.092	0.229
Type of Foundation	0.045	0.081	0.121	0.012	0.082	0.140
Depth of Foundation	0.038	0.089	0.130	0.014	0.075	0.132
Size of the Building	0.016	0.064	0.135	0.007	0.046	0.135
Presence of other Building between the buildings and slopes	0.037	0.102	0.168	0.008	0.107	0.233

Table 4. 4 Normalized Weights for Slow Moving and Rapid Landslides

The mean of the "Normalized Weights" for both the experts and the ESR's with the weights of the indicators of each factor is then used to calculate "Vulnerability Uncertainty Index" of buildings for each hazard.

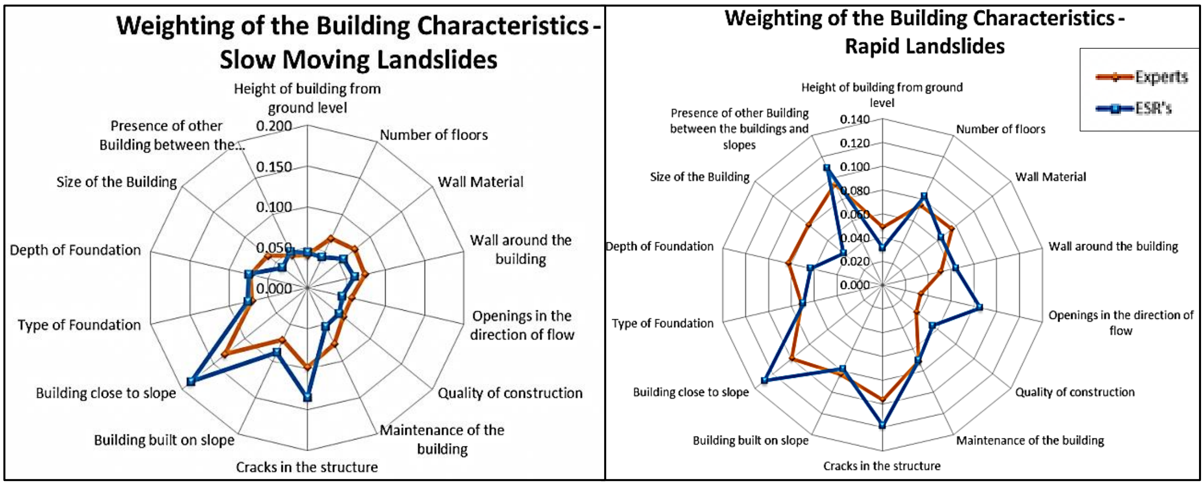


Figure 4. 5: Weights of the Building Characteristics by Experts and ESR's – Slow Moving Landslides and Rapid Landslides

The weights of the building characteristics to slow moving landslides seems to be perceived similar by both Experts and ESR's, Figure 4.5 shows that the for rapid landslides, the characteristics buildings built on slope and cracks in the structure were considered significant. Also the factors such as openings in the direction of flow and presence of buildings between the buildings and slope were considered significant due to the fact that openings in the direction of flow leads to flow of debris material inside the building causing severe damage to the structure. This is similar to the presence of buildings between the building and slope as this would reduce the direct impact of debris on the structure and reduces the damage of the structure.

4.6. Indicators for Floods and Landslides

Inorder to calculate the vulnerability uncertainty index for an individual building, it is necessary to weight the classes of the factors. The classes of factors were based on the filed survey and the weights were based on referring the literature review. The indicators for each factor are considered based on the data that was collected from the fieldwork. The limits are considered only from the values based on this as well. The weights to these indicators are also obtained similar to the ones for the building characteristic. The standardization values for each of the indicator are as shown in the Table 4.5.

Standardized weights for the Indicators for Floods and Landslides	Weights	Standardized weights for the Indicators for Floods and Landslides	Weights
Floor Height		**Maintenance of the Structure**	
0 m	0.649	High	0.058
<= 2 m	0.201	Medium	0.207
<= 5 m	0.11	Low	0.735
> 5 m	0.041	Inconsistency Ratio	0.099
Inconsistency Ratio	0.1	**Wall around the Building**	
Number of Floors		Yes	0.1
1	0.875	No	0.9
2	0.125	**Cracks in the Structure**	

Structural Type	
RCC, Steel	0.07
Masonry	0.178
Wood	0.751
Inconsistency Ratio	0.02
Wall Material	
RCC+ Brick, Steel	0.04
Wood+ Brick	0.079
Wood	0.242
Wood+ Adobe	0.64
Inconsistency Ratio	0.1
Presence of Basement	
Yes	0.9
No	0.1
Elevated Openings (Doors and Windows)	
>= 10	0.051
< 10	0.097
<= 5	0.209
< 2	0.643
Inconsistency Ratio	0.086
Yes	0.9
No	0.1
Building Built on Slope, Building Close to Slope	
Yes	0.9
No	0.1
Type of Foundation	
Stone+ Adobe	0.487
Brick + Adobe	0.435
Stone + Concrete	0.078
Inconsistency Ratio	0.1
Depth of Foundation	
Na (Not Available/ Not Known)	0.568
<= 20 cm	0.297
<= 50 cm	0.088
> 50 cm	0.047
Inconsistency Ratio	0.08
Presence of Other Buildings between the Building and Slope	
Yes	0.1
No	0.9
Construction Quality	
High	0.058
Medium	0.207
Low	0.735
Inconsistency Ratio	0.099

Table 4. 5: Standardized Indicators for both Floods and Landslides

This process is again carried out for all the indicators that are considered for both floods (river and flash flood) and landslides (slow moving and rapid moving landslides). The resulting “Normalised Weights” are the ones that are used to calculate the “Vulnerability Uncertainty Index.”

4.7. Qualitative Vulnerability Uncertainty Index

The vulnerability of each building is calculated using the standardized factors classes of building characteristics and the normalized weights of the indicators. The vulnerability uncertainty index is calculated in two groups of different perspectives experts and ESR’s.

Vulnerability Uncertainty Index = (A x a) + (B x b) + (C x c) + (D x d)… (Z x z)
Where
A,B,C,D… Z is the normalized weight of the factors that is the building characteristics (e.g.: Wall material, Number of Floors).
a,b,c,d….z is the normalized weights of the indicators of the building characteristics (e.g.: Wood+ Adobe, Wood, Wood+ Brick and Brick+ Block+ Concrete for wall Material).

Using the above formula, for a building with given characteristics and indicators, the building vulnerability is calculated as shown in the Table 4.6.

Building ID	**19WE05**	**Standardized Indicator Weight**	**Standardized Weight of the Factors -Experts**	**Standardized Weight of the Factors –ESR's**	**Vulnerability Uncertainty Index**
Floor Height from Ground Level (m)	2	0.201	0.142	0.079	
No. of Floors (G=1)	1	0.875	0.135	0.098	**River Flood** Experts = 0.6183 ESR's = 0.6668
Structural Type	Wood	0.751	0.085	0.095	
Size of the Building (sq. m)	182	0.041	0.093	0.064	
Wall Material	Wood+ Adobe	0.64	0.121	0.1	
Presence of Basement	Yes	0.9	0.074	0.169	
Elevated Doors and Windows	4	0.643	0.105	0.105	**Flash Flood** Experts = 0.6730 ESR's = 0.7296
Quality of Construction	Low	0.735	0.088	0.107	
Maintenance of the Building	Low	0.735	0.082	0.08	
Wall around the Building	No	0.9	0.075	0.078	

Table 4. 6: Building Characteristics of a Sampled Structure

Figure 4. 6: Interviewed Building

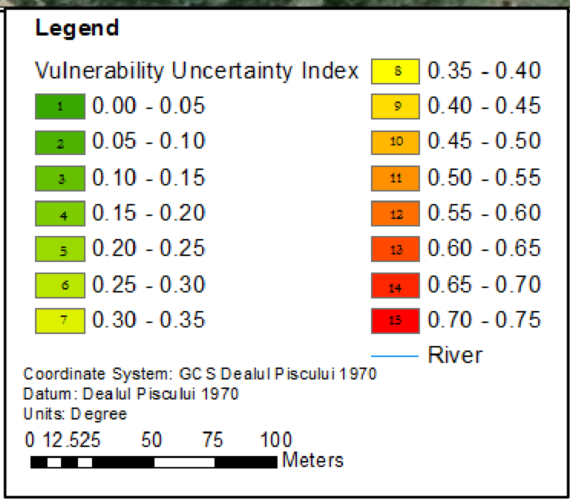


Figure 4. 7: Vulnerability Uncertainty Index for River and Flash Floods by Experts and ESR's for the Interviewed Building

4.8. Uncertainty Analysis

The predominant building types in the study were of wooden buildings. Hence the averaged vulnerability curve for the wooden buildings was used to calculate the vulnerability values. For individual buildings the vulnerability uncertainty index which was calculated based on expert based weights and the characteristics of a building, was then used to represent the specific vulnerability curve of a building. The index value of 0 was used to show the lowest vulnerability curve in the coloured part of the graph. A vulnerability uncertainty index value of 1, means that the particular building is at the maximum level of the coloured vulnerability area within the graphs.

The vulnerability curves for the interviewed buildings that were exposed to the flood hazard were plotted as shown in the Figure 4.8. The range of vulnerability uncertainty index values varies from 0.3 to 0.6 in the vulnerability curve. Although when tested for achieving the lowest and highest vulnerability uncertainty index values, the minimum reaches to 0, however the maximum goes up to 0.75 as the extreme. Similarly the vulnerability curve for landslides was also plotted as shown in the Figure 4.9.

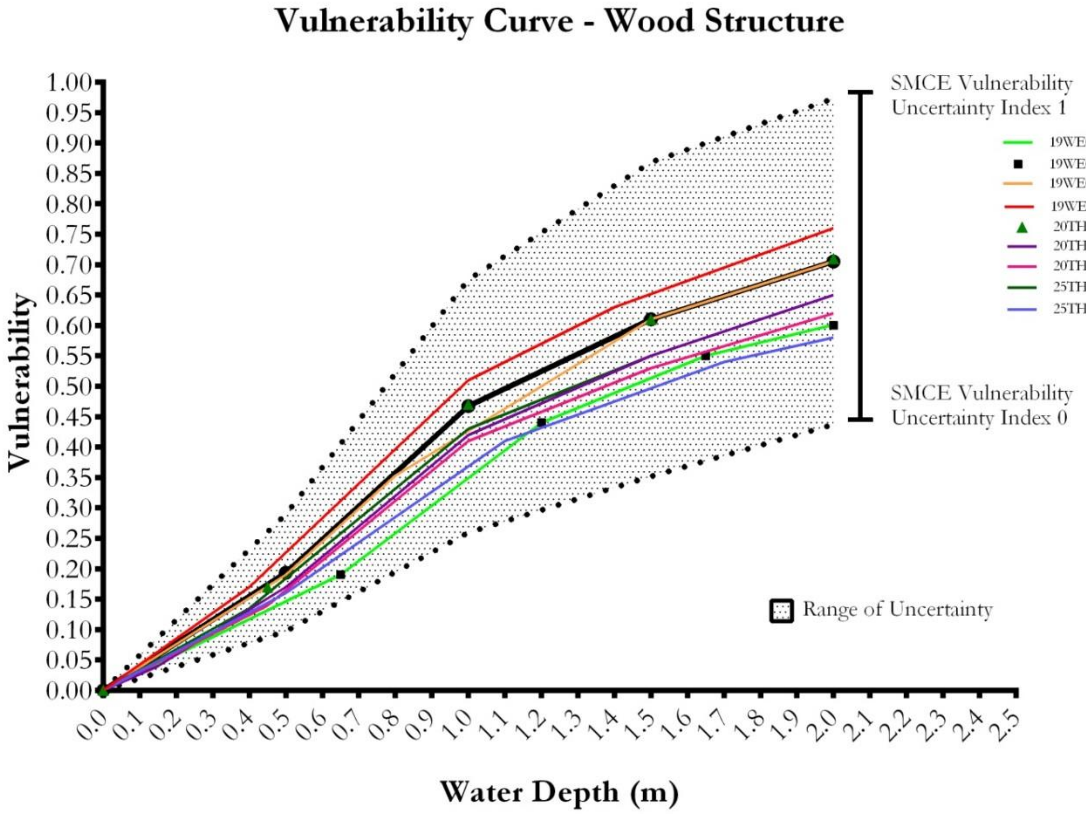


Figure 4. 8: Vulnerability Curve of Individual Wooden Buildings in the Study Area

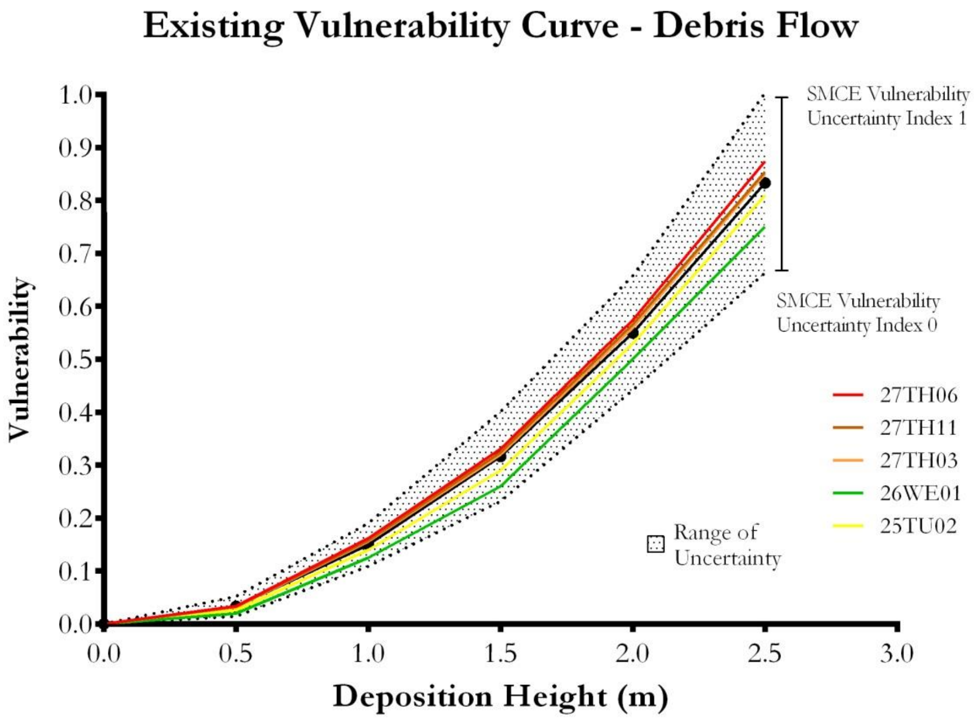


Figure 4. 9: Vulnerability Curve of Individual Wooden Buildings in the Study Area

5. QUANTITATIVE RISK ASSESSMENT

This chapter also falls under the "post-fieldwork" phase and it explains how the vulnerability values obtained from the existing vulnerability curves could be used for quantitative risk assessment for floods and landslides.

Risk can be defined as *"The probability of harmful consequences, or expected losses resulting from interactions between natural or human-induced hazards and vulnerable conditions"* (UNISDR, 2007) Risk is expressed result of the product of the hazard (frequency, magnitude), vulnerability and the elements-at-risk; it is also the probability of the likelihood of occurrence of the hazard. Risk assessment can be carried out qualitatively, semi-qualitatively and quantitatively depending on the detail of the available data. Qualitative risk assessment expresses risk on a relative scale from low to high, this is carried out when there is lack of quantitative information on temporal/ spatial/ intensity probability for the hazard and/or vulnerability information. Semi-qualitative methods are qualitative methods that express risk numerically on a scale of 0-1 using indicator based Spatial Multi-Criteria Evaluation, whereas the quantitative methods quantify the probability and the losses(van Westen, 2009).
For the study area it is not possible to carry out a quantitative landslide risk assessment, due to lack of data on landslide intensity for different temporal scenarios. Only a landslide inventory map is available, which is not sufficient, as we would need the results of landslide initiation modelling, flowed by landslide runout modelling, which is beyond the scope of this thesis. Therefore for landslides only an exposure analysis will be presented.
The method presented in the previous chapter for the flood vulnerability assessment will be in a simple flood risk assessment in the study area.

5.1. Flood Risk Assessment

A flood risk assessment was carried out, using the formula

Risk = Probability x Consequence

Consequence being the loss that is expected due to a hazard scenario is expressed as the product of vulnerability and the loss due to the damage of the elements at risk. Probability being the probability of occurrence both temporal and spatial (location based) to the particular hazard scenario with a return period(van Westen, 2009).

Risk = Probability x Vulnerability x Amount

A. Hazard Scenario (Return Period)

There is a very little information available on the past flood events and a very few events have been reported. The study area was exposed to a number of flood events, the 1975 floods was the biggest flood recorded over the past 40 years during the period of May-June (Neagu, 2012). The flood events of 27^{th}-31^{st} July 2004, 2005 and 2009 also caused severe damage in the study area. Based on the fact that that only known severe event occurred in July 1975 over the past 38 years, an uncertainty range of 35-50 years was assumed for the return period. The other 3 reported events occurred more frequently over the past 10 years. Assuming that the similar events also happened before 2004, the minimum return period range was considered to be 3-5 years. Hence there were 2 scenarios that were considered the 2004 flood (5 year) and 50 year return period.

B. Intensity (Flood Height)

Since the accurate flood height information for the particular return periods in the area is not available, a flood height map was created for the 2004-2005 events (See Chapter 3). The flood height calculated for each exposed building was used for estimating the physical vulnerability of the buildings, using the method explained in the previous chapter. For larger event we had to make an assumption on the water height, as no other information was available for that event. Therefore we considered that the major flood had a 2 meter higher flood level as compared to the smaller events. This is purely an assumption and future works should focus on the development of flood scenarios for different return periods.

C. Exposure

The flood maps for the floods of the two scenarios were produced in the similar method as explained in Section 3.7 and Figure 3.8. Using these flood maps and the building footprint map, the interviewed buildings that are exposed to the flood hazard were identified. The exposure of the buildings to these floods is as shown in the Figure 5.1.

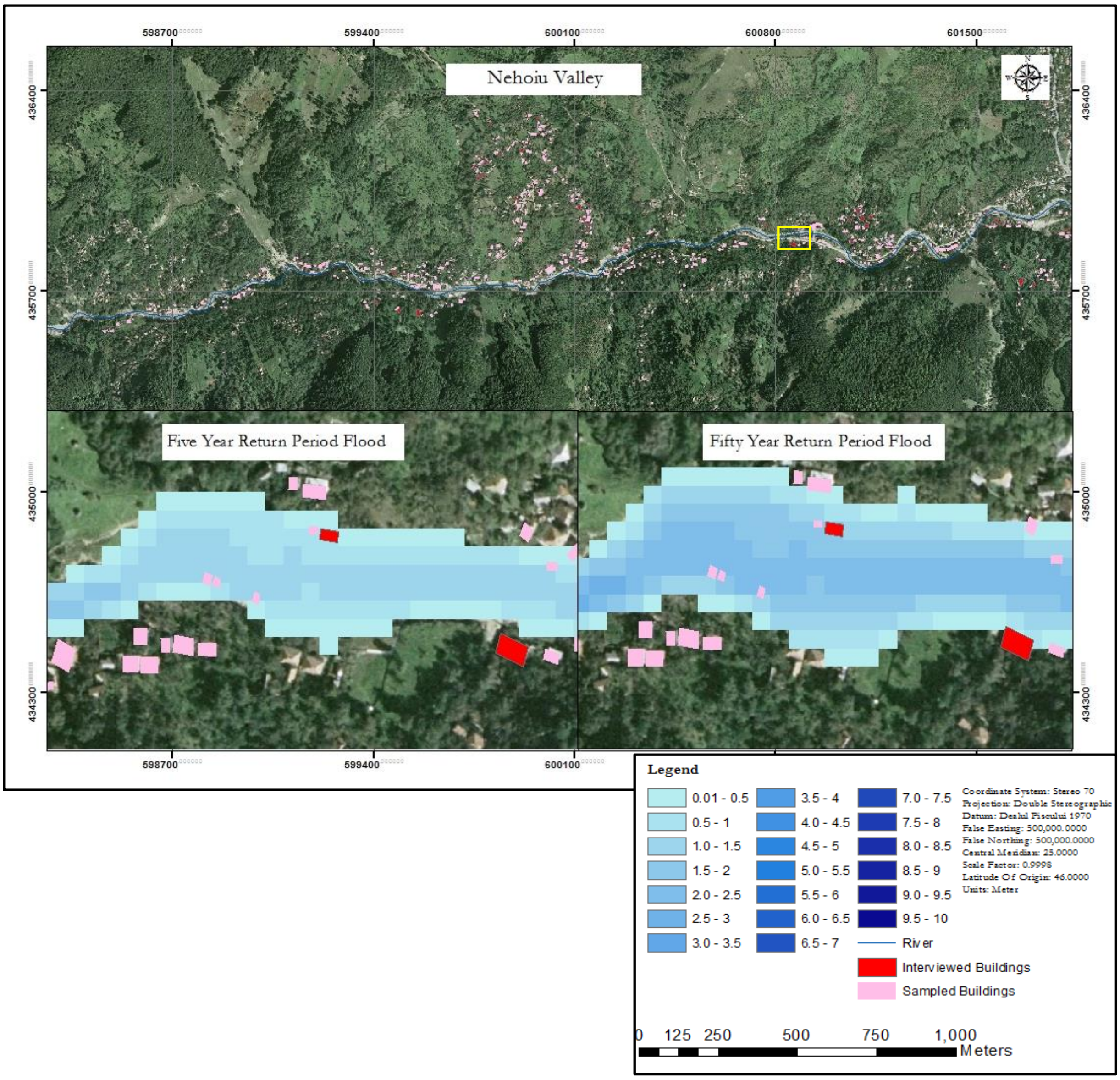


Figure 5. 1: Flood Map of 5 and 50 Year Return Period Flood

The two scenarios that were assumed were the 5 years flood which is the 2004 flood, with the height ranging from the actual height measure to 1 m higher and 50 year scenario with the variation in flood height ranging from 1 to 2 meters. The water height for the exposed wooden buildings for the floods of return period 5 years and 50 years were identified and are tabulated as shown in the Table 5.1

Building ID	**Scenario 1**		**Scenario 2**	
	2004 Flood(5 Years): Measured Flood Height (m)	50 Years Return Period-Minimum Flood Height (m)	5 Years Return Period-Max Flood Height (m)	50 Years Return Period-Maximum Flood Height (m)
19WE01	0.65	1.65	1.65	2.65
19WE02	0.65	1.65	1.65	2.65
19WE04	0.80	1.8	1.8	2.80
19WE05	0.40	1.40	1.40	2.40
25TU01	0.40	1.40	1.40	2.40
25TU03	0.11	1.11	1.11	2.11
20TH02	0.45	1.45	1.45	2.45
20TH03	0.15	1.15	1.15	2.15
20TH04	0.45	1.45	1.45	2.45

Table 5. 1: Water Depth for the Return Period

D. Vulnerability (V_{Min} and V_{Max})

The vulnerability values for the exposed elements at risk, the building vulnerability values are obtained from the vulnerability curves from the Chapter 4, as shown in the Figure 4.8. The minimum and the maximum vulnerability values are obtained from the curves. The vulnerability values used for the individual buildings are as shown in the Figure 5.2.

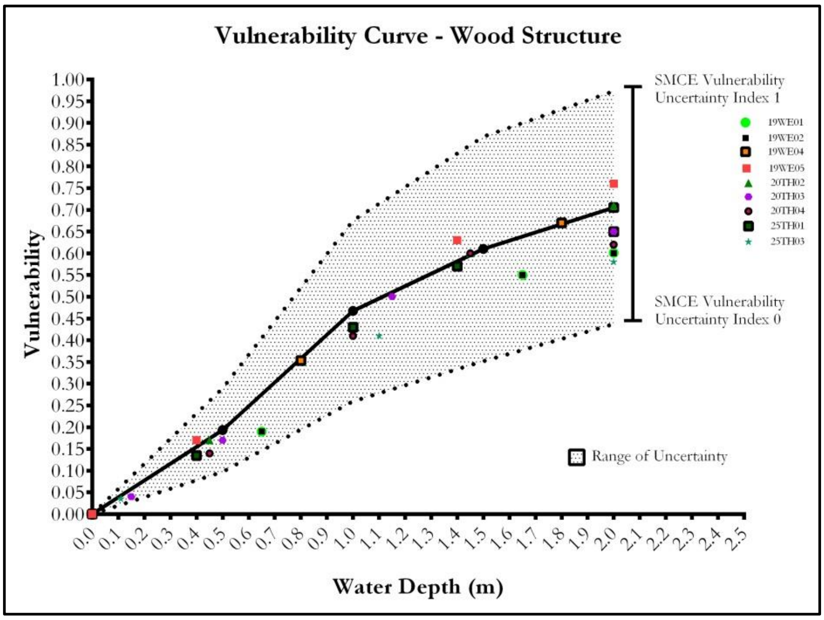


Figure 5. 2: Vulnerability Values for different Water Height for Individual Buildings

E. Losses

The reconstruction or the losses due to the damage of the structure were not available, also most of the residents during the interview were not eager to provide with the exact value of the structure. But based on the overall response of the residents and the response on the particular buildings that are exposed as per the exposure maps the average cost of a wooden building in the study area is worth approximately 1 to 1.5 Billion Rol (Old Lei). This comes to the range of 20000 - 30000 Euros. The Losses for each exposed building was calculated as shown in the Table 5.2 and Table 5.3.

Building ID	**Return Period**	**Temporal Probability**	**Amount (A) (Euros)**	**Vulnerability (V)**			**Losses$_{Min}$ = V$_{Min}$*A**	**Losses$_{Ave}$ = V$_{Ave}$*A**	**Losses$_{Max}$ = V$_{Max}$*A**	**Total Losses = ΣV*A**		
				V_{Min}	V_{Ave}	V_{Max}				$\Sigma V_{Min}*A$	$\Sigma V_{ave}*A$	$\Sigma V_{Max}*A$
19WE01	5 (2004)	0.05	22500	0.15	0.27	0.40	3375	6075	9000	23550 Euros	41750 Euros	66300 Euros
19WE02	5 (2004)	0.05	22500	0.15	0.27	0.40	3375	6075	9000			
19WE04	5 (2004)	0.05	20000	0.20	0.35	0.50	4000	7000	10000			
19WE05	5 (2004)	0.05	20000	0.07	0.17	0.22	1400	3400	4400			
25TU01	5 (2004)	0.05	30000	0.07	0.13	0.22	2100	3900	6600			
25TU03	5 (2004)	0.05	30000	0.10	0.16	0.30	3000	4800	9000			
20TH02	5 (2004)	0.05	30000	0.10	0.17	0.27	3000	5100	8100			
20TH03	5 (2004)	0.05	30000	0.02	0.04	0.07	600	1200	2100			
20TH04	5 (2004)	0.05	30000	0.09	0.14	0.27	2700	4200	8100			
19WE01	50	0.02	22500	0.37	0.65	0.90	8325	14625	20250	77250 Euros	141350 Euros	194400 Euros
19WE02	50	0.02	22500	0.37	0.65	0.90	8325	14625	20250			
19WE04	50	0.02	20000	0.40	0.67	0.92	8000	13400	18400			
19WE05	50	0.02	20000	0.32	0.63	0.82	6400	12600	16400			
25TU01	50	0.02	30000	0.32	0.57	0.82	9600	17100	24600			
25TU03	50	0.02	30000	0.27	0.60	0.70	8100	18000	21000			
20TH02	50	0.02	30000	0.35	0.60	0.85	10500	18000	25500			
20TH03	50	0.02	30000	0.30	0.50	0.75	9000	15000	22500			
20TH04	50	0.02	30000	0.30	0.60	0.85	9000	18000	25500			

Table 5. 2: Loss Calculation for the Floods of 5 and 50 Year Return Period (Scenario 1)

Building ID	Return Period	Temporal Probability	Amount (A) (Euros)	Vulnerability (V)			$Losses_{Min} = V_{Min}*A$	$Losses_{Ave} = V_{Ave}*A$	$Losses_{Max} = V_{Max}*A$		Total Losses = ΣV*A	
				V_{Min}	V_{Ave}	V_{Max}				$\Sigma V_{Min}*A$	$\Sigma V_{ave}*A$	$\Sigma V_{Max}*A$
19WE01	5	0.05	22500	0.37	0.65	0.90	8325	14625	20250	77250 Euros	141350 Euros	194400 Euros
19WE02	5	0.05	22500	0.37	0.65	0.90	8325	14625	20250			
19WE04	5	0.05	20000	0.40	0.67	0.92	8000	13400	18400			
19WE05	5	0.05	20000	0.32	0.63	0.82	6400	12600	16400			
25TU01	5	0.05	30000	0.32	0.57	0.82	9600	17100	24600			
25TU03	5	0.05	30000	0.27	0.60	0.70	8100	18000	21000			
20TH02	5	0.05	30000	0.35	0.60	0.85	10500	18000	25500			
20TH03	5	0.05	30000	0.30	0.50	0.75	9000	15000	22500			
20TH04	5	0.05	30000	0.30	0.60	0.85	9000	18000	25500			
19WE01	50	0.02	22500	0.60	0.92	1	13500	20700	22500	128800 Euros	205100 Euros	235000 Euros
19WE02	50	0.02	22500	0.60	0.92	1	13500	20700	22500			
19WE04	50	0.02	20000	0.70	0.96	1	14000	19200	20000			
19WE05	50	0.02	20000	0.52	0.85	1	10400	17000	20000			
25TU01	50	0.02	30000	0.52	0.86	1	15600	25800	30000			
25TU03	50	0.02	30000	0.45	0.90	1	13500	27000	30000			
20TH02	50	0.02	30000	0.57	0.87	1	17100	26100	30000			
20TH03	50	0.02	30000	0.47	0.75	1	14100	22500	30000			
20TH04	50	0.02	30000	0.57	0.87	1	17100	26100	30000			

Table 5. 3: Loss Calculation for the Floods of 5 and 50 Year Return Period (Scenario 2)

A. Risk Curve

Considering all the variations and the uncertainties, a risk curve for the minimum losses, average losses and the maximum losses was plotted. The risk curve was plotted as described in the Figure 2.11. This risk curve was drawn for both the scenarios with the range of probability and the range of intensity (water depth). The risk curves plotted are as shown in Figure 5.3. However for an accurate risk curve more information on the probability of occurrence and the intensities are needed.

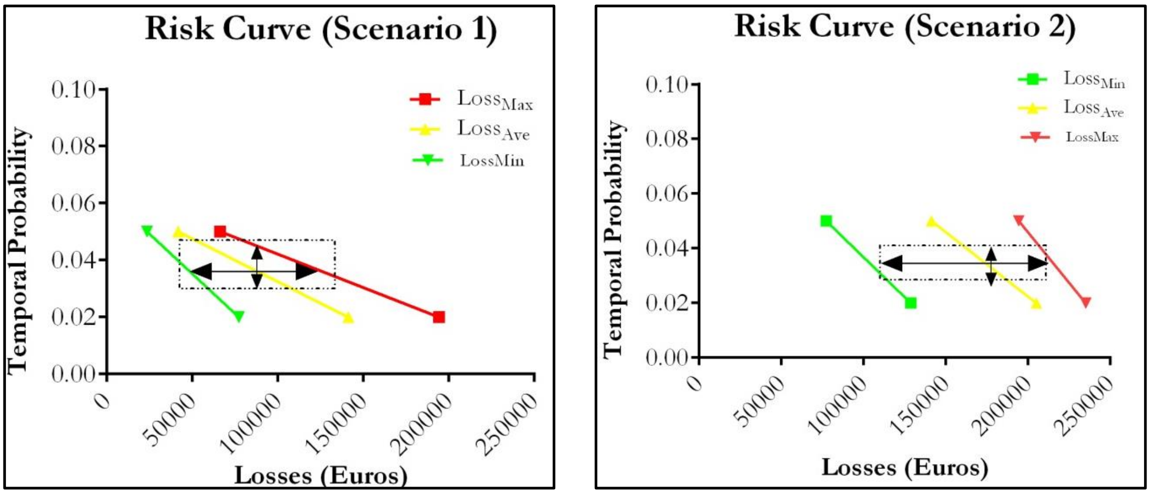


Figure 5. 3: Risk Curve for Minimum, Average and Maximum Losses for the 2 scenarios of 2004 Flood and 50 Year Flood

Using the data obtained from the municipality, on the Humanitarian Aid provided to the people affected from the 2004 flood. The aid was given in the form of construction material (such as: timber, cement, plaster boards, etc.,) for the affected people in the community. The humanitarian aid that was provided to the whole of Buzau county was 3400 million Lei (Rol) approximately 8 million euros. The materials were provided to 117 different houses in the Nehoiu based on the damage.

Product	Unit of Measurement	Amount aided
Cement	Ton	100
Timber	Cubic Meter	215
Brick	Number	3080
Tiles	Number	4400
Asphalt board	Square Meter	1430
Concrete iron	Ton	32
Asbestos cement boards	Cubic Meter	1274

Table 5. 4: Estimation of materials provided by Humanitarian Aid

Using the prices provided from the municipality and also prices obtained from an International Construction Cost Survey Report (Gardiner & Theobald LLP, 2011) an estimate was calculated which comes to approximately 85 thousand euros.

Comparing the estimated amount from the humanitarian aid to the calculated flood average loss for the flood event 2004, based on the vulnerability values using vulnerability uncertainty index (refer Table 5.2 and 5.3). The losses due to the damage calculated in Table 5.2 and 5.3 are the total cost of the building and not partial material costs and hence the losses seem higher for much less number of buildings. Given that there is exact information regarding the building (detailed damage inventory with the unit loss of materials and the location) loss calculation and the risk assessment can be carried out accurately.

5.2. Lanslide Risk

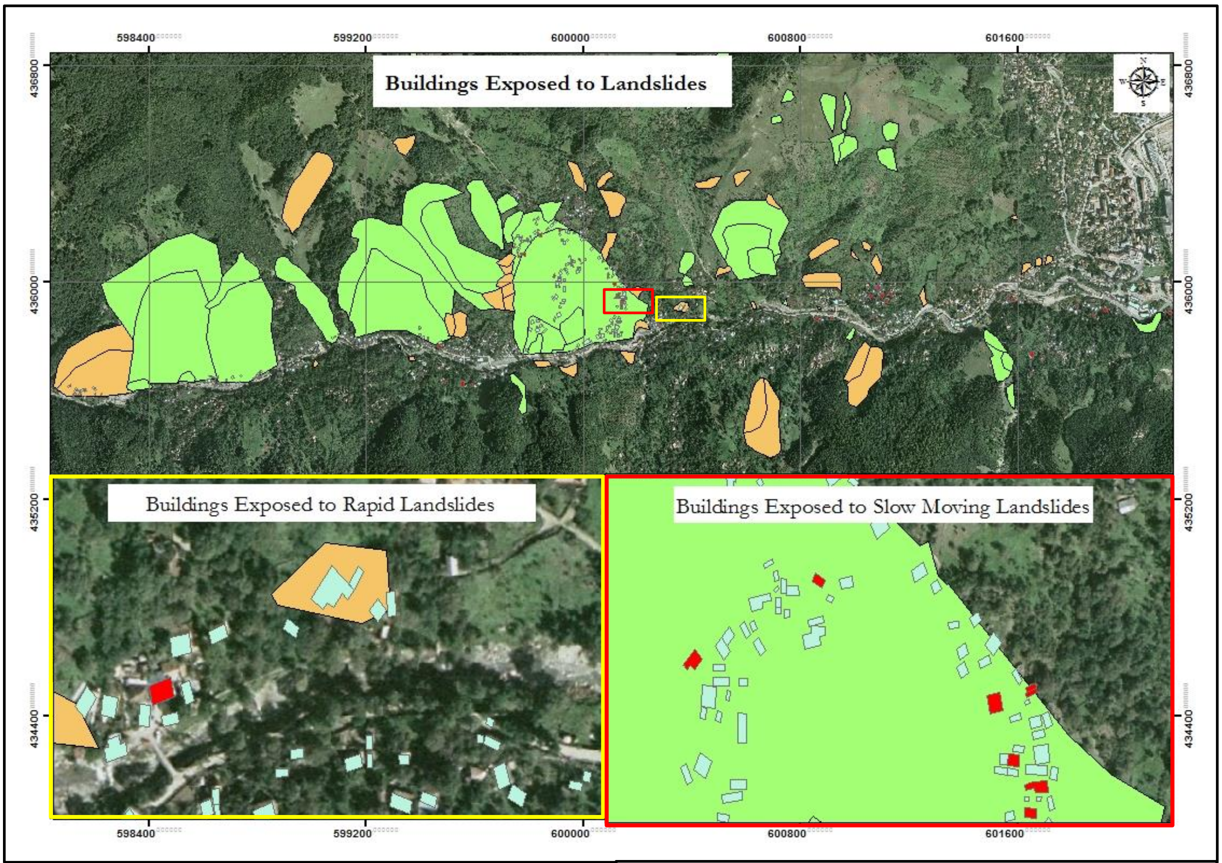
Inorder to be able to quantitatively assess the landslide risk, information regarding the intensity of the landslides and the return period of the hazard is required. Unfortunately no information was available on landslide intensities and return periods of landslide triggering events. The vulnerability values from the averaged vulnerability curves could not considered for the risk assessment in the research due to the following reasons

- The fact that these curves do not differentiate between the individual building types as in the flood physical vulnerability curves.
- Insufficient information on the hazard intensity (e.g. deposition height, impact pressure).

Since there was no available information for both hazard information and the return period, only the number of buildings that are exposed to landslide risk can be analysed.

For slow moving landslides, the buildings that are located on the landslide are the ones that are exposed to risk, whereas for rapid landslides, also the buildings that are located below the rapid landslide on the slope are at risk.

Total number of sampled buildings exposed to slow moving landslides = 203
Total number of interviewed buildings exposed to slow moving landslides = 20
Total number of sampled buildings exposed to rapid landslides = 70
Total number of interviewed buildings exposed to rapid landslides = 7



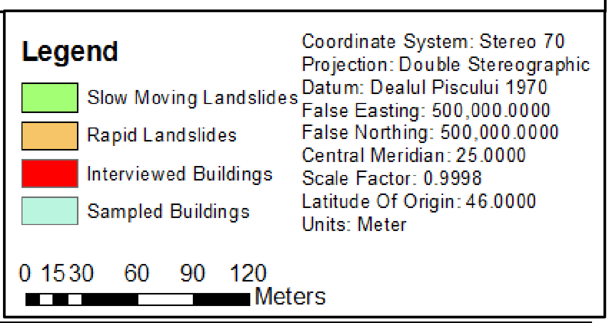


Figure 5. 4: Buildings Exposed to Slow Moving and Rapid Landslides

6. CONCLUSIONS AND RECOMMENDATIONS

This chapter comprises of the concluding part of the research. It provides the conclusions and discussion for each of the research objectives. Finally, this chapter suggests recommendations for future research.

6.1. Conclusion

The main objective of this research is to analyse the uncertainty related to physical vulnerability of buildings in terms of their structure, for hydro-meteorological hazards (floods and landslides) in the study are Nehoiu, Buzau County, Romania. The following sections conclude and discuss each of the research objectives.

To collect existing vulnerability curves for two building types and use these to analyse the level of uncertainty for different building types and hazard types. The existing vulnerability curves for floods and landslides were collected from literature, vulnerability curves for wooden and RCC structures for flood hazard were collected. There were relatively few vulnerability curves for flooding available for literature, and a very few for landslides. The vulnerability curves for the same building show a very large variation in vulnerability in relation to the intensity. This could be since they are from different areas and the buildings with different building characteristics and for floods that might be either flash floods or river floods. Nevertheless the difference between the vulnerability curves were quite large, this also has a huge impact on the risk calculation.

Chapter 2 deals with this objective, one of the main issues with vulnerability curves is that they are complicated, site specific, process specific and building specific. Vulnerability curves were collected for flood hazard, and the curves that represent only wooden and RCC structures were only considered. There exists uncertainty in the averaged vulnerability due to the various factors as such as the expression of the vulnerability in each of these curves (e.g. damage percentage, damage factor etc.,), other factors such as influence of velocity also plays a significant role. Vulnerability curves were also collected for landslide hazard, however these are not building specific.

To map and characterize the elements at risk and their significant factors that can be used to represent the differences in vulnerability of structures. To obtain this objective, the building characteristics that are considered to contribute to the vulnerability for both floods (river flood and flash flood) and landslides (slow moving and rapid landslides) were collected from the literature. Inorder to collect the building characteristics in the field, a questionnaire was designed that takes into account these major building characteristics. A total of 689 building were surveyed sampled for their structural type, state of the structural and non-structural elements and the numbers of floors, observations regarding any visible characteristics were noted. Interviews using the questionnaires were carried to collect detailed information on building characteristics and any information of previous hazard events and associated damage for 60 buildings. A building foot print map and a database was also created for these buildings. The majority of the buildings that were in the study area are wooden structures. Among the interviewed buildings, a significant number were affected by landslides and were subjected to cracks and differential settlement.

The main problems that were faced in the field were the language, which was quite a barrier and also accessibility problems to some of the buildings was also faced. Some of the issues such as unwillingness to answer and lack of knowledge on the detailed building information was also encountered. One of the most interesting observations was that the majority of the interviewed houses in the study area owned insurance toward natural hazards. Although most of the residents either did not know the information or they did not want to give out the information regarding the premium and other costs, however a few of them mentioned that the basic value the building was insured was 30000 euros.

The third objective that forms the major part of the analysis is *to develop a weighting method based on the expert opinion for building characteristics to determine vulnerability in the uncertainty range expressed by existing vulnerability curves*. To obtain this objective, a weighting method was developed based on expert judgement. Questionnaires with a vulnerability matrix listing down all the important building characteristics for floods (river and flash flood) and landslides (slow moving and rapid landslides) were filled out by a group of experts and ESR's in a CHANGES workshop at Dortmund during the period November 27th -29th 2012. The ratings obtained from the questionnaire for the building characteristics were then incorporated into the SMCE module in ILWIS to calculate their relative weights. The building characteristics that were rated the most important by the Experts and the ESR's are as

- For river flood: presence of basement and height of the building with respect to river.
- For flash flood: the structural characteristics such as wall material, quality and maintenance of the building seem to be the most important, as it would withstand the impact of the water pressure depending on the quality of the building.
- For landslides: It can be concluded that the characteristics such as building close to slope and cracks in the structure were significant for both slow moving and rapid landslides; moreover also the "presence of other buildings between the building and slope" was concluded to be one of the significant characteristics.

Based on the field study the ranges of the factors for these characteristics were assigned and standardized. Using the normalized weights of the building characteristics and the standardized weights of the factors, the vulnerability uncertainty index for individual buildings were calculated.

In order to achieve the third sub-objective completely, the vulnerability uncertainty factors were then plotted on the averaged vulnerability curve which was made in the pre-fieldwork phase. The predominant building type in the study area was wooden buildings. Hence the averaged vulnerability curve for wooden buildings was used to calculate the vulnerability values. Due to the lack of information of the flood height for the 2004 flood event, a flood height map was also produced. Using the values from this flood height map, the total number of 6 wooden buildings from the interviewed buildings was exposed to the 2004 flood event. The vulnerability curve for each building was then produced using the vulnerability uncertainty index and the flood height. The range of vulnerability from these buildings varied from 0.3 to 0.7.

The main issues that could be discussed in regard to this part would be that there is a variation in the ratings assigned to the building characteristics. This could be mainly due to the area of expertise and the depth of the knowledge of these characteristics for the specific hazard of both the experts and the ESR's. This however was also inevitable due to the following reasons such as the non-availability of the local residents due to their job and the lack of knowledge on the details of the building characteristics. Lastly the variation of the vulnerability uncertainty index for the individual buildings for different hazards was much smaller than expected and it can be seen that the majority of the variation is after the second digit of the vulnerability uncertainty index.

The final objective of the research is *to indicate how the vulnerability values can be used in the risk assessment*. The main idea was to express how the vulnerability uncertainty index and the vulnerability values from the curves could be used to carry out the risk assessment for flood. Due to the lack of information regarding the hazard return periods of 5 and 50 years were assumed considering the past flood events. Flood height map for these return periods were produced considering the range of 2004 flood height to 1 m water height increase for 5 years and a range of 1 to 2 m water height increase for 50 years return period. These maps were also used to identify the exposed interviewed buildings. The vulnerability values were used from the individual building vulnerability curves and the specific risk for these individual buildings was calculated. The risk maps were produced for the 2 scenarios, however these can be made accurate if there was data available regarding the probability of occurrence and the intensity of these events. But for landslides since the there was no information on either of them hazard probability or the hazard intensity. However the risk of buildings exposed to both slow moving and rapid landslides was shown in the landslide exposure risk map.

The lack of flood depth information leads to issues of the accuracy of the exact flood height during the previous flood event. Also the lack of the information on the exact extent of the flood event raised issues on the houses that were interviewed. The averaged vulnerability curve for the landslide hazard was not considered due to the fact that the existing vulnerability curves for landslides are not building specific and also due the fact that there was no available information on the landslide intensity in the study area.
Therein case there would be sufficient available information on the hazard intensity, return period and losses, a detailed risk assessment can be carried out resulting in producing the risk curve for the floods and landslides.

6.2. Recommendations

There were significant obstacles and limitations involved in the research. The aspects areas where significant improvement could be made are presented here. The two major limitations were that there was no available data on the previous hazardous events, especially in terms of flood there was no information on the flood depth and no accurate flood extent available. Secondly there was no available damage data relating to the previous hazard events, which caused a major obstacle in assessing the damage and loss due to these events.
Some of the recommendations for further research would be

- Considering the weights given by the experts and ESR's and the calculation of the relative weights of these building characteristics. An iterated second set of questionnaires could be given to the experts and ESR's with the most significant characteristics, which had the highest weights assigned to them. This would really narrow down the most significant characteristics and how they play an important role in assessing the building vulnerability.
- A detailed and accurate flood extent map should be made with the help of the local residents and the municipality. This would help identify the actual exposure of the buildings to the flood hazard.
- Flood hazard scenario modelling and landslide modelling could be done to identify the hazard intensity and this would help in assessing the vulnerability values on the averaged vulnerability curves.
- Since these floods are localized, there is a high relative loss in the study area; a study on the socio-economic characteristics of the area could be done which would give a better understanding of the vulnerability of the buildings in the area.
- The study should focus more on the coping mechanisms or mitigation measures against these hazards.

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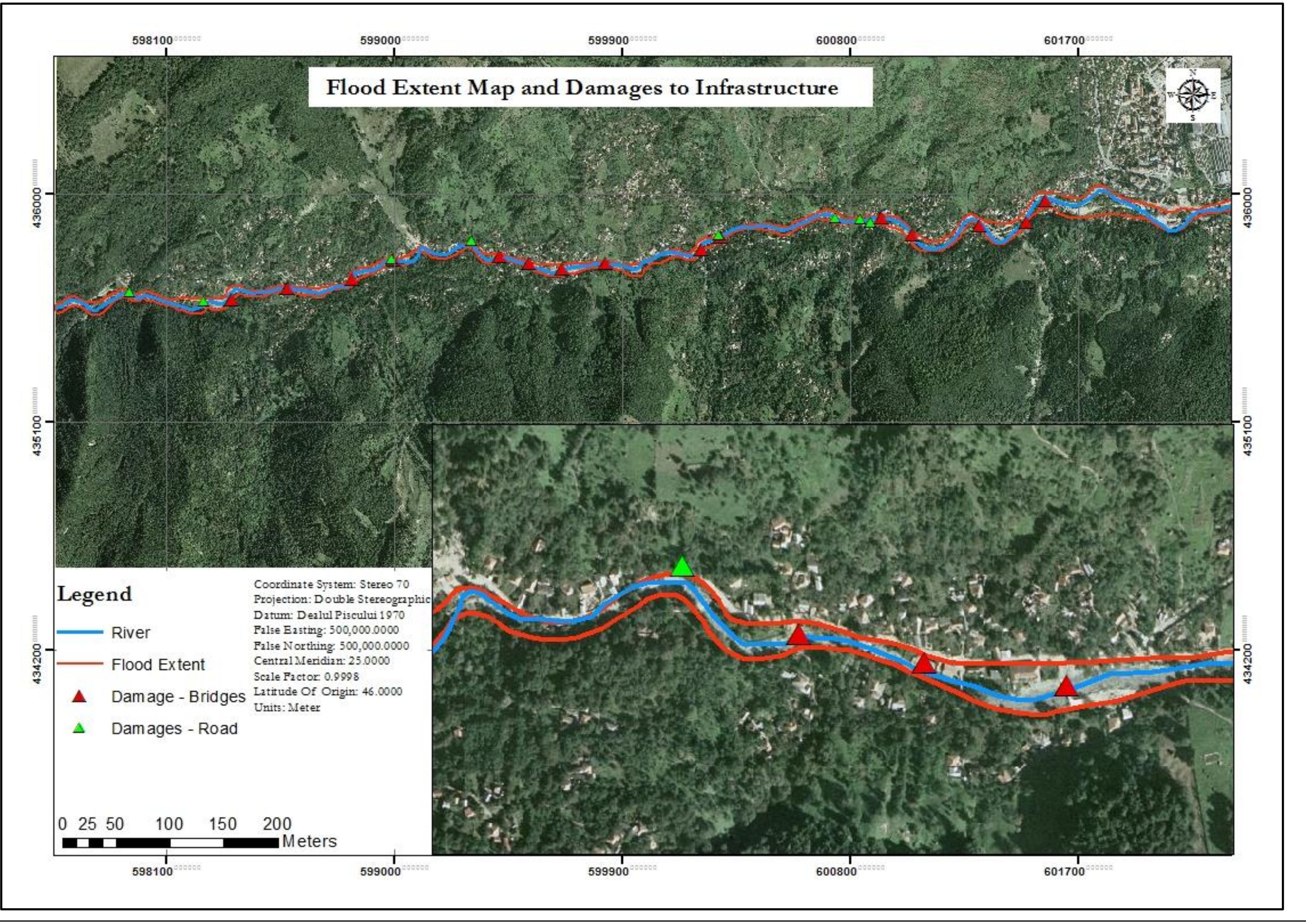
APPENDICES

Apendix A - Flood Extent and Damage to infrastructure



Appendix B- Database of Sampled Buildings (Attribute Table)

Sampled Buildings

FID	Shape *	Area	ID	OC_TY	ST_TY	STATE_ST	STATE_NST	NR_FL	NR_HH	REMARKS
0	Polygon	25.809025	1709004	STO	W	L	NE	1	0	wood keeping
1	Polygon	44.115827	1709005	STO	W	G	G	2	0	
2	Polygon	228.101134	1709009	STO	S	M	L	1	0	
3	Polygon	139.146951	1709010	MWOF	W	G	M	2	1	Wood waste stored in the garden
4	Polygon	68.796459	1709011	STO	W	G	G	1	0	
5	Polygon	180.048217	1709008	AR	WA	L	L	1	0	Deteriorated walls
6	Polygon	285.115929	1709007	CC	ST	G	G	1	0	Religious purposes
7	Polygon	37.290483	1709012	GA	W	G	G	1	0	
8	Polygon	28.360785	1709013	SRH	W	G	G	2	1	
9	Polygon	158.264619	1709014	SRH	W	G	G	1	1	
10	Polygon	23.72091	1709015	SRH	W	L	L	2	1	
11	Polygon	27.453183	1709016	GA	W	G	G	1	0	
12	Polygon	35.513946	1709017	GA	W	G	G	1	0	
13	Polygon	107.075866	1709018	STO	W	L	L	1	0	Wood Storage
14	Polygon	106.649068	1709019	STO	W	G	G	2	0	
15	Polygon	72.756472	1709020	MWSH	MBRW	G	G	2	1	Convenience Store + Residential
16	Polygon	41.770074	1709021	GA	W	G	G	1	0	
17	Polygon	41.35293	1709022	STO	W	G	NE	1	0	
18	Polygon	54.555453	1709023	SRM	W	G	G	1	1	
19	Polygon	129.290408	1709024	SRM	W	G	G	1	1	Landslide prone area, Fracture in structure
20	Polygon	22.220246	1709025	STO	W	G	G	1	0	Storage in the back of a house
21	Polygon	24.884126	1709026	GA	W	G	G	1	0	
22	Polygon	24.265113	1709027	STO	W	G	L	1	0	
23	Polygon	46.307403	1709028	GA	W	G	G	1	0	
24	Polygon	64.791156	1709029	SRM	W	G	G	2	1	
25	Polygon	64.038302	1709030	GA	W	G	G	1	0	
26	Polygon	285.96024	1709031	MSAB	MBLW	G	G	2	3	
27	Polygon	117.49776	1709032	SRH	MBLW	G	G	1	1	

Title	Description
ID	Building ID
OC_TY	Occupancy Type
ST_TY	Structural Type
STATE_ST	State of the Structural Components
STATE_NST	State of the non- structural components
NR_FL	No. of Floors
NR_HH	No. of Households

(Refer to Table 3.3 for the Description of the Occupancy Types, Structural Types and the State of the Structural and Non-Structural Components)

Appendix C- Database of Interviewed Buildings (Attribute Table Part 1)

Interviewed Buildings

FID	Shape *	ID2	Questionn	Area	Year	No_Fl	Fl_A_S	Ht_Bd	Fl_Ht_G	Shap	Doors	Wind	Ele_Do	Ele_Wi	Ele_tot	Basem	Use_ba	Wall_M	Floor_M	Clmn_M	Found_M	F_Dep	Balcony
30	Polygon	110023	01MO04	134.	1970	1	48	3	0	R	2	4	0	4	4	YES	STORAG	WOOD+ADOBE	ADOBE	NC	STONE+CO	0.5 m	NO
31	Polygon	110025	01MO05	155.	1960	1	120	3	0	R	2	5	0	5	5	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	NA	NO
33	Polygon	110031	01MO06	119.	1970	1	0	4	0.5	S	3	4	3	4	7	YES	STORAG	WOOD+ADOBE	CONCRET	WOOD	STONE+CO	NA	NO
32	Polygon	110030	01MO07	40.1	2012	2	18	6	0.5	R	1	1	1	2	3	NO	-	CONCRETE+BL	CONCRET	CONCRE	STONE+CO	NA	NO
57	Polygon	110041	01MO08	93.5	1974	2	90	6	1	S	1	5	1	5	6	NO	-	WOOD+ADOBE	CONCRET	NC	STONE+CO	1 m	YES
56	Polygon	110042	01MO09	49.2	2010	2	32	6	0	S	3	4	0	4	4	YES	STORAG	WOOD	CONCRET	WOOD	STONE+CO	1.5 m	NO
34	Polygon	210001	02TU01	114.	1977	2	100	6	-0.25	S	5	8	0	0	0	NO	-	WOOD+BRICK	ADOBE	NC	STONE+CO	0.8 m	NO
37	Polygon	210024	02TU02	40.5	2006	1	70	4	0	R	2	6	0	6	6	YES	STORAG	STEEL	CONCRET	STEEL C	STEEL+CO	8 m	NO
36	Polygon	210023	02TU03	76.8	2009	2	40	6	0	R	2	4	0	4	4	NO	-	STEEL	CONCRET	STEEL C	STEEL+CO	0.4 m	NO
39	Polygon	210030	02TU04	144.	1967	1	0	3	0	S	1	3	0	3	3	NO	-	WOOD	ADOBE	WOOD	STONE+CO	0.5 m	NO
35	Polygon	210016	02TU05	27.7	2012	2	90	6	0	S	1	4	0	4	4	YES	STORAG	WOOD+ADOBE	CONCRET	WOOD	STONE+CO	0.4 m	NO
38	Polygon	210029	02TU06	29.6	1962	1	0	4	0	S	2	4	0	4	4	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	0.5 m	NO
41	Polygon	210043	02TU07	92.0	1969	1	80	4	0	R	1	7	0	7	7	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	0.4 m	NO
42	Polygon	210059	02TU08	56.7	1979	1	30	5	0	S	2	6	0	6	6	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	0.4 m	NO
40	Polygon	210034	02TU09	73.8	1998	1	80	4	0	S	2	2	0	2	2	NO	-	WOOD+ADOBE	ADOBE	NC	STONE+CO	0.5 m	NO
43	Polygon	210063	02TU10	196.	1972	1	0	-	0	R	3	5	0	5	5	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	0.6 m	NO
44	Polygon	210064	02TU11	77.3	1932	1	9	3	1	S	1	1	1	1	2	NO	-	WOOD+ADOBE	ADOBE	NC	STONE+CO	NA	NO
45	Polygon	210068	02TU12	93.6	1969	1	0	4	0.5	S	4	6	4	6	10	NO	-	WOOD+ADOBE	ADOBE	WOOD	STONE+CO	0.5 m	NO
52	Polygon	1709001	19WE01	26.6	2000	1	26	4	0	S	1	2	0	2	2	NO	-	WOOD	CONCRET	WOOD	STONE + C	NA	NO
53	Polygon	1709002	19WE02	44.0	2000	1	25	4	0	S	1	2	0	2	2	NO	-	WOOD	CONCRET	WOOD	STONE + C	NA	NO
46	Polygon	210096	19WE03	113.	1987	1	12	4	0.5	S	3	2	3	2	5	YES	STORAG	WOOD+BRICK	ADOBE	WOOD	STONE + C	NA	NO
59	Polygon	210099	19WE04	101.	1960	1	64	6	0.5	S	2	6	2	6	8	NO		WOOD+ADOBE	CONCRET	WOOD	STONE + C	NA	YES
1	Polygon	1709040	19WE05	182.	1982	1	36	5	2	S	2	2	2	2	4	YES	STORAG	WOOD+ADOBE	CONCRET	WOOD	STONE + C	NA	NO
2	Polygon	1709047	19WE06	58.5	1980	2	72	8	2	R	5	6	5	6	11	YES	STORAG	BLOCK+WOOD	CONCRET	WOOD	STONE + C	NA	YES (WOOD)
51	Polygon	1809011	19WE07	108.	1990	2	200	8	1	R	3	10	1	2	3	YES	STORAG	BLOCK+WOOD	CONCRET	CONCRE	STONE + C	1 m	YES (WOOD)
50	Polygon	1809024	19WE08	12.0	1980	1	0	-	0	R	3	4	1	2	3	YES	STORAG	WOOD+ADOBE	ADOBE+	WOOD	BRICK	0.2 m	NO
48	Polygon	1809075	19WE09	35.4	1980	2	52	12	1	R	2	6	2	6	8	YES	STORAG	BLOCK (DIATO	CEMENT	BLOCK (	STONE + C	0.5 m	YES (WOOD)

Title	Description	Title	Description	Title	Description	Title	Description
ID2	Building ID	Shap	Shape	Ele_Tot	Total Elevated Doors+Windows	Clmn_m	Column Material
Questionn	Questionnaire Code	Doors	No. of Doors	Basem	Presence of Basement	Found_m	Foundation Material
No_Fl	No. of Floors	Wind	No. of Windows	Use_ba	Use of Basement	F_Dep	Depth of Foundation
Ht_Bd	Height of the Building	Ele_Do	Elevated Doors	Wall_m	Wall Material	Balcony	Presence of Balcony
Fl_Ht_G	Floor Height from Ground	Ele_Wi	Elevated Windows	Floor_m	Floor Material		

Appendix C- Database of Interviewed Buildings (Attribute Table Part 2)

Interviewed Buildings

Bld_Maint	Q_of_Cons	Bld_Adj	Bld_on_Sl	Bld_cls_Sl	Bld_bet_sl	Bld_cl_St	Ls_post	open_fldir	cracks	repair	wall_ard	ht_	Floods_PM	LS_PM	EQ_PM	Flood_Dep	LS	Insura
LOW	LOW	YES	YES	YES	YES	NO	TOE	5	YES	YES	NO	-	no	no	no	2005 with landsli	bulging of struvture, crack	YES
MEDIUM	MEDIUM	YES	YES	YES	YES	NO	TOE	4	YES	NO	NO	-	no	no	no	damage to the ex	cracks are formed due to	YES
GOOD	GOOD	YES	YES	YES	YES	NO	TOE	3	YES	YES	NO	-	elevated struct	no	no	no	cracks due to creeping of	YES
MEDIUM	MEDIUM	YES	YES	YES	YES	NO	TOE	4	YES	YES	NO	-	no	no	no	no	cracks due to creeping of	NO
MEDIUM	MEDIUM	YES	NO	YES	YES	NO	TOE	3	YES	NO	NO	-	no	no	no	no	cracks present on the buil	YES
GOOD	GOOD	YES	YES	YES	YES	NO	TOE	4	YES	YES	YES	0.5 m	no	no	no	no	settlement of part of the st	YES
GOOD	GOOD	YES	YES	YES	YES	NO	TOE	2	NO	NO	NO	-	no	no	no	no	no problems wrt to landsli	NO
GOOD	GOOD	YES	YES	YES	YES	NO		4	NO	NO	YES	1.5 m	elevated struct	no	no	no	no problems wrt to landsli	YES
GOOD	GOOD	YES	YES	YES	YES	NO		4	YES	NO	NO	-	no	no	no	no	no problems wrt to landsli	YES
GOOD	GOOD	NO	NO	YES	NO	YES	TOE	7	YES	YES	NO	-	no	wall built behind th	no	no	yes	NO
GOOD	GOOD	YES	NO	YES	NO	YES	TOE	4	NO	NO	NO	-	elevated found	no	no	no	no problems wrt to landsli	YES
GOOD	GOOD	YES	NO	YES	NO	YES	TOE	3	NO	NO	NO	-	no	no	no	no	no problems wrt to landsli	YES
GOOD	GOOD	YES	YES	NO	YES	YES	TOE	3	NO	NO	NO	-	no	no	no	no	no problems wrt to landsli	YES
GOOD	GOOD	YES	NO	YES	NO	YES	TOE	3	NO	NO	NO	-	no	no	no	no	no problems wrt to landsli	NO
GOOD	GOOD	YES	NO	YES	NO	YES	TOE	4	YES	NO	NO	-	stone wall behi	fences and stone	no	no	cracks due to creeping of	YES
GOOD	GOOD	YES	NO	YES	YES	NO	TOE	5	NO	NO	NO	-	no	no	no	no	no problems wrt to landsli	NO
LOW	LOW	YES	YES	YES	YES	NO	TOE	6	YES	YES	NO	-	no	no	no	no	cracks due to creeping of	YES
GOOD	GOOD	YES	YES	YES	YES	NO	TOE	3	NO	NO	NO	-	no	no	no	spring close by,	steep slope might cause l	YES
MEDIUM	MEDIUM	YES	YES	YES	YES	NO	TOE	5	YES	NO	NO	-	no	no	no	no	cracks due to creeping of	NO
GOOD	MEDIUM	YES	YES	YES	YES	YES	TOE	1	YES	YES	NO	-	no	no	no	no	cracks due to creeping of	NO
GOOD	GOOD	YES	YES	YES	YES	NO	TOE	6	YES	NO	NO	-	no	no	no	no	no problems wrt to landsli	YES
GOOD	MEDIUM	YES	NO	YES	NO	YES	TOE	3	NO	NO	NO		no	no	no	2m on street	-	NO
GOOD	MEDIUM	YES	NO	YES	NO	YES	TOE	3	NO	NO	NO		no	no	no	2m on street	-	NO
MEDIUM	MEDIUM	YES	NO	NO	YES	YES		2	YES	YES	NO		elevated struct	no	no	0.5m in basemen	-	YES
LOW	LOW	YES	NO	YES	YES	YES	TOE	6	YES	YES	NO		elevated struct	no	no	-	debris flow during rain	YES
LOW	LOW	YES	YES	YES	YES	YES	TOE	3	YES	YES	NO		elevated struct	Heightening of stru	no	0.5m in garden	movement of material ever	NO
GOOD	HIGH	YES	YES	YES	YES	YES	TOE	0	YES	NO	YES	1.5 m	elevated struct	1 m height stone w	no	-	bulging in wall (0.5 year)	YES

Title	Description	Title	Description	Title	Description	Title	Description
Bld_Maint	Maintenance of Building	Bld_bet_Sl	Building between Slope	Wall_ard	Wall around the Building	Flood_Dep	Flood Depth
Q_of_Const	Quality of Construction	Ls_post	Position of Landslides	Ht_wall	Height of the wall around	LS	Impact of Landslides
Bld_Adj	Presence of Adjacent Buildings	Open_fldir	Openings in the Direction of Flow	Floods_PM	Preventive Measures- Floods	Insurance	Insurance against Natural Hazards
Bld_on_Slp	Building on Slope	Cracks	Presence of cracks	LS_PM	Preventive Measures- landslides		
Bld_cls_Sl	Building close to Slope	Repair	Repairs in the building	EQ_PM	Preventive Measures- Earthquake		

Appendix D - Pictures of the some of the Interviewed Buildings

Building ID	Image	Building ID	Image
19WE02		19WE08	
27TH02		02TU08	

Appendix E - Estimation of Humanitarian Aid for 2004 Flood affected houses in Nehoiu

1 Lei = 10000 Old Lei (Rol), 1 Euro = 4.1 Lei

Material	**Amount**		
	Old Lei (Rol) (Million Lei)	Lei	Euro
Asphalt Board	43	4300	1050
Asbestos Cement Boards	127	12700	3097
Brick	3080		910
Cement	301	31000	7560
Steel			45787
Tiles	4400		2200
Timber	1072	107200	26150
Total			86750

Appendix F - Weights for Building Characteristics from ILWIS – Experts

EXPERT OPINION	A	B	C	D	E	F	G	H	I	Mean
RIVER FLOOD										
Height of Building from Ground level	0.065	0.083	0.102	0.247	0.228	0.112	0.079	0.043	0.316	0.142
Number of Floors	0.156	0.153	0.072	0.24	0.244	0.112	0.09	0.046	0.104	0.135
Structural Type	0.149	0.039	0.064	0.111	0.116	0.076	0.032	0.076	0.104	0.085
Size of the Building	0.264	0.021	0.059	0.103	0.05	0.057	0.097	0.157	0.03	0.093
Wall Material	0.149	0.042	0.153	0.104	0.19	0.151	0.133	0.128	0.037	0.121
Presence of Basement	0.023	0.149	0.011	0.062	0.045	0.076	0.073	0.206	0.021	0.074
Height of the Door and Windows	0.017	0.163	0.063	0.054	0.022	0.142	0.074	0.27	0.144	0.105
Quality of construction	0.076	0.071	0.22	0.019	0.061	0.091	0.137	0.036	0.083	0.088
Maintenance of the building	0.081	0.087	0.174	0.039	0.031	0.091	0.14	0.022	0.069	0.082
Wall around the building	0.019	0.192	0.084	0.021	0.015	0.091	0.144	0.016	0.093	0.075
FLASH FLOOD										
Height of Building from Ground level	0.141	0.05	0.11	0.089	0.026	0.11	0.044	0.029	0.129	0.081
Number of Floors	0.194	0.06	0.127	0.193	0.024	0.11	0.086	0.029	0.066	0.099
Structural Type	0.177	0.03	0.179	0.157	0.145	0.11	0.033	0.07	0.107	0.112
Size of the Building	0.159	0.025	0.136	0.086	0.024	0.013	0.105	0.03	0.044	0.069
Wall Material	0.101	0.169	0.098	0.091	0.154	0.11	0.189	0.231	0.062	0.134
Presence of Basement	0.046	0.147	0.068	0.123	0.024	0.105	0.108	0.202	0.02	0.094
Height of the Door and Windows	0.024	0.175	0.053	0.083	0.145	0.11	0.067	0.081	0.15	0.099
Quality of construction	0.11	0.178	0.123	0.059	0.085	0.11	0.093	0.221	0.106	0.121
Maintenance of the building	0.03	0.014	0.038	0.1	0.052	0.11	0.118	0.096	0.126	0.076
Wall around the building	0.018	0.152	0.067	0.018	0.32	0.11	0.158	0.012	0.189	0.116
SLOW MOVING LANDSLIDES										
Height of building from ground level	0.011	0.029	0.029	0.074	0.024	0.019	0.024	0.033	0.084	0.036
Number of floors	0.092	0.029	0.02	0.105	0.086	0.015	0.086	0.021	0.026	0.053
Wall Material	0.053	0.055	0.071	0.12	0.084	0.01	0.084	0.105	0.04	0.069
Wall around the building	0.014	0.065	0.09	0.166	0.07	0.088	0.07	0.04	0.073	0.075

Openings in the direction of flow	0.01	0.017	0.061	0.101	0.083	0.05	0.083	0.044	0.033	0.054
Quality of construction	0.027	0.104	0.112	0.118	0.055	0.152	0.055	0.077	0.071	0.086
Maintenance of the building	0.021	0.035	0.067	0.098	0.057	0.152	0.057	0.111	0.053	0.072
Cracks in the structure	0.139	0.125	0.062	0.047	0.107	0.05	0.107	0.044	0.099	0.087
Building built on slope	0.149	0.148	0.155	0.047	0.096	0.021	0.096	0.04	0.172	0.103
Building close to slope	0.175	0.103	0.1	0.042	0.057	0.067	0.057	0.051	0.063	0.079
Type of Foundation	0.106	0.113	0.041	0.037	0.069	0.085	0.069	0.178	0.05	0.083
Depth of Foundation	0.048	0.113	0.047	0.014	0.09	0.082	0.09	0.185	0.084	0.084
Size of the Building	0.123	0.016	0.045	0.015	0.097	0.045	0.097	0.041	0.067	0.061
Presence of other Building between the buildings and slopes	0.033	0.047	0.101	0.017	0.025	0.074	0.025	0.032	0.084	0.049
RAPID MOVING LANDSLIDES										
Height of building from ground level	0.01	0.018	0.031	0.023	0.025	0.009	0.026	0.019	0.026	0.021
Number of floors	0.077	0.018	0.028	0.043	0.086	0.009	0.084	0.016	0.078	0.049
Wall Material	0.048	0.111	0.093	0.057	0.108	0.128	0.106	0.076	0.09	0.091
Wall around the building	0.022	0.051	0.089	0.013	0.034	0.128	0.043	0.161	0.043	0.065
Openings in the direction of flow	0.018	0.011	0.04	0.04	0.022	0.075	0.023	0.053	0.021	0.034
Quality of construction	0.02	0.096	0.102	0.056	0.05	0.112	0.049	0.096	0.046	0.070
Maintenance of the building	0.01	0.01	0.072	0.044	0.056	0.112	0.056	0.042	0.094	0.055
Cracks in the structure	0.09	0.132	0.076	0.068	0.088	0.075	0.086	0.027	0.171	0.090
Building built on slope	0.217	0.182	0.095	0.092	0.103	0.045	0.101	0.055	0.112	0.111
Building close to slope	0.174	0.076	0.067	0.093	0.06	0.05	0.059	0.055	0.073	0.079
Type of Foundation	0.072	0.121	0.053	0.102	0.08	0.075	0.08	0.105	0.045	0.081
Depth of Foundation	0.038	0.121	0.065	0.13	0.102	0.075	0.102	0.098	0.068	0.089
Size of the Building	0.083	0.016	0.053	0.109	0.05	0.045	0.135	0.029	0.053	0.064
Presence of other Building between the buildings and slopes	0.119	0.037	0.136	0.131	0.134	0.062	0.049	0.168	0.079	0.102

Appendix G - Weights for Building Characteristics from ILWIS – ESR's

ESR OPINION	A	B	C	D	E	F	G	H	I	J	K	L	Mean
RIVER FLOOD													
Height of Building from Ground level	0.023	0.109	0.193	0.07	0.042	0.054	0.093	0.081	0.147	0.057	0.031	0.047	0.079
Number of Floors	0.174	0	0.032	0.11	0.043	0.021	0.073	0.092	0.147	0.229	0.037	0.1	0.098
Structural Type	0.111	0.075	0.108	0.114	0.091	0.141	0.105	0.05	0.035	0.027	0.136	0.147	0.095
Size of the Building	0.116	0.144	0.0228	0.054	0.019	0.039	0.06	0.014	0.032	0.014	0.018	0.237	0.064
Wall Material	0.166	0.077	0.108	0.083	0.131	0.103	0.1	0.046	0.035	0.111	0.13	0.114	0.100
Presence of Basement	0.014	0.178	0.126	0.248	0.197	0.04	0.115	0.189	0.381	0.258	0.211	0.075	0.169
Height of the Door and Windows	0.035	0.182	0.101	0.048	0.2	0.102	0.179	0.079	0.103	0.154	0.032	0.044	0.105
Quality of construction	0.13	0.071	0.161	0.094	0.097	0.111	0.094	0.144	0.04	0.08	0.176	0.084	0.107
Maintenance of the building	0.129	0.03	0.05	0.016	0.064	0.054	0.042	0.294	0.04	0.021	0.128	0.09	0.080
Wall around the building	0.102	0.016	0.092	0.163	0.117	0.038	0.139	0.011	0.04	0.049	0.102	0.063	0.078
FLASH FLOOD													
Height of Building from Ground level	0.021	0.042	0.124	0.049	0.046	0.021	0.037	0.028	0.045	0.057	0.032	0.101	0.050
Number of Floors	0.091	0.052	0.025	0.067	0.41	0.029	0.02	0.048	0.024	0.044	0.032	0.131	0.081
Structural Type	0.118	0.161	0.074	0.115	0.105	0.103	0.2	0.113	0.097	0.013	0.131	0.165	0.116
Size of the Building	0.143	0.065	0.02	0.06	0.016	0.036	0.027	0.013	0.074	0.024	0.019	0.186	0.057
Wall Material	0.139	0.146	0.124	0.117	0.117	0.103	0.149	0.155	0.143	0.159	0.131	0.088	0.131
Presence of Basement	0.018	0.218	0.149	0.169	0.211	0.231	0.136	0.066	0.045	0.02	0.213	0.035	0.126
Height of the Door and Windows	0.019	0.175	0.111	0.05	0.131	0.017	0.27	0.067	0.143	0.094	0.033	0.077	0.099
Quality of construction	0.155	0.09	0.124	0.159	0.106	0.121	0.066	0.208	0.143	0.268	0.179	0.101	0.143
Maintenance of the building	0.254	0.026	0.063	0.037	0.039	0.28	0.012	0.294	0.143	0.042	0.127	0.07	0.116
Wall around the building	0.043	0.024	0.187	0.178	0.188	0.061	0.181	0.009	0.143	0.28	0.103	0.046	0.120
SLOW MOVING LANDSLIDES													
Height of building from ground level	0.198	0.027	0.03	0.076	0.011	0.035	0.019	0.048	0.014	0.013	0.029	0.017	0.043
Number of floors	0.166	0.021	0.072	0.063	0.015	0.015	0.015	0.034	0.014	0.01	0.045	0.073	0.045
Wall Material	0.13	0.118	0.073	0.051	0.037	0.044	0.101	0.03	0.06	0.074	0.017	0.047	0.065
Wall around the building	0.123	0.052	0.147	0.053	0.061	0.021	0.015	0.022	0.233	0.048	0.017	0.063	0.071

Openings in the direction of flow	0.104	0.052	0.062	0.068	0.056	0.014	0.018	0.025	0.014	0.025	0.114	0.05	0.050
Quality of construction	0.024	0.05	0.101	0.053	0.067	0.063	0.077	0.061	0.06	0.129	0.076	0.064	0.069
Maintenance of the building	0.061	0.021	0.018	0.032	0.037	0.069	0.024	0.059	0.06	0.091	0.063	0.091	0.052
Cracks in the structure	0.029	0.118	0.026	0.047	0.079	0.072	0.101	0.094	0.06	0.057	0.036	0.059	0.065
Building built on slope	0.021	0.219	0.256	0.116	0.131	0.21	0.104	0.183	0.233	0.065	0.291	0.075	0.159
Building close to slope	0.035	0.132	0.093	0.115	0.177	0.214	0.039	0.226	0.06	0.029	0.111	0.085	0.110
Type of Foundation	0.009	0.045	0.045	0.08	0.079	0.076	0.145	0.107	0.06	0.239	0.067	0.118	0.089
Depth of Foundation	0.012	0.026	0.049	0.074	0.071	0.119	0.165	0.097	0.06	0.185	0.067	0.127	0.088
Size of the Building	0.055	0.084	0.012	0.068	0.012	0.028	0.093	0.008	0.017	0.01	0.045	0.074	0.042
Presence of other Building between the buildings and slopes	0.034	0.035	0.016	0.104	0.167	0.02	0.083	0.005	0.055	0.024	0.023	0.056	0.052
RAPID MOVING LANDSLIDES													
Height of building from ground level	0.026	0.026	0.029	0.061	0.015	0.031	0.022	0.03	0.031	0.01	0.06	0.024	0.030
Number of floors	0.084	0.011	0.063	0.059	0.012	0.054	0.013	0.063	0.028	0.014	0.06	0.042	0.042
Wall Material	0.106	0.072	0.081	0.092	0.044	0.061	0.085	0.05	0.132	0.037	0.014	0.053	0.069
Wall around the building	0.043	0.132	0.126	0.054	0.039	0.023	0.172	0.022	0.031	0.074	0.014	0.093	0.069
Openings in the direction of flow	0.023	0.046	0.046	0.076	0.069	0.047	0.192	0.079	0.011	0.101	0.062	0.043	0.066
Quality of construction	0.049	0.066	0.109	0.047	0.064	0.066	0.065	0.029	0.122	0.137	0.076	0.046	0.073
Maintenance of the building	0.056	0.021	0.019	0.026	0.019	0.07	0.024	0.042	0.132	0.07	0.063	0.104	0.054
Cracks in the structure	0.086	0.108	0.061	0.028	0.078	0.101	0.04	0.026	0.132	0.117	0.018	0.054	0.071
Building built on slope	0.101	0.102	0.18	0.126	0.177	0.122	0.059	0.178	0.029	0.052	0.281	0.088	0.125
Building close to slope	0.059	0.106	0.103	0.096	0.136	0.079	0.046	0.229	0.038	0.029	0.07	0.11	0.092
Type of Foundation	0.08	0.045	0.08	0.077	0.088	0.14	0.012	0.031	0.132	0.064	0.107	0.128	0.082
Depth of Foundation	0.102	0.014	0.042	0.077	0.088	0.132	0.017	0.031	0.132	0.049	0.107	0.104	0.075
Size of the Building	0.135	0.071	0.02	0.059	0.015	0.064	0.021	0.007	0.039	0.012	0.055	0.058	0.046
Presence of other Building between the buildings and slopes	0.049	0.178	0.041	0.121	0.156	0.008	0.232	0.183	0.01	0.233	0.014	0.053	0.107