



Community-Based Flood Risk Assessment Using GIS for the Town of San Sebastián, Guatemala

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Abstract

The municipality of San Sebastián, considered one of the most prone to natural hazards in Guatemala, was selected as one of the pilot areas of the UNESCO program on “Capacity Building for Natural Disaster Reduction”. The town is located within the Samalá basin, near the active channel of the river, which is heavily affected by lahars related to the active Santiaguito-Santa María volcanic complex. The town is threatened both by lahars as well as by flooding. As is often the case in towns such as San Sebastián, very little data (e.g., cadastral, topographical, hydrological and meteorological) was available to perform a flood risk assessment based on traditional hydrological modeling.

To perform a basic flood risk assessment, an alternative method for producing several sets of data was implemented by combining aerial photo interpretation, the use of data questionnaires in a community-based field data collection campaign, and subsequent analysis using Geographical Information Systems (GIS). A cadastral base map with an attribute database was generated as key inputs for flood hazard and vulnerability assessment. Information collected by means of a small-scale survey on a home-by-home basis, in cooperation with a local NGO, was used to reconstruct the last flood that affected the town during Hurricane Mitch in 1998.

Based on this historic flood scenario vulnerability curves relating water height and speed with expected level of damage were constructed for three of the main elements at risk within the urban area: buildings, building contents, and road network. Vulnerability maps were generated using GIS and combined with cost information to derive estimated losses.

The resulting cadastral database containing physical and social information at the parcel level as well as detailed information on flood hazard, vulnerability and expected losses, can be used by municipal authorities as a valuable tool in municipal planning, including a wider range of applications in addition to risk management.

Key words: flood hazard, risk assessment, risk, community-based methods, GIS

Resumen

El municipio de San Sebastián es considerado uno de los más susceptibles a amenazas naturales en Guatemala. Por esta razón fue seleccionado como una de las áreas piloto del programa “Fortalecimiento de Capacidades Locales para la Reducción de Desastres Naturales” de la UNESCO. Este municipio se localiza dentro de la cuenca del Río Samalá, cuyo cauce activo esta siendo constantemente afectado por lahares provenientes del complejo volcánico activo Santiaguito-Santa Maria. Para la cabecera municipal y pequeñas villas localizadas en sus márgenes

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esta conjugación de factores constituye una amenaza, tanto por la ocurrencia de lahares como por inundaciones.

Por lo general, no sólo en Guatemala sino en muchas regiones de países en desarrollo, las municipalidades pequeñas como San Sebastián no poseen las bases catastrales y topográficas ni la información y los registros hidrológicos y meteorológicos requeridos para llevar a cabo un análisis de riesgo por inundaciones; basado en modelación hidrológica tradicional.

Se implementó un método alternativo para producir una serie de datos que permitiera llevar a cabo un análisis básico de riesgo por inundaciones, combinando la interpretación de fotografías aéreas, el diligenciamiento de cuestionarios en una campaña de recolección de datos con soporte comunitario y finalmente su análisis usando Sistemas de Información Geográficos (SIG). Un mapa catastral y una base de datos y atributos fueron generados como elementos claves para evaluar la amenaza y vulnerabilidad a inundaciones. La información recolectada por medio de una encuesta a pequeña escala, casa por casa en cooperación con una ONG local, fue usada para reconstruir la última inundación que afectó la cabecera urbana de San Sebastián durante el Huracán Mitch en 1998.

Tomando como base este escenario histórico se construyeron curvas de vulnerabilidad, que relacionaran la altura y velocidad del agua con el nivel de daño esperado, para tres elementos en riesgo, considerados vitales dentro de un área urbana: construcciones, contenido de las mismas y red vial. Se generaron igualmente mapas de vulnerabilidad mediante análisis en SIG, los cuales fueron combinados con información de costos para derivar finalmente información de daños esperados.

Se espera que tanto la base catastral, la cual contiene datos físicos y sociales al nivel de parcela; como la información de amenazas, vulnerabilidad y daño esperado se constituyan en elementos valiosos para las autoridades municipales; y que dicha información sea integrada tanto a los planes de gestión del riesgo, como a otro amplio rango de aplicaciones que incluyan los planes de ordenamiento y desarrollo municipal.

Palabras Claves: Amenaza por inundación, análisis de vulnerabilidad, riesgo, métodos comunitarios participativos, SIG

Introduction

Floods are one of the most common disaster phenomena, causing considerable personal injury and property damage. Problems related to flooding and vulnerability of the population have greatly increased in recent decades due to several factors including changes in land-use in the hinterlands, urbanization of flood-prone sites, squatter settlements and sub-standard constructions, and increased household density (Munich Re., 2002; Pelling, 2003).

In light of the limited financial resources of developing countries, the cost-benefit implications of disaster reduction alternatives must be carefully assessed. The expected damage (or risk assessment) provides one of the necessary inputs in cost-benefit analyses. Defined as the expected losses (e.g., casualties, injuries, property damage, and disruption of economic activities) due to hazardous events in a given area during a specific reference period, *risk* can be estimated as the product of hazard, vulnerability and cost of the elements at risk (UNDRO, 1991).

Traditional methods for flood risk assessment are based on hydrological and hydraulic modeling software packages. These models are useful in depicting the spatial and temporal distribution of floods. However, few are well integrated within spatial modeling environments (i.e., GIS) and few are capable of non-expert implementation (Al-Sabhan et al., 2003). In addition to the specific data requirements (quality and quantity), these types of models demand



considerable expertise in hydrological data evaluation, model application and the efficient management of large spatial and temporal datasets (FEMA, 2003).

Remote or rural areas in developing countries usually lack most of the technical data required to carry out such studies. Furthermore, local authorities often lack the required staff with expertise to use the specialized techniques and models. Additionally, small budgets for investment restrict the acquisition of basic datasets through consulting companies. To bridge this information gap, alternative methodologies and data sources should be used, such as those used in community-based approaches which offer the possibility to compile, organize and reconstruct the collective memory of the inhabitants from a flood-affected region. Examples of vulnerability and risk assessment studies using community-based approaches can be found in IFRC (2002) and Coburn, Spence and Pomonis (1994). The use of GIS tools in such studies has been demonstrated by AGSO (2001) and FEMA (2003).

One of the objectives of this study was to provide an alternative method for a basic flood risk assessment in data-poor environments by combining aerial photo interpretation, data questionnaires in a community-based field data collection campaign, and its subsequent processing and analysis using Geographical Information Systems (GIS). Datasets produced by these means and managed under GIS could be used by local authorities to carry out many of the municipal planning activities related to risk management. Moreover, these data could be used for other administrative and decision-making purposes. In fact, data collection for risk mitigation does not usually rate high on the priority lists of local authorities as there are a range of other problems which are perceived as more pressing. For example, the implementation or updating of basic cadastral systems is important for local authorities seeking to increase municipal revenues through better tax collection (van Westen et al., 2002).

Within the framework of the UNESCO program on "Capacity Building for Natural Disaster Reduction" (UNESCO-CBNDR), a Regional Action Program for Central America was initiated which focused on training and the development of case studies in most Central American countries. One of these case studies was conducted in the town of San Sebastián, Guatemala, located in an area exposed to a range of natural hazards. Over the last 50 years, the town has been affected several times by floods from some of the tributaries of the Samalá River. The most recent event occurred in October 1998 and was caused by extreme precipitation related to Hurricane Mitch. The 1998 flood scenario was reconstructed through interviews with local people. The data were then used to conduct a vulnerability assessment and a loss estimate calculation. An overview of the methodology used is presented in Figure 1.



Figure 1 - Schematic overview of the flood risk assessment.

The Study Area

San Sebastián is one of 8 municipalities in the Retalhuleu Department, located in the southwest of Guatemala (see Figure 2). With an area of 28 km², it is comprised of rural communities and an urban district (San Sebastián) which is divided into 4 cantons. Its population is 21,070 inhabitants, 56.8 percent of which are of indigenous origin. Agriculture is the most important activity and constitutes the base of the local economy (USAC, 2002).

San Sebastián is located in the center of the Samalá watershed, at a distance of 22 kilometers from the very active Santa María – Santiaguito volcanic complex (Rose, 1987). The region is prone to a range of natural hazards, the most important ones include floods, earthquakes, volcanic eruptions and lahars. Due to the continuous volcanic activity in the upper part of the watershed, the eastern part of the municipality is frequently affected by lahars and flooding during the rainy season (September to November). In fact, Rose (1987) reported that since the 1983 explosion of the Santiaguito volcano, the sediment load has been moving down through



river courses affecting population and infrastructure in the medium and lower sections of the basin.



Figure 2 - Location of Samalá river basin and San Sebastián.

El Palmar is one of the villages located along the Nima I and Nima II tributary rivers, flowing from the Santiaguito volcano to the Samalá River. El Palmar was completely destroyed by lahars in the period 1982 to 1998. In May 1988, all its inhabitants were evacuated and the village had to be relocated (Venzke et al., 2003). The International Pacific Highway (CA2), which crosses the Samalá River just north of San Sebastián, has been closed frequently (e.g. in 1988 and 1993) due to deposits from floods and lahars covering the highway. The riverbed of the Samalá River experienced frequent aggradations causing peak flows that have almost reached the highway overpass. In order to prevent destruction of the bridge, a 1 kilometer section of the riverbed should be dredged annually. Reports also indicate that on several occasions since 1983, during the rainy season the Samalá River has been diverted into the catchments of the Ixpatz River, which flows into San Sebastián. A barrier was constructed along the right flank of the Samalá River to protect San Sebastián from the lahar threat (Venzke et al., 2003; Green and Rose, 2003).

Regarding flooding, local tributaries of the Samalá River such as the Tzununa, Ixpatz and Cachel cause most of the problems in the study area. In the urban district of San Sebastián, flooding is aggravated due to anthropogenic factors, such as drastic changes in the land cover, uncontrolled and unplanned urban growth along riverbanks during the last 50 years, and the



dumping of garbage in the streams. The last flood event took place at the end of the rainy season in 1998 coinciding with Hurricane Mitch's landfall in Central America.

Rainfall from Hurricane Mitch was exceptional because it was geographically widespread, prolonged over a period of about two weeks, moderate to heavy in intensity, and occurred at the end of the rainy season when the ground already had a high moisture content. The area received between 200 and 600 mm of rain over a 13-day period between October 25th and November 6th. Meteorological stations, which are distantly and sparsely distributed across Guatemala, provided a general picture of the precipitation associated with Hurricane Mitch throughout the country, which ranged from 182 mm to 1,069 mm (USGS, 2002). In the Samalá River basin, torrential rains caused floods three times during the last weeks of October in 1998, although no lahars were reported. In the vicinity of San Sebastián, the near to flat watersheds of the minor tributaries of the Samalá River caused the excess drainage to flow from one basin to another, during major rainstorms (October 27, 1998). Such was the case of the Tzununa River that runs west of San Sebastián, which overflowed north of the urban area at the bridge on the road to Buena Vista Farm. From this point and for more than two kilometers down, the road acted as a channel for the water, which was finally transferred to the upper part of the Ixpatz basin. The Ixpatz River also overflowed just before reaching the urban district of San Sebastián, spreading throughout the street network. Once there, the distribution of flood and damage was determined by local topography, configuration of the streets and building blocks (particularly passages or empty spaces between constructions), and presence of bottlenecks created along streams due to encroachment of buildings in the streams. In other words, building features played an important role in the behavior of the floodwater. This is an important point as it highlights the need to obtain building footprint information (opposed to only parcel information) to accurately model the distribution of the water during a flood event.

Data Collection

This survey started by collecting three sets of aerial photographs from San Sebastián (years 1964, 1991 and 2000). These images were ortho-rectified using GPS data and a 1:50,000 scale topographic map. The orthophoto from 2000 was used as the basis for mapping cadastral units and elements at risk. The remaining two sets were used to evaluate the growth pattern for the urban district over the last four decades.

Multi-temporal analysis of the aerial photographs and other data (USAC, 2002) revealed that the rate of population growth is low (3 %), and that the urban area did not grow extensively in size over that period. Instead, growth took place in the form of densification within the urban area, as it is common practice for people to sub-divide their land among their children. Accordingly, the number of plots inside one building block increases while the average plot size decreases. The analysis also revealed that growth in the urban area occurred along the floodplain. The densification process has also affected watercourses, which are often directly bordered by houses and confined to very narrow channels. Other factors contributing to increased susceptibility to flooding include the poor state of the sewage system, the absence of a public solid waste collection system (both have led to waste disposal in the streets and local streams), and changes in land use since impermeable surfaces hamper infiltration and speed up run-off.

The orthophoto from 2000 was used to generate a cadastral base map containing information on individual plots and buildings, with attached attribute information related to ownership, building features and land use. Preliminary delineation of building blocks (or 'manzanas') and roof inventory was made by means of detailed digital image interpretation and 'on-screen' digitizing. Plot boundaries were later checked during fieldwork and significant discrepancies were identified mainly in areas near the main square. Most were due to the complex densification



pattern that significantly increases the number of individual dwellings inside a building plot. For example, a single roof may cover more than one home or a given plot may have more than one type of roof (see Figure 3). The preliminary interpretation map was then verified and adjusted during inspection transects along the streets and inside the blocks.

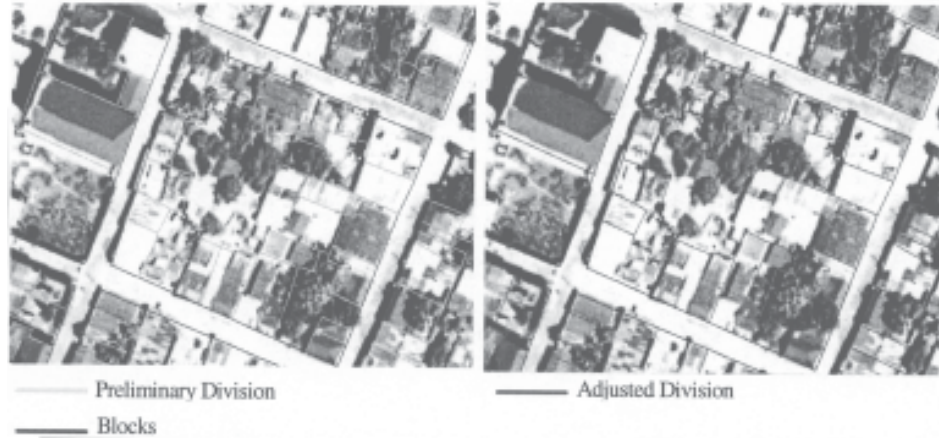


Figure 3 - Comparison of digitized plots before (preliminary roof inventory - left) and after field inspection (right), for a section of San Sebastián.

Attribute information for cadastral plots was collected through extensive fieldwork. In this stage, a community-based tool (small-scale survey) was used to capture data in the urban area. This ‘census’ was carried out in October 2002 with the aid of the “FEMID” group (Fortalecimiento de Estructuras Locales en Mitigación de Riesgos), a local NGO working on an early warning system for hazards (mostly lahars) in San Sebastián (FEMID, 2000). The survey was carried out on a house-by-house basis by three groups of 2 interviewers, of which at least one was of local origin. The survey included a technical description of the building and an interview with the inhabitants. Whereas the technical description of the building was made for all cadastral plots, interviews were only conducted at locations affected by flooding. Information about three main topics: characteristics of the building and its contents, socio-economic aspects and information on the magnitude and damage of historic flood events was obtained through a questionnaire adapted from the National Commission for Disaster Reduction (CONRED).

The collection of reliable information about flood events that occurred before the 1998 Mitch flood proved to be a difficult task. Difficulties such as the resident’s age (e.g. too young to remember the past events), recent settling down and lone dwellings reduced the survey’s effectiveness. Nevertheless, several inhabitants confirmed that similar events had taken place on at least two occasions over the last 50 years: one during the 1950’s and one at the beginning of the 1970’s. Most of the inhabitants were able to indicate the flood height and describe damages caused by the inundation related to Hurricane Mitch in 1998. In several cases, especially for buildings that had not been repaired or repainted, it was possible to measure floodwater marks and use them for corroboration purposes later on.

Most of the survey was performed using traditional paper questionnaires. One of the teams implemented a mobile GIS consisting of a palmtop computer with a GIS including a database. This tool-set was used for visualizing the orthophoto image, digitizing cadastral units and entering the attribute data. The information stored in the database for elements at risk was linked to the cadastral base map by means of geographic attributes in the GIS. An overview of some of the most important attributes is presented in Table 1.

Attribute Name	Description
<i>Name</i>	Unique identifier for each plot. First character and number correspond to Zone, next two numbers identify block or "Manzana," and last two characters identify a plot inside a block
<i>Function</i>	Plot's land use (e.g., residential, shop, warehouse, school, etc.)
<i>Age</i>	Age of the building
<i>State</i>	Describes the actual condition of the building
<i>N_Floors</i>	Number of floors in each building
<i>Damage</i>	Qualitative assessment of damage reported for the 1998 flood (see Table 2)
<i>Height_cm</i>	Water height(in centimeters) reached during the 1998 flood
<i>Material</i>	Building materials
<i>Height_st</i>	Measurement (in centimeters) of height,above street level, for the first point from which water can enter a building
<i>Socioe_level</i>	Socio-economic level assessed to a building based on physical parameters such as: conservation-maintenance state, building material, building contents and general income
<i>Comcontent_vl</i>	Cost of building's content for land uses other than housing, such as shops, stores, schools, etc.
<i>Com_value</i>	Building's market value based on parameters such as type, land use, conservation-maintenance state, construction system and number of floors

Table 1 - Description of some of the most significant attributes identified as risk elements during the field survey.

Flood Scenario Mapping

Based on the information collected during the survey, it was possible to develop two maps representing the flood scenario for 1998: one for the water height and one for the damages. Figure 4 shows the cadastral plots from which information on water heights and damage levels was obtained. It should be noted that greater focus and more detailed survey data were collected in those areas affected by flooding in 1998.

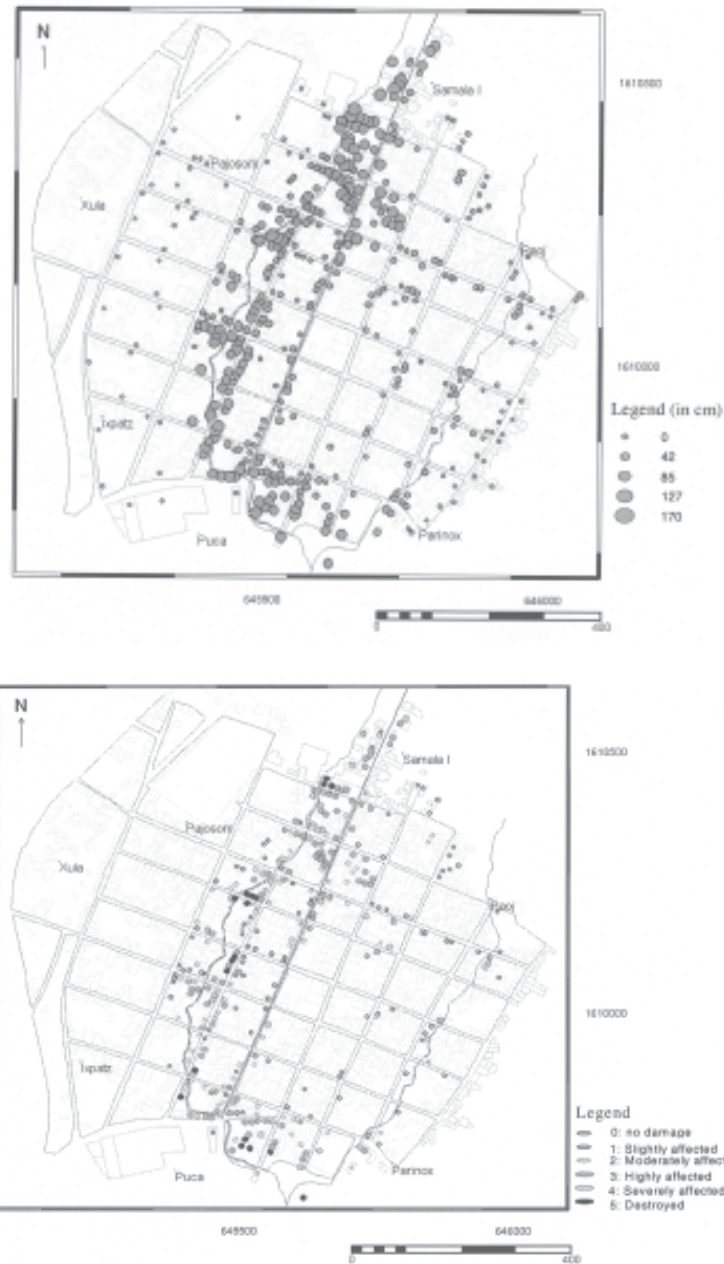


Figure 4 - Plots from which information on 1998 floodwater height was collected (top); Plots with damage information from 1998 flood (bottom).

A GIS point interpolation method (ordinary Kriging) was performed from plots containing water height data (see Figure 5). Regarding damage, descriptive information on both the buildings and their contents was compiled during the survey. This qualitative report was subsequently converted into numerical values for every specific level of damage (see Table 2).

The water height map shows that the 1998 flood spread across all four urban “cantons” in San Sebastián. Building blocks near the watercourses of the Ixpatz and Cachel and along the Avenida Central were particularly affected. By analyzing the most severely damaged areas, it

was noticed that the water height reached 130 centimeters at some point during the flood (points 1 and 2 in Figure 5). In those zones, 6 houses were destroyed, 3 were severely damaged and 16 were highly damaged (see Table 2). Moreover, the water removed most of the bricks covering the streets, which people later used to rebuild their houses or piled them up as temporary flood protection. Severe damage was also caused to roads connecting San Sebastián with the National Pacific Highway. At some points the asphalt surface was completely removed. Flood heights also exceeded 1 meter in four spots identified as bottlenecks along the Ixpatz River (points 3 to 6 in Figure 5). In most cases, bridges built above the street level behaved as source points for overflowing at higher velocities resulting in 9 houses destroyed, 14 severely damaged and 48 highly damaged.

Damage Class	Damage Value	Vulnerability Value for Wooden (W) Buildings	Content Damage Description	Building Damage Description	Results for the Survey on Building's Damage
No damage	0	0.00	No damage	No damage	1082
Slightly affected	1	0.05	People had to move objects to a higher elevation, mop and clean.	No damage, wall paint deteriorated.	104
Moderately affected	2	0.10	Minor losses - particularly kitchen cupboards, clothes, shoes, and mattresses (rotten due to soaking); Residents had to mop and clean.	No structural damage, wall plaster may need repair and painting. Wooden frames need to be treated.	77
Highly affected	3	0.50	Almost total loss of the content, especially furniture, equipment, kitchen cupboards, etc.; People had to remove dirt and mud from inside.	Considerable structural damage to wooden doors and frames, plaster and painted walls.	90
Severely affected	4	0.80	Total loss of content.	Partial destruction of foundations, walls and doors.	29
Destroyed	5	1.00	Total loss of content.	Total destruction of the dwelling.	18

Table 2 - Qualitative and quantitative classification and description of damage levels with an example of vulnerability values for wooden buildings. Total report of damage for buildings (all materials).

At point 7 in Figure 5 the flooding heights were above 1 meter. In this sector water coming from the Ixpatz watercourse covered Avenida Central spreading out in all directions, particularly towards the southeast due to topographical features. In this zone, many houses are built on the flat tops of the Ixpatz and Cachel watersheds. This leveled topography is conducive to water accumulation. The pattern of flooding seemed to be related to the existence of empty spaces, passages and inner constructions. In this sector, 2 houses were reported as severely damaged and 16 as highly affected.

The critical flooding spots located along the Cachel River (points 8 and 9 in Figure 5) were caused by buildings that confine the watercourse, channels that have progressively been in-filled with sediment and garbage, and deficiencies in sewerage and run-off collection systems whose capacity has been further reduced by dumped rubbish and garbage. Dwellings built be-

low the street level have a higher vulnerability, as small floods can also take place during normal rainy seasons. Flooding for building blocks in the central part of the town ranged from 0 to 100 cm, with levels decreasing further away from streams. In this area, the damage that occurred was mainly to building contents. Blocks located towards the eastern and western borders of the urban district were not affected, as they are situated in a relatively higher terrain.

The occurrence of this flood in 1998 was associated with heavy rains caused by Hurricane Mitch, which is recognized as one of the strongest in Central American history. This scenario could be considered as the hypothetical maximum for inundations with a return period of 25 to 50 years.

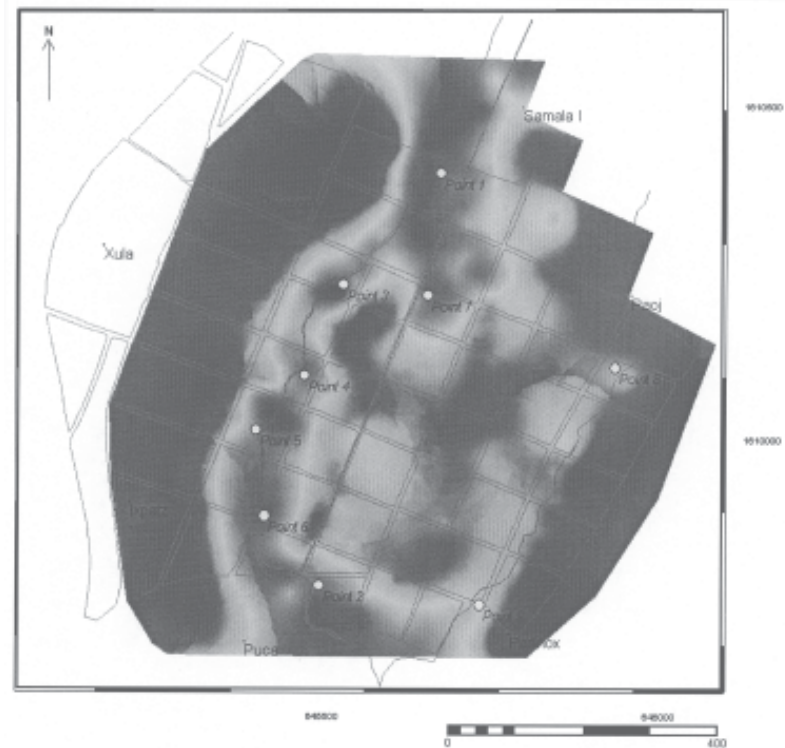


Figure 5 - Interpolated map for water height and main bottlenecks (indicated as points) during the 1998 flood event in San Sebastián.

Vulnerability Analysis

Flood damage is determined by several factors such as flood-height, flow velocity, duration, sediment concentration and pollution. Water height and flow velocity (related directly with distance from element to the stream) were taken into consideration in this study, as reliable data for other factors were not available. Duration was not used because the 1998 flood was categorized as a flashflood, lasting less than four hours. Vulnerability assessments were conducted for buildings and their contents, as well as for the street network. People's vulnerability was not evaluated based on the assumption that people had enough time to evacuate the flood-endangered areas as no casualties were reported.

The basic methodology to evaluate urban losses depends on the development and use of stage-damage curves (also called loss functions or vulnerability functions). A stage-damage

curve is normally related to a specific class of building or crop and establishes the relationship between flood damage and depth of flooding (or stage) (Smith, 1994). The damage function estimates the damage as a value between 0 (no damage) to 1 (total destruction). The method developed in this research uses a combination of the “Existing databases” and the “Valuation Survey” approach (Penning-Rowsell and Chatterton, 1977). Estimations relied on databases created for elements at risk within the urban area of San Sebastián and information about damage related to the 1998 flood. Several stage-damage functions specific for the area were developed and applied by means of GIS in order to replicate actual conditions of elements at risk.

Building Vulnerability

To determine the vulnerability to flooding for buildings, three factors were taken into account:

- *Height of water column affecting each single plot.* In this step, for each plot the height above the street (measured during fieldwork) was subtracted from the floodwater’s height, resulting in the precise amount of water inundating a given building. Due to heavy rains (typical of tropical weather) many of the buildings in San Sebastián are protected from frequent small floods by elevated thresholds in front of the doors.
- *Position of plots in relation to streams.* A distance map for the watercourses (Ixpatz, Cachel and Avenida Central) was calculated in GIS. The average distance for each cadastral plot was introduced in the database.
- *Material.* In this case, for houses reported as destroyed the material existing before the flood was surveyed and used in the analysis.

Three building construction types were identified as prevailing in San Sebastián:

- *Reinforced concrete and masonry (BC):* consisting of concrete columns reinforced with steel bars and in-fill walls made of clay bricks, all covered with plaster.
- *Wood (W):* frame made out of wooden poles with walls built out of overlapping horizontal boards, without foundations.
- *Mixture of concrete blocks and wood (CW):* includes a small wall, often less than 70 cm high, built out of bricks, stones or concrete blocks and topped by overlapping wooden boards.

A comparative analysis of these construction systems determined that wood and mixed concrete-wood performed relatively similarly during flooding. However, the latter type (CW) could have sustained considerably less damage with water levels lower than the base wall. Significantly, only buildings of these two types were destroyed in 1998. Some reinforced concrete and masonry buildings (BC) were damaged but none were fully destroyed.

In order to establish relationships between damage and floodwater height, two graphs were plotted for each construction type: damage level (assessed from the building damage report) against averaged flood, and damage level against distance from the streams (see Figure 6).

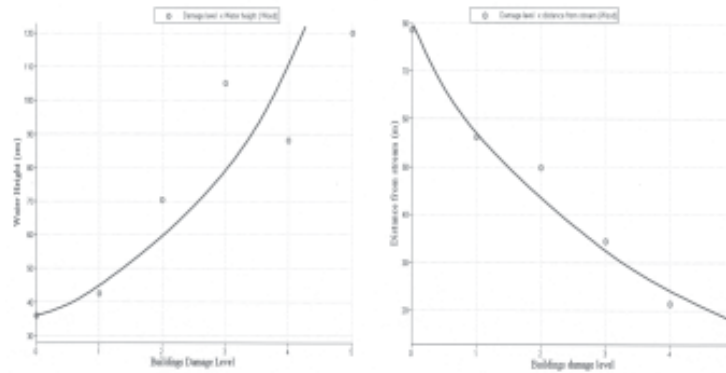


Figure 6 - Stage-damage curves relating Damage versus Water Height (left) and Damage versus Distance from the street (right) for wooden buildings. Dots represent the averaged value for all plots with equal damage level (see Table 2).

These graphs were converted into stage-damage curves by assessing vulnerability values from 0 to 1 for each qualitative damage class and construction type (see Table 2). Based on these functions a building vulnerability map was generated for the 1998 scenario. Consistency was checked afterwards through comparison with plots reported as damaged during fieldwork (see Figure 7a and 7b).



Figure 7a - Building vulnerability map.





Figure 7b - Building content vulnerability map.

Building Contents Vulnerability

In order to estimate damage to building contents, two factors were evaluated: content replacement value and percentage of damage. Replacement values were obtained by sampling building contents for different socio-economic classes. Four socio-economic levels were recognized in the urban area: Low, Middle-Low, Middle, and Middle-High. By interviewing both the FEMID group and several inhabitants and by tracking across the town some particularities in San Sebastián people's life style were identified:

- The strong indigenous heritage influences customs. For example, many inhabitants tend to keep valuables in the form of jewelry instead of having expensive items or furniture in their houses.
- The average number of inhabitants per house varies according to socio-economic level (jointly with ethnicity and religion). For calculations of building contents the official average of 4.9 (USAC, 2002), was used for Middle and Mid-high levels. However, an average of 7 inhabitants per house was used for Low and Mid-Low classes.
- A list of typical items present in a house was prepared for each income class. In many cases, an article was present in all socio-economic classes. However, the price and number of articles vary according to income level.

During fieldwork one of the four lists of articles (for houses) was assigned to each plot according to its socio-economic class (see Table 3). Prices for articles were obtained from shops in San Sebastián and the neighboring city of Retalhuleu. When evaluating flood damage to houses or buildings, it was assumed that articles remained at their location and were not re-

moved from the house or moved to a higher elevation in response to flood warning. This assumption is justifiable as the 1998 event, classified as a flash flood, allowed no early warnings.

Percentages for damage to content values are usually derived from loss estimation curves or tables. Although damage curves for content loss have been developed for different locations around the world, extrapolation proved to be difficult due to differences in building type, content and warning time. In addition, almost all reported studies have been carried out in developed countries, with data coming primarily from (re)insurance companies (Yohe et al, 2001). Despite the fact that standardization by income level or socio-economic class has been attempted on several occasions, the applicability of this method should be regarded with caution since it is evident that life style strongly differs according to development level.

Item	List 1	List 2	List 3	List 4
Socio-economic Level	Low	Middle-low	Middle	Middle-high
Sofa set			(1) 1,500	(1) 4,000
Dining set	(1) 600	(1) 1,000	(1) 2,200	(1) 3,500
Beds	(2) 600	(3) 4,500	(4) 6,000	(5) 9,000
Mattresses	(2) 300	(3) 1,200	(4) 2,000	(5) 2,500
Bedside tables	(2) 200	(2) 350	(3) 650	(5) 1,200
Wardrobe	(1) 250	(2) 600	(3) 1,000	(4) 2,000
Sewing machine	(1) 1,000	(1) 1,300	(1) 1,300	(1) 1,500
Typewriter machine			(1) 1,000	
Television set	(1) 400	(1) 850	(2) 2,300	(3) 5,500
Radio system	(1) 250	(1) 1,500	(2) 5,000	(2) 8,000
Computer system				(1) 3,500
Video, DVD			(1) 1,200	(1) 1,800
Video camera				(1) 2,000
Fixed telephone			(1) 300	(1) 400
Mobile telephone			(1) 600	(2) 1,600
Washing machine				(1) 5,500
Refrigerator		(1) 1,500	(1) 3,000	(2) 7,000
Vacuum cleaner				(1) 1,000
Gas stove		(1) 1,200	(1) 3,000	(1) 3,500
Microwave oven			(1) 850	(1) 1,000
Electric stove				(1) 4,500
Food processor/Blender			(1) 450	(1) 650
Rice cooker				(1) 900
Iron	(1) 150	(1) 150	(1) 250	(1) 250
Juicer				(1) 400
Coffee machine				(1) 500
Electric fan		(1) 200	(1) 350	(2) 700
Bicycles		(2) 1,600	(4) 3,600	(4) 5,600
TOTAL	3,750	15,950	36,550	78,000

Table 3 - Lists of articles for estimating building contents for different socio-economic classes. Number of articles and the average prices (per list) are indicated. Prices are given in Quetzals (1 USD = 8 Quetzals).

Content vulnerability assessment was based on damage reports collected during fieldwork. Floodwater height was determined for each of the five damage levels (previously described in Table 2). The last two levels (Very High and Total Destruction) were grouped together as the total loss of building contents was reported for both classes (Vulnerability = 1). Regarding floodwater heights, the vulnerability of every article in each of the four lists was evaluated based on interviews with people who suffered losses during the flood, as well as with local experts. Assessed vulnerability values represent the percentage of expected damage for a particular item due to a specific floodwater height. The expected damage (cost) of each item was obtained by multiplying the item's cost by its individual vulnerability value (see formula 1a). Total expected damage (TED) in a list was obtained later on by adding up the expected losses of the individual items (formula 1b). In order to translate monetary cost for the list into a single vulnerability value (from 0 to 1), the TED was finally divided by its total replacement cost (formula 1c).

$$IE_D = R_V * I_Vn \quad (1a)$$

$$TED = \Sigma IE_D_1 + IE_D_2 + \dots + IE_D_n \quad (1b)$$

$$L_Vn = TED/RV_L \quad (1c)$$

Where:

IE_D	=	Item's expected Damage
R_V	=	Replacement value
I_Vn	=	Item's vulnerability
TED	=	Total expected damage (for a list)
L_Vn	=	List's vulnerability
RV_L	=	Replacement value (cost) of the list

This procedure was performed for three different floodwater heights and only for household contents (excluding shops, workshops, schools and other buildings). For buildings other than houses, the content cost was estimated directly, depending on the nature of the assets. However, due to lack of time and detailed information generalizations had to be carried out; for instance vulnerability values for small warehouses were considered to be higher than for houses, based on the fact that articles were often observed placed or laying down directly on the floor.

Figure 7 illustrates the vulnerability map for building contents. The map indicates in terms of flooding contents vulnerability was higher and more widespread than building vulnerability. The procedure also evidenced how damage is influenced by socio-economic class as buildings having more assets inside will show greater expected damage.

Road Network Vulnerability

The road network is considered a critical element of a community's infrastructure. Its damage is one of the most significant problems caused by flooding often resulting in the isolation of towns from aid and facilities (i.e., hospitals and shelters) (IFRC, 2002).

During the flood in 1998, more than 80 percent of the urban district in San Sebastián was isolated from the main exits to neighboring cities (Retalhuleu and Quetzaltenango). For the duration of the flooding, streets acted as channels for the floodwater coming out from the Ixpatz and Cachel Rivers, or flowing in via Avenida Central.



Damage to the road or street network basically depends on the material and quality of the road surface in relation to the height and velocity of the floodwater. In order to evaluate the vulnerability of the urban area's road networks, four main types of surface material were differentiated:

- Asphalt (AS): Main roads and highway.
- Concrete (C): Avenida Central and recently paved streets.
- Concrete bricks (CB): Secondary streets. This seemed to be the most common material.
- Earth (E): Rural or recently delineated streets.

For the assessment of vulnerability, values for road loss functions were not used because data on this topic was not found in the literature. Instead, the analysis relied directly on information collected from interviews and observations during fieldwork. For instance, given that the asphalted connections from San Sebastián to the CA2 Highway were destroyed by the flood, a vulnerability value of 1 was given to the minimum floodwater height reported for this road (60 cm). For asphalt roads, rainwater run-off heights from 15 to 20 cm were considered normal during the rainy season; therefore, these surfaces are able to deal with these flood heights without experiencing damage. Twenty (20) cm was assigned as the threshold for undergoing damage (vulnerability = 0) accordingly. Vulnerability values for other road materials were determined in the same way.

Risk Estimation

Since the flood scenario for 1998 lacked a well-defined return period, it was not possible to estimate the total flood risk in terms of probability of occurrence. Instead, calculations for expected losses to buildings, building contents and roads due to a similar flooding event (similar to that in 1998) were performed.

A database including information related to the commercial value of the plots and a link to the lists of contents for the buildings was constructed during fieldwork, based on the input of local FEMID group members. Building features such as type, land use, state of conservation-maintenance, age, construction system, size and number of floors were taken into consideration for this valuation. For the valuation of the lists for building contents, refer to Table 2. For the roads valuation, a list of prices per square meter for each material type was obtained from local experts in Guatemala.

The next step following the determination and valuation of the elements at risk was to generate the Expected Damage map using GIS tools. The steps included:

- For buildings: building vulnerability (see Figure 7) was multiplied by the market value of each parcel;
- For contents: building contents vulnerability (see Figure 7) was multiplied by an attribute map displaying the building contents' costs. This map was obtained by classifying all houses according to socio-economic class. Non-residential buildings were classified according to land use type. This map was later reclassified by linking the costs of the list according to the socio-economic class. In mixed-use cases (e.g., housing and commercial), the values of both lists, residential and non-residential, were combined;
- For roads: area covered by each type of surface was multiplied by its respective price per square meter, and then multiplied by the flood vulnerability value.

Finally, a total loss value was calculated by adding up the damage for buildings and their contents and displaying the expected losses for roads in the areas surrounding the plots (see Figure 8).

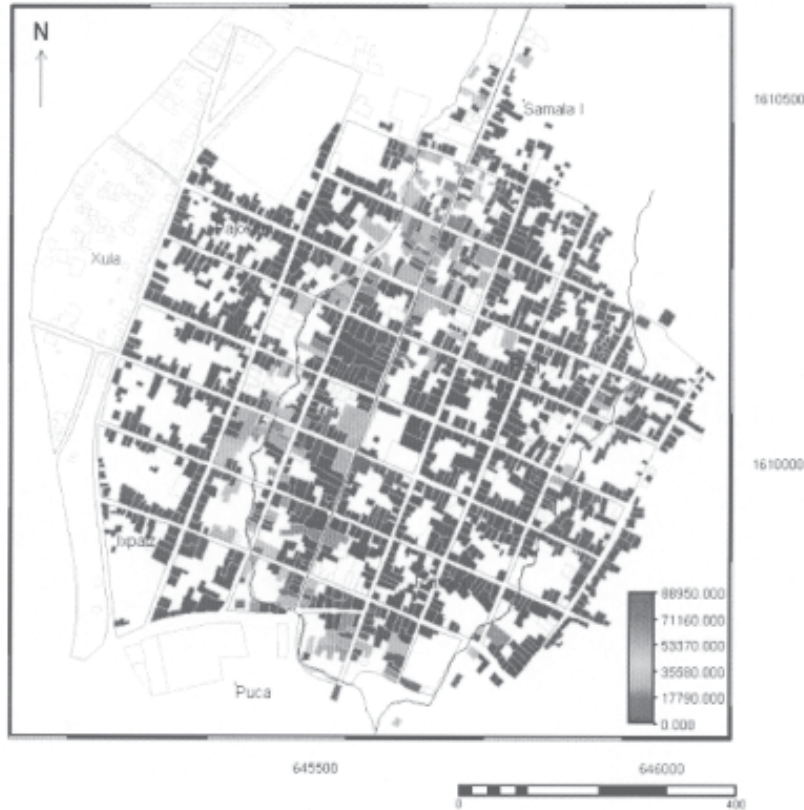


Figure 8 - Map of Total Expected Damage for elements at risk (combined building and content loss). Prices are given in Quetzals (1 USD = approx. 8 Quetzals at the time of this research - October 2002).

Discussion and Conclusions

The generation of flood risk maps in areas with very limited data is filled with a considerable number of restrictions and distinct disadvantages. Ideally, one would use hydrological modeling to estimate peak discharges for different return periods. This would be complemented by hydraulic modeling using profile information to estimate the associated flood heights and flow velocities. In the absence of detailed rainfall, discharge and altitude information, the use of these models is too uncertain, especially if flooding takes places in an urban area, and is caused by several small rivers, as was the case in San Sebastián.

To overcome flood-related data scarcity in this study case, researchers decided to combine several methods for data acquisition such as photo-interpretation, digitizing in GIS, and collection of historic flood information through an extensive field campaign consisting of interviews with the aid of local experts. This last activity turned out to be relatively successful in San



Sebastián, where a local emergency committee group (FEMID) had been established earlier with the aid of the national Committee for Disaster Reduction (CONRED).

Reliable data on maximum flood heights and flood damage was collected for a large number of points within the urban area. However, it was not viable to collect data for several flood events, due to limitations on the collective memory of the community. It was only possible to collect information on the last major event that took place (i.e. hurricane Mitch in 1998). Although some inhabitants also indicated that similar flood events had occurred during the 1950's and the 1970's, it was not possible to obtain sufficiently reliable information in order to reconstruct those flood events. In general, one can conclude that the use of this method is more reliable if carried out relatively soon after a major event has happened. This is a serious limitation to the application of the method for disaster prevention in areas with infrequent high magnitude events.

In this study, a method was used to overcome data scarcity by attempting to reconstruct a past event based on community knowledge. However, for those environments in which data is available to conduct hydrological modeling, both methods can be implemented together. The scenario depicted through reconstruction is a useful complement since is based on facts, and constitutes a valuable means for calibrating and verifying the results of modeling.

Another aspect to consider when applying this method is that collection of data on maximum flood heights and flood damage is more reliable if it is gathered through interviews with people that were directly affected. Nevertheless, measures were taken during data collection to corroborate the information given by affected inhabitants with that given by neighbors and with remaining flood marks, in order to avoid exaggeration in values for flood heights and damage. Stage-damage curves according to the local conditions were also developed using the information collected through interviews. The curves obtained show the same trend as those found in literature.

Data collection on past flood events was combined with the data collected on elements at risk. The participation of the local FEMID group also proved crucial for gathering information on buildings and its contents. This approach highlighted the importance of understanding the local context as it was found that, apart from the socio-economical level, factors like ethnicity and cultural background strongly influence the life style, and therefore the building contents.

In this study, information on social vulnerability was also collected, including aspects such as ethnicity, religious background, gender, age distribution, as well as people's capacity and ways of coping with flood events (e.g., having a small farm in the countryside, existence of family or other relations on which they could rely in case of evacuation, and attitudes towards disasters which was often religiously determined).

The results of the data collection campaign were linked to a database that can also be used for cadastral purposes. In many small urban areas in developing countries, municipal authorities still lack a basic system for cadastral mapping. Using a basic GIS, disaster prevention information can be combined with cadastral information to allow municipal authorities to increase tax collection, thereby reinforcing the justification for investment in the spatial database. Thus, this type of multi-functional spatial database can be used, not only for establishing the cost-benefit implications of possible risk reduction measures, but also for a number of other municipal spatial planning activities in the field of waste disposal, health, education, etc. Therefore, the method presented can potentially be used as a multipurpose tool enabling municipal authorities to collect relevant information at a low cost that can be applied to make effective management decisions.

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References

- AGSO, 2001. Natural hazards and risk they pose to South East Queensland. Geoscience Australia in conjunction with the Bureau of Meteorology. (http://www.agso.gov.au/urban/factsheets/risk_modelling.jsp).
- Al-Sabhan, W., M. Mulligan, and G.A. Blackburn, 2003. "A Real-time Hydrological Model for Flood Prediction Using GIS and the WWW." *Computers, Environment and Urban Systems* 27:9-32.
- Coburn, A.W., Spence R.J.S. and Pomonis, A. (1994). Vulnerability and risk assessment. United Nations Development Programme. Disaster Management Training Programme. 69 p. (http://www.undmtp.org/modules_e.htm).
- FEMA, 2003. Flood Hazard Mapping. Online tutorials. (http://www.fema.gov/fhm/ot_main.shtm).
- FEMID, 2000. Proyecto para el fortalecimiento de estructuras en la mitigación de desastres. (<http://disaster-info.net/cepredenac/femid/web/paginas/femid.html>).
- Green, B.D., and Rose, W.I., 2003. Volcanic Risk Map for Santa María, Guatemala. (<http://www.geo.mtu.edu/volcanoes/santamaria/volcrisk/>).
- IFRC, 2002. Toolbox for Vulnerability and Capacity Assessment Disaster Preparedness. International Federation of Red Cross and Red Crescent Societies. Geneva, Switzerland. (<http://www.ifrc.org/what/disasters/dp/planning/vca/guidelines.asp>).
- Munich Reinsurance, 2002. Topics: Annual review: Natural catastrophes 2002. Munich Reinsurance. 52 p. (<http://www.munichre.com>).
- Pelling, M. 2003. The Vulnerability of Cities. Natural Disasters and Social Resilience. Earthscan Publications Ltd. London, UK. p. 184.
- Penning-Rowsell, E. & Chatterton, J., 1977. The Benefits of Flood Alleviation: A Manual of assessment techniques. England: Saxon House.
- Rose, W.I., 1987. Volcanic Activity at Santiaguito Volcano, 1976-1984: Geological Society of America Special Paper 2121, p. 17-27.
- Smith, D. I., 1994. Flood Damage Estimation - A review of urban stage-damage curves and loss functions. *Water SA*, 20(3), 231-238.
- UNDRO, 1991. Mitigating Natural Disasters: Phenomena, Effects and Options. United Nations Disaster Relief Coordinator, United Nations: New York. 164 pp.
- USAC, 2002. Diagnostico participativo año 2002. Municipalidad de la Villa de San Sebastián Retalhuleu August 2002. Universidad San Carlos. Centro Universitario de Oriente División de Ciencias Económicas.
- USGS, 2002. United States Geological Survey. Landslides triggered by Hurricane Mitch in



- Guatemala. Inventory and Discussion. Open-File Report 01-443. USGS Hurricane Mitch Relief Program. (<http://mitchnts1.cr.usgs.gov/response.html>).
- Venzke, E., Wunderman R.W., McClelland, L., Simkin, T., Luhr, J.F., Siebert, L., and Mayberry, G. (eds.), 2003. Global volcanism, 1968 to the Present. Smithsonian Institution, Global Volcanism Program Digital Information Series, GVP-4 (<http://www.volcano.si.edu/gvp/reports/>).
- Westen, van C.J., Montoya, L., L. Boerboom and Badilla Coto, E., 2002. Multi-hazard risk assessment using GIS in urban areas. A case study for the city of Turrialba, Costa Rica In: Proceedings Regional Workshop on Best Practices in Disaster Mitigation: Lessons Learned from the Asian Urban Disaster Mitigation Program and other initiatives. Asian Disaster Preparedness Center, 24 – 26 September, 2002, Bali, Indonesia. pp 120-136.
- Yohe, G., Tol, R. Sj. & Thompson, D., 2001. Indicators for social and economic coping capacity – moving toward a working definition of adaptive capacity. Department of Economics, Wesleyan University, Middletown.

