Community based debris flow risk appraisal for local risk management. Case Study: Villa Restrepo, Colombia.

Edward Alexander Garcia

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COMMUNITY BASED DEBRIS FLOW RISK APPRAISAL FOR LOCAL RISK MANAGEMENT. CASE OF STUDY: VILLA RESTREPO TOWN, COLOMBIA.

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by

Edward Alexander Garcia

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: (fill in the name of the specialisation)

Thesis Assessment Board

Prof .Dr. V.G.Jetten (Chair)
Prof. Dr. A. van der Veen (Examiner)
Drs. J.J. Verplanke (First Supervisor)
Drs. N.C. Kingma (Second Supervisor)
Dr. G. Peters Guarin (Second Supervisor)

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Abstract

Although many activities relating to community based risk assessment of different hazard types are currently undertaken, only a few of these activities actually focus on debris flow hazards.

This case study was developed in Villa Restrepo a small town in Colombia. The town is located in the central cordillera, specifically in the Combeima valley close to Ibague, city. Because of its location in the confluence of three basins (La Sierra, El Salto and Gonzales river basins) with steep slopes, Villa Restrepo is highly prone to the occurrence of debris flows, particularly at the end of the rainy season. Besides along the history several debris flow events have occurred affecting lives, causing economic loss and disruption of activities.

Due to scarcity of information on this area, this research attempts to develop a community based methodology for debris flow appraisal for local risk management with hazard, vulnerability, risk perception and local adaptation capacity (risk reduction actions) factors integration. Villa Restrepo people's experience, knowledge and participation in dealing with the debris flow hazard are key information resources to carry out this research. Furthermore the application of different tools and methodologies in this study were aimed to provide new ideas to solve a problem related to poor environment information.

The research followed a three stage approach. The first phase was used to identify the data available and the actors to be involved in the participatory activities. During the second phase or fieldwork all the information for risk appraisal was collected by means of community-based activities and secondary data necessary to complement the risk appraisal. The last phase the data coming from the community was integrated and modeled in GIS in order to produce the risk appraisal and scenarios for risk reduction

The present research is aimed for local municipality activities and planners applications considering mostly activities related to debris flow risk management , mitigation and preparedness and as well as an important support document for studies related with debris flow risk assessment on small scale study area with scarcity of base information.

Acknowledgements

"The Freedom consists in being able to do what must be done"

This thesis is especially dedicated to my small family: *Piedad, Jenny, Eliza, Eduardo, Sandra* y a mis angeles guardianes *Gilma* y *James* (*El recorrido sin ustedes me llena de tristeza , pero me fortalece al llevar sus ideales y a visualizarme con sus deseos*) .All yours are my strength and my reason for living.

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1. Introduction

1.1. Background

In many parts of the world debris flows are one of the most dangerous of all mass wasting events. They can occur suddenly and inundate entire towns in a matter of minutes. Furthermore the mass can travel long distances over fairly gentle slopes damaging structures and many other elements that lie in their paths. Different elements at risk such as people and infrastructure, whether in urban or rural environments, are directly affected by the occurrence of these events disturbing their economy, development and sustainability.

In Colombia, most of the debris flow events have occurred in towns and cities close to the Cordillera Central (Kunzler, 2008) affecting both the life and properties of the communities since the early history of Colombia. In addition some of the valleys e.g. the Combeima valley, are located close to ice caped volcanoes and therefore having lahars and flood hazards.. In the Combeima valley steep and unstable slopes are ubiquitous, heavy rainfall is the main trigger factor to cause debris flows with several events been registered in the last decades in this valley (Godoy, 1997).

Despite the existing hazards people have decided to settle in the Combeima valley because it offers several opportunities for improved livelihoods, due to its tourism and fertility of soils. Debris flow hazards have affected Villa Restrepo town several times in recently years ago and negatives impacts have occurred such as injuries, loss of lives, increased disease incident, loss of crops, damage to infrastructure, loss of land and water shortages. Because all these negatives impacts it has been deemed as necessary to identify and evaluate the debris flow risk and the local coping strategies, actions or mechanisms taken by the communities to adapt to this threatening hazard. On the other hand because of the speed at which the threats are happening, it is urgent that the vulnerability of the community in the Combeima valley is reduced through the implementation of adequate adaptation strategies such as dissemination of knowledge, preparedness and mitigation activities, improve housing design and others.

The community participation and engagement into the process of identification, analysis and implementation is considered as an appropriated action according the UN-ISDR Hyogo Frame work for Action (2005).For this reason Disaster Risk management has been proposed as a broader and more proactive approach in which decision-making is supported by structured and systematic process and procedures such as participatory, collaborative and community- based risk assessment (Peters, 2008).

The risk reduction scenarios with local adaptation measures may assist planners of Ibague municipality to explore the best action or strategies to implement and finally reduce debris flow risk face by the community, according their resources, budget and capacities. The aim is that debris flow risk identification and assessment may help them to plan and take decisions accordingly in order to manage the risk they face.

1.2. Research Problem

The study case of this research is Villa Restrepo town located in the Combeima Valley which lies in the Cordillera Central ,Colombia and is part of Ibague city .According to Barrios and Olaya (2007) Villa Restrepo town has the best infrastructure of Combeima valley towns offering a comfortable ecological environment to visitors. For this reason is has become an important touristic place for the urban dwellers of Ibague.

The town is built on the alluvial fans of La Gonzales, El Salto and La Sierra rivers. In these three river basins several debris flow events have occurred in the past which are related with rainfall events and land uses changes. La Gonzales, El Salto and La Sierra rivers are important tributary rivers to the Combeima River. In addition to rainfall-triggered landslides, the Combeima valley is endangered by hazards from the glacier-capped active volcano Nevado del Tolima.

By other hand in 1952 debris flows and landslides occurred on the Combeima valley and approximately 120 people died on the Combeima valley including Villa Restrepo population (Vegara and Moreno, 1992). For this reason some of the last events occurring during 1945, 1952,1996, 1998, and 2006 have been kept in Villa Restrepo community’s memories because these events have affected the town causing considerable damage to human being, buildings and crops among others (Kunzler, 2008). The recurring events are therefore a serious threat to life, welfare and local economy. So far, activities have mainly been focused on reconstruction after disaster happened, and prevention and preparedness activities have not been sufficiently been developed Huggel (2008).

The town was declared as a national calamity place after the debris flow disaster in 2006 according to the national authority for disaster management in Colombia (rule number 1495; (Minambiente Colombia 2006). More than 40 families were affected by this event, as well as 52 dwellings, and vital infrastructure.

Furthermore crops, dwelling and touristic infrastructure were damaged affecting the tourism which is the main economic activity in this town. After the event national funds (approximately 107.000 USD) were received by the authorities of Ibague for reconstruction works (Picture 1.1).

Picture 1.1 Reconstruction works after debris flow event in 2006. Interpraevent (2009)

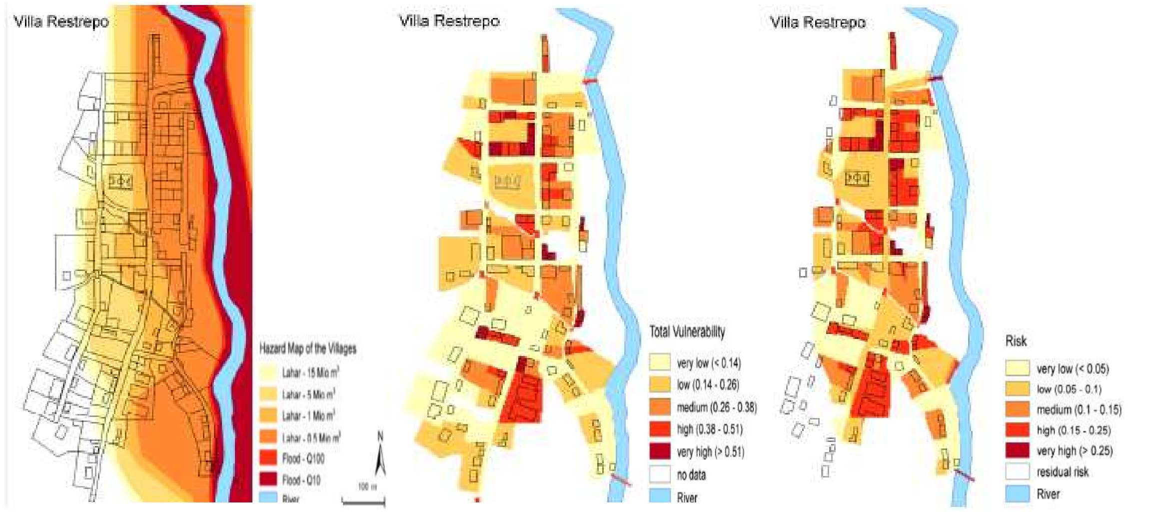
In general terms it can be said that even if the community of Villa Restrepo is facing a real threat by remaining in this area, most of the people do not have plans to leave or resettle in other, safer, towns or cities. According to them moving to other places would reduce their livelihood and change their life style. Ibague city (about 10 km distance of Villa Restrepo) is for them an unsafe place as this city has one of the highest unemployment rates in the country, is highly contaminated and an unsecure place to live; therefore the community prefers to stay and face the local 'natural' hazards (Barrios and Olaya, 2007)

1.3. Previous researches in the study area.

Villa Restrepo is affected mainly by lahars and floods coming from Combeima River, debris flows from El Salto, La Gonzales and La Sierra river basins. The threats from natural hazards in the Combeima Valley have been recognized by international institutions and for this reason some projects such as Colombian-Swiss project for the prevention of glacio-volcanic and hydro-meteorological disasters *(Proyecto Colombia-Suiza de Prevención de Desastres Glacio-Volcánicos e Hidro-Meteorológicos*) have been carried out Combeima valley and Ibague city (Zurich University, 2008).

The project developed a rapid risk assessment on a first- order analysis of lahars and rainfall related flood hazards and vulnerability (See figure 1). The models LAHARZ for lahars and HEC-RAS for floods were applied to generate hazard maps. For the vulnerability analysis the poverty and age of the population in the towns were taking into consideration for the final vulnerability map (Kunzler, 2008).

In addition the University of Tolima developed a study in Villa Restrepo known as Debris and flash flood risk assessment in Villa Restrepo (Evaluation Integral de Riesgo por avenidas Torrenciales, caso Villa Restrepo) supported by local institutions which analyzed the factors triggering debris flow as well as the characterization of the watersheds surrounding Villa Restrepo were using Flo-2D software . Yet, the lack of adequate information limited the evaluation according to the conclusions of the study.



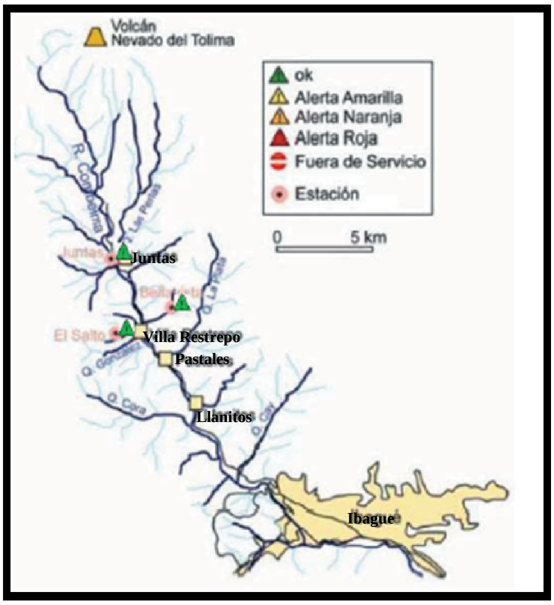
Flood Hazard Map | Vulnerability map | Flood risk map

Figure 1.1 Rapid assessment of hazard, vulnerability and risk of lahars in Villa Restrepo (Kunzler, 2008).

The University of Zurich has supported other activities in the Combeima valley with the local authorities collaboration related with early warning system in 2008.

The objective of this project presented in Davos on 2008 (IDRC, 2008) was identification and quantification, of landslide risks and the set-up of an early warning system for an improved protection of vulnerable people. The weather stations installed use internet connection to monitor the rainfall across the basin. Besides this system included geophones in order to communicate by internet the occurrence of debris flow in the uplands, so that it allows the residents downstream of the Combeima river to evacuate in case of an emergency.

Regarding debris flow risk analysis however one of the most relevant problems is the poor information management existing both in Villa Restrepo and the municipality of Ibague. For this reason the officers in the planning office have limitations to adequately design plans for debris flow risk reduction.



Map 1.1 Rain gauges located on the Combeima valley with their respective alert level Interpraevent (2009)

1.4. Research Objectives

1.4.1. Main Objectives

This research attempts to develop a community based methodology for debris flow risk appraisal for local risk management using Villa Restrepo as a case of study. The proposed methodology develops approaches for assessing hazard, vulnerability, risk perception, risk estimation and identified and evaluates local risk reduction scenarios for local authorities and planner in data poor environments.

1.4.2. Specific Objectives

1. To develop community based debris flow hazard analysis based on past events experienced by the community in Villa Restrepo.

2. To carry out a vulnerability analysis to debris flow based on social, economic and structural parameters.

3. To explore possibilities for spatial representation of risk perception and its integration into social vulnerability assessment.

4. To generate qualitative and quantitative debris flow risk scenarios to estimate expected damage according to a given return period.

5. To identify and evaluate local risk reduction strategies [local adaptation capacities] in qualitative debris flow risk analysis.

1.5. Research Questions

Objectives	Research Question	Proposed Methods
1	1. Regarding debris flow, what knowledge do communities have?	-Collect data on intensity, magnitude and damage caused by previous debris flow events according to specific return periods. - Meeting with key people which have experienced debris flow events in the town.
	2. Which participatory and spatial tools are adequate to uncover and collect data on historical debris flow events?	-Transect walks with people that have experienced past events supported with GPS and maps. -Meetings with local community supported with maps and conventional pictures of the study area.
2.	1. How to acquire adequate data about structural and socioeconomic factors contributing to vulnerability and needed for its analysis?	- GIS-based home-basis survey.
	2. Which indicators of vulnerability are relevant for analysis and applications at municipality level?	-Data analysis for each vulnerability indicator through maps, figures and tables.
	3. How to develop a vulnerability assessment in a data poor environment?	- To use Spatial multi-criteria evaluation methods for developing vulnerability maps -Meeting with local authorities and community for weighing up the criteria for vulnerability assessment
3.	1. How people in the studied community perceive the risk from debris flows?	- To develop participatory tools that allowed to elicit and collect the knowledge and perceptions about flow risk existing among the community members. - Home by home survey.
	2. How to integrate the risk perception of the community into vulnerability assessment?	- Compare risk perception with vulnerability indicators and develop a method to integrate risk perception into vulnerability and risk analysis.
4.	3. What are the elements at risk and how to get data required for the analysis of risk due debris flow?	-Identification of the essential facilities and lifelines utilities of Villa Restrepo town by means of maps and transect walks with community leaders. - GIS based interviews.

		-Meeting with key people in the community (leaders, eldest people, local government)
	2. How to develop quantitative and qualitative debris flow risk assessment in a data poor environment such as villa Restrepo?	- To develop risk assessment by combining hazard and vulnerability factors. - To develop expected damage of structural elements based on building cost.
5.	1. What local adaptation capacities have developed the people in Villa Restrepo to deal with the risk represented by debris flows?	-Home-basis survey. -Analysis of coping mechanisms carried out by the community before, during and after the occurrence of debris flow events.
	2. How integrate local adaptation strategies into risk analysis?	-Develop risk scenarios with ILWIS spatial support system module.

Table 1.1 Research Questions

1.6. Research Design and Thesis Structure

This research consists of nine chapters as shows the Figure 1.2.

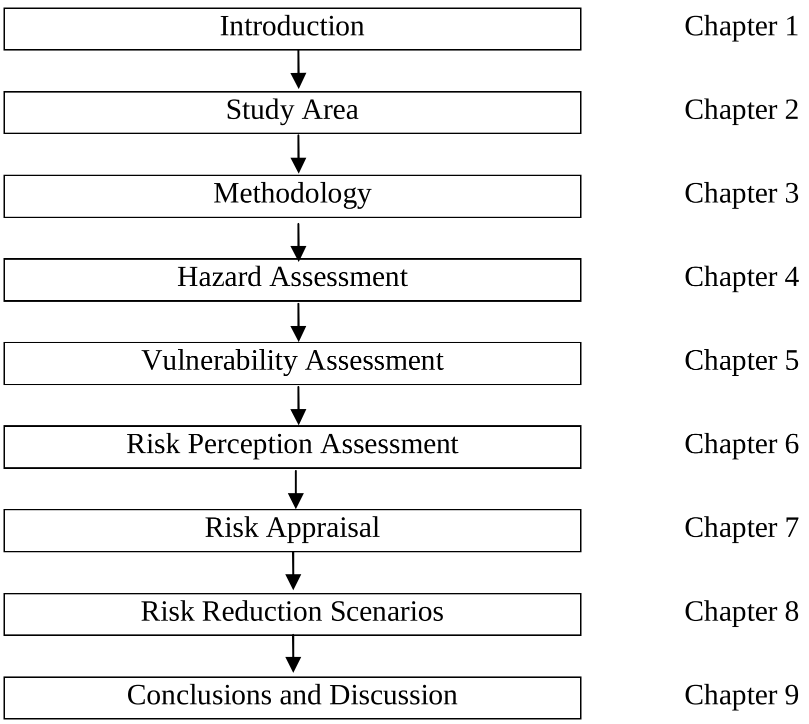


Figure 1.2 Shows the chapters integrated into the research design

Chapter one to chapter three contains the introduction, study area as well as the methodology. The chapter four constitutes a hazard assessment in which local People's knowledge of debris flow is retrieved by means of participatory GIS. The identification of vulnerability and risk perception factors used to develop a final vulnerability assessment based on data gathered from fieldwork constitutes the chapter five and six.

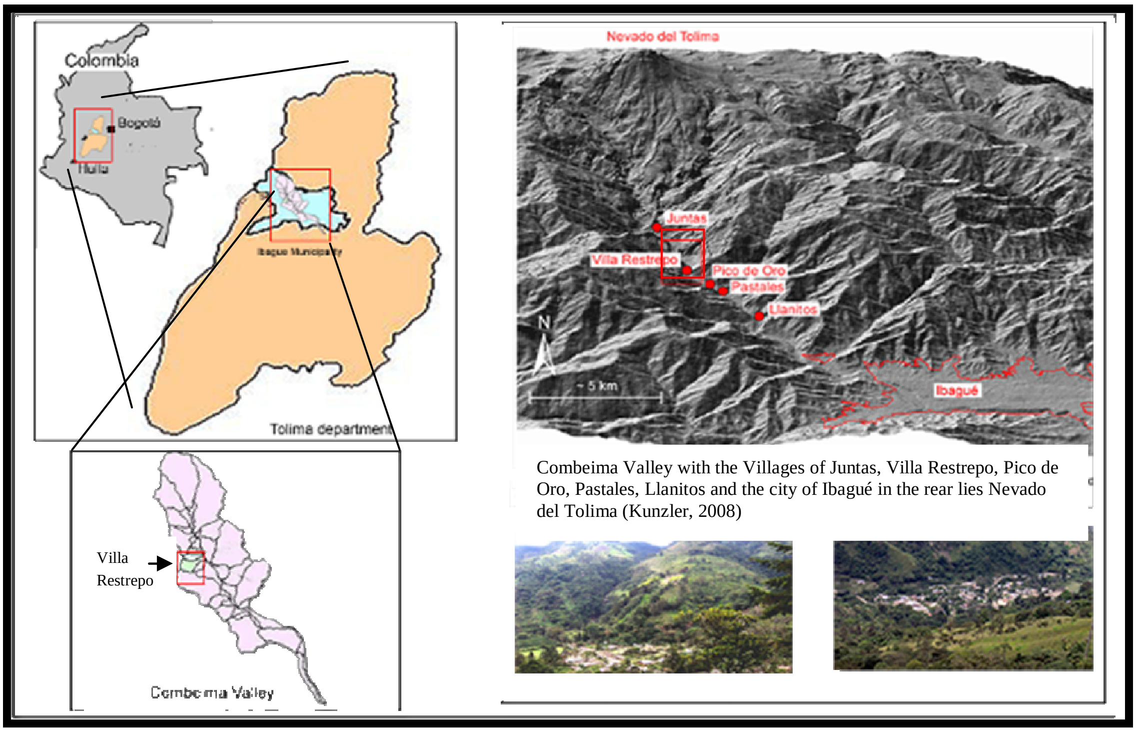
The chapters seven and eight consider a debris flow risk appraisal and management integrating hazard and vulnerability information which is presented in Chapter seven. The chapter 8 makes up the four steps which integrates the analysis of local adaptation capacity [local risk reduction strategies] performed by the community into risk scenarios. Thesis ends with specific and general conclusions and recommendations for further work.

2. Study Area

This chapter contains a general description about the study area and a brief description of probable causes for the occurrence of debris flow. A short description about the characterization of Gonzales, el Salto and the Sierra river basin is given. The influence of the three river basins on the town along the time is also described.

2.1. Generalities about Villa Restrepo

This research was carried out in the town of Villa Restrepo. Located 1630 meters above mean sea level, Villa Restrepo belongs to Ibague municipality which in turn is the capital of Tolima department. Ibague city has 440.000 inhabitants (estimate for 2008, by Municipio de Ibagué) and has been built on a volcanoclastic fan with deposits from lahars and pyroclastic flows having their source on Nevado of Tolima (Thouret and Laforge, 1994, Vergara Sanchez and Moreno Espitia, 1992) (See figure 2.1).



Combeima Valley with the Villages of Juntas, Villa Restrepo, Pico de Oro, Pastales, Llanitos and the city of Ibagué in the rear lies Nevado del Tolima (Kunzler, 2008)

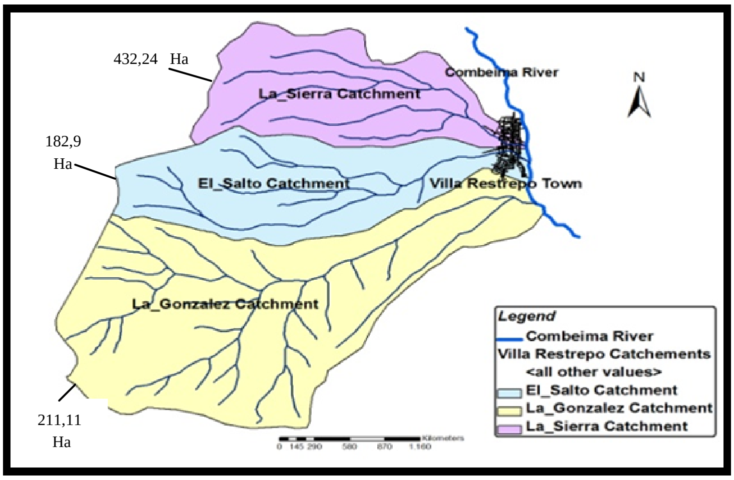
Figure 2.1 . Study location.

The town of Villa Restrepo has about 230 inhabitants which earn their living mainly by agriculture, stock breeding, and tourism . Villa Restrepo was established in the Combeima valley located in Cordillera central, Colombia (Barrios M. Olaya E. 2007) and drained by the Combeima River which flows close to the settlement of Villa Restrepo.

As result of this geographical context the community of Villa Restrepo faces other natural hazards such as lahars and flooding. The Combeima River, which flows through Ibague, becomes the main water supplier for the city. El Salto and La Sierra river basins flow trough Villa Restrepo too and provide the water supply for this community. These two rivers are part of the Combeima river basin, and therefore when debris flow occurs the Combeima River is affected too. In addition the catchment of the El Salto and La Sierra river basins present steep and unstable slopes and heavy rainfalls are frequent (Godoy, W and C. Amp, 1991).

2.2. Characterization of Gonzales, el Salto and the Sierra river basins.

La Gonzales, El Salto and La Sierra river are located within the rural portion of the municipality of Ibague. Administratively the river basins belong to Villa Restrepo town (see map 2.2).



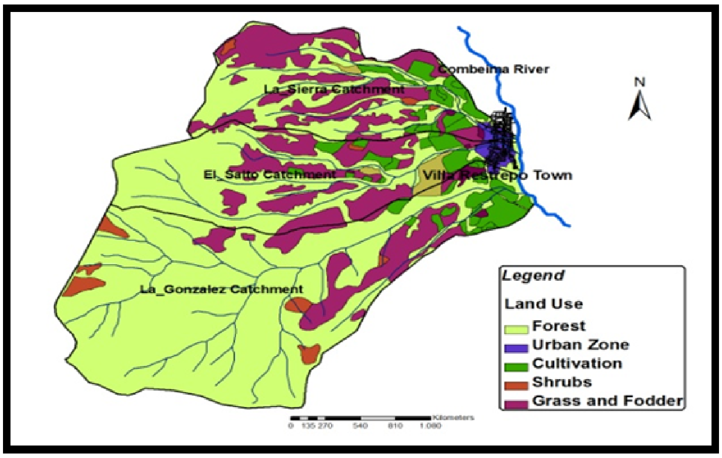
Map 2.1. The three river basins catchments.

The Sierra river basin is the longest river basin in the study area with approximately 432, 24 Ha. La Gonzales river basin has 211, 11 ha and finally El Salto river basin with approximately 182, 9 Ha (See map 2.1). As mentioned before the location and configuration of the Salto, Gonzales and Sierra Basin Rivers make Villa Restrepo a region highly prone to debris flow events. From these three basins El Salto presents the highest incidence of debris flow to Villa Restrepo town.

The hazard faced by the region represents a burden because of the large social and economic losses associated to the occurrence of debris flows. Damaged homes, disturbance to people’s lives and livelihood activities particularly the tourism which is the main source of revenues in the zone are some of the negative consequences of these events (Barrios M. Olaya E. 2007) .In this way this situation affects directly and indirectly the inhabitants, especially the poor, which main livelihood depends on tourism and farming activities.

2.3. Debris flow contributing and triggering factors in Villa Restrepo

2.3.1. Land Use of Gonzales, El Salto and La Sierra catchments



Map 2.2 .Gonzales, El Salto and La Sierra river basins Land use

The land use on the three river basins highly influences the economy of Villa Restrepo but it also contributes to increase the debris flow hazard levels. The soil in the study area, mainly in the upper part of the catchments, is very productive as it is originated in volcanic source materials rich in minerals and nutrients. However, the active land use change, mainly on steep slopes, causes slides during the rainy season. Therefore the unprotected areas on volcanic soils in the catchment are becoming increasingly susceptible to landslides which constitute the source of material for debris flows.

The different land uses observed and mapped during the transect walks in the fieldwork phase are presented in map 2.2 and table 2.1

The *urban zones* land use is represented by the settlement of Villa Restrepo. This zone offers to the people a wide quantity of services, infrastructure and basic urban elements but on the other hand constitutes an impervious area that can increase the runoff on the surrounding unprotected soils and therefore cause landslides. *Transitional Crops* land use consider the short cycle Crops (Their vegetation cycle is generally up to one year), this category includes bean crops. This type of crops requires bare soil which favours a major infiltration of runoff generating superficial erosion and landslides (See picture 2.1). Other land use present in the river basins is *Permanent Crops* including all crops with a long life cycle which allow many harvest along the years such as coffee, banana and blackberry. This land use covers an area of 4,54 ha with 1.03 % of total area of Gonzales river basin, 7,01 ha in the sierra river basin and 4,79 ha representing 2,26 % of the total area on El Salto river basin (In the map 2.2 is represented with green colour).

Land cover class	**Land Use**	**River Basin**					
		Gonzales		**EL Salto**		**La Sierra**	
		Ha	**%**	**Ha**	**%**	**Ha**	**%**
1. Urban Zones							
Population Zone	Residential	0.71	0.16	5.82	2.74	3.36	1.83
Transitional Crop	Commercial	2.92	0.66	1.68	0.79	1.97	1.07
Permanent Crop	Commercial	4.54	1.03	4.79	2.26	1.36	0.74
Mosaic crops	Commercial - to live	11.13	2.53	7.33	3.45	7.01	3.82
Grass	Animal Food	57.53	13.08	65.7	30.95	86.2	46.98
Fodder Grass	Animal Food	0.60	0.14	0.34	0.16	0.84	0.45
Forest	Protection	349.89	79.52	125.28	58.02	78.44	42.75
Shrubs	Recuperation	12.67	2.88	1.34	0.63	2.28	1.34
Total		**439.98**	**100.00**	**212.28**	**100**	**183.46**	**100**

Table 2.1 .Land Use in the river basin around Villa Restrepo. Modified from Barrios and Olaya (2007)

Mosaic Permanent and Mosaic Crops are considered adequate covers due to the presence of trees and shrubs that protect the soil from runoff and excessive infiltration. Landslides in these two types of land cover were scarce and related more to the inclination of the terrain (see picture 2.2).

The *Grass and Fodder grass* land use include all the area covered with clean grass which is used for livestock. One of the main problems associated with this land use is overgrazing which generate ruptures, accumulation of runoff and increased infiltration of rain in the terraces created by the cattle (see picture 2.3).

Finally the *Forest and Shrubs* land use Consist of all the natural and second generation forest. Shrubs were included in this class. This cover is considered as protective of the soil and therefore no contributing to landslides occurrence.

Picture 2.1. Bean crops (Transitional crops) represented in La sierra river basin.

Picture 2.2 .Mosaic crops in this case coffee crops mixed with banana trees and forest

Picture 2.3 .Grass land use represented in Gonzales river basin

2.3.2. Seismicity

The low density of monitoring points in the Colombian National Seismological Network (RSNC) did not allowed to perform a correlation analysis between the seismic activity and the generation of mass movements associated to the debris flow events in Villa Restrepo.

The recording of seismic activity for the study area is carried out by means of a monitoring station closest to Gonzalez, El Salto and La Sierra river basins, which is located at coordinates: 4.59 ° latitude and 75.34 degrees longitude and a height of 2520 meters, in the foothills of the Tolima snow mountain. The review of information provided by the seismic daily Colombian National Seismological Network generated by INGEOMINAS and past studies such as Barrios and Olaya (2007) allowed concluding that no significant seismic activity was reported before or during the days in which mass removal in the study area took place. Therefore the internal geodynamic process (seismic activity) was discarded as the trigger mechanism for the mass movement phenomenon that took place in June 4, 1996, 27 August 1998, 28 September 1998 and June 22, 2006.

2.3.3. Rainfall

Rather heavy precipitations and accumulation of humidity in the soil at the end of the rainy season were found as the detonating factors for landslides, according the last studies such as Barrios and Olaya (2007) .This factor is integrated into consideration in this study to support the development of a debris flow hazard.

The historical rainfall of the study area will allow determine the critical rainfalls that have generated debris flow events in Villa Restrepo .So the final aimed to integrate this factor in the study is determine debris flows return periods in Villa Restrepo .This information will be related with the debris flow events according local knowledge of the community of Villa Restrepo in debris flow hazard assessment development.

3. Research Methodology

This section presents a brief description about the methodology applied to achieve the research objectives, the proposed approach and the research conceptual framework. The Research methods were divided into three stages: pre-fieldwork, fieldwork and post fieldwork.

3.1. Proposed approach

According to Community Based Disaster Risk Management (2006) by 'community' is meant certain characteristics of a group or more or less homogenous unit that has reasonably defined decision-making processes with shared goals and values and also have a clear spatial or conceptual boundary. A community may share one or more aspects in common such as living in the similar environment, same hazard exposure, or having been affected by a natural disaster.

The community in this research is the main source of information to achieve the proposed objectives. People's experiences, and knowledge about the debris flow occurring in their context along the history as well as their perception of the hazard they represent are considered important contributions to risk assessment. Common problems, conce1rns and hopes regarding disaster risk may also be shared. Different persons making part of a community can have different vulnerability levels and capacities, for instance depending if the person is an adult or a boy, has been in the place for long time and the like. In this way some people may be more vulnerable or more capable than other with respect to a given hazard . More of the times these circumstances are well known by the people in the communities making their awareness a valuable source of information.

The approach proposed in this research considers a debris flow risk assessment which takes into consideration community's knowledge , risk perception and local adaptability capacities to face debris flow were identified among the community and were therefore integrated into the final analysis under the figure of risk scenario analysis .The study aims to be a tool for local municipality and organizations working with decision-making processes with regards to risk reduction and mitigation activities .The figure 3.1 explains the role of the research in the local community and local authorities context. In this way the knowledge and perception of the community is used in the process of debris flow risk management and assessment (modified from Peters Guarin 2008).

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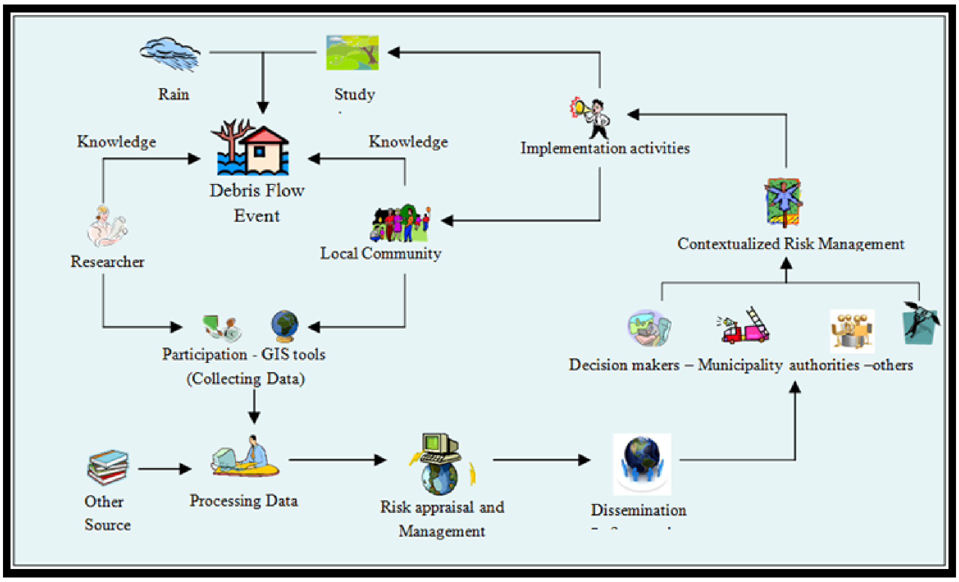


Figure 3.1. Shows the proposed approach.

The study was developed in three phases: The pre- fieldwork, the fieldwork and the post field phase The first phase was used to identify the data available and the actors to be involved in the participatory activities. During the second phase or fieldwork all the information for risk appraisal was collected by means of community-based activities. The last phase the data coming from the community was integrated and modeled in GIS in order to produce the risk appraisal and scenarios for risk reduction (See figure 3.2).

With respect to debris flow risk the knowledge present among the community was initially collected through the participatory use of GIS. The PGIS (Participatory geographic information system) tools such as sketch maps, GPS, PDA, pictures, transect walks are tools and activities supporting the collection of people's knowledge and the spatial representation of their experiences, understanding of risk and local coping mechanisms to deal with a hazard. According to Peters Guarin (2008) participatory use of GIS enable the communication between local actors, community and researchers; it offers opportunities to both the researcher to acquire a deep understanding of the situation at hand and to the community to express their awareness and convert it into further actions for identifying, analyzing and managing he risk posed by debris flow.

Later on the information collected in the fieldwork was transformed into spatial and non spatial inputs for risk assessment applications.

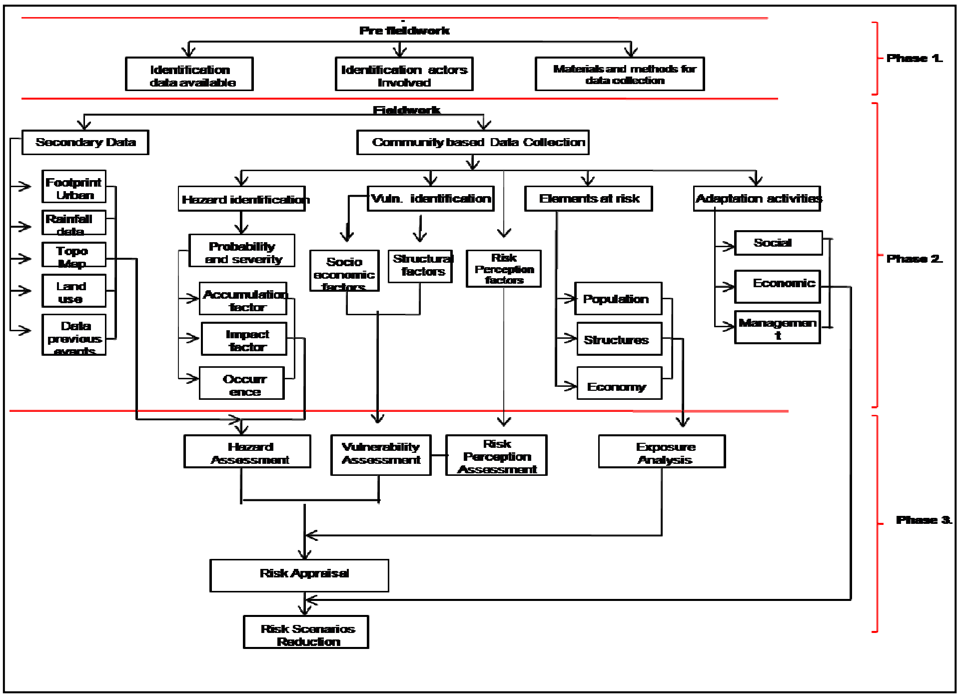


Figure 3.2. The conceptual framework research.

As mentioned the application of different tools and methodologies in this study was aimed to provide new ideas to solve a very common problem at local level which is related to the lack of data for risk assessments. It also seek for acknowledging the existence of local community knowledge and understand the role it plays when communities have to deal with the occurrence of debris flow in their town (Villa Restrepo) .The proposed methodology seek for contributing to the growing application of community based and PGIS tools for risk assessments with the aim that it could be applied in study zones facing similar hazards and with similar data scarcity characteristics.

3.2. Data Collection

In this phase a workplan was followed in order to obtain all the data required to develop a risk assessment at local level for debris flows. The table 3.1 shows the different activities by time, work topic and actors involved in each stage. Aside from the data collected through these activities other data were acquired and involved in the analysis. The secondary data available for this study were as follows:

- Urban Foot print map from year 2005-2006 in scale 1: 10000 made by local authority
- Debris flows hazard Map (amenaza por avenidas torrenciales) for this area based on the 2006 event, scale 1: 750 made by University of Tolima.
- Land use map for the rural area (2005), scale 1:10.000 made by Yulima NGO

- Historical rain records of the study area (IDEAM)
- Analysis of risk lahars and floods in Combeima valley (2008) by Zurich University..

SELECTION OF COMUMNITY	UNDERSTAND THE COMMUNITY	PREPARATON	DATA COLLECTION	DATA COLLECTION AND GATHERING	ANALYSIS
0.5 Week	1 Week	1 Week	1 Week	0.5 Week	2 Days
Verify Preliminary Information	Meeting with actors involved in the fieldwork phase.	Work shops PDA and CyberTracker management.	Collection Data Home by Home with the both methods PDA and questionnaires on papers.	Transect walks with maps, photos and PDA to identify the hazard in the town.	Sharing briefly analysis of information with students and local authorities.
Visiting the study area.	Communicate Objectives ,limitations and goals about the research project.	Collection external data required	Sketch maps to identify capacity indicator of the community with older and younger people.	Discuss with the community the problem perception.	Collection external data required.

Legend: EXPERT GROUP (ITC, UNIVERSITY OF TOLIMA; COMMUNITY VILLA RESTREPO; NGO (CORTOLIMA, INGEOMINAS; LOCAL AUTHORITY (CLOPAD); GIS APPLICATIONS

Table 3.1.Activities, time and actors involved in the fieldwork phase

The data was acquired in some local government institutions as University of Tolima, INGEOMINAS and CORTOLIMA. Some of these main dataset available in first instance were updated during fieldwork (i.e the land use) in order to improve the reliability of the analysis.

3.3. Field data collection Preparation

The data collected in the fieldwork was collected with the support of 23 forestry engineering students of University of Tolima and seven community leaders of Villa Restrepo supporting the process of collection of information carried out on September month. Besides in order to optimize the data collection phase with the support of students it was deemed necessary to develop a workshop a week before entering the study area (See pictures 3.1).

The workshop was used to explain the research objectives and results expected providing training in the use of the GPS and PDA as well as some basic concepts on community participation in risk analysis. The next step was performance of all the activities related to data collection in Villa Restrepo with the students and leaders according to the research objectives (See picture 3.2).

Theoric classes manage mobile GIS.

Theoric classes manage mobile GIS.

Practical exercises with PDA and GPS

Practical exercises with PDA and GPS

Picture 3.1. Shows the workshop activities done along a week with students.

The lack of the required detailed information for debris flow risk assessment made it necessary to implement a survey adapted to the study area were data about the building type, number of people, income per household and other attributes was collected. The survey allowed to obtain the minimum data required to develop a hazard, vulnerability and perception analysis and identification of the local adaptation capacities. The questionnaire included a field for an unique identifier which constituted the identification code per building in the database (See questionnaire in the appendix 1). Some of the requirements to develop the survey considered were that the interviewee should reside in the study area, should have more than 18 years old and finally should not be mentally disable.

Picture 3.2. On the left arrival of the data collection team (researcher, students and leaders) to Villa Restrepo Town and on the right the group of students integrated to fieldwork.

3.2.2 CyberTracker as a tool for collection data

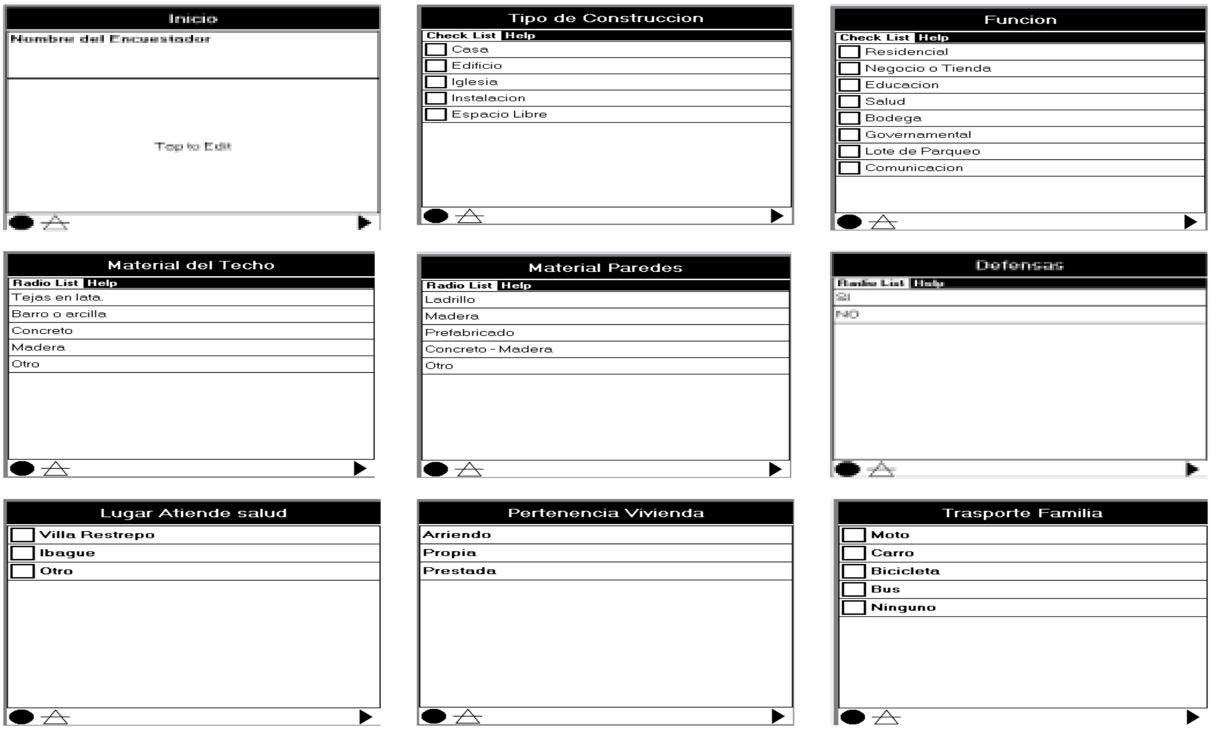
CyberTracker is the most efficient way to gather large quantities of geo-referenced data for field observations at a speed and level of detail not possible before. Observations can be entered with a simple Radio List or a Check List (CyberTracker Conservation, 2008). The CyberTracker Screen Designer makes it possible for users to design their own Electronic Field Guides with the information required to collect in the fieldwork

The questionnaire developed and adapted by this research was integrated in CyberTracker software collection. According Louis Liebenberg , author of this software (CyberTracker, 2008) a survey research theory has indicated that paper-based data collection methods do not provide the scope for frequent data collection and fast data processing .Although the previous statement in this study was applied both techniques in practical (based paper and CyberTracker integrated into a PDA) in order to obtain an analysis comparison.

The intuitive data capture sequences and touch-screen iconic options developed for this survey of Villa Restrepo town makes the capture of highly detailed data possible by semiliterate and non-literate users who have no computer literacy skills (see figure 3.3). In the case of this study the user were students of last semester of forestry engineering and some leaders of the Villa Restrepo community who contributed during the collection data phase.

CyberTracker base station software in this study also provided a query system that allowed the user to perform tabular queries and simple GIS (Geographical Information System) analyses related mainly with vulnerability analysis. The data was exported to Microsoft excel 2007 allowing the feeding of data from other sources for instance the paper questionnaires. During fieldwork both techniques were applied and definitely the CyberTracker application showed easier to collect data and decrease the error while entering the data with respect to the paper-based collection data.

As mentioned a home by home basis interview was developed in order to collect most of the required data for risk analysis. Carrying out the interview took approximately fifteen minutes when the students used paper-based formats, and about seven minutes when a PDA with CyberTracker was used. Another point about the use of palm and CyberTracker for the application of home-basis questionnaires is that that this technique motivates the students to get a better involvement and understanding of the risk issues during the process of data collection. Regarding the constrains and problems faced, the weather (specifically heavy downpours) in Villa Restrepo constituted the only limitation in the data collection process as the PDAs and other electronic devises could be affected by humidity.



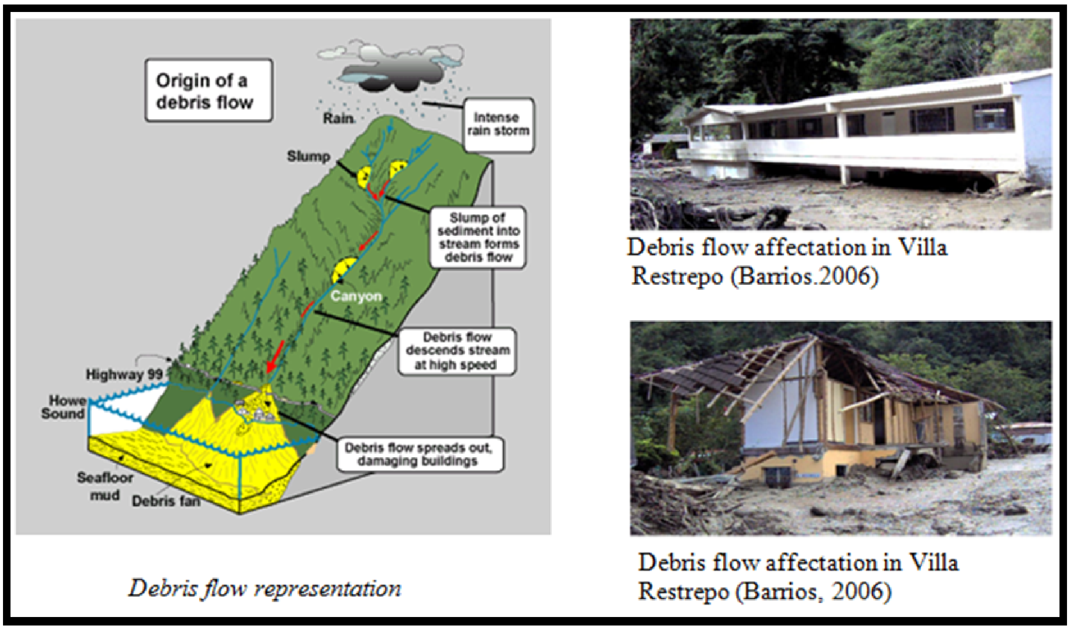
3.3 Visualization of some screens related with the survey designed on CyberTracker program and implemented in a PDA (Compaq Palm with GPS)

4. Hazard Assesment

This chapter presents the methodology applied to develop a debris flow hazard identification and assessment based on local knowledge and some secondary data such as rainfall data. It describes debris flow as a hazard and the use of rainfall data analysis for obtaining return periods for the events experienced by the community.

4.1. Debris flows as a natural hazard.

Debris flows are one of the most dangerous of all mass wasting events normally this is viscous to fluid like motion of debris. Debris flow events can occur suddenly and inundate entire towns in a matter of minutes (Earth science, 2009). Debris flows occur when rain water begins to wash material from a slope or when water sheets off of a freshly burned stretch of land. A debris flow (sometimes called mudflow) is a flowing mixture of water-saturated debris that moves down slope under the force of gravity. Debris flows consists of material varying in size from clay to blocks several tens of meters in maximum dimension. When moving, they resemble masses of wet concrete and tend to flow down slope along channels or stream valleys (See figure 4.1).



Debris flow representation

Debris flow affectation in Villa Restrepo (Barrios.2006)

Debris flow affectation in Villa Restrepo (Barrios, 2006)

Figure 4.1. Role of Hazard analysis for community-based disaster management.

In order to obtain comprehensive community based debris flow risk analysis it is necessary to count with a reliable hazard analysis. A hazard assessment is the ultimate outcome of the process of hazard identification, analysis and mapping (IDRM, 2004). In the other hand a detail understanding of what hazardous events have occurred in the past and their effects provides the basis for understanding what could happen in the future (Peters Guarin, 2008).

In absence of official historical records local knowledge about the occurrence of past events has been proved as an important information resource in order to establish the probability for future events. The community through their local knowledge and experiences represents an accessible solution to overcome the lack of detailed data for hazard and risk assessments (Peters Guarin, 2003 and 2008; Marschiavelli, 2008).

Due to the poor information available to develop a detail hazard assessment that takes into consideration several return periods for the debris flow phenomena in Villa Restrepo the community knowledge was used as the main source a source of information for the present study.

Data related to hazardous characteristics of debris flows such as intensity, magnitude, probability of occurrence and degree of destruction was taken into consideration for this study in order to develop a community based hazard assessment. The factors previously mentioned were deemed appropriate to analyze the threat represented by debris flows as they help to determine the degree of hazard embodied by this natural phenomenon. In addition they were found to be the most easily to identify, remember and represent in spatial terms by the community.

4.2. Community-based hazard mapping of past debris flow events.

Community-based hazard mapping is aimed to demonstrate that communities have the capacity and ability to identify and reconstruct previous events experienced along time.

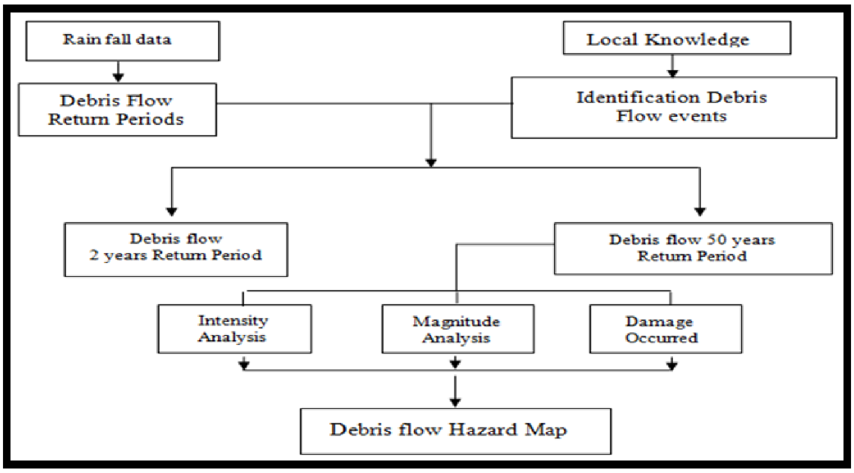


Figure 4.2. Flow chart showing the approach to develop debris flow hazard regarding an event with a return period of 50 years.

The information kept as mental records on the occurrence of the most damaging debris flows events was found a useful tool for developing scenarios and to identify and represent the hazard they embody for the people in the study area.

Figure 4.2 shows the different steps followed in this research to develop a final debris flow hazard of Villa Restrepo. Through correlation with secondary rainfall data the main event reconstructed by means of community-based information was correlated to a 50-year return period according to critical rainfall development in this research. With respect to debris flow hazard, the factors collected on the home-basis survey were related to magnitude, intensity and damage caused to the buildings by two events occurred in 1945 and Jun of 2006 which correspond to a 50-year return period and extremes events categorized by the community. The events with return period of 2 year were not integrated into consideration to hazard analysis because they are not considered as relevant debris flow event for the community according to level of damage.

1. Home-basis collection information.

2. Meetings for reconstruction of past events

3. Transect walks with elderly people using maps and GPS.

4. Identification critical affected elements

Picture 4.1 . Exercise with community in hazard identification, interpretation and analysis in Villa Restrepo.

The reconstruction of past events was carried out based on the testimonies of people between 50 and 70 years old who were able to identify and describe the characteristics of these past events and who were living in the area by that time. The task to obtain a spatial representation of every past event was carried out by using GPS, transects walks and paper-based mapping (see pictures 4.1).

Date	Triggering factor	Location	Damage
1945	Rain	La Sierra river basin	Approximately 50 houses damaged. Especially those located near to the current central park. The church and school were affected by the accumulation of debris
Jun. 4 of 1996	Rain	El Salto river basin	100 people affected, 2 houses destroyed. Drinking water system moderately destroyed. Affectation of Ibague city water system
August 27 of 1998	Rain	El Salto river basin	Landslides affecting 25 ha (crops) in El Salto river basin.
Jun. 22 of 2006	Rain	El Salto river basin	4 houses totally destroyed 54 houses partially destroyed 5 injured people 57 people left people
Jun. 22 of 2006	Rain	Gonzales river basin	Farms affected by debris flow (Crops and fish industry)

Table 4.1 . Local knowledge on the largest and most dangerous debris flows affecting Villa Restrepo.

During the practical activities with maps, pictures and meetings people in the community were able to remember different experiences related to particular debris flow episodes. In this case people act as a "sensor' which records images, sounds and experiences that later on can be represented in spatial formats. The presence of local knowledge among the eldest members of the community allowed to develop the historical reconstruction of events presented in table 4.1 which describes the most important debris flow occurred in the study area (according to people's remembrances).

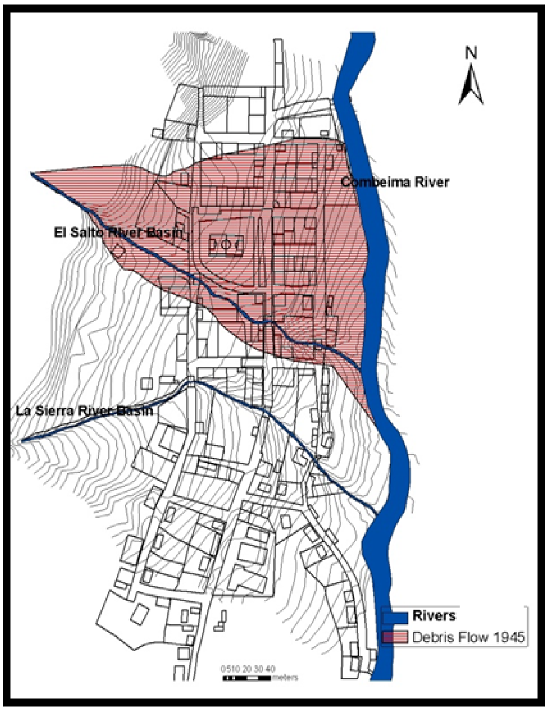
With respect to the reconstruction of past events, the main objective was to get an idea on the temporal and spatial distribution of debris flow in the Town as well as the damage caused by them. The information collected from the community was converted into maps that represent the most important events remembered by the community. Moreover the community was able to provide descriptions on the most important events which included differences in debris flow patterns and behaviour depending on the magnitude of the given event and the features of the zone where the event took place. As mentioned the community was able to recognize and remember past events occurred in Villa Restrepo as far as fifteen years back in the past without difficulties. However, for them was easier to fully describe the last events (i.e those on 1998, 1996 and 2006) than those happening 20 or more year ago. According to some meetings with external sources such as INGEOMINAS, CORTOLIMA, Villa Restrepo Police and municipality officers as well as historic newspapers the largest debris flow event in this area took place in 1945 coming through La Sierra river; the second one was the event occurring in Jun 2006 coming from El Salto river.

From the meetings with locals it was not possible to clearly map the event of 1945 most probably as result of the time span since its occurrence. For this reason it was deemed necessary to interview people in Ibague city who were living in Villa Restrepo when this event took place and could support the spatial reconstruction of the debris flow event in 1945 taking into consideration intensity, magnitude and damage occurred on dwellings by that time. A brief description of the most important events occurred in Villa Restrepo, as they were described by the communities and reconstructed for this study, is as follows:

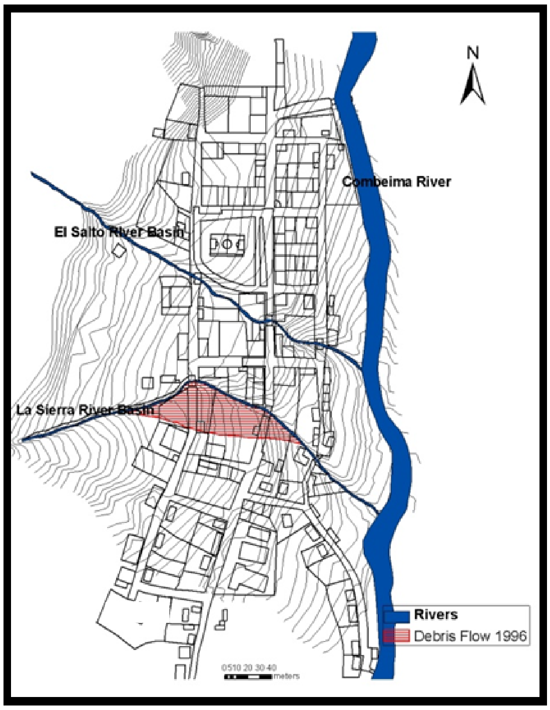
-Debris Flow of 1945, River basin La Sierra: According to the people in Villa Restrepo a massive slide of rock and soil at approximately 2550 m.a..s.l caused a debris flow which moved down affecting the centre of Villa Restrepo. This event totally destroyed two houses located close to the downtown, where the central park is located nowadays. Both the school and the church were affected by the accumulation of debris. This event did not cause deaths or injured people but severely affected the farmers who lost a vast amount of their crops. According to the community leaders would this event occur nowadays it could affect more than the 50 % of the community in the town and about 70 % of the community's vital elements such as church, pipe line water, telecommunications and the like (See maps 4.1 , event 1945).

-Debris Flow of 4 Jun of 1996, El Salto River basin: According to Vergara (1998) and some records found in the local newspaper at around 2:30 pm a huge rock was removed at approximately 2200 m.a.s.l causing a debris flow along this river. This event destroyed two buildings as result of the impact of the flow (see map 4.2).

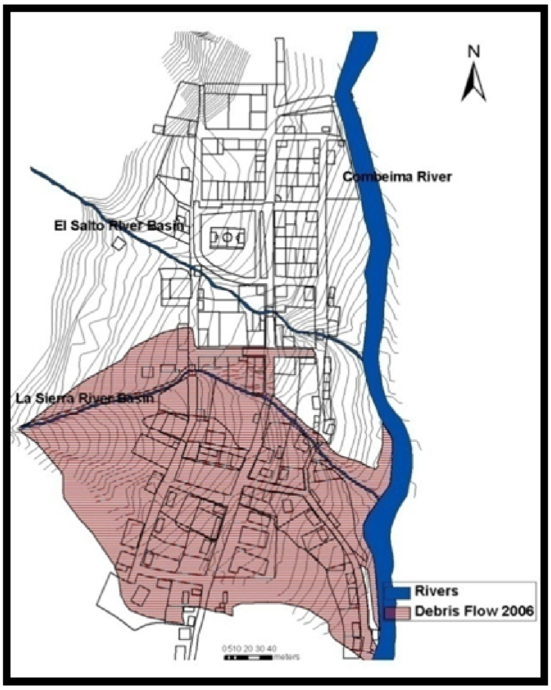
-Debris Flow of 22 Jun of 2006, El Salto river basin: This event occurred as a mixture of mud, wood and debris that flowed through the center of Villa Restrepo. The debris flow occurred at around 8:30 pm. and had heavy rains as triggering factor. The flow affected several houses due to the accumulation of debris.According to the interviewees the accumulation represented by the magnitude of debris reached nearly three meters depth in some zones. Four buildings were completely destroyed and the Villa Restrepo School was severely affected. In the other hand this event affected about 54 houses and caused total damage of fishing pools. The aqueduct was destroyed affecting water supply for Villa Restrepo and Ibague, 4 persons were injured and 57 left homeless (see maps 4.3, event 2006).



Map 4.1. Debris flow event of 1945 according to local knowledge



Map 4.2. Debris flow event of 1996 according to local knowledge

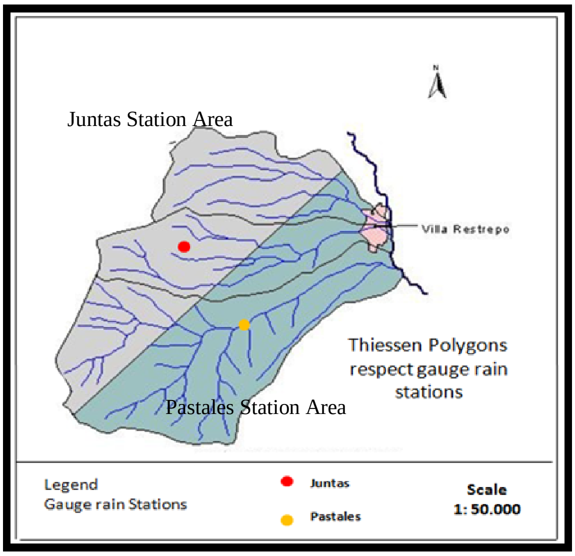


Map 4.3. Debris flow event of 2006 according to local knowledge

Between 1945 and 2007 other small scale events have occurred in the town causing fewer damages that those previously mentioned. According to the community the reason why these small events did not affect them was due to the profundity of the river channel which capacity has been enough to contain the amount of debris, rocks and wood materials flowing on these smaller events. In fact with direct observations in the fieldwork phase the valley depth in some sectors reaches 10 meters, contributing to minimize the debris flow hazard for some places.

4.3. Assessments of return periods for debris flows based on rainfall data

As mentioned before the rainfall is considered the main triggering factor for debris flows in the study area. Therefore an analysis of historical rainfall was carried out in order to correlate the return periods of the precipitation that triggers debris flow events as those experienced by the community. The first step to calculate return periods was to indentify the gauge rain stations closer to the study area (see Map 8). Afterwards the Thiessen polygons method was carried out in ArcGIS software in order to determine the area of influence of the rain on the gauge rain stations available. The events occurred in 4 of Jun1996, 27 of august 1998, 28 of September 1998 and 22 of Jun 2006 were taken into consideration for developing the rainfall analysis.



Map 4.4. Catchment of Gonzales, la sierra and el Salto river basin and the location of the gauge rain station.

The map 4.4 shows Juntas (red point colour) and Pastales (yellow point color) gauge rain stations. During the meetings with farmers living in the catchments of the river basins it was know that usually most of the landslides take place on the area of influence of the Juntas station.

For this analysis the daily rainfall information from July 1971 to December of 2005 provided by IDEAM was used. The event of 22 Jun 2006 was not taken into consideration as during the time at which it took place the Juntas rain gauge station was under maintenance and therefore no records exist for the period April and Jun of 2006.

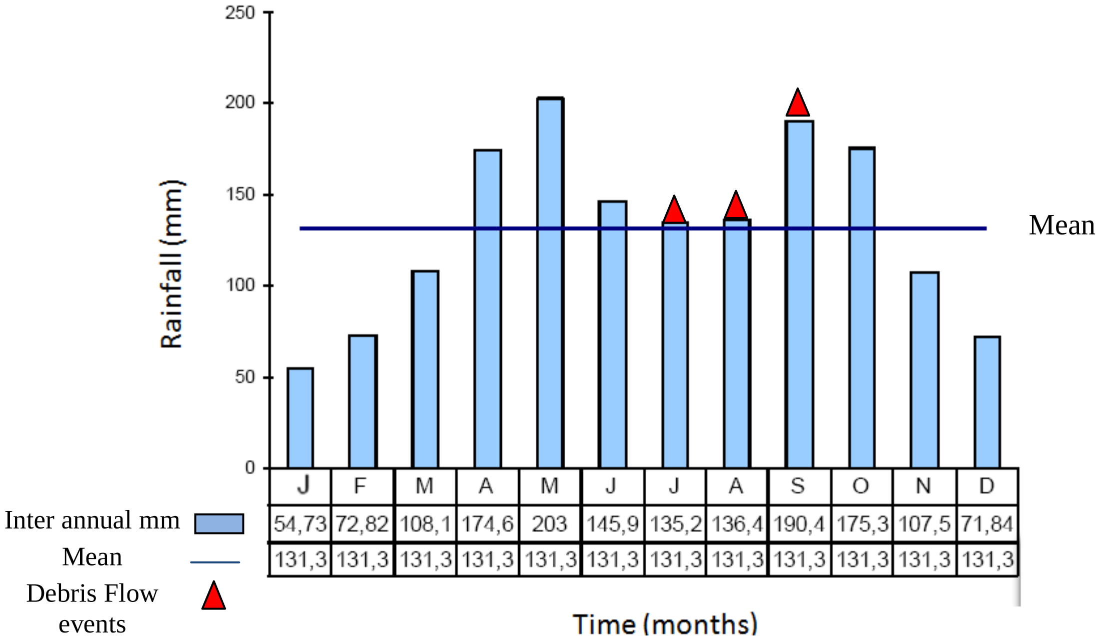


Figure 4.3. Medium measurements inter-annual of rainfall in the period 1971-2005 IDEAM (2008)

From figure 4.3 it can be seen how the highest rainfall occur during the period April - Jun and August – October. The red triangles on the histogram represent debris flow events occurred in the study area The first period coincides with the landslides and debris flows remembered by the community (see above). The four events (landslide) occurred in the study area correspond to an inter-annual measure of 131, 3 mm considered as larger with respect to the general medium showing a direct correlation between heavy precipitations and the occurrence of landslides on el Salto, la sierra and Gonzales catchments.

4.3.1. Analysis daily rainfall with reference to debris flow.

In order to know the amount of critic rainfall that may have caused mass movements it was deemed necessary to study the past behaviour of rainfall to be able to establish correlations with the occurrence of debris flows.

The statistic Gumbel method or Extreme value index Type 1 was used to know the extreme rainfall for the study area. This method allowed determining the threshold of critic rainfall that may cause landslides according to the specific events under study. By these means it is possible to establish return periods for specific events and therefore determine if the rainfall factor is related to the occurrence of landslides which finally are the source of material for the debris flow affecting Villa Restrepo. In the case of he 4 of Jun (1996) event , it was found that the accumulation rainfall fits a return period of 2 years with rains falling for space of 43 days and an accumulate rainfall volume of 357,6 mm (see figure 4.4).

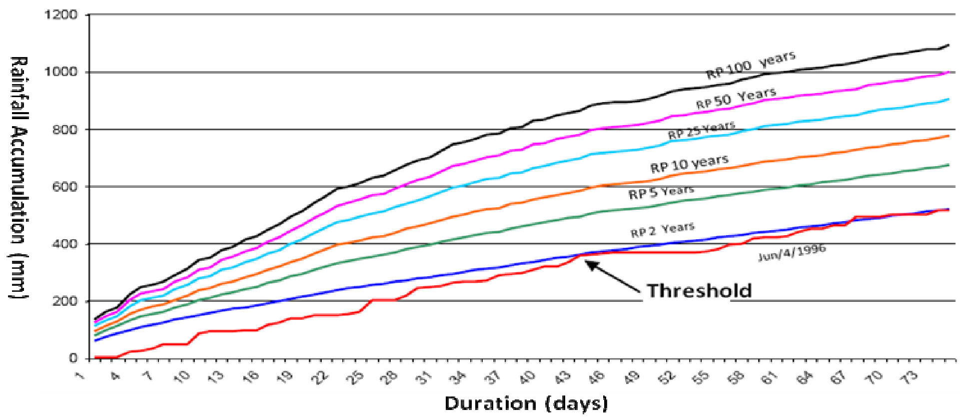


Figure 4.4. Accumulation of rainfall, frequency and duration for the event of 4 of jun-1996 (Juntas station .1975- 2005)

Regarding the 27 of August (1998) event, the critical rainfall reported was of 77, 1 mm as result of rainfall accumulation during three days (See figure 7.5).

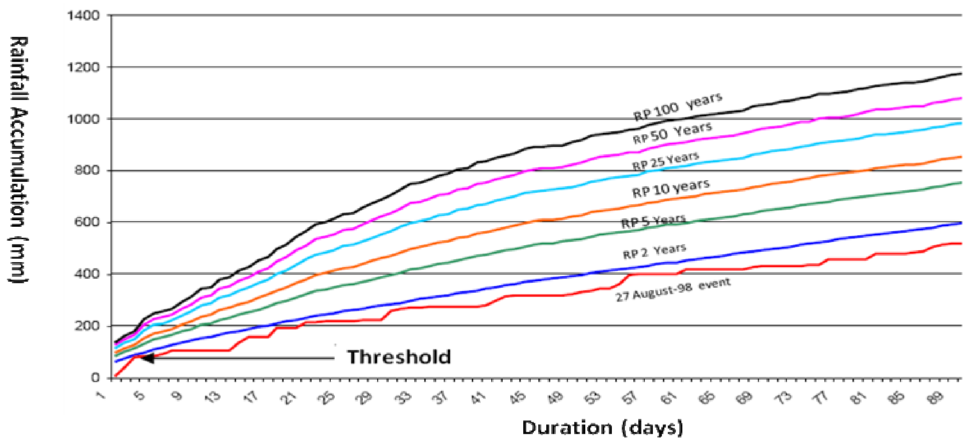


Figure 4.5.Accumulation of rainfall, frequency and duration for the 27 of Agoust-1998 event (Juntas station .1975- 2005).

The analysis for the event taking place 28 of September of 1998 produced a threshold of critical rainfall of 462 mm in 63 days for this episode (See figure 7.6).

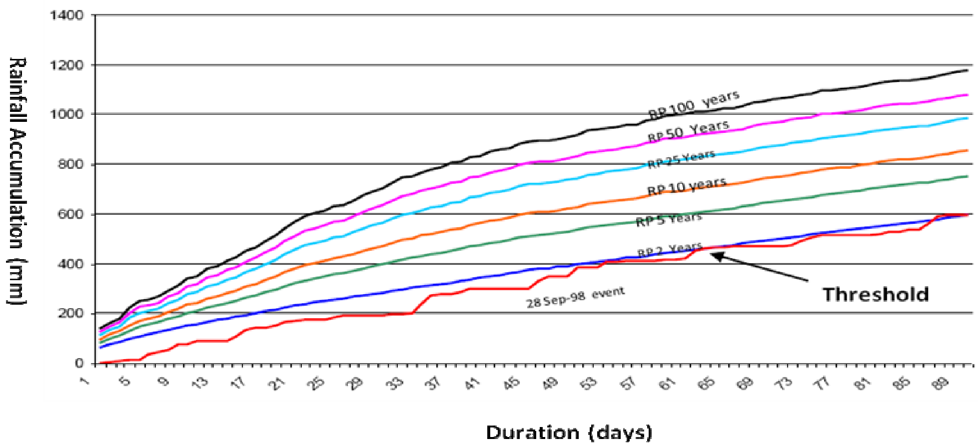


Figure 4.6. Accumulation of rainfall, frequency and duration for the episode on 28 of Sep-1998 (Juntas station .1975- 2005)

Based on the previous analysis, the landslides and debris flows in the study area can be triggered by two types of rainfall episodes. The first one requires an accumulation of 7 to 8 mm of daily rainfall during an average period of 43 days or more. The second type is related to more intense rains with an accumulation of 25 mm falling in a time span of three days (in average). The analysis therefore determines that in the Gonzales, El Salto and La Sierra two types of rainfall can trigger landslides and subsequent debris flows; one of them represented by high intensity-short accumulation period with heavy rains falling within few days and other related with low intensity-long accumulation period or medium to normal rains continuously falling during 43 days or more.

From interviews with community members and farmers in the upper catchment of El Salto and La Sierra river basins, it was estimated that during the Jun 2006 event rains fall during 4 days with episodes of about 40 minutes (daily rainfall of 50 mm approximately). According to the Gumbel model the whole episode, lasting 3 days, could have had an average accumulation of 200 mm days; representing a 50-year return period event.

4.4. Debris flood hazard scenario for a 50-year return period event

In order to develop a debris flow hazard scenario for a 50-year return period, the damage, intensity and magnitude factors were evaluated according to the 1945 and Jun 2006 events. As mentioned intensity and magnitude indicators are the factors that allow determining the level of hazard and destruction that could affect a building.

As previously mentioned through the interpretation of historical records and people's experiences related to debris flows, newspapers information, base data and meetings with leaders (who have lived by long time in this town), it was possible to achieve a better understanding on the causes, behaviour and damage caused by the debris flow events in Villa Restrepo. This research takes

Impact and accumulation indicators as the factors to develop debris flow analysis in Villa Restrepo for they were the factors that the community identify as most dangerous when these events occurred. For instance the pictures 4.2 show a house in Villa Restrepo affected by the accumulation of a debris flow during the 2006 event (left). So both concepts, Intensity and magnitude, are briefly described as follow:

Intensity: It's a factor assessed by the community which indicates the zones where the rocks, wood and debris carried by the flow collide against elements such as buildings, infrastructure, and crops on Villa Restrepo. This Impact causes a force that can damage the elements depending on the velocity and the specific weight of the mass on movement.

Picture 4.2. Debris flows in Villa Restrepo, left picture was taken during the event in June 2006 (50 years return period event). Right picture was taken in 2008 during fieldwork. (Source: Red Cross).

Magnitude: According to the community this factor is represented by the accretion of materials or volume of displaced materials involved in a landslide hazard. So the resulting damage is not caused by debris depth reached by the flow. This factor represents the accumulation of debris obstructing and causing huge damage on buildings, their contents, roads and other vital infrastructure as show the picture 4.2.

4.4.1. Intensity Factor Analysis

To develop an *intensity* analysis it was necessary to collect data in the field through a home-basis survey integrated on CyberTracker. The *intensity* factor was described and classified according to three levels which mainly relate the damage to structures and buildings, as follows:

In order to represent the *intensity* factor or level of impact per building reported during the interviews a point map was drawn from the GIS-based survey (see map 4.5 and table 4.2).The red points in the represent buildings where high impact was reported, the yellow points represent moderate impact and the green points a low impact from the last debris flow events.

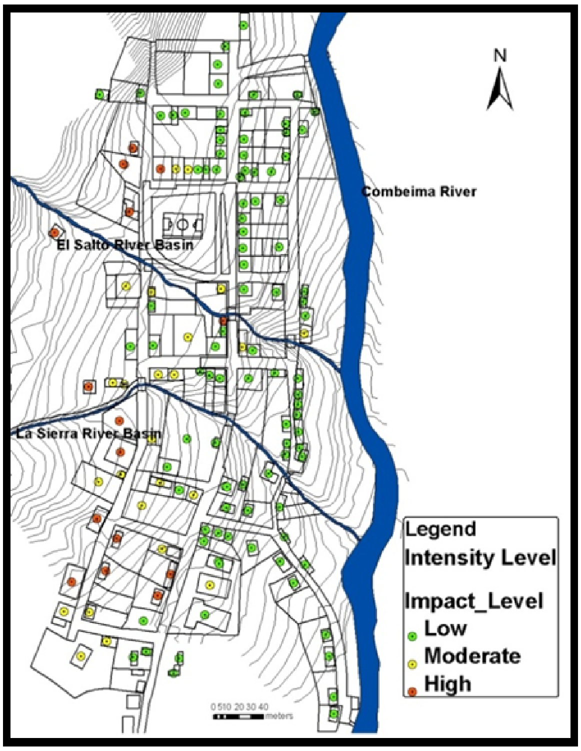
Value	Intensity Category	Characteristics	Percentage damage
1	Low Intensity	- Slight to No Impact to the building was reported by the people according to the different debris flow events. -This class also includes houses were information was not obtained or people hardly remember mainly because the damage was negligible.	**Light damage(less 10 %)** Do not involve damage to the building structure. Small destruction of floors, doors and windows, dwellings and furniture are mostly affected by the rocky and muddy materials. Walls may need a paint repair. In general the building stability and structural elements are not affected
2	Moderate Intensity	-The house was somewhat affected by the Impact of debris flow. According to community reports the energy produced by these events affected the house structure and destroyed fences, doors and wooden components of the buildings and houses and block the exits	**Moderate damage (10 – 50 %)** Important damage in columns. Affects Building stability and evacuation to secure place was needed. Need building structural reparation.
3	High Intensity	- The energy delivered by the event was the main factor causing damage to the houses. Extended damage to houses built in concrete and wooden materials. doors, walls, columns, floors was reported.	**High Damage (more 50 %)** High damage on the buildings. Almost complete destruction of the structure, its necessary the evacuation to a secure place. High affectation to building stability.

Table 4.2 Categorization of Intensity as a factor of debris flow hazard

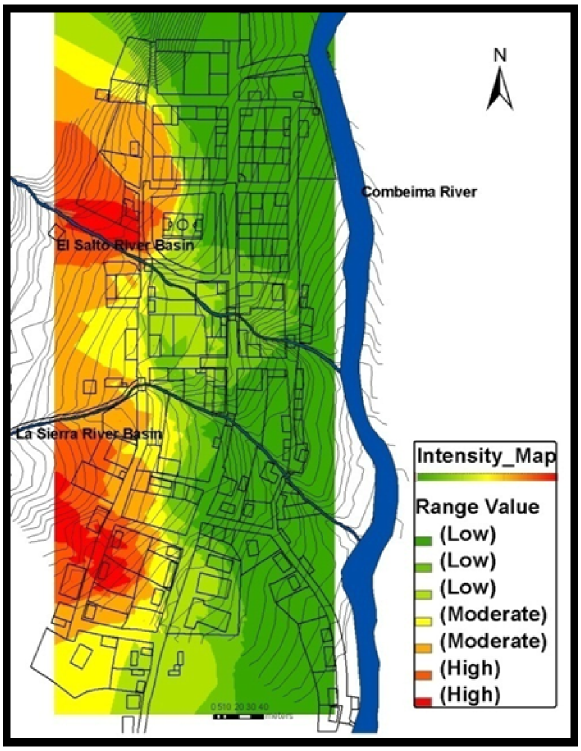
To calculate an intensity map for the whole study area a Kriging surface interpolation from the previous points map was applied. In this case the Ordinary Kriging method with a spherical semivariogram model integrated into ARGIS software was deemed adequate to represent the *Intensity* surface map (see map 4.6).

On the map 4.6 the red colour represents the area prone to high impact which constitutes 34 % of the total built area, where severe building damage can be expected during a 50-year event. The yellow colour represents the areas that can undergo moderate impact and the green colour the areas with low intensity and potentially low damage (depending on the characteristics of the exposed elements).

The houses close to the break in slope (left side) are the most prone to be affected by this factor (intensity or impact). According to the characterisation in table 4.2 these buildings may undergo more than 50 % of damage which will affect almost the complete structure. Most probably people inhabiting these buildings will have to evacuate them even before the event take place in order to protect their lives and belongings



Map 4.5. Spatial point representation of debris flow magnitude level in Villa Restrepo.



Map 4.6 .Intensity map for a 50-year return period debris flow

From the final *intensity* map is can be seen that some houses reported as highly damaged by intensity factor were located far away from the streams (see building located on the bottom left corner on map 4.5). According to the people this was the result of changes in the direction of the flow due to small topographical features which deviated the mud and materials such as wood and rocks, affecting houses in areas where the people was caught unaware as they did not expect the event would arrive there.

4.4.2. Magnitude factor

The *magnitude* factor represents the flow accumulation used to calculate the level of hazard posed by the depth reached or volume by the debris. During fieldwork this factor was found as the easiest to remember and identify by the community, at least for the last events. Data on the depth and the damage caused at certain depth levels (especially to buildings and residential houses) was requested to the interviewee. The depth reported was measured with a tape and recorded in the questionnaire. In some cases it was found that people perceived this as the most important hazardous factor due to the potential damage it embodies.

While carrying out the interviews it was still possible to identify and measure some watermarks left by the last episode in Jun, 2006 associated to a 50-year event. In most of the cases however it was found that people did not remember the accumulation or magnitude of the debris flow taking place during 1945. This may imply that some residents in Villa Restrepo, particularly the new residents, are completely unaware that events like this may happen there. In these cases it was necessary to ask neighbours or leaders who indicated the depth that the debris reached before in theses buildings. The data collected covered the total number of buildings in the town as show the map 4.7.

Picture A

Picture B

Picture C

Picture D

Picture 4.3 .The accumulation depth was another factor for hazard analysis in Villa Restrepo. The pictures show the examples of local knowledge with respect to magnitude of debris flow events.

As can be seen from picture B in some cases the debris flow mark was easily identifiable, in some other cases people show and pointed the depth (Picture C and D) and in other cases a neighbour helped to identify the debris depth (Picture A) .The data collected was classified in three categories as show the table 4.3 regarding to the damage to the building when these events occurred

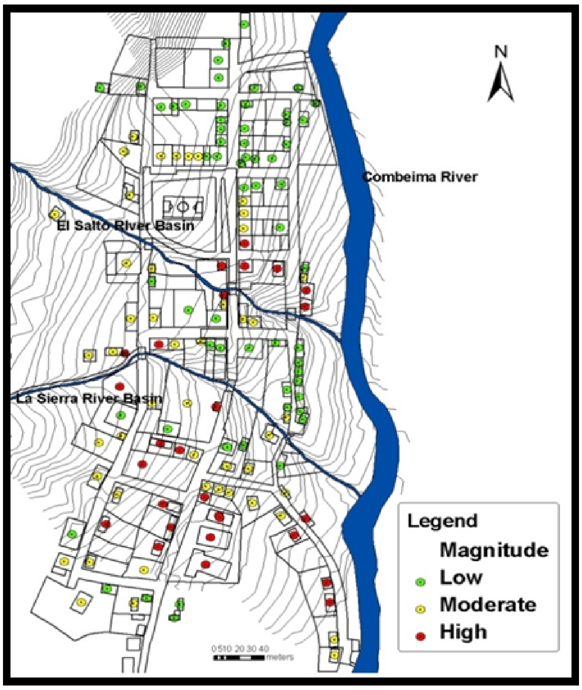
In this case the data collected for debris flow depth during the interviews was represented by points across the study area .The yellow points in map 4.7 represent low magnitude and houses where the debris flow depth did not affect the building. The building in this case was slightly affected (see description damage in table 4.3).

Value	**Magnitude Category**	**Characteristics**	**Percentage damage**
1	Low Magnitude	Less than 30 cm depth for past event with 50-years return period No damage to the house. This class includes houses were no information was obtained as the people did not remember or the people was not there in the moment the event occurred.	**Light damage (less 10 %)** Do not involve damage to the building structure. The amassing of muddy caused minimum problems on main wall and front doors. Walls and doors may need a paint repair. In general the building stability and structural elements are not affected.
2	Moderate Magnitude	Between 30 cm and 60 cm depth for past event with 50-years return period The building was moderately and slightly affected by the accumulation in past debris flow. This debris accumulation produced by last events was easily removed without affect directly the buildings.	**Moderate damage (10% - 50%)** Important damage by muddy amassing inside the dwellings .The Building stability affectation require a immediate clean up of materials in order does not evacuate to other secure place .The accumulation of materials affected slightly the human health
3	High Magnitude	Above 60 cm depth accumulation for past event with 50-years return period Extended damage to buildings in concrete and wood. The accumulation of debris was the main factor of affectation or destruction of the buildings related past events occurred in the study area.	**High Damage (more of 50 %)** High damage on the **buildings**. Amassing of debris and mud more of 1 meter which obligate to people **evacuate** to a secure place. High building stability affectation. High affectation by health human.

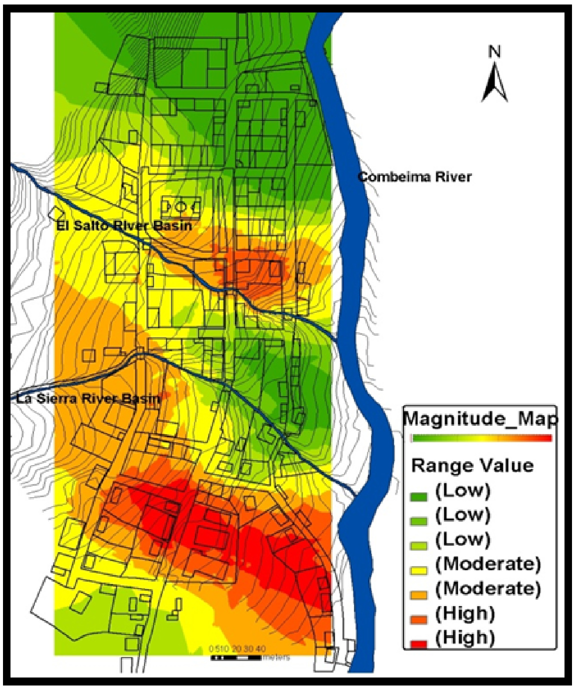
Table 4.3 .Characterization of debris flow magnitude categories according to a event of 50 years return period.

The red points represented in the map 4.7 indicate high magnitude .At some buildings the red point colour represent a high destruction level as result of the accretion or volume of material that affected both inside and outside the dwellings.

The next step to obtain a better visualization and useful information for hazard analysis was to perform an Ordinary kriging with a spherical semivariogram model (operation available in ARGIS) in order to obtain a surface that represents the debris flow accumulation map for Villa Restrepo. In map 4.8 the red colour represents the high accumulation areas and green colour areas where low accumulation can be expected. The magnitude map shows two areas with high magnitude. Each area correspond to a specific event (1945 and another event in 2006).



Map 4.7 .Shows magnitude level according to a debris flow event with 50 years return period.



Map 4.8 .Debris flow magnitude map.

From the map it can be seen how the area where the park is located exhibits a high to moderate accumulation hazard. From the meetings and transects walks with the eldest people of Villa Restrepo it was know that this zone was the most affected by debris accumulation in the event of 1945.The debris flow event in 2006 change its flow in La Sierra river directly affecting buildings where people was not aware that they could be reached by this type of events.

4.5. Debris Flow Hazard Assessment

To obtain a final debris flow hazard assessment and representation for the study area both the debris flow impact and accumulation were combined in a matrix that relates the magnitude of these two factors with hazard levels (see table 4.4).Afterwards the matrix in table 4.4 was converted into conditional ‘if’ rules in ILWIS software (See appendix section 2 formulas applied in ILWIS.).

To develop a classification representation for the final hazard map the values were classified by *equalities* method in ArcGIS. By these means a map that displays three levels of debris flow hazard was obtained (see map 4.9).

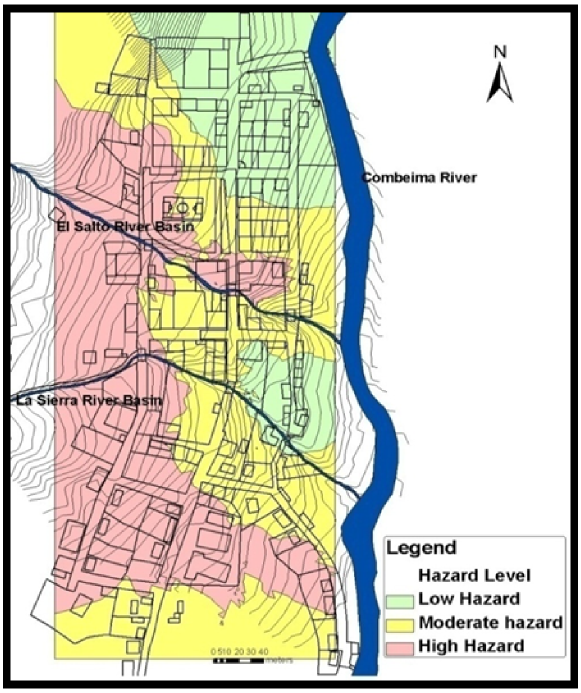
Intensity / Magnitude	Low Intensity	Moderate Intensity	High Intensity
Low Magnitude	Low Hazard	Moderate Hazard	High Hazard
Moderate Magnitude	Moderate Hazard	Moderate Hazard	High Hazard
High Magnitude	High Hazard	High Hazard	High Hazard

Table 4.4 Final debris flow hazard Matrix relating magnitude and intensity factors.

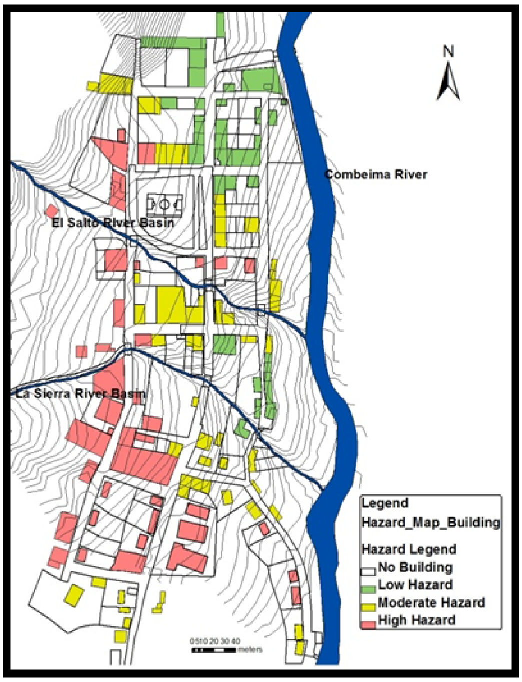
In map 4.9 the red color represents the high debris flow hazard zones ,the yellow represents areas with moderate hazard and the green color low hazard areas. According to the spatial distribution of this hazard at a building level (map 4.10), 42 families are located in a high debris flow hazard representing a 30 % of the total number of buildings in Villa Restrepo (See figure 4.7). The debris flow with moderate hazard comprises 55 houses and debris flow hazard with low level is represented with 39 buildings.

Once the final debris flow hazard map was available the location of critical facilities such as schools, church, library, parks, municipality and others with regards to hazardous areas could be obtained as shown in map 4.11. This map represents a valuable output of this study, as it can help to support mitigation activities that may need to be carried out for authorities and planners in order to implement restructuration or maintance to reduce the structural vulnerability.

From map 4.11 it can be seen how the central park, one of the main attractions for the tourist on weekends is located in high to moderated hazard areas, besides t he church which holds a vast amount of pilgrims during weekends (coming from Ibagué) occupies a high hazard zone. According to the final hazard map some other vital infrastructure such as the municipal town hall, shops and library are located in a low hazard zones (see map 4.10). According to this analysis if a 50-year debris flow event would take place the school could be affected and potentially undergo about 50 % of damage. The schooling activities could be affected directly for more than two weeks.



Map 4.9 Final debris flow hazard regarding to a return period event of 50 years.



Map 4.10 . Families Hazard map representation

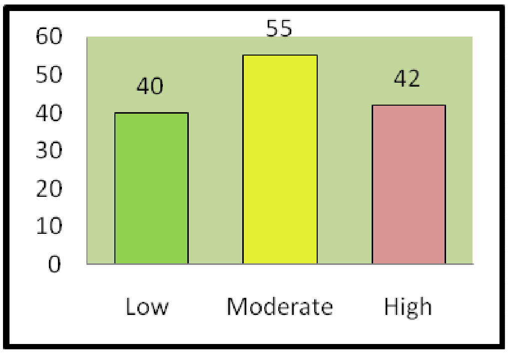
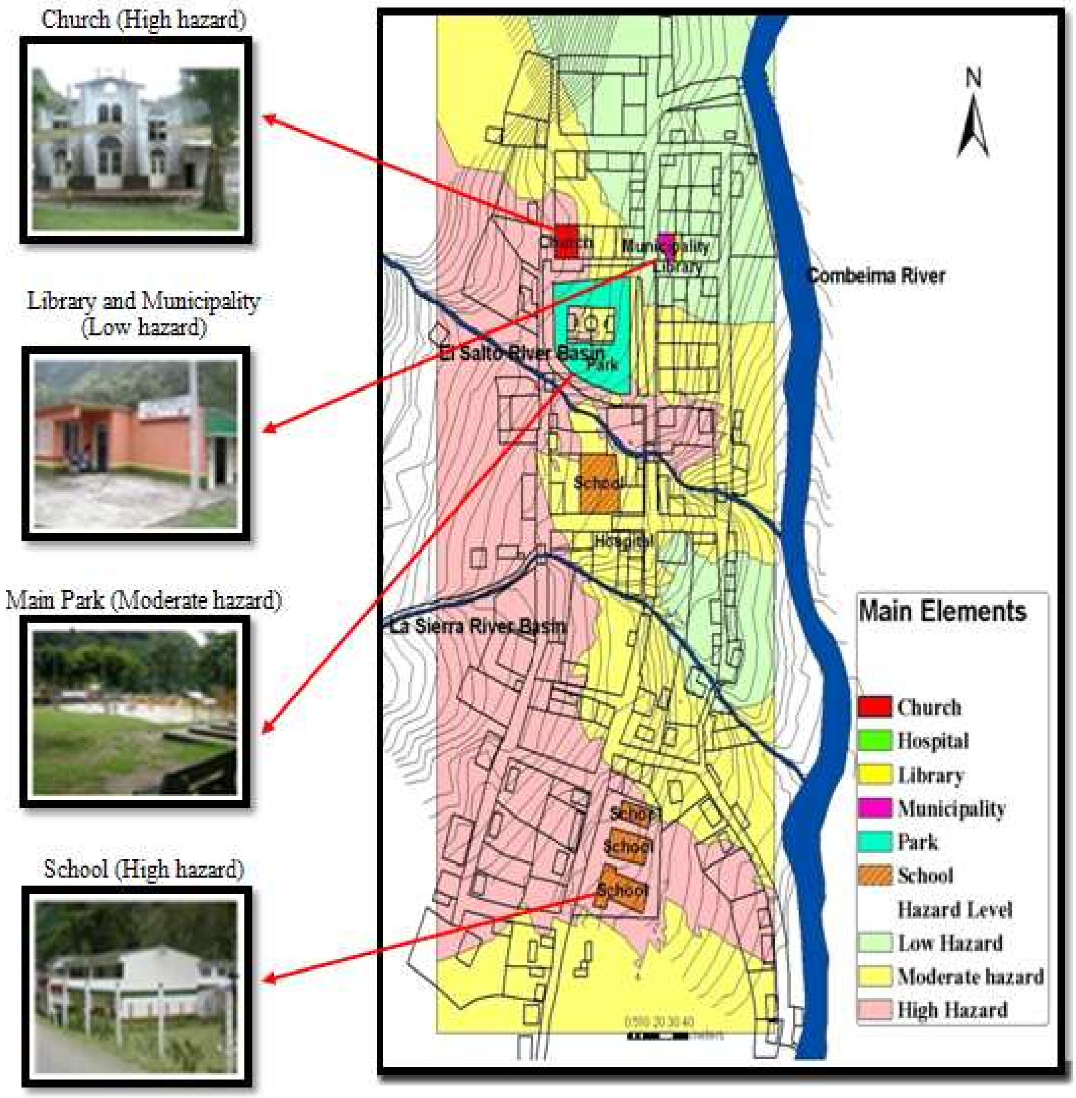


Figure 4.7 Number of buildings or families within hazard level.



Map 4.11. Essential Facilities at Debris flow hazard level.

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5. Vulnerability Assesment

This chapter describes the methodology to calculate and develop a community based vulnerability assessment in Villa Restrepo. The first part comprises the analysis of physical, socioeconomic and emergency factors involved into the vulnerability analysis. The second part presents a spatial multi-criteria evaluation carried out to integrate the parameters analysed into a vulnerability assessment.

5.1. Vulnerability definition.

The United Nations International Strategy for Disaster Risk Reduction (UN-ISDR) developed accepted and conceptual basis and definition for terms involved in risk assessment, as follows:

-Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure (UN-ISDR, 2009).

-Elements at Risk: Means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure etc, at risk in a given area.

According AGSO (2001) the vulnerability term have been accepted in all the methods of risk assessment involving several components such as social, economic and physical components. Methods for vulnerability assessment, particularly loss estimation, are available in the form of loss e- damage curves which can be developed from actual debris flow events and are used to simulate damage for future events. The expected losses are the results of a generalized relationship between debris flow characteristics such as magnitude represented by accumulation (debris flow depth), intensity or impact and physical damage. Additionally based on UNDRO (1991), the definition of vulnerability means the degree of loss to a given element at risk or set of such elements resulting from occurrence of a natural phenomenon of a given magnitude. It expressed on a scale from 0 (no damage) to 1(total loss).

These methods are mostly based on field interviews and questionnaires on damage to properties and levels of injury to people. These results depend on the response of the interviewees and difficulties exist in extrapolating the curves from one place to another as a result of differences in warning time, building type and content (Sande Van der, 2001).

The previous section on hazard analysis evidenced how the community is highly threatened by debris flows and how in absence of conventional information the local knowledge was used to develop a spatial analysis for debris flow hazard. In order to perform a risk assessment however it is necessary to incorporate also a vulnerability analysis. Vulnerability analysis is complex and dependent on large data sets, and on qualitative analysis that requires the involvement of the people concerned in the evaluation of their vulnerability (Cannon, 2000). Vulnerability assessment is intended to provide communities and local authorities with information on measures for mitigation and preparedness. When this assessment is carried out in a spatial way these actors will also be able to know the geographical distribution of people and elements which can be negatively affected (Peters Guarin, 2008).

In this research socioeconomic and physic factors are analyzed with regards of their contribution to a household's vulnerability to debris flow; the data used for the analysis of vulnerability to debris flow was collected through the home-basis survey (see questionnaire in the Appendix section 1). The list of indicators taken into consideration in this study to evaluate the household vulnerability to debris flow in Villa Restrepo is provided in Table 5.1. Each factor contains the indicators and categories used to define them .Besides the vulnerability rating in the table mentioned the level of vulnerability according the categories integrated into the indicators. For instance high values represent a high vulnerability according to the category.

5.2. Socio-economic Status Factor

This factor has six indicators that represent the influence of the social and economic conditions of a family on their vulnerability to debris flows. The indicators used for the socioeconomic analysis are occupation or source of income, Income Dependency ratio, family size, members of the family in vulnerable age groups ratio, family income, and time of residence in Villa Restrepo and ownership status of the residence.

5.2.1. Source of Income or Occupation.

This indicator designates the main economic activity performed at family level. Through interviews it was found that occupations such as farmer, employer, and house workers have an influence on the vulnerability of the family.

Factor	Indicator	Category	Vulnerability Rating
Socioeconomic status	Occupation	Employee	1
		Housework	2
		Informal worker	3
		Farmer	4
		Small in-house shops	5
	Income Dependency Ratio	1 to 1	1
		2 or 3 to 1	2
		4 to 1	3
		5 or more to 1	4
	Family size	Less than 3	1
		4 to 6	2
		6 people	3
	Members of the family in vulnerable age groups ratio	18 - 54 years old	1
		13 – 17 and years old	2
		< 13 and > 54 years old	3
	Family Income	> 3 minimum daily wages	1
		1- 3 minimum daily wage	2
		Less than 1 daily wage	3
	Time of residence in Villa Restrepo	More 5 years	1
		1 - 5 years	2
		Less 1 year	3
	Land Ownership	Owned	1
		Rented- tenancy	2
		Illegal	3
Structural	House type	Concrete	1
		Wood	2
Emergency	Distance of building from the main road	<10 mts (Easy access to evacuation)	1
		10 -20 mts (Moderate access to evacuation)	2
		> 30 mts (Difficulties for evacuation)	3
	Transportation means	Car	1
		Motorcycle	2
		Bus	3
		No transportation mean	4

Table 5.1 Factors and indicators involved in the Vulnerability Analysis of Villa Restrepo.

The home-basis survey helped to identify the main activity from which the family derives their livelihood. The survey showed that the more affected or vulnerable once a debris flow take place are those who depend on a small in-house shop or business and farmers working close to the town (see picture 5.1).

Picture 5.1 Small in -house shop in Villa Restrepo.

The analysis of information collected during the survey shows that a 10 % of people depend on small shops in home activity and other 10 % is represented by farmers. A high percent of people depend on housework (30 %) .

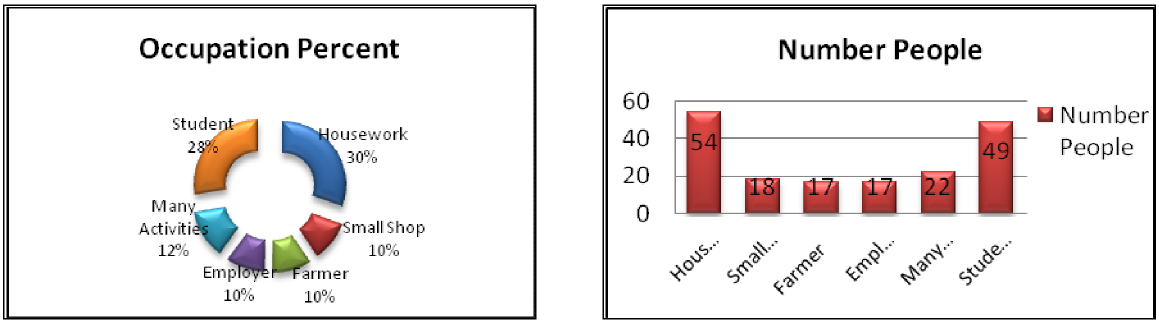
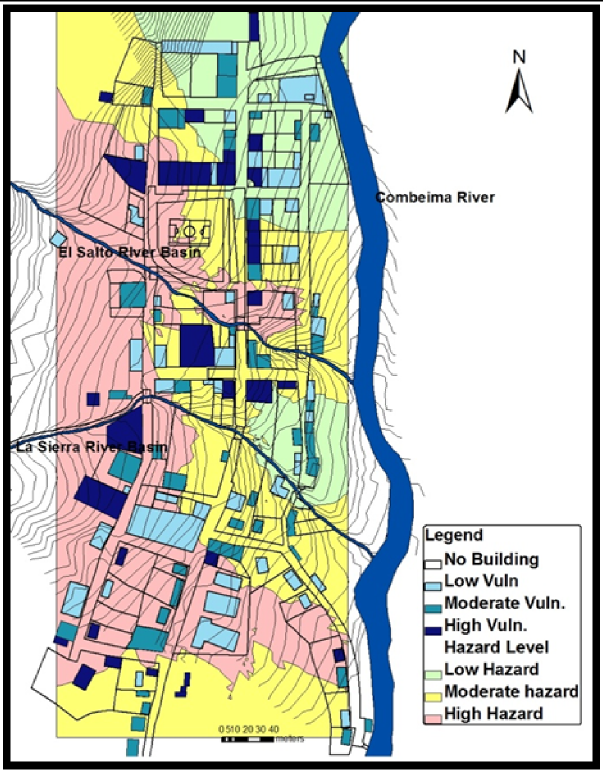


Figure 5.1 Representation of number of people according to their occupation in Villa Restrepo.

The indicator related with occupation was classified in three levels: low, moderate and high vulnerability. High vulnerable occupations were farmers and people that depend of their small shop. Moderate vulnerability were informal workers and house workers and low vulnerability was assessed to people who are employees working in different activities in Ibague as their income is not threatened by debris flows. The spatial distribution of these categories is presented in map 5.1

The percentage distribution of vulnerability as result of income source or occupation shows that in Villa Restrepo there are 30 of families (22 %) with highly vulnerable occupation, 53 (39%) with moderate vulnerability occupation and other 54 (39%) with low vulnerable sources of income. The Furthermore with reference to figure 5.3, 25 families located on a moderate hazard level in Villa Restrepo are considered with a moderate vulnerability with regards with source income indicator



Map 5.1 Source of income indicator and hazard level

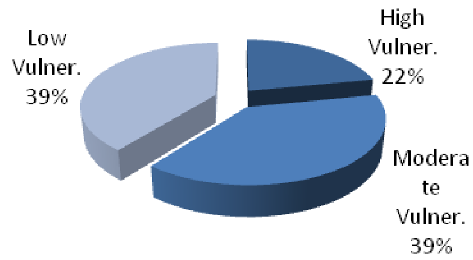


Figure 5.2 Distribution of income vulnerability in Villa Restrepo

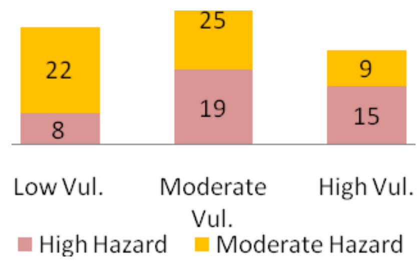
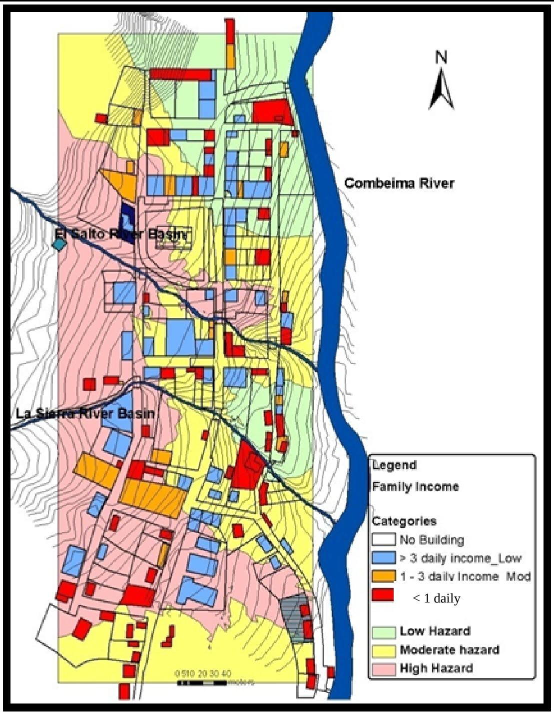


Figure 5.3 Number of families when is compared with source of income and hazard level.

5.2.2. Family Income

This indicator refers to the amount of money available at family level to cover their basic needs on a daily basis. In this case the categories were established taking into consideration if the income earned by the family was enough to keep them above the poverty line and satisfied the needs of the family members regarding food, shelter, education, health and other basic needs, in which case they were characterised as less vulnerable. By the time of this research (2008) the minimum monthly wage was established at $461.500 Colombian Pesos (equivalent to $256 US Dollars) and therefore the daily wage was around $15.380 Pesos (around $8.5 US dollars per day).

Families with funds below this poverty line are considered more vulnerable as these needs are not meet even during what is called ‘normal’ times (no disaster occurrence). These households therefore will be less able to withstand critical times as those following the occurrence of debris flows as the one under analysis (50-year return period event).



Map 5.2 Family income categories

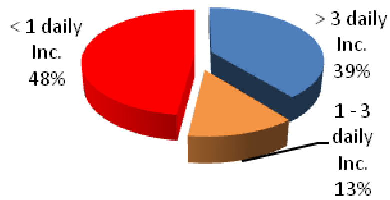


Figure 5.4 Percent of family Income category

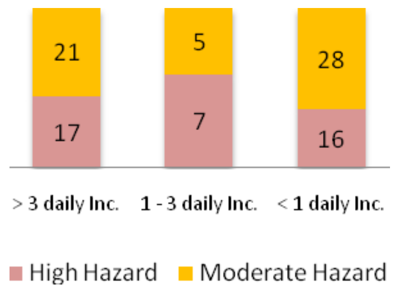


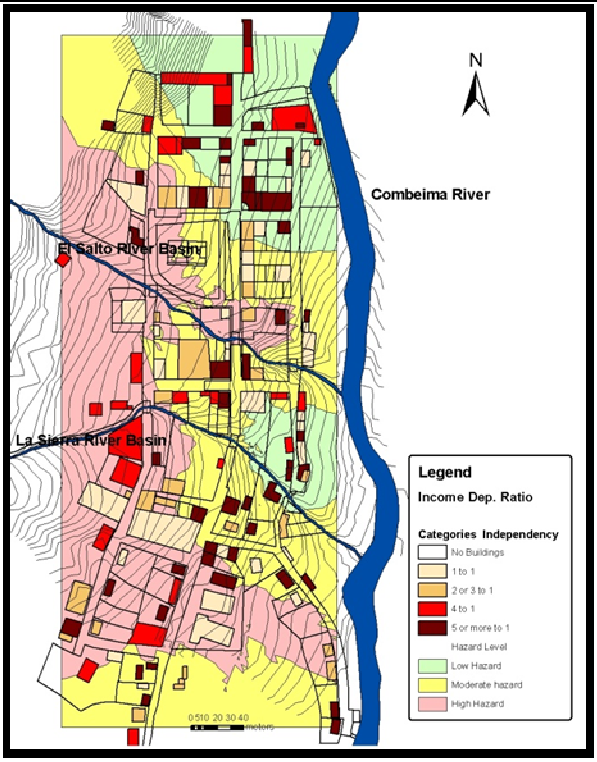
Figure 5.5 Number of families when is compared family income and hazard level

The data collected through the survey allowed to determining that for instance people who depends on small in-house shops received more than 3 minimum wages income and therefore their vulnerability from the point of view of income available was considered low. On the other hand, farmers and people working in informal activities (informal workers) were found as earning less than one minimum daily wage (families with red color in the map) and then were considered as living below the poverty line and therefore highly vulnerable. Families in this group will find more difficulties in recovering in case they are affected by a debris flow.

Families living below the poverty line (<1 minimum daily wage) comprise 48 % of the households in Villa Restrepo (see red colour in the map 5.2), those receiving between 1-3 minimum daily wages are around 13% and families earning above 3 minimum daily wages represent nearly 39% (see figure 5.4 and map 5.2 the orange colour). On figure 5.5 the relationship between hazard level and family income categories is presented. It can be seen how for instance 16 of the vulnerable families that live with less than 1 daily minimum wage are located in a high hazard area and 28 poor families live in moderate hazard areas.

5.2.3. Income Dependency Ratio

This indicator represents the economic dependency by the member of a family. This indicator was obtained by calculating the family members relying on each worker. Figure 5.6 shows the category percent of this indicator .By other hand the figure 5.7 shows the percent of buildings or families which is compared the income dependency ratio categories and level of hazard.



Map 5.3 Income Independency ratio categories by family level.

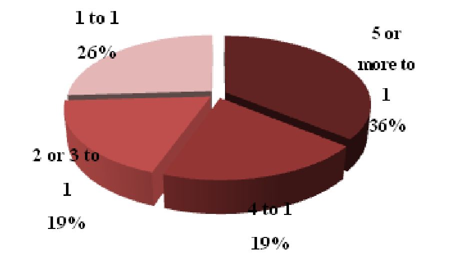


Figure 5.6 Categories of local Independency by percent.

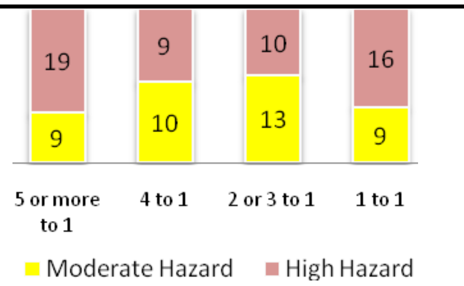


Figure 5.7 Percent of building regarding level of IDR and hazard level.

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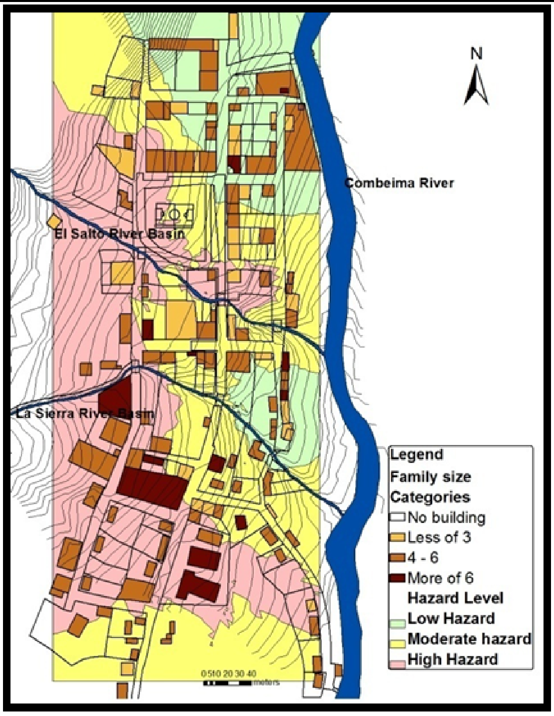
The vulnerability analysis it was considered that those families were 5 or more members depend on the income of a solo worker are highly vulnerable. In Villa Restrepo this families constitute around the 36% of the total. Families with IDR 4 to 1 constitute the 19%, IDR 2 or 3 to 1 represent another 19% and finally families were one worker is responsible for another person and him/herself (IDR 1 to 1) represent 26% of the households. In the study area, 9 families of the highly vulnerable families were found settled moderate hazard and about 19 families in a high hazard (see map 5.3 and figure 5.7)

5.2.4. Family Size

Family size represents the number of members of a family living in a building. A numerous family is considered more vulnerable and will find more difficulties in recovering in case to be affected by debris flows than a family with few members, especially if as I can be seen from the previous analysis big families tend to rely just on the income from solo workers.



Map 5.4 Representation family size indicator

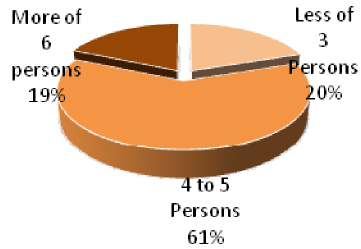


Figure 5.8 Categories of family size

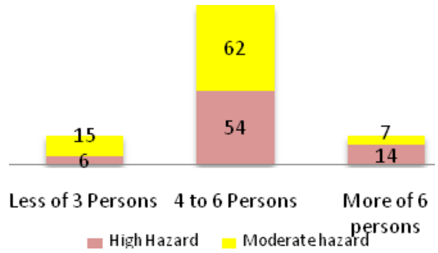


Figure 5.9 Displays the number of families considering family size indicator and hazard level.

On the other hand from the experience of previous debris flow events it was known that local authorities had more difficulties in handling and taking care of families with many members that small families. For instance during emergencies a large family would take more time to evacuate and put all their members at safety that a small size family.

The spatial representation of families regarding the categories used in these analyses is shown in map 5.4. From it, it can be seen how large families (more than 6 persons, dark brown colour) represent 19% of the households in the study area. Moderately large families (4 to 5 members) constitute 61% and small families (less than 3) are around 20% and this category is display in the map 5.4 and figure 5.8 with light brown colour. According to the figure 5.9 from the category considered moderately large (4 to 5 members) 54 families are located in a high debris flow hazard areas and 62 in moderate hazard .

5.2.5. Members of the family in vulnerable age groups.

This indicator considers that depending on their age there are members of a family less able to defend by themselves, in case of a debris flow, than others and therefore they are considered as more vulnerable. family members younger than 13 years and older than 65 years old. During the interviews these groups of persons were found to be the most affected by the events that have hit Villa Restrepo for instance.

AGE CLASS	POPULATION IN VILLA RESTREPO URBAN ZONE		POPULATION IN VILLA RESTREPO RURALZONE	
	WOMENS	MENS	WOMENS	MENS
<5	8	6		
5-9	8	12	2	
10-14	5	10		2
15-19	6	13		
20-24	9	7		
25-29	6	8		
30-34	4	9		
35-39	9	4	2	1
40-44	6	8		
45-49	6	6		
50-54	6	4		1
55-59	5	6	1	
60-64	6	3		
65-69	3	3		
70-74	3	4		
75-79	1	1		
80-84	1	2		
85 y +				
Total	92	106	5	4

Table 5.2 Population distribution according to gender and age categories

5.10

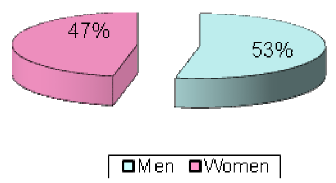


Figure 5.11 Percentage of gender

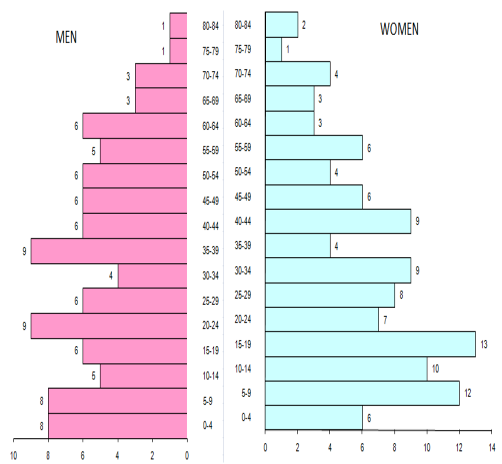


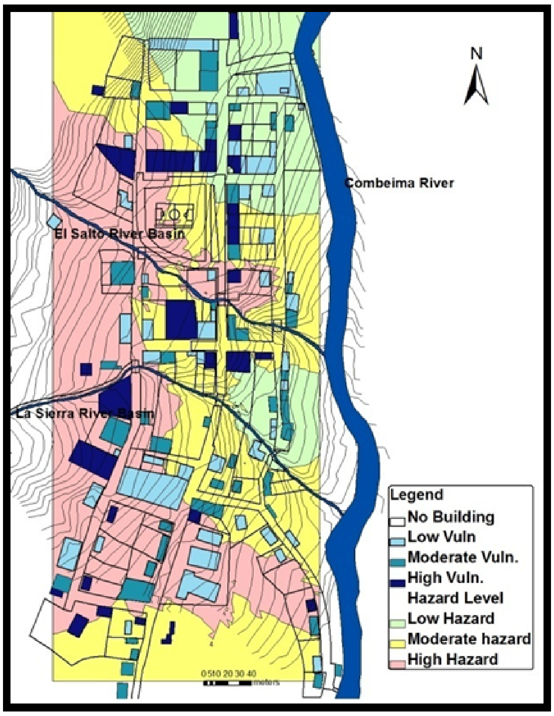
Figure 5.12 Distribution of age classes population in Villa Restrepo.

In order to evaluate the distribution of this indicator in the study area members of each family were categorised according to their age and gender and differentiated into urban and rural population as shown in Table 5.2 and Figure 5. 11 and 5.12.

The categories of age vulnerability indicator were developed according the capacity and hability of the age people of Villa Restrepo in previous events related with debris flow.In this way individuals < 13 years and >

65 years old were considered with a high vulnerability. Members of a family between 13 and 17 years were considered with a moderate vulnerability and finally according the experience with previous debris flow, members of a family in the range of 17 and 54 years were considered with a low vulnerability. This indicator that represents the age vulnerability was calculated and represented by family level. To calculate this indicator of vulnerability were considered the number of members in high vulnerability with respect to the total members of a family.

The total population was found composed by 53 % male and a 47 % women (see figure 5.11), from which the largest feminine population was found in the range 20 to 24 years old (9 persons). For male from the range was between 15 to 19 years old (12 persons).



Map 5.5 .Representation of family members in vulnerable age group

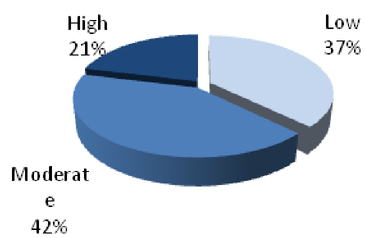


Figure 5.13 .Percentage of age indicator in Villa Restrepo.

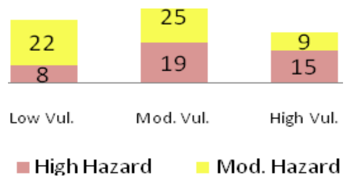


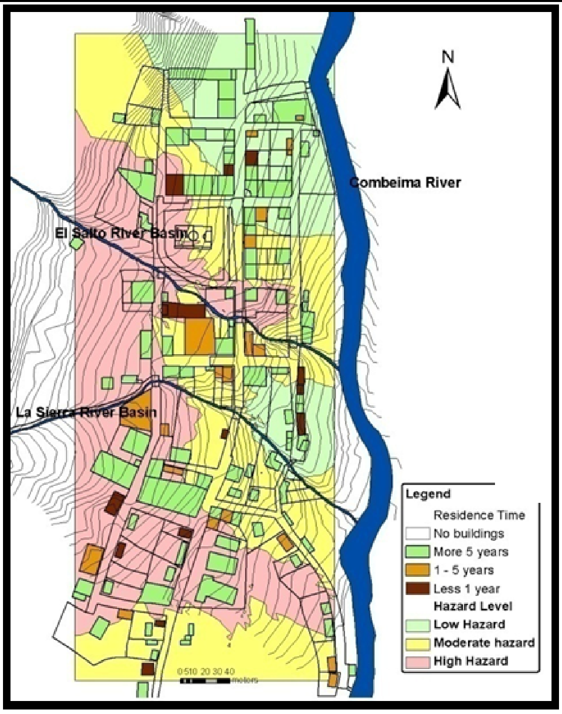
Figure 5.14 . Number of families regarding age indicator levels and hazard levels

The spatial representation of families according to the categories used in this analysis is shown in map 5.5. From it, it can be seen how those families which majority of members are found in vulnerable groups (<13 and > 54 years old,) represent 21% in the study area. Moderately vulnerable families (members between 14 to 17 years old,) constitute 42% and families with a low vulnerability (18 – 54 years old) are around 37% and this category is display in the map 5.5 and figure 5.13 with light blue colour.

Figure 5.14 shows how from the families with majority of members in high vulnerable age class are located in a high debris flow hazard areas and 22 in moderate hazard. The second figure represents a combined analysis using level of hazard and the final results of age vulnerable group indicator. Regarding this analysis the moderate vulnerability age factor are larger in moderate and high hazard (see figure 5.14).In this way the families with low vulnerability are represented 8 in high hazard and 22 families in moderate hazard.

5.2.6. Time of residence

This indicator represents the time that a family has resided in the study area. Through interviews it was know that there are people who have just recently settled in the town and therefore are not knowledgeable of the occurrence of previous debris flows and the disastrous situations they have caused.



Map 5.6 .Representation of the categories of the time of residence

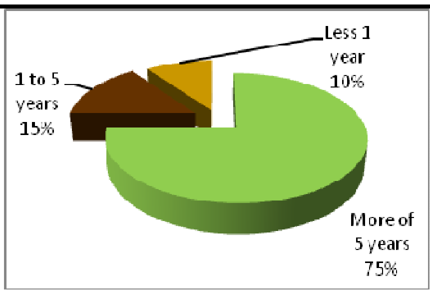


Figure 5.15 .Percentage of family income categories in Villa Restrepo

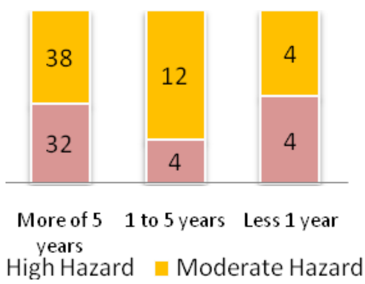


Figure 5.16 .Time of residence categories compared with hazard levels.

This indicator is related with the experience and knowledge that long-residents have about debris flow events .For instance if a family have resided more than 5 years in Villa Restrepo is likely to have experienced several of the debris flow that took place in the last years (particularly the one in 2006). For this research they are considered as more knowledgeable and aware (and therefore less vulnerable) than a family that have just arrived to the town or have been living there for less than one year, which in turn are considered as highly vulnerable..

For Villa Restrepo it was found that nearly 75 % of the families have resided in the town for most than 5 years. Families settled there between 1 to 5 years are 15% and those with less than 1 year represent 10 % (see figure 5.15 and map 5.6). Figure 5.16 represents a combined analysis between level of hazard and the time of residence categories. 4 Families between 1 to 5 years of residence are located in high hazard areas and 12 in moderate hazard ones.

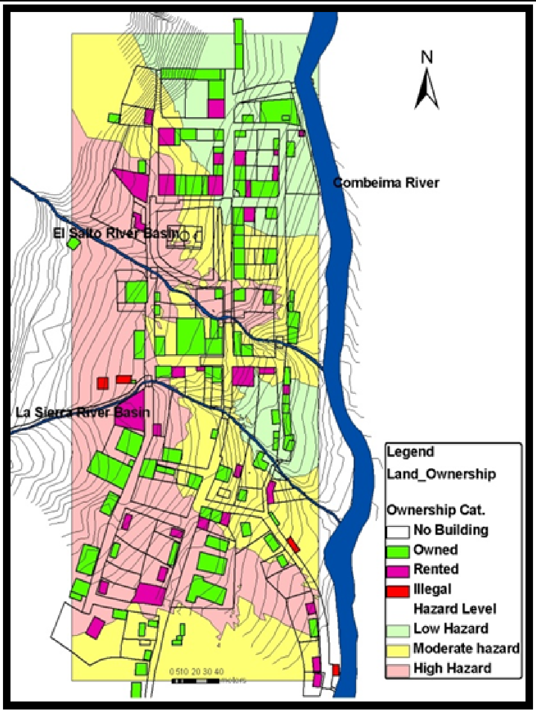
5.2.7. Land Ownership

Families living in illegal buildings are more vulnerable than those who own or rent the land. According to the municipal authorities (informal communication, 2007) during the 2006 event it was very complex to assist these families with subsidies for repairing or rebuilding their houses as they have no legal deeds on the land they occupy. Families that own their house become then less vulnerable not just because they have more economical resources but also more direct access to subsidies after each calamity (see picture 5.2).

Illegal housing in the study area comprise 3 % of the total buildings (see map 5.7 and figure 5.17), other 25 % were found as rented and 72 % of the buildings are owned by their inhabitants .

Picture 5.2 .Left illegal buildings and right represents an owned building used to tourism on weekends.

The vulenrability analysis performed in this research considered that people living in their own houses as low vulnerable, those inhabiting rented houses are moderately vulnerable and illegal settlers as highly vulnerable. The figure 5.18 shows the number of buildings comprised in each ownership category compared with the hazard level. As shown 27 buldings in owned category are located in a high hazard and 35 buildings located in a moderate hazard



Map 5.7. Representation of Ownership categories

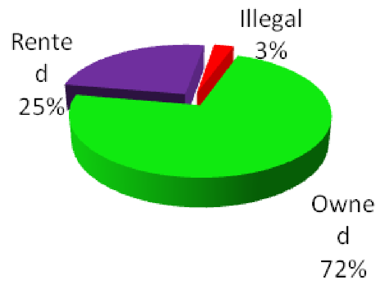


Figure 5.17 . Percent of ownership categories in Villa Restrepo.

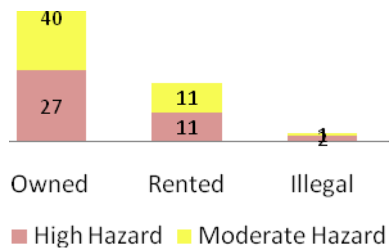


Figure 5.18. Ownership categories compared with hazard level.

5.3. Structural factor

For this research the structural factor was analysed based on the type of materials of the buildings. Regarding vulnerability this aspect is related with the level of protection or exposure that a given type of house can provide to its inhabitants. In this case safety was related to the type of material from which the house is made off.

5.3.1. House Type

The type of material has a high influence in the type of structural damage that a building can undergo when it is stricken by a debris flow. Picture 5.3 shows some of the typical houses found in the study area. The preferred materials for buildings are brick and reinforced concrete, wood or a mix of both. From them the houses in wooden materials where found to be the most vulnerable to debris flows as they can get easily damaged by both the impact of the flow and the accumulation of debris materials.

Concrete and Wood material buildings

Wood material Building

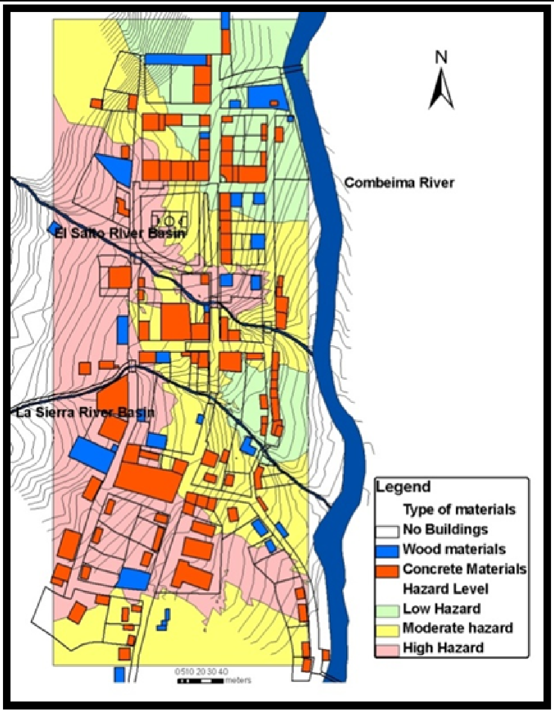
Concrete buildings

Wood material building

Picture 5.3. Typical houses in different building materials in Villa Restrepo

Map 5.8 presents the distribution of buildings in Villa Restrepo according to the material used for their construction. Figure 5.19 shows how concrete buildings comprise 79 % of the total number of houses. The other 21 % corresponds to buildings in wooden materials. Figure 5.20 shows the number of buildings per category (wood – concrete) and hazard level. In this case 40 concrete buildings and 10 buildings in wooden materials are located in high hazard areas. 37 buildings in wood and 12 in concrete are located in moderate hazard areas.

This information should be useful for local authorities and planners in order to mitigation activities. If the municipality know where and how the most vulnerable buildings are located with regards the occurrence of a debris flow they can be more willing to support to the resettlement of more vulnerable and poor people to safer areas or to encourage people to build in stronger materials so that the house can withstand the occurrence of debris flows and provide safety to the family when these events take place.



Map 5.8. Map of materials type buildings categories in Villa Restrepo.

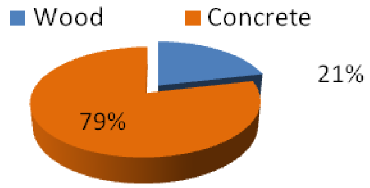


Figure 5.19. Percent of categories according to house type

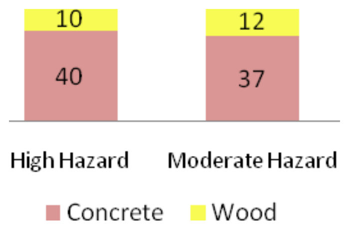


Figure 5.20 .Number of buildings represented by Type of material and hazard level.

5.4. Evacuation Factor

Prevention and emergency response capability of the people residing in potential debris flow areas can make a difference when one of these events take place .Moving away from the path of the flow to a stable area can reduce people's exposure and therefore their vulnerability. People living close to disaster evacuation routes and having the means to escape on time are more able to protect themselves and minimize loss.

In order to evaluate the capacity of families to evacuate on time two indicators were taken into consideration: distance from the building to the main road and the type of transportation used by the family. These indicator are related with the performance of the family during emergency activities which contribute to increase or decrease their level of vulnerability and physical exposure.

5.4.1. Distance to main Road

During open community meetings, it was know that the people is aware of the likelihood that during the rainy months of after heavy rain showers debris flow can take place. Therefore they are used to carefully listen in case that a debris flow is approaching the town and get ready to evacuate in order to save their lives.

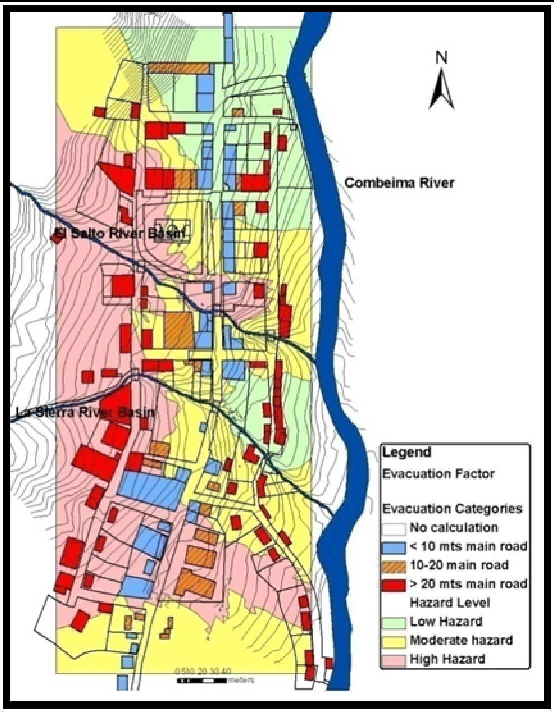
Local authorities and people in the community mentioned that the first action taken by the community once they know an event is approaching is evacuating to the main road because in their perception it provides the safest escape route.

To calculate this indicator three distance buffers were considered as follows: buildings located less than 10 meters from the road, buildings between 10 - 20 mts and finally buildings that are farther than 20 mts. People living in the buildings inside each of these buffers were considered as low, moderate and highly vulnerable respectively.

Pictures 5.4 represent two categories in these indicator with buildings in the left picture located less than 10 meters from the main escape road and houses located farther than 20 m from it.

Picture 5.4 Representation distance from building to main road indicator.

The map 5.9 represents the spatial distribution of this indicator in the study area. The blue color in the map represents buildings with a distance to the main road less than 10 meters; it comprises 22 % of the total buildings in Villa Restrepo. Buildings in red color are those located farther than 20 meters from the main road. Their inhabitants are considered highly vulnerable and correspond to 53 % of the houses in the town. From them 28 buildings were found in areas of high debris flow hazard and 26 in moderate hazard (see figure 5.22).



Map 5.9. Distance from building to main road categories

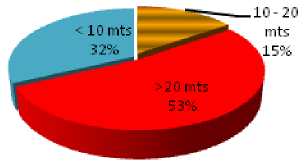


Figure 5.21 Percent of categories distance from building to main road.

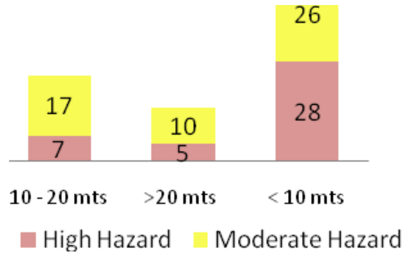


Figure 5.22. Distance from building to main road categories compared with hazard level

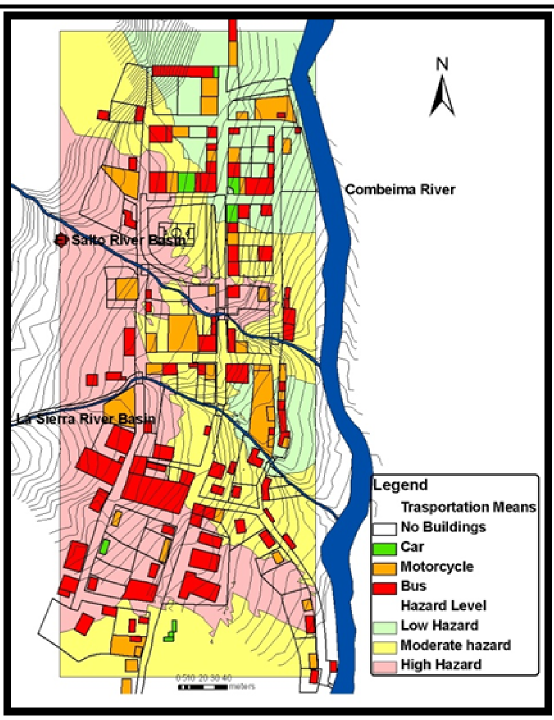
5.4.2. Transportation means

The last indicator taken into consideration for evaluating vulnerability to debris flows was the transportation means. This indicator was considered important as cars, buses and other transport action means can help people to rapidly leave a dangerous place and besides they can support a mass evacuation during emergencies. As mentioned debris flow is a fast destructive event but according to the local experience, some people (60 %) have had time in previous events to evacuate to safe locations; nevertheless it should be mentioned that the capacity to perform fast and timely evacuation activities depend on the time at which the event takes places. Evidently an event taking place during the night when people is resting will demand more time for them to get ready and make use of these means to escape.

During the interviews it was know that some families have used cars or motorcycles to evacuate the town when significant debris flows have taken place. However they also mentioned how they use the vehicles to supported them during recovery activities for instance after the disaster in June 2006.


Picture 5.5 .Type of transportation means in Villa Restrepo.

On the other hand it was found that this indicator provides information about other aspects such as family income and family size. For instance if a family owns a car they are considered less vulnerable because, in the Colombian context, it implies the moderate to high economic level. Pictures 5.5 show two of the most common trasportation means found in the community.



Map 5.10 Shows the transportation means categories by family

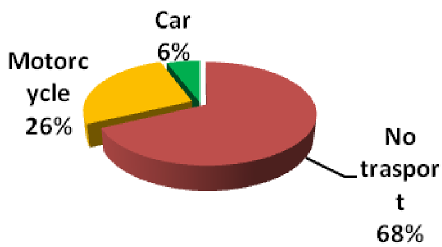


Figure 5.23 Percent of categories distance from building to main road.

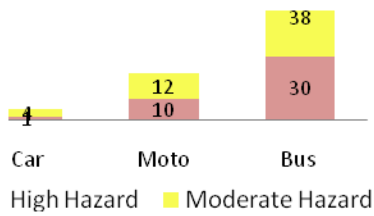


Figure 5.24 Distance from building to main road categories compared with hazard level.

From map 5.10 it can be seen how an important number of families do not own a vehicle or have access to private transportation means. These people normally have to make use of public buses for transportation during normal times. During critical times these people have to rely on vehicles provided by the local authorities and civil defence or get some assistance to evacuate from neighbours and relatives.

5.5. Spatial Multicriteria Evaluation for vulnerability assessment

Spatial multi-criteria evaluation (SMCE) module available in ILWIS software was used to calculate a vulnerability index that integrates all the factors and indicators previously explained. The SMCE become useful as it helps to determine how and in which proportion every indicator and factor contributes to the overall vulnerability of the families to debris flow.

In a SMCE the data is input as raster maps and tables so that criteria could be compared against each other. The criteria tree was created by following the structure of factors, indicators and categories listed before and are fully presented in the figure 5.25.

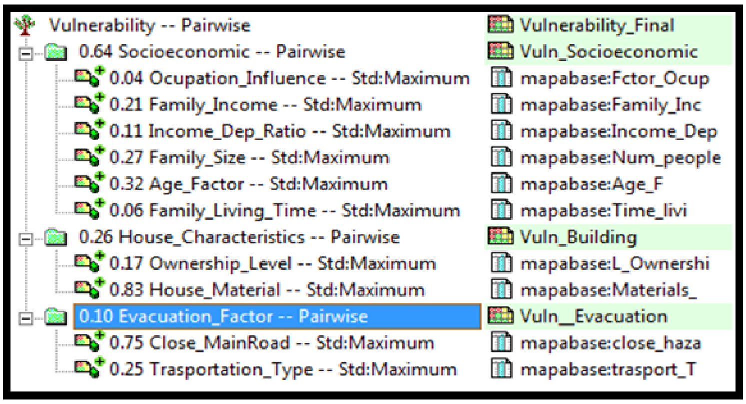


Figure 5.25 Multicriteria evaluation tree.

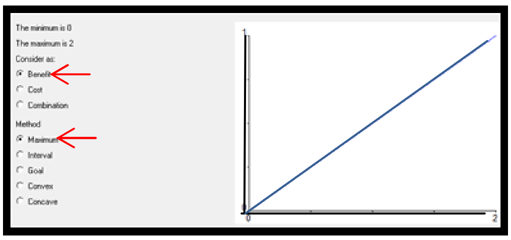


Figure 5.26 Standardisation of vulnerability indicators (family size) where high values contribute to high vulnerability (1).

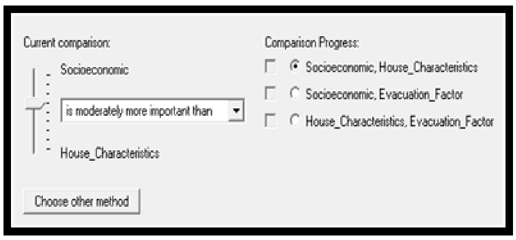


Figure 5.27 Show the Pair wise function used to weights all the factors and indicators

Each indicator was standardized as shown in figure 5.26 and evaluated against each other through pair wise comparison methods as shown in figure 5.27.

The figure 5.26 shows for example the standardization of the family size indicator. In this case high values (big families) contribute to increase the overall vulnerability of the household and therefore the indicator is considered as a 'Benefit'. The opposite if higher values of the indicator contributes to decrease the vulnerability (i.e. higher income) then it was considered as a 'Cost''.The red arrows in figure 5.26 shows the option chosen in the family size indicator to develop its standardization.

After standardising all the categories the next and final step was the weighting process which was meant to assign the relative importance for debris flow vulnerability of the whole criteria. The weighting was performed between the indicators forming a factor and finally the weighing of the factors themselves. The method to make this weighting was pairwise comparison (see figure 5.27).

The weight given for indicators and factors comparison were given according the criteria of community and direct criteria observation in the fieldwork phase.

5.6. Vulnerability Analysis

As explained in section 5.5 , the spatial multicriteria evaluation was developed in order to calculate a final representative vulnerability map in the study area with values of 0 to , in which 0 represents low vulnerability and 1 represent high vulnerability. The figure 5.28 shows the distribution values from 0 to 1 representing the families vulnerability for Villa Restrepo.The clasification of these values were created through *quantile method* available in ArcGIS sofware .

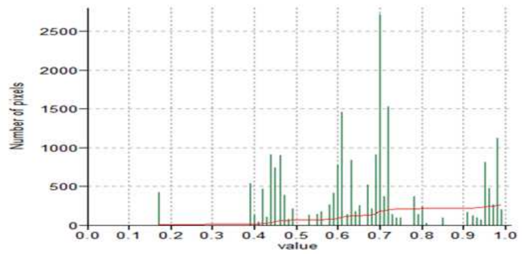


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Figure 5.28 Histogram that represents the distribution of values in the vulnerability map

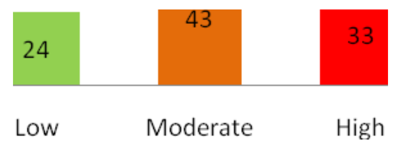
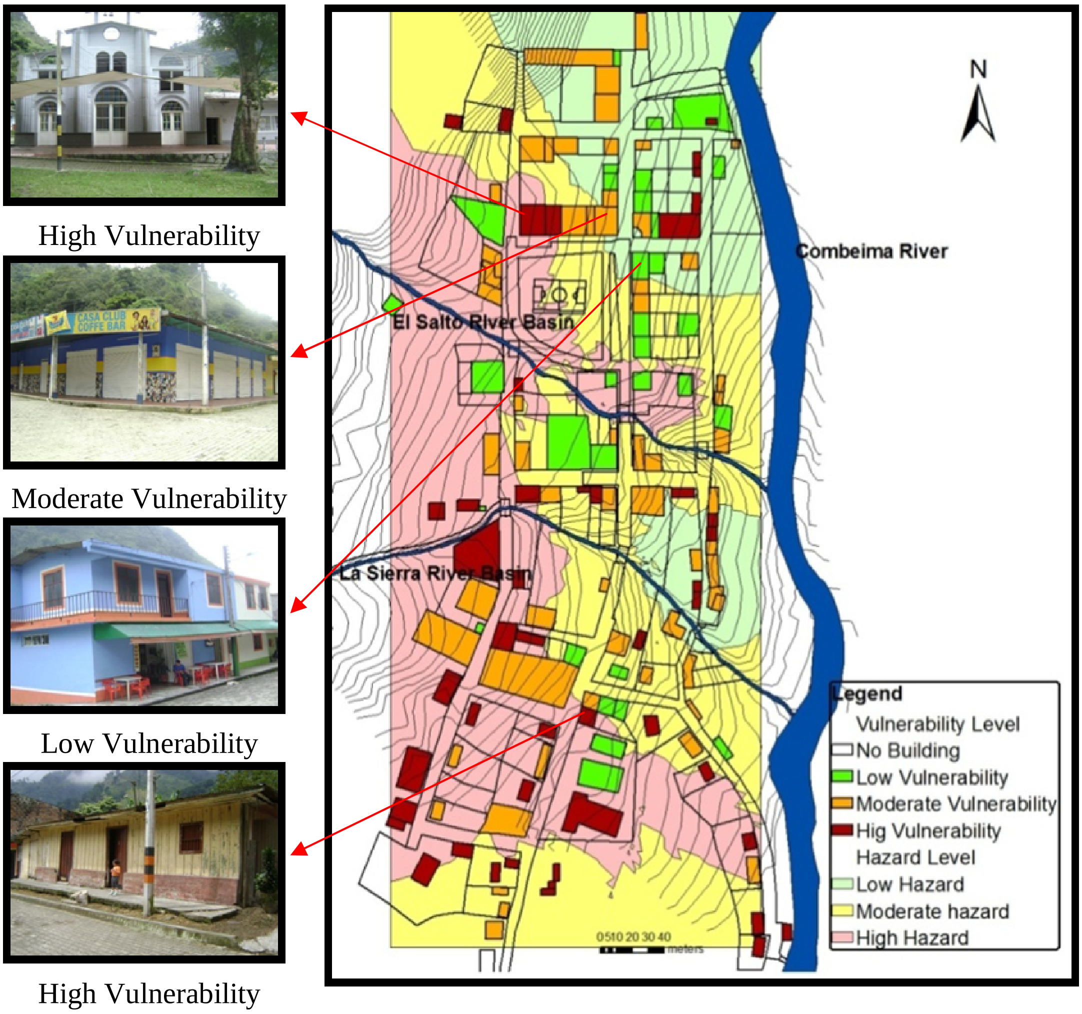


Figure 5.29 Percent of families units according to their vulnerability level in Villa Restrepo.

The figure 5.29 and the map 5.11 represent the final vulnerability for the families in Villa Restrepo in number of families and spatial means. Besides 24 families were classified with low vulnerability, 43 with moderate vulnerability and finally 35 families were found as highly vulnerable.

The pictures related with the map 5.11 help to visualize the vulnerability of families in Villa assessed through the SMCE module, after combining all the factors, and indicators presented in

Table 5.1. The first picture show the main church of Villa Restrepo which is conidered with a high vulnerability. two families small inhouse-shops were considered with moderate and low vulnerability and finally a woden building represented with a moderate vulnerability.



Map 5.11 . Vulnerability map of Villa Restrepo. The bottom layer displays the hazard map of debris flow with a return period of 50years.

This qualitative vulnerability analysis represents for local authorities an important source of information for activities related with mitigation, prevention and attention of emergencies. Although a final debris flow vulnerability analysis was developed, local authorities and planners should analyze separately the vulnerability indicators in order to obtain relevant analysis according to specific requirements.

6. Risk Perception Assessment

In this chapter the risk perception by family is analysed and evaluated. Nine questions were integrated into the home basis survey in order to collect information on how the households perceived the risk from debris flow. Risk perception was also analysed regarding its incidence in increasing or decreasing the vulnerability of the households and the vulnerability indicators.

6.1. Risk perception definition

There has been a considerable amount of empirical research undertaken on the way people perceive risk, how they manage it and how they live with it. An important starting point is that, in some important instances, perceptions of risk do not appear to correlate with measurable probabilities of risk and therefore other factors are clearly important in understanding how people understand risk.

This can have an important impact on the ability of policy makers to communicate risk analysis decisions in cases where such mismatches occur. It has been suggested that societies select particular risks for attention and that risks are therefore “exaggerated or minimized according to the social, cultural, and moral acceptability of the underlying activities” (Covello and Johnson , 1987).

Personal experience, memory and other factors have influence in the way people perceive the risk and these may ignore the probability of the event’s occurrence – thus risk perception is socially constructed . In addition, it appears that people have a level of risk with which they feel comfortable and will adjust the riskiness of their behaviour in the presence of safety measures.
The personal perception during hazardous events is considered in this research as an important aspect in for the final appraisal to hazard, vulnerability and risk regarding debris flow. In the process of developing perceptions of risk, a person understands the hazardous context in which is living and depending on how he/she interpret the threat will take actions (or not) to avoid or adapt him/herself and the circumstances to the threatening environment.

6.2. Risk Perception assesment for debris flow

In this research the knowledge, experience and participation of the families to debris flow hazard are indicators considered to calculate and represent a final risk perception in Villa Restrepo. However, given time constraints, the nine-question interview was carried out just for the head of the households and it was assumed that this was representative of the whole family (although that may not be the case). These question where carried out integrated to the home-basis survey for vulnerability data collection.

Indicator	Question involved	Answers options	Evaluation
Experience - Knowledge	1. Have you experienced a debris flow event in Villa Restrepo?	No I havent	1
		No but I was informed	2
		Yes. I lived this experience	3
	2.Given a debris flow who you rely on for protecting your life and saving belongings?	God	1
		God and myself	2
		Only myself	3
	3. In case of a debris flow which loss do you consider more important?	Anything	1
		Material properties	2
		Family and material properties	3
		Family wellbeing	4
	4. Do you think that a debris flow can take place in Villa Restrepo in?	No. I don't think it can occurs	1
		100 years	2
		50 years	3
		10 years	4
		2 years	5
		Yes, with justification.	6
	5. Do you think that your house could be affected by a debris flow?*	No	1
		Yes/Not. Without Justification	2
		Yes/No with justification and matching the hazard map.	3
	6. Are you concerned about he occurrence of debris flows in this town? *	No	1
		Yes	2
Participation	7. Do you participate in activities carried out in order to reduce the risk?	No activities	1
		Attending municipality workshops	2
		Attending municipality activities and proposing measures to reduce the risk	3
	8. Do you know what to do in case of an emergency triggered by a debris flow?	I don't know	1
		Be at home	2
		Get out of my place	3
		Follow the instructions given by the municipality	4
	9.Do you know which are the zones considered as very hazardous due to debris flow ?	No idea	1
		More or less	2
		Yes I know	3

Table 6.1 Questions Involved with Answerers to evaluate risk perception on families in Villa Restrepo.

The table 6.1 shows the indicators and the question and the potential answers considered in order to develop a risk perception appraisal. According the table 6.1 if the evaluation in the question is 1 this represents a head of household with a low perception regarding the indicator evaluated. An answer of 4 or 5 would mean that the person has a high perception (see questions and answers developed to integrate in risk perception). Finally each question involved was represented in maps in order to analyse the spatial distribution of these risk perception factors. Finally the spatial multicriteria module was used to integrate the indicators in a final risk perception index.

The questions integrated for risk perception analysis were focused to participation and knowledge factors related to debris flow event. For instance if a person that represent the family in the interview has not experienced a debris flow event in this town, the study considers this person has a lower perception regarding a person who has experienced a debris flow event. So each map has a question involved which the answers are represented spatially. The next perception indicators described are analyzed by maps and graphics in order to have a wide understanding about the influence of each factor in debris flow hazard and risk perception

6.3. Experience and knowledge Indicator

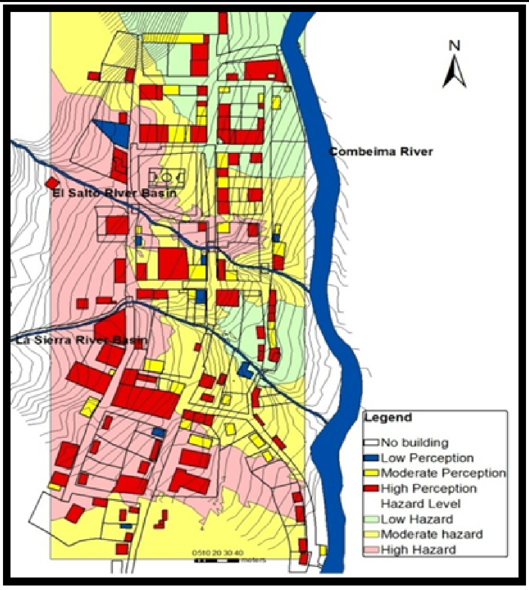
This factor comprises the experience and the knowledge of the families as factor to evaluate risk perception. This indicator was evaluated with six questions (see table 6.1). To illustrate the analysis carried out in this indicator three questions will be explained in this section as follows:

6.3.1. Family experience on debris flow events.

The question (1) was meant to determine if the family has experienced a debris flow event in the town. To evaluate this indicator three categories or potential answers were considered .The first when the family had experienced a debris flow and therefore this experience has increased their awareness and knowledge. These families then where considered as having a high perception. The second category is represented by families that have not experienced a debris flow event, mostly because they are new in the town, but have been updated about previous events by neighbours, news or local authorities. In this case the household was classified as moderately vulnerable. The final category corresponds to those families that have not experienced debris flows and besides know anything or very little about them and have not been updated about previous events such as the ones occurred in 1996, 1998 and 2006.

According to the analysis in figure 6.1 around 97 (70%) of the families in Villa Restrepo have experienced a debris flow event and therefore their knowledge and perception about the hazard was found as high. 35 families (15%) have not experienced debris flow event up to know but they were informed about the previous events and hence they were considered with a moderate risk perception. In the last category 8 families were found as no having perception of the risk of debris flows either because they have not experienced any of the events or because they have not received any information about their occurrence in the past. Through the interviews it was also found how these households do not have a clear understanding of the hazard itself nor about the level of damage they can cause.

In Map 6.1 the spatial distribution of families according to their perception of risk from debris flow is presented.



Map 6.1 Spatial representation of families that have experienced debris flow events.

Question involved (1): Have you experienced a debris flow event in Villa Restrepo?

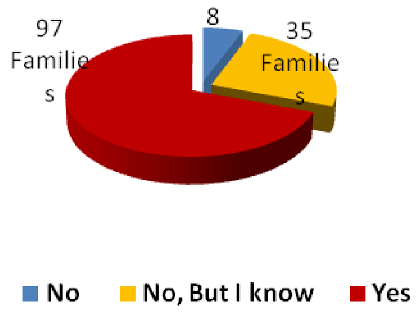


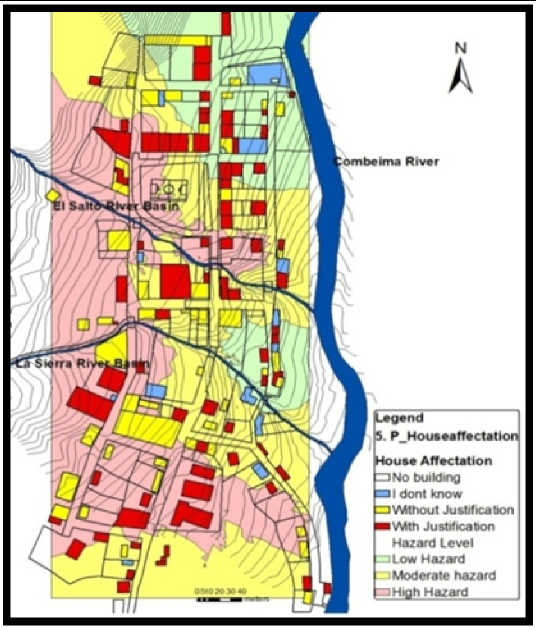
Figure 6.1 Shows the Number of buildings in each category of answers.

From figure 6.1 it can be seen how around 60 % of the families with high risk perception are located in a high hazard level. It can be also noticed how even in some areas where the hazard from debris flow was considered as low the families have a high perception of the risk they embody. Finally, and most important, are those families that were found as newly arrived and without risk perception living in areas considered prone to be highly affected by debris flow (high hazard) such as two or three families living close to the streams.

6.3.2. Family awareness about building susceptibility to debris flow

This indicator assesses the knowledge that families have about the likely impact of debris flow event on their home and the consequences. Three categories of answers were evaluated to calculate a representative indicator.

The question (5) tries to analyze the perception of the families regarding the safety of the building they inhabit and the possibilities they consider that a debris flow will affect them. Depending on the answer this questions can indicate the perception the household regarding their own location and exposure (vulnerability) with respect to the hazard and the need to look for safe refuge during this events (preparedness).



Map 6.2 Representation risk perception according to building affectation awareness

Question Involved (5): Do you think that your house could be affected by a debris flow?

Figure 6.2 Shows the number of building in each category of answers

Families that believe that a debris flow event could cause damage to their residences or not but provided a logic justification for the answer and besides it matches the hazard map were considered as having a high risk perception. The main reason provided by these families for their perception about possibilities to be or not affected were related with their closeness or distance from the rivers The families who perceived that their houses can/cannot be affected by debris flow but did not provide a justification for their answer were considered as having a moderate perception. Finally the last category was assessed to the families who did not answer or their response (yes/no) did not match the hazard map were considered as having a low risk perception.

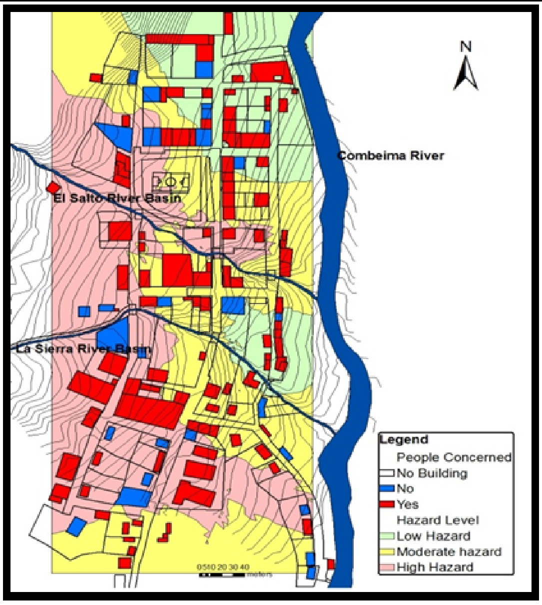
The statistical distribution presented in figure 6.2 shows that 53% of the families (73 families) perceive that their house (and therefore they) can be affected by a debris flow event and provided a coherent reason for their answer mostly related to the perception of the strength/weakness of the building (type of materials) or their location with relation to the river. In the other hand 37 % of the households (51) fall in the category of moderate risk perception because they understand that their buildings can/cannot be affected but did not present a justified reason for their answer. Finally 10 % of the families (14) were found as having a low or no risk perception for debris flows for they do not know if their buildings can be affected by a debris flow or not. As mentioned the families in this category were mostly those that arrived to the town less than 1 year ago and have a very poor or no understanding about the magnitude and affectation that debris flow can cause in Villa Restrepo. According to map 6.2 two of these families are located on areas with high debris flow hazard.

6.3.3. People concern about debris flow events

This indicator is related to the concern that the family may have with respect to the occurrence of debris flow in the study area.

Families whose response was affirmative were considered as having a high perception of risk. They have a high awareness level about the possibilities for a debris flood to hit the town and they are sensitized about the hazard. According to figure 6.3 this category comprises 78% of the total number of families in the town.

Families not concern represent 22 % and were categorised as having a low risk perception. .From map 6.3 it can be seen that 15 of these families are located in high hazard areas. The interviews determine that some of the reasons for their low concern of these households were that they do not have expensive possessions or economic assets that can be damaged by a debris flow. Some of them were also found as renting other people house or being squatters.The contrary people who have money investments or valuables in their dwellings, for instance in small shops were found as being seriously concerned about the occurrence of a debris flow event as they can lose their livelihood and properties.



Map 6.3 Representation risk perception according to concern of families with respect to a local hazard.

Question Involved (6): Are you concerned about the occurrence of a debris flow in this town?

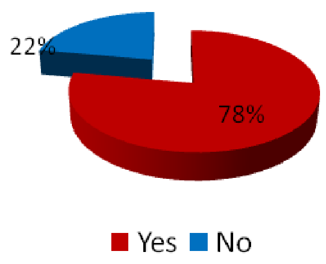


Figure 6.3 Shows percentage of families in each category of response

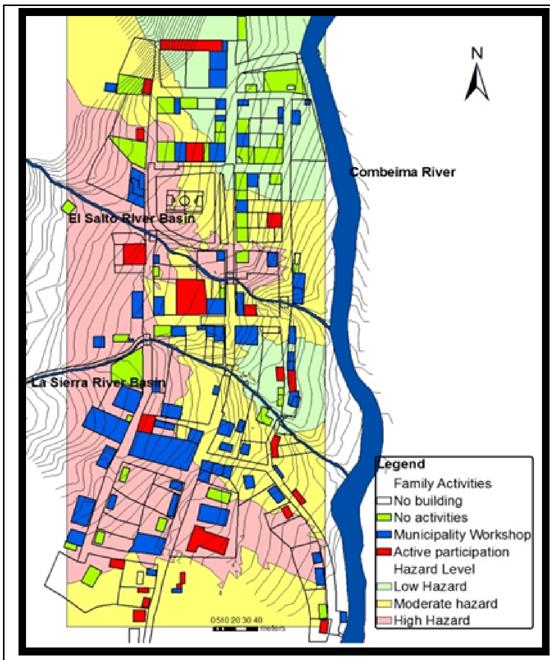
6.4. Participation and attention of emergencies

These indicators are represented by the perception of the community in the moment that an emergency related to a debris flow in Villa Restrepo can take place .Three factors were incorporated to calculate a risk perception about participation and attention of emergency analysis. The first indicator was considered the activities taken by the people to reduce the debris flow risk, the second the activities taken during an emergency and finally the debris flow hazard awareness.

6.4.1. Activities taken to reduce the risk

This indicator represents the level of participation of the family in activities or measures carry out (by themselves or local authorities) to reduce or mitigate this risk in Villa Restrepo.

The question (7) involved in this analysis seek to evaluate the importance that the households attributes to get involved and become part of the activities carried out to reduce the risk and raise awareness. Activities related with awareness raising and reduction of risk were workshops by local authorities in relation to early warning programs, emergency attending and preparedness and mitigation. All these activities have been carried out in order to increase the awareness and emergency actions..



Map 6.4. Representation risk perception according to activities taken by the families to reduce the risk

Question Involved (7): Do you participate in activities carried out in order to reduce the risk

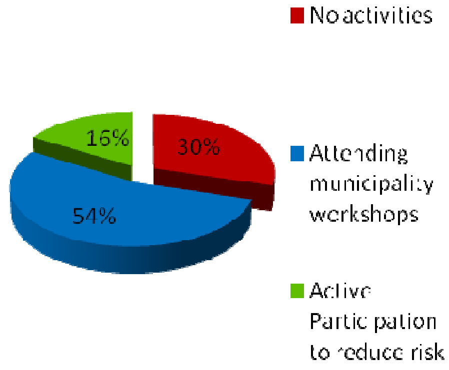


Figure 6.4 Shows the percent of buildings in each category of answers.

People comprised in the category of active participation to reduce the risk were considered as having a high risk perception. According to figure 5.6 they were 19 families comprising 16% of the total households in the town. The survey showed that most of these families are located in the center of the town (see Map 6.4).This is a touristic sector were most of the small in house-shops, school, church, bars and park are located. This group of families usually reinforce their buildings, attend the workshops, early warning actions and participate in emergency activities

The second category of families is considered those that occasionally attend workshops programmed by the municipality but are not really committed to collaborate with risk reduction activities in the town. For these reason these families were considered as having a moderate risk perception. They were found as comprising 54 % of the households. These families with moderate risk perception were found located mostly in high debris flow hazard (see Map 6.4)

Finally the families that do not perform activities to reduce the risk are considered with low risk perception and were found comprising 30 % or around 35 families. Families who were affected in the debris flow event of 2006 correspond mostly to the moderate risk perception category for they have attended workshops implemented by the municipality for community preparedness and evacuation.

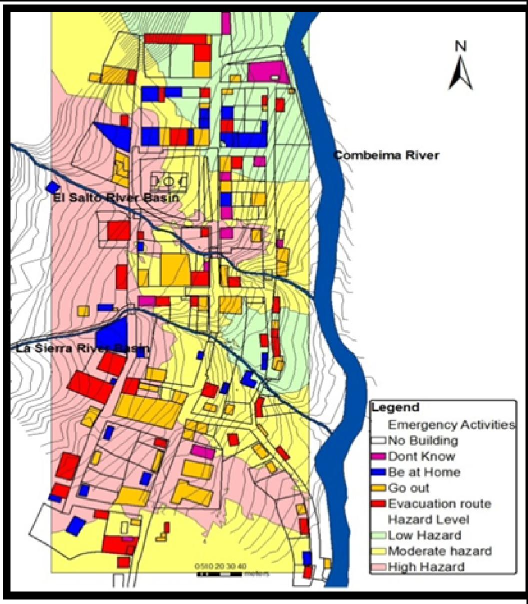
The information provided by this indicator can be useful for local authorities as it made evident areas were more activities and motivation for active participation of the community may need to be implemented. The municipality can easily target the families that do not attend or participate in risk reduction activities and optimise the use of their, often scarce, resources.

6.4.2. Actions taken in case of an emergency

The second indicator regarding participation and attention of emergencies in the town was the actions taken by the community in case of an emergency. The question used in the interview with the families was: do you know what to do in a case of an emergency triggered by a debris flow.

For this indicator four categories were created according to the responses given for the families during the survey (See fig 6.5).

The first category comprises the families that, once a debris flow take place, follow the evacuation routes and know where the safe places are. This indicates also that these families most probably are active and take part of the awareness raising and risk reduction activities programmed by the local authorities. These families were considered as highly aware and knowledgeable and therefore with a high risk perception. They comprise 27 % (36) of the total families of Villa Restrepo.



Map 6.5 Representation of action taken by the families in case a debris flow event.

Question Involved (8): Do you know what to do in a case of an emergency triggered by a debris flow?

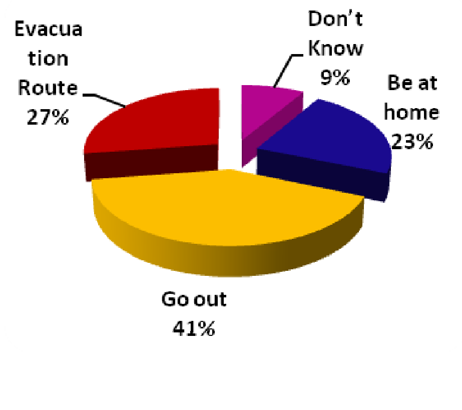


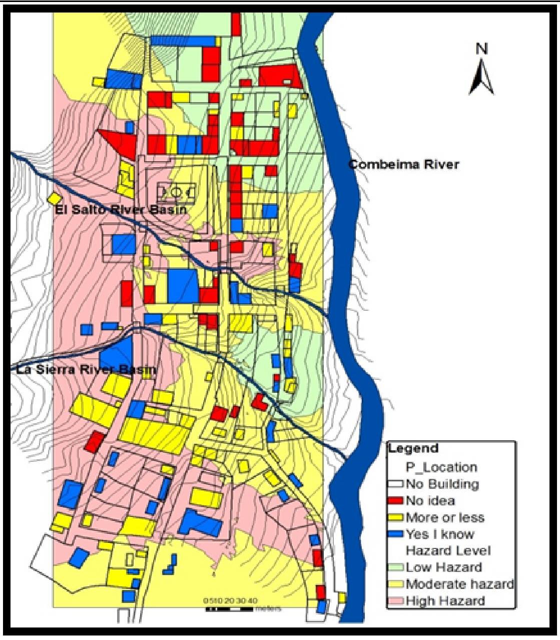
Figure 6.5 Shows the percent of building in each category of answers.

Figure 6.5 shows that 41 % of the families move out of their buildings but do not have a clear idea about the safest routes to take and places where to evacuate. Often people are aware that a debris flow is approaching because of the sound they produce while flowing down from the mountain. However as most of them have not attended the official drills or workshops for evacuation they do not know the adequate routes for escaping and just take the main road as evacuation route but without following a plan, making evacuation activities more difficult to implement. This was found as the most widespread practice of the people in Villa Restrepo.

According to the interviews there are families that do not know what to do in case of an emergency and other that often prefer to stay at home for they perceive being safe there. These families were considered having a Low risk perception. According the community these people have a short residence in Villa Restrepo and some of them do not have any knowledge about the occurrence of debris flows (see map 6.5)

6.4.3. Hazard Awareness

The knowledge of the people regarding where are located the hazard zones in Villa Restrepo was an indicator to evaluate the risk perception of the families in Villa Restrepo.



Map 6.6 Representation of risk perception according to family hazard awareness.

Question involved (9): Do you know where the high debris flow hazard zones are located?

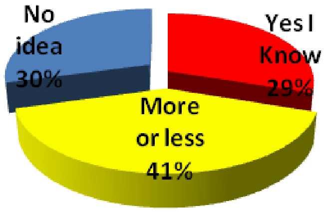


Figure 6.6 Shows the percent of building in each category of answers.

Figure 6.6 shows that 29 % of the households have a high perception because they were able to spatially locate the most dangerous zones with regards to the 2006 event. They also identified the areas where debris flows can cause most damage. In general it can be said that people who have lived or experienced a debris flow event can easily identify, locate and differentiate areas with different level of hazard within the town. 30 % of the households were found as having no idea about the location of hazard zones. Often they do not attend municipality workshops nor attend preparedness activities. They were assessed low risk perception.

According to map 6.6 the households with high risk perception are located on moderate hazard area (debris flow event with a return period of 50 years) .One of the reasons found for their high perception is because normally these families have large time of residence in Villa Restrepo.

6.5. Final Risk Perception assessment

The spatial multicriteria evaluation was implemented to develop a perception assessment as the same manner was used it in vulnerability assessment .This evaluation was developed to obtain a final risk perception that represents a family perception level (low-moderate or high).

For this analysis the participation of the families in workshops, awareness raising activities and evacuation drills and other emergency-related activities were considered as more important than actually experiencing the debris flow events. This assumption was considered logic as during interviews it was know that for instance persons that have a good emergency reaction and is an active person working in mitigation and reduction had a higher risk perception.

During the final weighting process a 0.75 was the assessed to participation factor and 25 % to experience and knowledge factors (factors explained and analyzed in previous section).

According to the International Risk Governance council in Reen (2006) analyzing risk perception is important as it can shed light about how people take responsibility for managing risks for their health, emphasizes the importance of understanding and reacting to risk perceptions

This represents that is more important the first category (participation and attention of an emergency) on perception analysis (See figure 6.8).

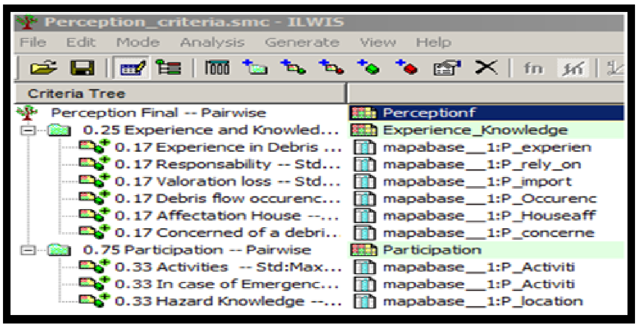


Figure 6.8. Spatial Multicriteria Evaluation three to calculate final perception map in Villa Restrepo.

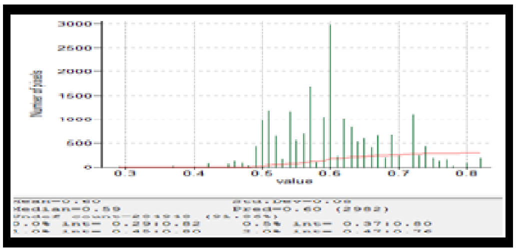


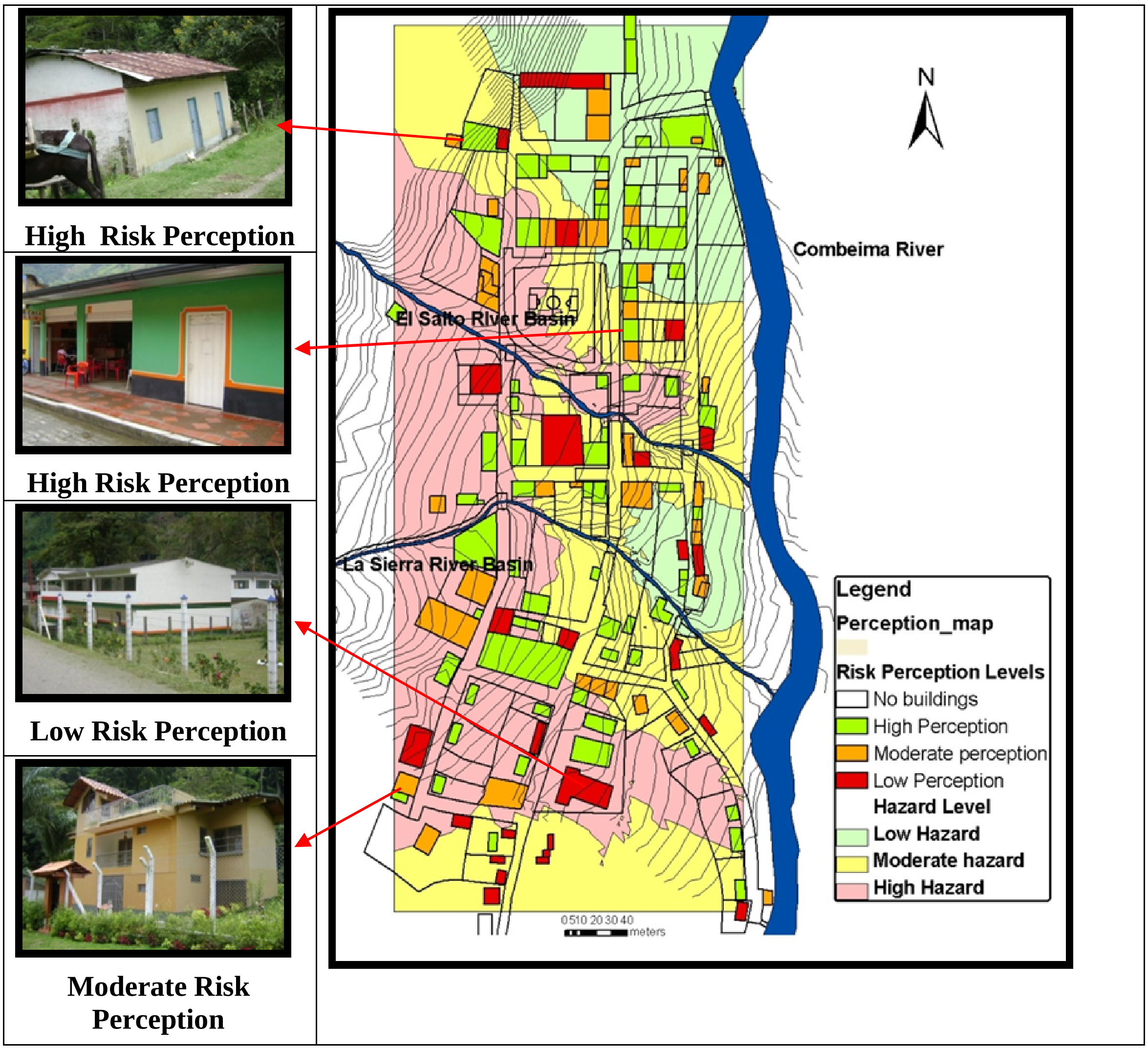
Figure 6.9. Distribution of values regarding risk perception in Villa Restrepo.

The figure 6.8. shows the entire factors involved with theirs weights.A final map was developed according to the spatial multicriteria evaluation process . This map was classified with a *quantite method* visialization becasue the values that represents a final perception were distributed on a righ side of the histogram (0.3 – 0.9) and this method contributes to obtain a better visualization about the values calculated with the SMCE ,see the figure 6.9 .

The map 6.7 represents the risk final perception level by family. As can see according the buildings pictures integrated into the map 6.7 the type, condition or value of the dwelling is not represented with the level of risk perception of family.

Besides the figure 6.10 shows that 51 % of families are represent with high risk perception. Besides supported with the figure 6.11, 51 % of this family with high perception, 29 families are located on a high debris flow hazard, 23 in a moderate 17 in a low debris flow hazard. As can see these families with high perception have experienced previous debris flow hazard and other of them are located on the oldest areas close to the main park.

In the town 18 % families have a low perception and 32 % a moderate perception which are represented in the map 6.7 and figure 6.11.Besides 5 families with low perception according to the figure 6.11 are located in a high debris flow. These buildings should be taken for the local authorities as priority buildings in order to implement actions and activities in order to increase the risk perception. This study implement the risk perception into vulnerability assessment and risk assessment as will be seeing in the next chapter.



Map 6.7. Debris flow Risk Perception in Villa Restrepo.

The map 6.7 shows some buildings in which are related with the family risk perception level. So the pictures represent the level of risk perception according to the questions indicators involved in the study to evaluate the risk perception.

As mentioned although the study area is considered a with a high hazard many people have a low to moderate risk perception .This reason become the families more vulnerable.

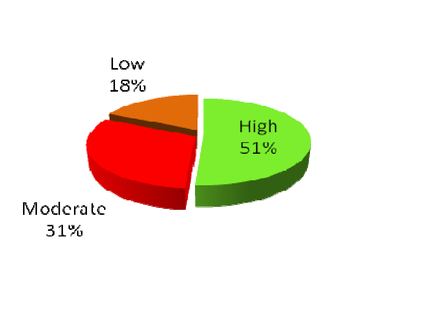


Figure 6.10. Distribution percentage of risk perception levels.

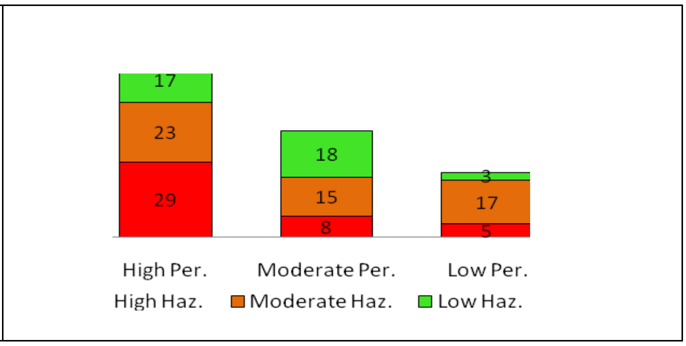


Figure 6.11.Number of families when is compared risk perception and debris flow hazard level.

The perception analysis developed in this chapter is an important indicator for further analysis related with vulnerability and risk assessment. The families with a high risk perception will be less vulnerable and thus with a lower risk level. In the same way that the vulnerability assessment, the e risk perception assessment should be used for local authorities and planners in activities and rules implementation in order to reduce and mitigate the risk in Villa Restrepo.

For instance the risk perception is a dynamic factor and could be increased through socials programs. Different activities could be implemented to the families in order to increase their risk perception level. Further community activities related with risk perception increasing depend on the local authorities' needs and the budget to implement community programs. Relation of Risk Perception and vulnerability indicators.

The relation between risk perception and some factors that integrate the vulnerability analysis were compared in order to understand the influence of risk perception in the study area. In this idea the vulnerability factors were compared with previous risk perception .The comparison was analyzed in low, moderate or high relation as shows the figure 6.12.

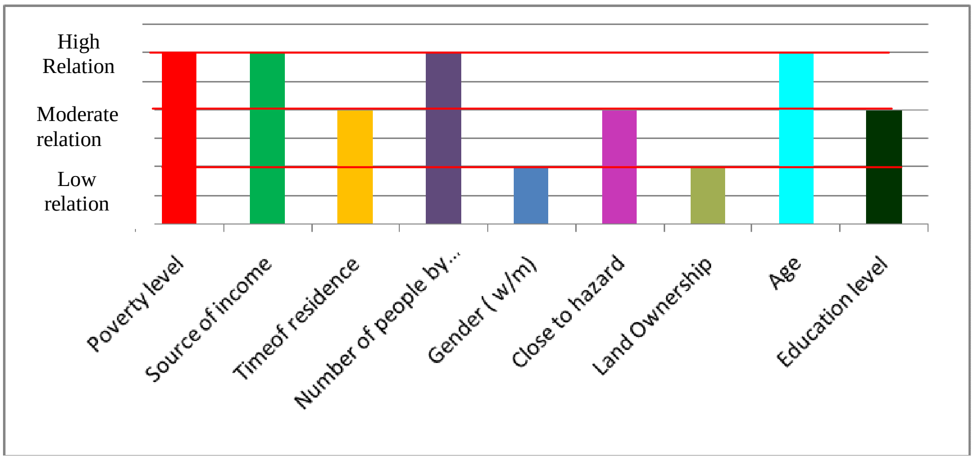


Figure 6.12. Relation risk perception compared with some vulnerability indicators.

Indicator of vulnerability such as the land ownership shows a low relation regarding the families risk perception. The age factor indicator in Villa Restrepo represents a high perception in a person in the study area (see figure 6.12).

Other vulnerability indicator such as the time of residence by the community in Villa Restrepo shows a moderate relation when is related with risk perception. Although a family with a large time of residence in Villa Restrepo the risk perception expected should be higher in this case is moderate. Besides 48 % of the families with more of 10 years in Villa Restrepo have a low perception, 46 % moderate perception and 7 % low risk perception.

These outcomes would be considered because the new people living in Villa Restrepo (new generation) have not lived or experienced a debris flow event .They are representing the families with low to moderate risk perception. The gender indicator has a low risk perception relation. In this way 40 % of men have low perception and 60 % moderate risk perception, besides 52 % women have low risk perception 43 % moderate perception.

The occupation or source income vulnerability indicator shows that the farmers have a strong relation regarding the perception level. In this way 63 % of farmers have high perception and 22 % a low perception. By other hand 71 % of informal people (many activities) have a low perception. These results determine that the hazard awareness by the occupation indicator has a high influence regarding the risk perception level. When a debris flow event occurs the most affected are mainly the farmer which the loss of land and crops is reflected with economic losses too. For this reason they are close related with the hazard and understand their affectation level.

7. Debris flow risk appraisal

This chapter presents an approach for qualitative and quantitative appraisals to risk of debris flows at local level in data poor environments. The risk perception calculated on the chapter 6 is integrated into risk analysis in order to create two qualitative risk scenarios (with and without risk perception involved). Besides it provides a calculation and evaluation for quantifying the consequences of a 50 years return period debris flow event in Villa Restrepo

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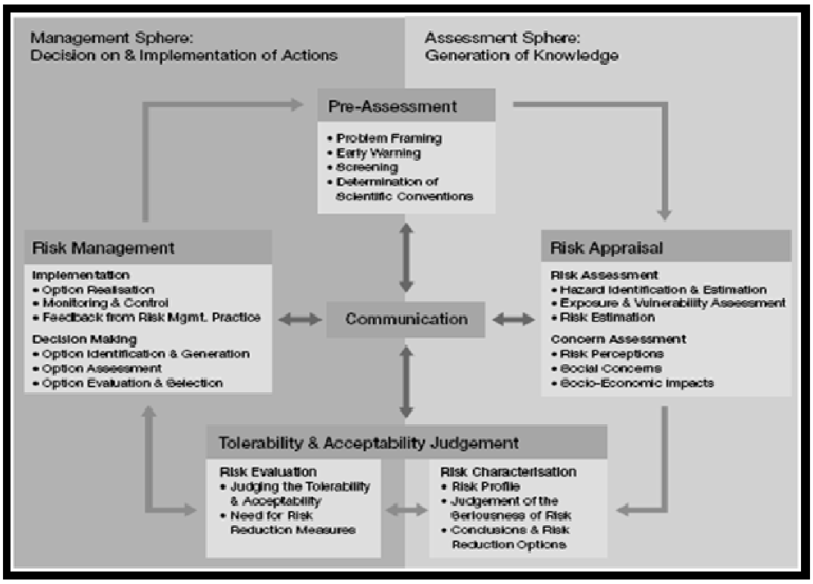
7.1. Qualitative risk analysis

The purpose of risk assessments (or appraisals) is the generation of knowledge linking specific risk agents with uncertain but possible consequences (Dewi, 2007). The final product of risk assessment is an estimation of the risk in terms of a probability distribution of the modelled consequences (drawing on either discrete events or continuous loss functions). A risk appraisal has the objective of providing the knowledge base for the societal decision on whether or not a risk should be taken and, if so, how the risk can possibly be reduced or contained.

Figure 7.1 shows how the risk appraisal is a process that bring together all knowledge elements necessary for risk characterization evaluation and management. This includes not just the results of (scientific) risk assessment but also information about risk perceptions and economic and social implications of the risk consequences.



7.1 Risk appraisal function .Taken from IRGC Risk Governance Framework (2008)

The Risk appraisal in this study comprises the assessment of both the actual risk and the risk that stakeholders may perceive concerning its social and economic implications. The first component of risk appraisal, risk assessment, seeks to link a potential source of harm, a hazard, with likely consequences, specifying probabilities of occurrence for the latter.

Taken the concepts of risk and risk appraisal, this work develops a qualitative debris flow analysis according to a specific debris flow hazard with a return period of 50 years which was assimilated to the events in 1945 and Jun 2006 occurred in Villa Restrepo.

The final outcome of this analysis it is meant to be used by local authorities to select priority areas for implementing disaster risk reduction measures. The intention of this analysis is provide municipality authorities a contextualized information and tools that help them to anticipate the debris flow impact on their community and moreover to develop an adequate risk management policies aimed to strengthen the socioeconomic situation of the families in order to avoid disastrous situation in their normal life each time a debris flow takes place.

The qualitative risk analysis is information for the community and the local authorities that are interested in knowing the spatial location on families that could be badly affected by debris flow event. To develop the qualitative assessment the general equation for risk was considered as follows: Risk = Hazard * Vulnerability

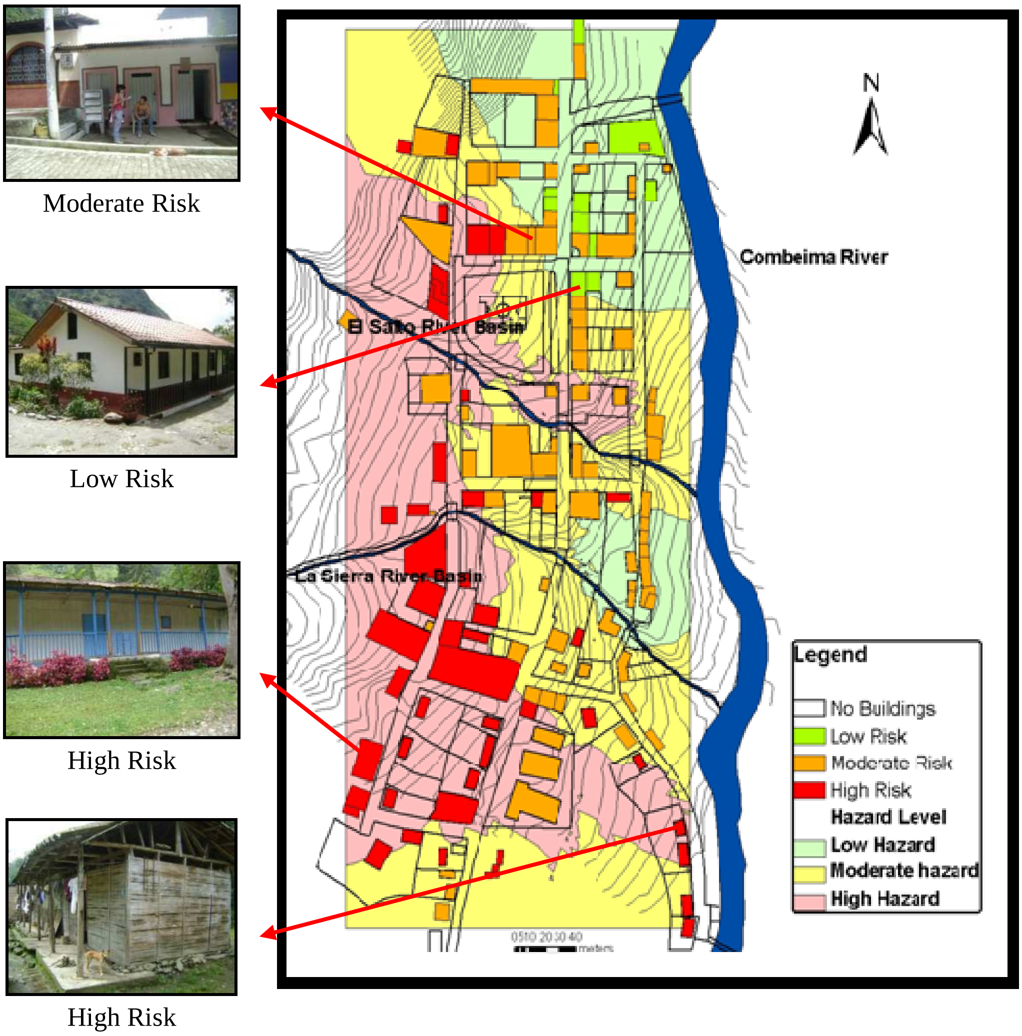
A matrix was developed in order to calculate a representative debris flow risk map that combines the hazard and vulnerability assessment developed in chapters 4 and 5 (see table 7.1). The matrix determines that, if for instance, a family found as low vulnerable is settled in an area with low hazard therefore they are at low risk from debris flow. However if a highly vulnerable family is settled in the same low hazard area, the final risk assessment assess a moderate risk to it because, given the family's high susceptibility to be affected even small events represent a high risk for them.

Hazard / **Vulnerab.**	**Low Hazard**	**Moderate Hazard**	**High hazard**
Low Vulnerab.	Low Risk	Moderate Risk	High Risk
Moderate Vulner.	Moderate Risk	Moderate Risk	High Risk
High Vulnerability	Moderate Risk	High Risk	High Risk

Table 7.1 Final risk Matrix among hazard level and vulnerability to calculate debris flow risk map.

These categories were applied to combine the hazard and vulnerability maps in ILWIS in order to generate a map that displays the spatial distribution of risk. The formulas applied are presented in Appendix 3.

Map 7.1 shows the distribution of (qualitative) risk categories for Villa Restrepo. The qualitative assessment determined that 79 families (59%) are at high risk from debris flow and therefore can expericence heavy damage and disruption from the ocurrence of a 50-year return period event. 48 families (33 %) were represented with a moderate risk. Finally 11 families (8%) were assessed with low risk and therefore may not experience any or very low damage in case of a debris flow with a return period of 50 years.



Map 7.1 Debris flow risk level of families in Villa Restrepo town. In the left side some buildings with their risk level.

Pictures in Map 7.1 were integrated to give a visual approach to the risk levels faced by families. The pictures in the lower left corner show two buildings whose families belong to diferent vulernability categories (moderate and low) but their high levels of exposure to debris flows make their risk equally high for a 50-year event.

This information could be used for local authorities to develop risk mitigation activities and polices such as resettlement, retrofitting of buildings, attention and prevention of emergency and early warning in order to reduce the risk of the most at risk families.

7.2. Integrating Risk Perception into Vulnerability assesment.

In this step the risk perception factor developed in the chapter 5 was integrated into a risk qualitative analysis as follows: Vulnerability 2 = Vulnerability* Risk Perception .The table 7.2 shows the way how the vulnerability 2 is calculated when is integrated risk perception and vulnerability. These categories were applied to combine the vulnerability and risk perception maps in ILWIS in order to generate a map that displays the spatial distribution of vulnerability 2 .

Risk Perception / Vulnerab.	Low Risk Perception	Moderate Risk Perception	High Risk Perception
Low Vulnerab.	Low vulnerability2	Moderate vulnerability2	High vulnerability2
Moderate Vulner.	Moderate vulnerability2.	Moderate vulnerability2	High vulnerability2
High Vulnerability	Moderate vulnerability2.	High vulnerability2	High vulnerability2.

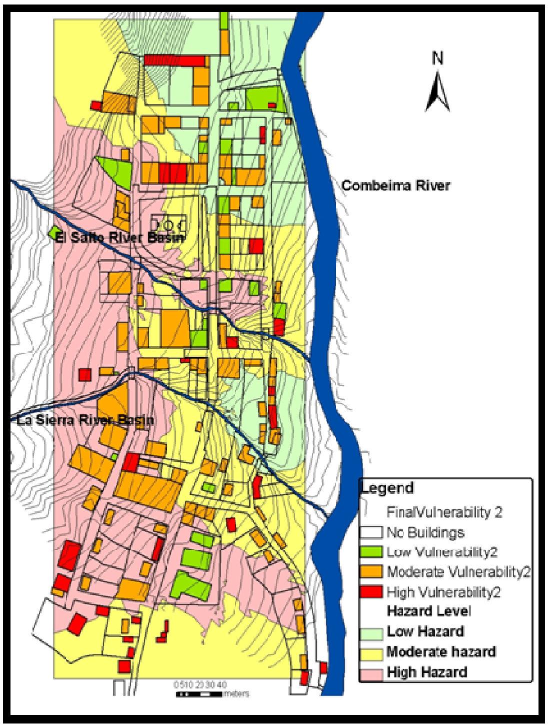
Table 7.2 Final risk Matrix among vulnerability at family and risk perception to calculate vulnerability2.

In this research the integration of risk perception into vulnerability analysis is proposed as during fieldwork it was found that the knowledge, experiences and participation in awareness raising and risk reduction activities can decrease the susceptibility of the family. In this sense one can argue that risk perception is part of the capacities of the household to deal with the risk derived from debris flows.

The vulnerability2 analysis was performed moreover to emphasise the importance of activities that help communities to raise their awareness, use their knowledge and experiences to keep high the alert levels and to encourage both authorities and communities to carry out more activities that actively involve the community and their experiences as this type of research.

In the map 7.2 buildings with high vulnerability after integrating the risk perception factor are represented in red colour. The orange color represents families with moderate vulnerability and the green color represents buildings with a low vulnerability. This map symbolizes the level of a family to respectively recover, face or deal an event occurrence with the risk perception involved.

Maps 7.3 and 7.4 show the resulting debris flow risk before and after integrating the risk perception factor. The results showed that when is involved risk perception the level of risk at family level tend to increase.. So 6 families in the town changed their risk level from low to moderate and high level when it was integrated the risk perception.



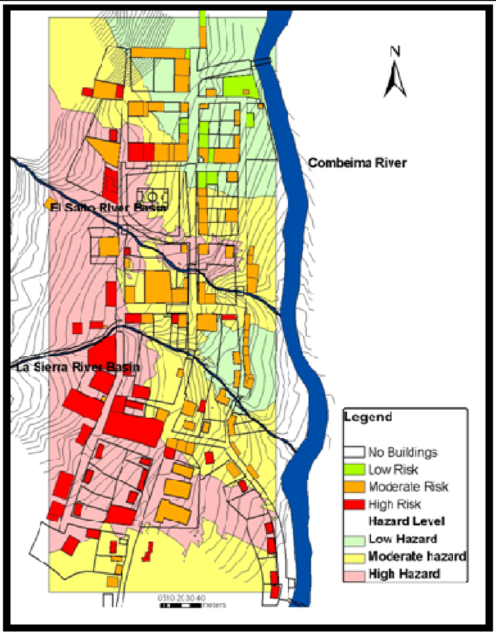
Map 7.2 Debris flow vulnerability2 (risk perception involved) of families in Villa Restrepo town.

The complementary analysis in figure 7.1 and 7,2 show how the perception from the families considering the knowledge ,experience and participation activities are influence factor to reduce the risk status of the families. This is the case of those families living close to the central park (see maps 7.3 and 7.4).

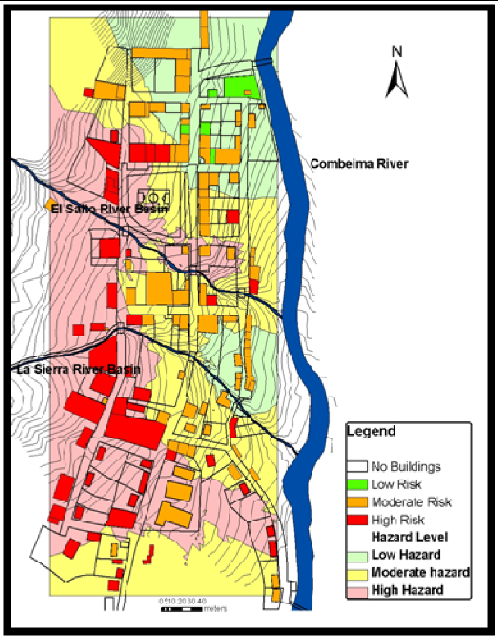
Even though their physical exposure and socioeconomic conditions remain the same in the analysis the fact that several families in the town have not experienced most of the events (knowledge) and participate in the few preparedness activities (awareness) determine that their risk level is high.

Besides if higher the awareness of a family of their risk situation the more willing they will be to take actions oriented to reduce their vulnerability such as the two families located in the bottom right in the map7.4 which changed their status from high to moderate due to risk perception influence..

The actions taken from the community due their high perception can range from strengthening their dwelling if they have the economic means to do so but also for the poorer to look for assistance from the authorities or to legalise their illegal settlement status in order to access to subsidies and low-rate loans. People may also decide to resettle in less hazardous areas or to have insurances and savings they can use in case of such events.



Map 7.3 . Debris flow risk without risk perception involved .



Map 7.4 Debris flow risk with risk perception involved.

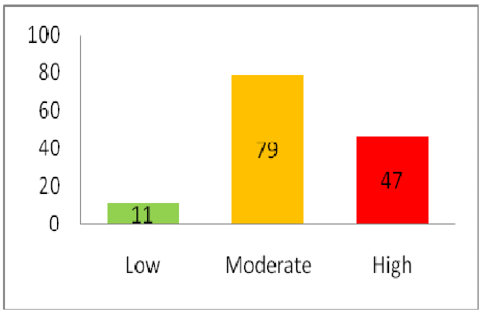


Figure 7.2 Shows the number of families in each risk level. Without perception involved

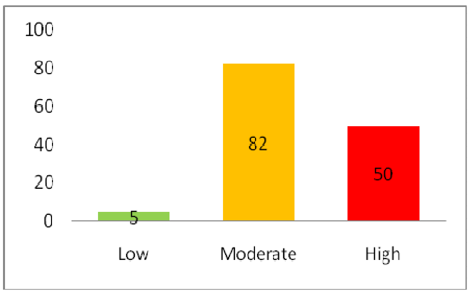


Figure 7.3 Shows the number of families in each risk level with risk perception involved.

7.3. Quantitative Risk Analysis

It is clear that the risk assessment would be more relevant and useful if it is accompanied by quantitative information such as the number of persons directly affected, the economic losses and the implication, in monetary terms, of evacuation and recovery activities for local authorities when a debris flow takes place.

Understanding the economic and societal impacts of debris flow is essential for informed decisions that address the implications of the occurrence of debris flows for communities at risk. Documentation of number of people injured, dead, economic disruption, property damage, relief and repair costs , and environmental consequences is part of such an understanding. According to the committee on review of the national landslide hazards mitigation strategy (2007) loss and risk assessment are essential for creating mechanisms for risk avoidance and sharing involving the public and private sectors through insurance and evaluating the cost-effectiveness of proposed interventions for hazard-prone areas.

The quantitative risk analysis presented here evaluates the economic consequences derived from the occurrence of a debris flow event in Villa Restrepo. Ideally several events need to be included in a risk analysis to determine the possibilities for multi-purpose risk reduction measures (protection to several return period events) and their cost-benefit analysis, among others. However, due to the scarcity of information related to the reconstruction of several return period debris flow hazard , this study evaluates and develops a risk quantitative analysis for one of the most relevant debris flows found as it was the 50-year return period event.

As mentioned the risk means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of vulnerability, cost of elements at risk and probability of occurrence of event.

To calculate the specific annual risk the following expression was used:

Specific Annual Risk = Annual probability * Vulnerability * Cost

In this formula the elements to calculate the specific annual risk express:

Annual probability: The probability that an event will occur within one specific year. In this case it means the probability that a debris flow event with a return period of 50 years will occur in a given year. The final value used in the equation is: 1/ 50 = *0.02*

Vulnerability = The level of susceptibility of the element under evaluation with respect to the hazard expected. In this case the vulnerability element evaluated were the buildings according to the structural factor analysis in Section 5.3.

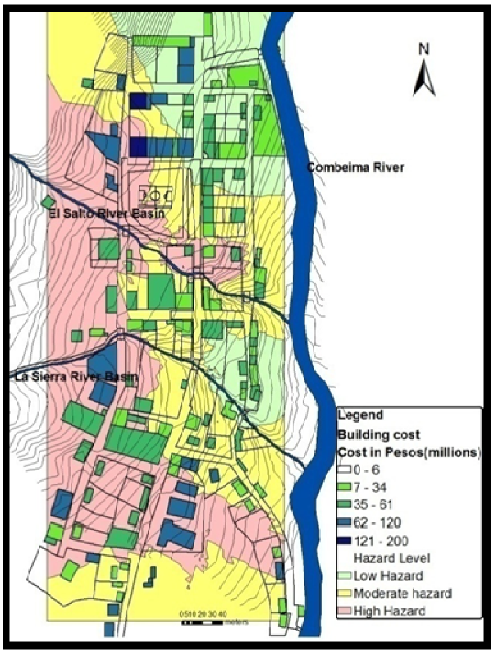
Cost = Cost of the element under analysis. The current analysis used the value of the houses and buildings for 2008 (expressed in Colombian Pesos).

7.3.1. Buildings cost

The analysis of the buildings cost was carried out in this research in order to integrate it into specific annual risk estimation. The real cost about the buildings and facilities was acquired through open meetings with leaders and local authorities.

The factors to evaluate the cost with respect to the buildings were: socioeconomic level, land use, materials and distance to main road (see pictures 7.1, visual representation cost of buildings in Villa

Restrepo). The cost of the building was not requested during the survey as it was found that this is a sensitive issue for households, as they may think the survey is related with tax collection activities.



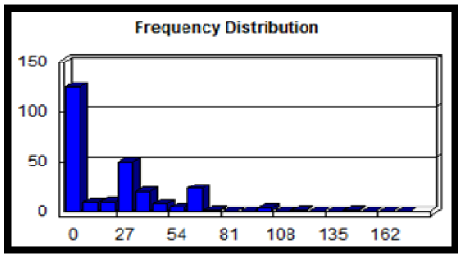
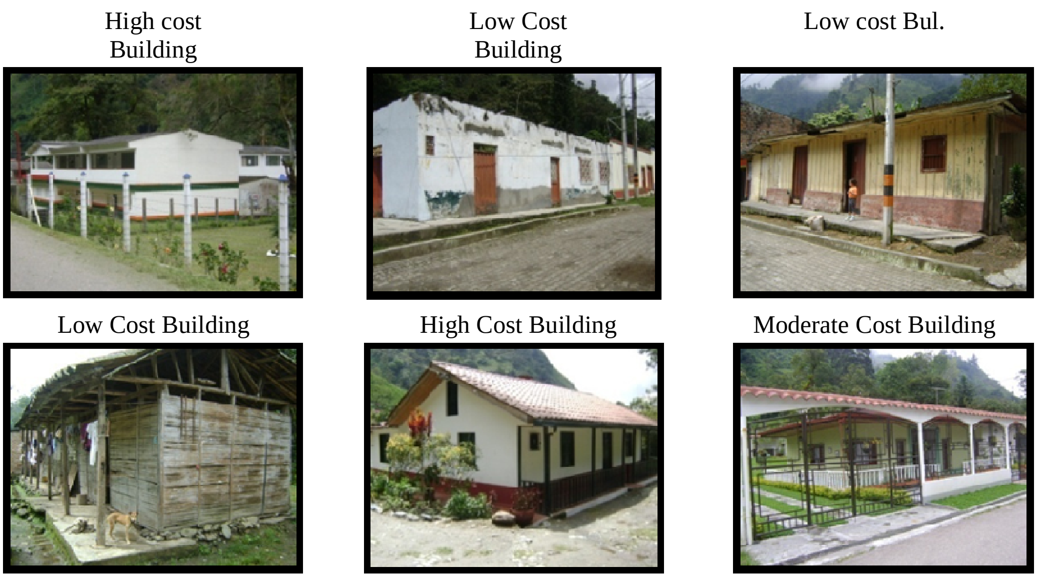


Figure 7.4 Frequency distribution cost building in Colombian pesos (millions)

Map 7.5 Cost of building in pesos miles with level of hazard.

In map 7.5 buildings in blue dark color represents have high cost (121 – 200 millions of pesos). Light green color represents buildings with lowest costs (less than 30 million). The differences in cost and type of building can be better appreciate in Picture 7.1



Picture 7.1 Show some buildings regarding their cost level according

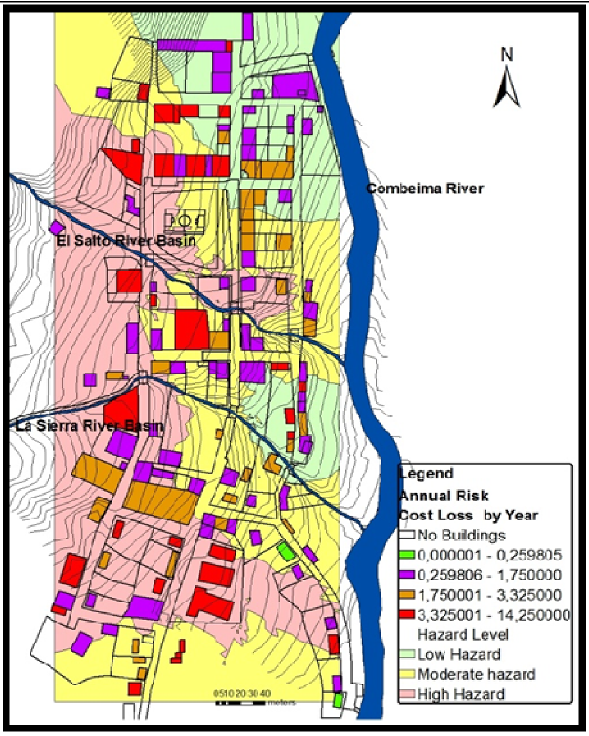
7.3.2. Final specific annual risk map analysis

Regarding buildings, the specific annual risk in Villa Restrepo represents the loss expected in one year in case that an event with a specific return period of 50 years take place.

The histogram (figure 7.4) displays the frequency distribution of the expected damage in monetary terms per building. It shows that most of the economic losses per building/household are between 1 to 3 millions of Colombian pesos (2.1 to 6.5 minimum monthly wages in 2008).

Map 7.6 displays the spatial distribution of building losses for a 50-year return period debris flow in Villa Restrepo.

From figure 7.5 it can be seen that the annual amount of losses from buildings in high risk areas (expected in 2008) amounted 114,20 millions of pesos. The buildings located in a moderate hazard represent annual economic losses of 123, 6 millions of pesos. Finally the buildings located in a low debris flow hazard represent annual economic losses of 81,5 millions of Colombian pesos (See figure 7.5).



Map 7.6 Annual economic loss by building represented in millions pesos by a 50 year return period.

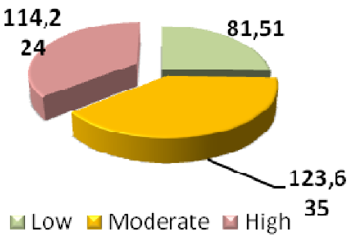


Figure 7.5 Annual economic risk loss of the buildings according to hazard level.`

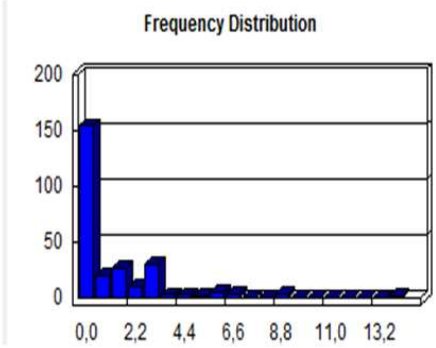


Figure 7.6 Histogram of distribution according to the annual cost loss.

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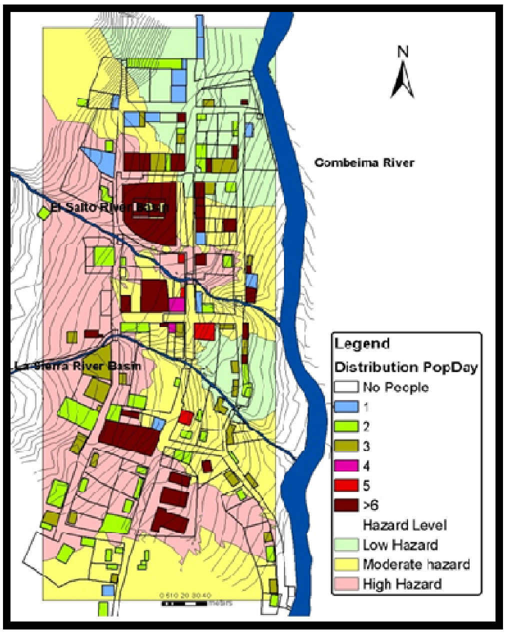
7.4. Elements in Risk

As previously explained an element is considered at risk when is exposed to damage or loss by the occurrence of a natural hazard, in this case debris flows. The elements at risk considered in this analysis were buildings, bridges, facilities, and the population from Villa Restrepo. Essential facilities were classified herein as those buildings and areas that could be functional for the population when a debris flow event could occur (i.e hospitals, schools, town hall etc). Lifeline utilities such as electricity and telecommunication distribution networks were also considered as elements at risk.

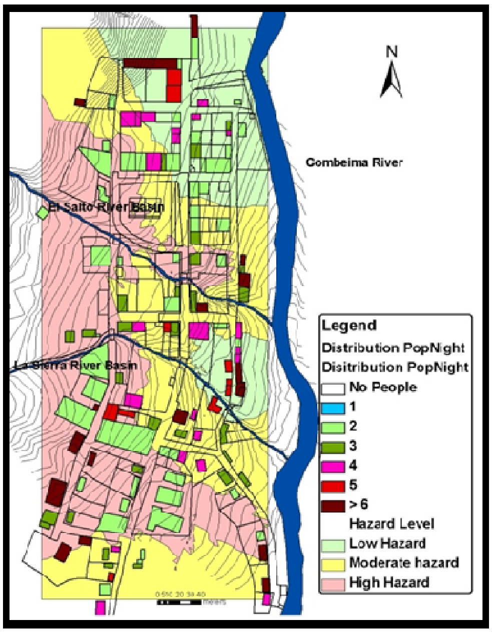
7.4.1. Risk analysis according to distribution of population.

For this analysis the distribution of individuals in Villa Restrepo depending on the time of the day was taken into consideration. The presence of people in a given building depends on the activities of their normal life carried out during day or night time. As has been mentioned Villa Restrepo has becoming a touristic spot for the people in Ibague; therefore many activities are located in the center of the town. In addition the affluence of people changes depending on the day of the week and during the day with more people coming during the weekends and day time (see map 7.7).

Normally during daytime people can be found in small shops, butcher, commercial houses, recreational areas, library, school, municipality and the church. These buildings are located in high to moderate risk level (see map 7.4). The buildings with brow color in the map 7.7 and 7.8 represent buildings with a high population (> of 6 individuals) and the blue color represent buildings with only one individual in the nigh or day time.



Map 7.7 Distribution of population day time



Map 7.8 Distribution of population night time

The buildings on day time and located within a high risk level contain most of the individuals with 2, 3 and more than six people .The buildings on nigh time and located within a high risk level contain mostly groups of 1, 2, an 3 individuals as shown in Map 7.8. From these maps it can be seen how during day time the number of people in high hazard area is higher than during night time.

7.4.2. Lifeline Utilities

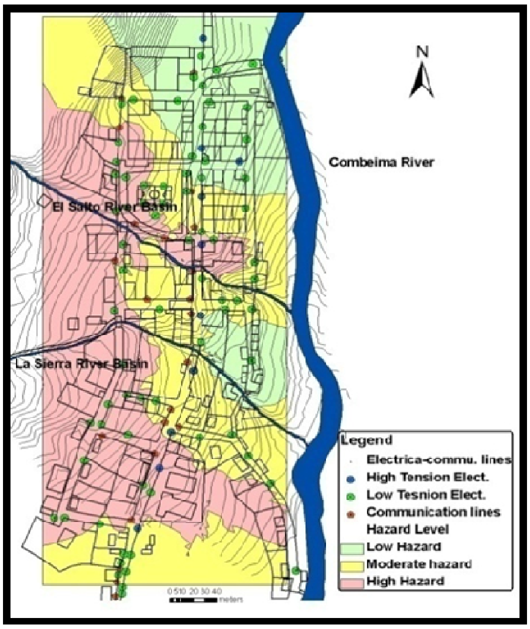
The utility lines in this study are the electrical and telecommunication distribution networks. In Villa Restrepo 27 low electrical stations were found located within a high hazard level and 18 in a moderate hazard (see green color points in the map 7.9).

The map 7.9 shows three high voltage electrical utilities for the town in a high hazard level and 4 in moderate hazard. Finally with respect to the communication lines (telephone and television) 7 are located in a high hazard and 6 in a moderate hazard.

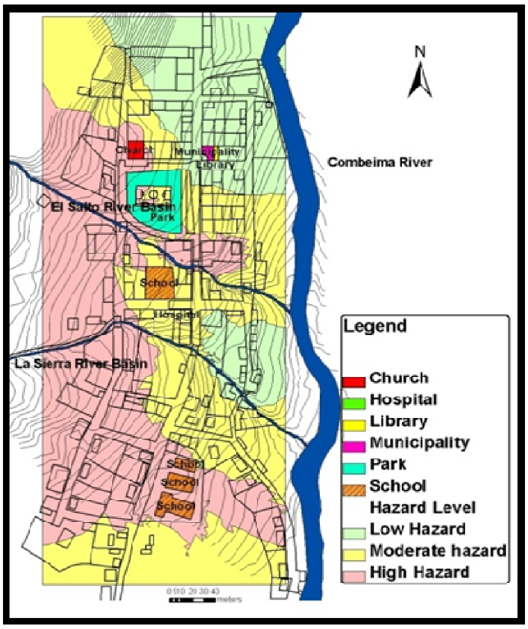
7.4.3. Essential Facilities

From the risk of disaster point of view essential facilities are buildings and other structures that are intended to remain operational in the event of extreme events such as debris flow. They include hospitals, schools, health care centers, police, fire brigades etc that should offer services as emergency response, medical care and shelter.

The map 7.10 shows the location of the essential facilities in Villa Restrepo town. Seven facilities were identified. The table 7.2 shows the essential facilities with respect to their risk level. Three facilities are located in a high risk level and four in moderate risk level. This analysis should be considered for municipal planning in order to apply mitigation and risk reduction measures that ensure that after an event such as the 50-year return period debris flow these facilities continue providing they more needed services to the affected community.



Map 7.9 Lifelines in Villa Restrepo.



Map 7.10 . Essential facilities in Villa Restrepo.

Others essential facilities identified in the town were the main bridges located on the main road. They according to the hazard map are directly affected if occur a debris flow event. The affectation of these bridges could affect the economy of the town and disruption of other important activities such as tourism; fulfil food requirements and transportation to or from Ibague – Villa Restrepo.

It is recommended that the essential facilities have a good condition in order to resist a debris flow event. The investment in restructuration and reinforcement of the facilities should be an achievement and commitment for local authorities.

Essential Elements	**Risk Level**
Municipality	Moderate
Church	High
Park	Moderate
School 1	High
School 2	Moderate
Hospital	High
Library	Moderate

Table 7.3 Hazard level of the essential elements

8. Risk Reduction Scenarios

In this chapter the influence of local adaption capacities for managing the risk of debris flow is evaluated. A brief description about the role of local adaptation in risk management and assessment is given. The next procedure was to develop and compare risk reduction scenarios

8.1. Local adaptation capacity

The local adaptation is considered as other factor that may influence the risk from natural events. In hazard prone areas it has been found that communities have the ability to adapt certain aspects of their life in order to deal and face the hazard. The identification of local coping mechanism or local adaptation activities should be integrated into a debris flow risk management as a mechanism of mitigation in the risk reduction process.

Nevertheless, as Peters Guarin (2008) pointed out not all the coping mechanisms have the aim to reduce the impact about a possible hazard, instead some copies strategies may increase the threat posed by a hazard and lead to further marginalization and impoverishment. Adaptation activities should especially reduce the vulnerability of the communities at risk by improving their socioeconomic conditions or otherwise modifying the threat form the natural event. According to United Nations into the Third Assessment Report "Climate Change 2001" (2008) many adaptation strategies could provide multiple benefits in the near and longer terms. Enhancement of adaptive capacity reduces the vulnerability of sectors and regions, including variability and extremes, and thereby promotes sustainable development and equity.

Although the terminology of local adaptation capacity is considered in the global literature into climate chance, this research considers local adaptation capacity as the local activities carry out for the community to cope and to deal with the debris flow hazard and reducing their vulnerability status in the medium to long term. For this reason local adaptation capacities, risk reduction activities or coping mechanism are considered as activities that are carried out for the community in long or medium term in order to reduce their risk level.

8.2. Local adaptation assessment

A comprehensive and integrated analysis and identification of local adaptation activities was evaluated in this study in order to determine if certain activities carried out for the community are the most appropriate and could be implemented as good activities for risk mitigation or reduction. In this consideration activities carried out for the families of Villa Restrepo are analyzed and evaluated as part of risk scenarios. The information to develop this analysis was collected through the home-basis survey carried out in the town. During interviews the people was asked about the adaptation or reductions activities they perform based on their knowledge and previous experiences with debris flows. About 30 % of the families in the town were found as having implemented activities of adaptation in order to reduce or manage the risk (See table 8.1).

Adaptation activity	**Benefit period**	**Risk Perception level**	**Number of buildings**
Dwelling Reinforce structure	During event	Moderate level	7
Preparedness and Early Warning	Before – During – After event	High - Moderate	29
Home Insurance	After event	Moderate	6

Table 8.1 Shows the local adaptation activities indentified in the study area.

Families that have implemented risk reduction activities are associated with a high and moderate level perception. It explains again why the risk perception should be a factor integrated into the process of risk analysis and moreover reduction and management.

The activities identified as implemented for risk reduction were: reinforcement of dwelling structure, attending and following preparedness and early warning activities and home insurance. The Preparedness and early warning activities are related to the actions carried out for families in order to attend an emergency or increase their preparedness or awareness to face the hazard. The home insurance activity is a transfer of the risk of loss, and should be promoted as a small inversion that prevents a large, possibly devastating loss (see table8.1). This is the most expensive adaptation activity for the community and for this reason is a limited reduction activity taken by the families.

8.3. Risk debris flow scenarios.

A scenario is a statement of assumptions about the operation environment (driving force) of a particular system at a given time, it describes: the decision and uncontrollable variables and parameters for a specific modelling situation (Sharifi, 2008). Risk scenarios assist the decision-making process in identifying an appropriate reduction activity according their budget and requirements.

In this order of ideas the risk scenarios in this study are aimed to provide planners and local authorities with new entrance points for analysing and making decisions about debris flow risk reduction. Three debris flow risk scenarios were developed in this research with the objectives of highlight different strategies that can be taken for reducing future risk (what happen if?) and create new knowledge related with debris flow risk reduction and management.

Table 8.2 provides an insight into the adaptation activities analysed into each risk scenario. It can be seen how each activity target specific factors which modification can decrease the structural, physical (exposure) and economic vulnerability status of the families to debris flow. The reasoning is that if for instance a building is insured, five vulnerability factors would be modified and therefore the overall vulnerability could be changed to lower levels of vulnerability and in this way the risk level will be changed.

Adaptation Activity	Vulnerability Indicator Involved	Vulnerability Factor class	Risk Scenario Number
1. Dwelling Reinforce structure	House Type	Structural	Risk Scenario 1
2. Preparedness and Early Warning	Family Size	Socioeconomic	Risk Scenario 2
	Members of the family in vulnerable age groups ratio	Socioeconomic	
	Time of residence	Socioeconomic	
	Distance with respect to the main road	Evacuation	
3. House Insurance	Occupation	Socioeconomic	Risk Scenario 3
	Income dependency	Socioeconomic	
	Family income	Socioeconomic	
	Land ownership	Socioeconomic	
	House type	Physical	

Table 8.2 Shows each adaptation activity evaluated with respect to its vulnerability indicators involved. Besides each adaptation is related with specific risk scenarios.

Qualitative risk scenarios (hazard x vulnerability) were calculated by using the hazard and vulnerability data developed in previous chapters. In figure 8.1 the evaluation criteria of the risk reduction scenarios (alternatives) is presented .In this case three alternatives were developed which propose risk reduction scenarios related to the adaptation activities identified before. The risk scenarios are developed in the module of spatial multi-criteria evaluation (SMCE) module in ILWIS within the option of *alternatives* (see figure 8.1).

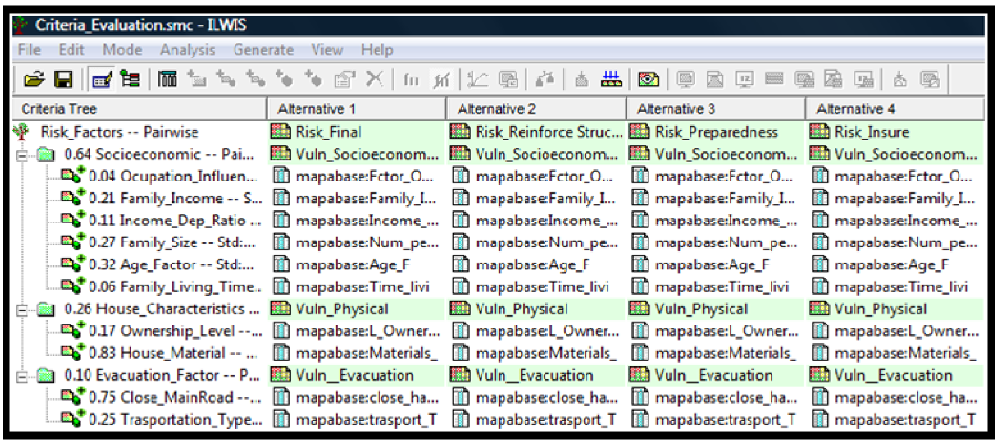


Figure 8.1 Criteria trees for three reduction risk scenarios.

The procedure to calculate the risk scenarios followed a similar approach with respect to the vulnerability and perception assessment.

Figure 8.2 shows one of the standardization methods used during the base vulnerability analysis (in chapter 5). As explained In this case high value of the indicator implies the families are more vulnerable. Figure 8.3 presents the adaptation measure used to remove the vulnerability indicators to calculate the reduction risk scenarios. In this case a goal of no vulnerability (0) is kept and therefore the line designating vulnerability remains flat. The red arrows in both cases show the different methods chosen (Benefits, Goal) to include the analysis of adaptation strategies into risk scenarios

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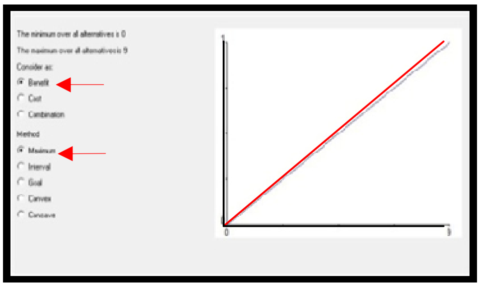


Figure 8.2 Standardization of vulnerability indicators for the base analysis.

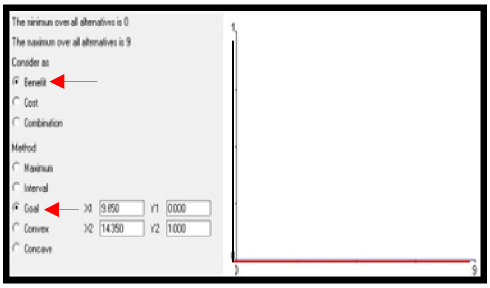


Figure 8.3 Standardization of vulnerability indicators for the three risk scenarios

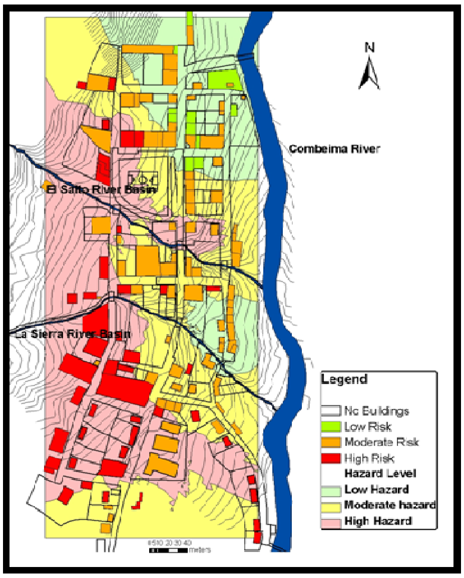
The maps 8.2, 8.3 and 8.4 represent the risk scenarios after implementing the local adaptation activities identified.

The second risk reduction scenario integrates Preparedness and early warning activities, which was found as the most widespread action taken inside the community. Because the lower cost of implementation, this is the activity of reduction more applied by the authorities in the town after the event of Jun 2006 (see map 6.4). Map 8.3 shows the spatial distribution of risk once this activity has been fully implemented within the community. In this way 3 families changed their risk statues from moderate to low and 1 family from high to moderate as shows the figure 8.4 and 8.6.

The third scenario is related to house insurance as adaptation activity or action taken by the family in order to decrease their vulnerability. Map 8.4 and figure 8.7 compared with map 8.1 and figure 8.4 show that this strategy is the most appropriate for implementation because more families will be benefited. In this strategy is encouraged nine families will change their risk level from moderate to low risk status. Besides one family will change its risk level from high to moderate risk level.

This risk reduction scenario represents for the local authorities and planner the best mitigation or reduction activity to decrease the risk in the community. Nevertheless even if this scenario constitutes the most appropriate mitigation measure, it is necessary carry out a cost- benefit analyses that takes into consideration the building type, income of the family, ownership status and moreover that takes into consideration the willingness of insurance companies to design schemes for this type of events and to the level of involvement and economic support (subsidies) required from the municipality.

Scenario Base



Map 8.1. Qualitative base debris flow risk.

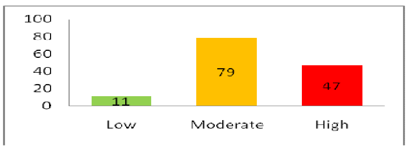
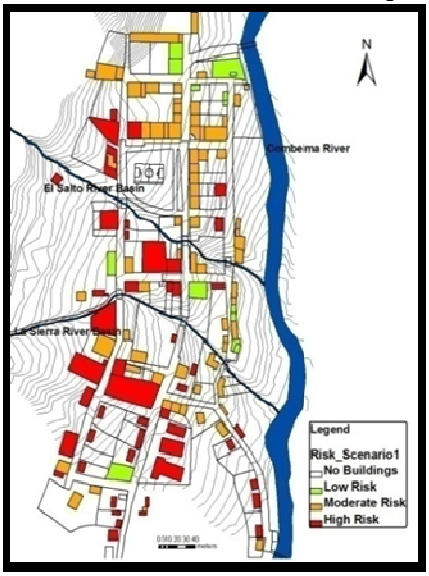


Figure 8.4. Number of families by risk level.

Scenario 1: Reinforce Building.



Map 8.2. Qualitative debris flow risk scenario 1.

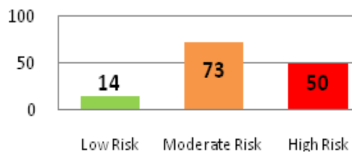
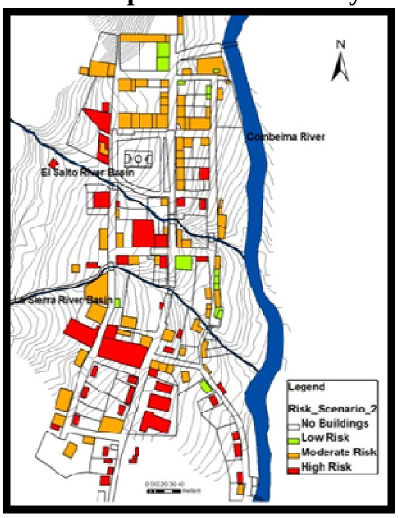


Figure 8.5. Number of families by risk level.

Scenario 2 : Preparedness and early warning



Map 8.3. Qualitative debris flow risk scenario 2.

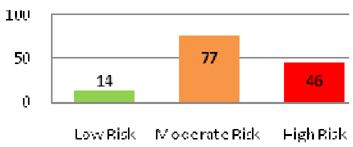
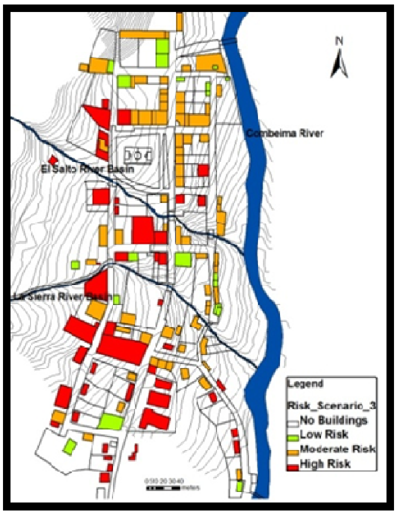


Figure 8.6. Number of families by risk level.

Scenario 3: Home Insurance



Map 8.4. Qualitative debris flow risk scenario 3.

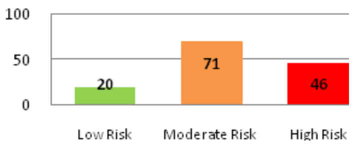


Figure 8.7 Number of families by risk level.

9. Conclusions and Recomendations

9.1. Conclusions

Debris flow hazard Assessment.

The people of Villa Restrepo have experienced two events that can be considered as ‘extremes’ being them the 1945 and 2006 debris flows. These events have affected them in economic, social, physical and emotional terms but have also determined the development of a type of local knowledge that relates the occurrence of natural hazards and people’s behaviour, experiences and perceptions of risk.

-Communities in hazard-prone areas are knowledgeable of some of the main characteristics of hazardous events. In the study area people was able to provide descriptions of debris flows which included differences patterns and behaviour depending on the magnitude and intensity and level of affectation with regards to theirs buildings.

- Rainfall plays an important roll in debris flow occurrence. In this research historical rainfall data was used to indentify two main return periods: once every two years and every 50 years.

-During data collection the community were actively engaged with maps, surveys, pictures, transect walks and meetings to identify, analyse and monitor the process of hazard assessment and analysis.

Vulnerability assessment

- Social, economic, structural and evacuation of the families were parameters used to develop a vulnerability assessment.

-From interviews and direct observations it can be concluded that physical aspects of the buildings are strongly related with social and economic status of the house holds living in it.

-CyberTracker software integrated with PDA and GPS in the fieldwork phase demonstrated to be an efficient way to collect large quantities of data required developing the vulnerability and risk perception assessment. Community leaders and students of forestry engineering did not experience problems using these technologies. The CyberTracker application enables easier collection of data and decreased the errors encountered while entering the data with respect to paper-based collection of data.

-The vulnerability assessment for families in Villa Restrepo was possible with the spatial multicriteria evaluation .The use of Spatial Multicriteria evaluation for vulnerability assessment facilitated the understanding of people’s priorities and provide new knowledge related to community risk.

Risk perception

-The questions integrated for risk perception analysis were focused on participation, knowledge and behaviour of people before, during and after the occurrence of debris flow. These aspects were found important for determining the output of debris flows and are often ignored in risk assessments.

- The direct experience of debris flows along time was found as determining the level or risk perception. People who have lived in the town and have been confronted with several events were found as having higher risk perception that those that have just arrived to the city or have not experienced high magnitude events.

-Although many people have been affected by several debris flow events and have a high perception of risk they do not have other alternative that continue living in Villa Restrepo as moving to other place would decrease their livelihood and change their life style.

- The risk perception was found as influencing the adaptation activities taken by community. Households that were found as highly aware of the damage and disruption that debris flow can create were more willing and determined to take local adaptation strategies to reduce or eliminate the risk level.

-Risk perceptions belong to the contextual aspects that risk managers need to consider when deciding whether or not a risk should be taken as well as when designing risk reduction measures.

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Risk Appraisal and Scenarios of Risk reduction.

-The intention of the risk appraisal is provide municipality authorities with contextualized information and tools that help them to anticipate the debris flow impact on their community. Moreover they can help to develop adequate risk management policies aimed to strengthen the socioeconomic situation of the families

-A quantitative risk analysis improves the risk assessment in order to know the affectation of different vital elements, buildings and infrastructure placed in Villa Restrepo.

-The qualitative debris flow reduction risk scenarios improve the capacity of thinking for planners with regards to mitigation activities implementation.

-Several analyses could be developed with these debris flow risk scenarios depending on the requirements of the local authorities and planners.

-Finally debris flow risk scenarios alternatives improve the entrance points to risk reduction for planners as they allow more discussion about the implementation of mitigation and risk reduction activities.

-Risk scenarios are spatial planning support information that can help to foresee the consequences of implementing or not adaptation measures in the town.

9.2. Contributions and Recommendations

- The approach can be undertake in other towns in the Combeima valley with data scarcity problems such as Pico de Oro, Pastales, Juntas and LLanitos.

- The issues of this work should be shared with all the government authorities of Ibague municipality in order to motivate them to carry out spatial information risk analysis.

-The mapping and reconstruction of debris flow events performed in this research illustrate the potential of the combined use of local knowledge and experiences and geospatial analysis and methods to bridge this information gap. Besides as demonstrated this research the combination of local knowledge and technical resources can support a joint work on process of debris flow hazard identification and analysis.

-The combination of methodologies used in the approach followed in this study provides new ideas for tackling two old problems at local or community level: lack of data and the needs for detailed hazard assessments, for further mitigation and prevention of programmes.

-In order to develop a better and accurate debris flow hazard assessment in the study area is necessary include other source of information to this analysis such as elevation contours at detail scale and image satellite such as Ikonos at acceptable resolution (> 1 mts).

-The debris flow appraisal proposed in this research should help both the communities and the local and municipal authorities looking to improve their risk management and planning measures.

-The vulnerability analysis for buildings and families can be used as valuable information for local authorities and planners to asses and design policies and activities related to preparedness, awareness and mitigation activities.

- Processes of information sharing between local community and authorities of Villa Restrepo have the capacity to increase their knowledge, improve their risk perception and increase their awareness related to debris flow hazard.

-Ccommunity knowledge was found to have a *time span* and therefore should be collected after every event**.**. The experiences from specific events can disappear with time or the occurrence of new events. Therefore it is necessary implement mechanism such as workshops and home basis survey just when a debris flow event has occurred that allow collecting the information and experiences of the people and converting them into useful data for the municipality.

-Although a final debris flow vulnerability analysis was developed, local authorities and planners should analyze separately vulnerability indicators in order to design adequate measures to deal with each factor, according to their requirements.

-Debris flow risk scenarios with local adaptation activities integration would be more relevant information if it is carried out with a cost and benefits analysis.

-In the research the concept of local adaptation was used to confirm that the community has the capacity to adjust to certain hazardous circumstances through strategies and actions that modify their risk environment either by managing the hazard or decreasing their vulnerable circumstances.

-One of the challenges of using community-based approaches for vulnerability analysis is to express this information in spatial terms. Moving beyond the analysis of individuals cases to more representatives scales, such as the building level, is one of the difficulties faced by researches, authorities and other actors , particularly when are very few data at hand.

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Appendices

Appendix 1: Home basis questionnaire

The follow survey was integrated into CyberTracker software and then incorporated to PDA (Compaq Ipaq) in order to collect the required data:

Name of Interviewer:
Elements at Risk
Inventory

Place: Villa Restrepo	
Zona (canton) :	
Block:	
Plot id:	
Number of Families in dwelling:	

Phisical Inventory:

Construction Type:	Function:	Floors	Dwelling
House	Residential	1	0 - 5 years
Building	Business shop	2	5 - 10 years
Installation	Government	3 or more	10 - 20 years
Hut	Education	Basement	20 - 30 years
Church	Health		30 - 50 years
			> 50 years

Materials

Roof	**walls**	**Fences**	**Height /street**
Mud tiles	Brick - Concrete	yes: height	> 10 cm
Absbest sheet	Concrete - wood	no	10 - 30 cm
Iron Sheet	wood		30 - 50 cm
Concrete	Prefabricated		50 - 70 cm
other	others		> 70 cm

Socio- economic

Occupation	**In come Dependency Ratio**	**Family Size**	**Member of family in vulnerable groups**
Small shop in house	1 to 1	Less than 3	< 13 and >54 years
Farmer	2 or 3 to 1	4 to 6	13 to 17 years old
Employee	4 to 1	6 people	18 to 54 years old
House work	5 or more to 1		

Time of residence	**Family Income**	**Family Transport**	**Parcel:**
Less 1 year	Less than 1 daily wage	car	Ownership
1 – 5 year	1-3 minimum daily wage	Moto	Rented
More 5 years	>3 daily wages	bus	Illegal
		Anything	

Where do you attend your health care? ___________________________

Debris flow Events knowledge:

1996 Damage	1998 Damage	2006 Damage
Height event	Height event	Height event
No remember	No remember	No remember
yes: High cm	yes: High cm	yes: High cm
Event Affectation: Damage General:	Event Affectation: Damage:	Event Affectation: Damage:
Health	Health	Health
Inside Goods	Inside Goods	Inside Goods
Daily Incomes	Daily Incomes	Daily Incomes
Structural Dwelling	Structural dwelling	Structural Dwelling
other	other	other
Anything	Anything	Anything
The Impact was: Very High/High/ Moder/Low/Very Low	The Impact was: Very High/High /Moder/Low/Very Low	The Impact was: VeryHigh/High /Moder/Low/Very Low
Damage by Impact:	Damage by Impact:	Damage by Impact:
The Acumulation was :	**The Acumulation was :**	**The Acumulation was :**
Very High/High/Moder/Low/Very Low	Very High/High/Moder/Low/Very Low	Very High/High/Moder/ Low/Very Low
Damage by Acumulation:	Damage by Acumulation:	Damage by Acumulation:

Adaption activities:

Dwelling Reinforce structure	Dwelling Reinforce structure	Dwelling Reinforce structure
Preparedness	Preparedness	Preparedness
Fences building, Obstacules	Fences building	Fences building
Financial Government support	Financial Government support	Financial Government support
Insurement	Insurement	Insurement

Indicator	**Question involved**	**Answers options**

Questionnaire of Risk Perception :

Experience and Knowledge	1.Have you experienced a debris flow event in Villa Restrepo?	No I havent
		No but I was informed
		Yes. I lived this experience
	2.Given a debris flow who you rely on for protecting your life and saving your belongings?	God
		God and myself
		Only myself
	3. In case of a debris flow which loss do you consider more important?	Anything
		Material properties
		Family and material properties
		Family wellbeing
	4. Do you think that a debris flow could occur in Villa Restrepo in?	No. I don't think it occurs
		100 years
		50 years
		10 years
		whatever time (with justification)
	5. Do you think that your house could be affected by a debris flow?*	Not answer
		No or Yes. Without Justification
		No or Yes. With Justification
	6.Are you concerned about the occurrence of debris flows in this town? *	No
		Yes
Participation and attention of emergercy	7. Activities taken in order to reduce the risk*	No activities
		Attending municipality workshops
		Attending municipality activities and participate in own proposals to reduce the risk
	8.Do you know what to do in case of an emergency triggered by a debris flow ? *	I don't know
		Be at home
		Go out of my home
		Take the evacuation route or go to secure zones
		Follow the instructions given by the municipality
	9.Do you know where the high debris flow hazard zones are located?*	No idea
		More or less
		Yes I know

Appendix 2: Criteria used for debris flow hazard classification in ILWIS.

If Intensity = *Low* and Magnitude = *Low* then **`Low´**
If Intensity = *Low* and Magnitude = *Moderate* then **` Moderate ´**
If Intensity = *Low* and Magnitude = *High* t hen **`High´**
If Intensity = *Moderate* and Magnitude = *Low* then **`Moderate´**
If Intensity = *Moderate* and Magnitude on = *Moderate* then **`Moderate´**
If Intensity = *Moderate* and Magnitude = *High* then **` High ´**
If Intensity = *High* and Magnitude = *Low* then **` High ´**
If Intensity = *High* and Magnitude n = *Moderate* then **` High ´**
If Intensity = *High* and Magnitude = *Low* then **` High ´**

Appendix 3: Criteria used for debris flow hazard classification in ILWIS to calculate debris flow risk map.

If Hazard = *Low* and Vulnerability = *Low* then **`Low´**
If Hazard = *Low* and Vulnerability = *Moderate* then **` Moderate ´**
If Hazard = *Low* and Vulnerability = *High* t hen **`Moderate´**
If Hazard = *Moderate* and Vulnerability = *Low* then **`Moderate´**
If Hazard = *Moderate* and Vulnerability = *Moderate* then **`Moderate´**
If Hazard = *Moderate* and Vulnerability = *High* then **` High ´**
If Hazard = *High* and Vulnerability = *Low* then **` High ´**
If Hazard = *High* and Vulnerability = *Moderate* then **` High ´**
If Hazard = *High* and Vulnerability = *Low* then **` Moderate**