Analysing Vulnerability to Volcanic Hazards: Application to St. Vincent

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‘I, Catherine Jane Lowe, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.’

Signed ____________________________ Date __________________

Abstract

Volcanology and volcanic risk assessment have in the past been strongly biased towards pure physical sciences and the study of hazard mechanisms. Traditional vulnerability analyses undertaken at volcanoes have focused on the vulnerability of buildings and the probabilities of loss of life given proximity to a volcanic hazard. These alone, however, cannot explain losses from historical volcanic eruptions. There is an additional strong vulnerability component to volcanic disasters that includes livelihoods, demographics of the population, and economic resources.

This thesis reports research findings on vulnerability to volcanic hazards on the island of St. Vincent in the Eastern Caribbean. Four different methods are used to conduct a vulnerability analysis entailing: calculation of a Social Vulnerability Index, analysis of building vulnerability, creation of stakeholder mental maps, and evaluation of historical vulnerability. This mixed-method approach has been adopted as it combines both traditional quantitative methods with qualitative techniques. Only by applying such a range of methods at one location is one able to appraise the methods and compare the geography of the different elements of vulnerability captured.

The results show that high levels of social and building vulnerability do not coincide, and that proximity to the threat was the most important variable identified by stakeholders. The historical analysis suggests that vulnerability on St. Vincent is a product of the island’s colonial history, and years of slavery, indentured labour, and the culture of migration for work and education abroad. It was determined that in the case of St. Vincent, no single method is able to capture all elements of vulnerability that are important to stakeholders. This research provides evidence of the need for context-specific vulnerability analyses that utilise a variety of quantitative and qualitative methods, rather than the broad application of global standardised metrics.

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List of Acronyms

CARICOM – Offices of the Caribbean Community Secretariat

CDB – Caribbean Development Bank

CDERA – Caribbean Disaster Emergency Response Agency (now known as Caribbean Disaster Emergency *Management* Agency from September 1st, 2009)

CRED - Centre for Research on the Epidemiology of Disasters

DRI – Disaster Risk Index (from UNDP)

EM-DAT – Emergency Management Database

EXPLORIS - Explosive eruption risk and decision support for European Union populations threatened by volcanoes

FEMA – United States' Federal Emergency Management Agency

GDP – Gross Domestic Product

GIS – Geographic Information System

GPS – Global Positioning System

HAZUS – MH – Hazards US Multi-Hazards tool (from FEMA)

IADB – Inter-American Development Bank

IDNDR – International Decade for Natural Disaster Reduction

ISDR – International Strategy for Disaster Reduction

NEMO – St. Vincent's National Emergency Management Office

OAS – Organisation of American States

PAR – Pressure and Release model

SIDS – Small Island Developing State

SMU – Soufrière Monitoring Unit

SoVI – Social Vulnerability Index (from Cutter et al., 2003)

SRC – Seismic Research Centre

SVI – Social Vulnerability Index (created in the research presented here)

UK – United Kingdom

UN – United Nations

UNDP – United Nations Development Programme

UNDRO – United Nations Disaster Relief Organisation

US – United States

USAID – United States Agency for International Development

VEI – Volcanic Explosivity Index

VoP – Vulnerability of Place model

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Chapter 1: Introduction

1.1. The rising number of disasters

Disasters as a result of natural hazards are increasing in frequency and having a greater impact on populations and economies worldwide (Berz, 1999; ISDR, 2004; World Bank, 2005). According to the Centre for Research on the Epidemiology of Disasters (CRED) (Rodriguez et al., 2009) there has been an upward trend in the occurrence and impact of natural hazard related disasters over the last decade. In 2008 alone, 235,000 people were killed and 214 million affected by 354 natural hazard disasters leading to estimated damages of US$190 billion. The increase in frequency of disasters is a result of the nature and scale of human settlement in the present age.

The number of disasters is increasing despite international efforts to reduce the loss of life and damage from natural hazards. The 1990s were declared the International Decade for Natural Disaster Reduction (IDNDR). Ten years of international research and activity were dedicated to improve countries' capacity to mitigate the effects of natural hazards; better apply and transfer existing scientific and technical knowledge; and develop programmes of education and training (Jeggle, 1999). The success of the IDNDR is debatable (see Wisner, 2001; Twigg and Steiner, 2001 for discussion). What is clear is that during the 1990s and in the decade that followed losses from natural hazard disasters continued to rise. Between 1990 and 1999 a total of 2794 disasters were reported; between 2000 and the middle of 2009 a total of 4223, an increase of over fifty percent[1]. Why, after a decade of international research and collaboration aimed at reducing the impact from natural hazards should the numbers rise so sharply? Improved data collection after a disaster is one explanation. In addition, the IDNDR has been criticised for being narrowly scientific in its

[1] Data from the Emergency Events Database (EM-DAT) http://www.emdat.be/database. Accessed August 8th, 2009.

focus when disasters are complex and require multi-disciplinary solutions (Twigg and Steiner, 2001). Despite advancements in science and technology aimed at monitoring the hazard, more and more people live and work in exposed areas increasing the risk of disaster.

One recent disaster that gained much media attention was Hurricane Katrina in 2005. It opened the eyes of the world to the fact that it was not just developing countries that could be severely impacted by natural hazards. The Category Three storm hit the Gulf Coast of the United States in August 2005, affecting areas from Florida to Texas and becoming the most costly and devastating hurricane in US history. More than 1300 people were killed, over one million displaced, and damages exceeded US$80 billion (Cutter et al., 2006, citing FEMA, 2005). The City of New Orleans was one of the worst affected areas, and received the most media attention as it highlighted the deficiencies in the American emergency management system. It showed how an urban area could be severely impacted by a natural hazard, especially with its high population density and dependence on technological systems (Colten, 2006). New Orleans is built on a flood plain, lying below sea level, and ringed by a system of constructed levees. It was these levees that were breached during the hurricane causing the flooding of around 80 percent of the city. The topography dictated which areas were flooded, however the population residing in those areas was not impacted equally. Race, gender and class were the dominant characteristics determining who suffered most (Cutter and Emrich, 2006). Why was this the case when middle and high-income homes were also flooded? The answer lies in the *vulnerability* of the population. Many low-income families lived in the areas of the city with the lowest elevation. All but two of the city’s public housing projects were built below sea-level (Colten, 2006). While wealthy residents also lived in flooded areas, they were more likely to have insurance to relocate or rebuild. Furthermore, in the case of Hurricane Katrina, vulnerability was determined to a large extent by mobility (Colten, 2006). Evacuation plans relied on people driving themselves out of the city. Public transport was organised for those without access to a vehicle, however many could not afford the bus ride. The hurricane struck two days before pay, welfare and disability cheques were issued and so people did not have the money for transport (Cutter et al., 2006). In addition, vehicle ownership in the poorest areas was well below the city average. In the flooded areas of the city, where low-income families lived, 20 percent of people were without a vehicle. The city-wide average was 10 percent (Colten, 2006). The impact of the hurricane was not a surprise to natural hazard researchers and emergency managers - it was often discussed as a worst-case scenario (Cutter et al., 2006). What it served to do was demonstrate how the pre-disaster vulnerability of a population could dictate the distribution of the impacts.

More than 10 years before Hurricane Katrina, Cutter (1994b, p.xi), when considering the increasing number of natural hazards in the early part of that decade, asked *"are these extreme events becoming more frequent? More severe? Or is the frequency of events remaining the same, but is society becoming more vulnerable to them?"* Although the changing climate is thought to be increasing the frequency and severity of meteorological hazards such as Hurricane Katrina (see McGuire et al., 2009a), the occurrence of geophysical hazards in general is not thought to be increasing (Alexander, 1995; Bankoff, 2001). Consequently, the explanation for growing losses lies in the rising vulnerability of people exposed to hazardous events. Understanding and analysing people's vulnerability forms the topic of this thesis.

1.2. Volcanic hazards: a special case

When considering the rising losses from disasters, volcanic eruptions contribute a small percentage of the total in terms of loss of life, the number of people affected and economic damages. According to the EM-

DAT database between 1900 and 2008 volcanic eruptions were responsible for only 0.3 percent of total deaths from natural hazards[2], 0.08 percent of total affected, and 0.17 percent of economic damages[3]. Why then study vulnerability to volcanic hazards?

Volcanic hazards and disasters have unique characteristics when compared with other natural hazards that require special consideration even though they only contribute a small percentage to global losses. Chester et al. (2001) argue first that it is only a matter of chance that major volcanic eruptions in the 20th Century have occurred in areas of low population densities (e.g. Katmai, Alaska, 1912, Bezymianny, Kamchatka, Russia, 1955/56). Second, data on hazard losses do not illustrate the present and future dangers from volcanic eruptions. Due to rapid urbanisation more people are exposed to volcanic hazards – currently 500 million people worldwide are estimated to live near active volcanoes (Tilling and Lipman, 1993; ISDR, 2004). This increasing number of people exposed is partly the result of many of the world's fastest growing cities, and four of the world's 20 largest cities[4] - Tokyo, Mexico City, Jakarta and Manila - being located in areas of active volcanism (Chester et al., 2001; Chester et al., 2002; Ewert and Harpel, 2004). Furthermore, a study by Small and Naumann (2001) quantifying the global distribution of human populations and recent volcanic activity found that the areas experiencing sustained population growth, such as tropical developing countries (Indonesia, Philippines, Latin America), were also areas with the densest populations residing on active volcanoes.

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[2] Natural hazards as defined by EM-DAT include drought, earthquakes, epidemics, extreme temperature, flood, insect infestation, mass movements (dry and wet), storms, volcanoes and wildfires.

[3] It is acknowledged that the new volcanic database in Witham (2005) is more complete than EM-DAT, however the EM-DAT figures have been used here in order for them to be compared to the losses from other natural hazards.

[4] The four of the 20 largest world cities are Tokyo (population 35,197), Mexico City (19,411), Jakarta (13,215) and Manila (10,686). Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. *World urbanisation prospects: The 2005 revision.* http://esa.un.org/unup. Accessed February 27th, 2007.

The continued migration to these large urban centres can partly be explained by poor living conditions and fewer employment opportunities in rural areas, particularly in developing countries. Volcanoes also offer a number of benefits to those living on their slopes, such as fertile soils for agriculture. In addition, some volcanoes such as Merapi in Indonesia are considered sacred by locals (Head, 2006; Donovan, 2009). Therefore it is a challenge for local officials to reverse this trend of migration into volcanically active areas.

It is not only volcanoes in developing countries that are densely populated. Vesuvius, Italy, is considered one of the most dangerous volcanoes in the world owing to the large population living on and around its slopes (Baxter, 2005). The city of Naples, with over one million inhabitants, is located just 10km from Vesuvius, and with no land-use planning on the slopes of the volcano since 1994 there has been extensive urbanisation. The National Emergency Plan for the Vesuvian Area (NEPVA) estimates that there are around 600,000 people living in the high risk ‘red zone’ who would be affected by pyroclastic flows and lahars in the event of an eruption similar to that in 1631. More than 1,100,000 people are located within the ‘yellow zone’ potentially exposed to heavy ash falls and lahars. Despite some sections of society having an accurate perception of the volcanic risk they face, studies suggest they have insufficient knowledge of NEPVA thus leading to potential problems in a future evacuation (Carlino et al., 2008). In addition, work by Solana et al. (2008) suggests that civil authorities around Vesuvius have an incomplete understanding on how to respond during an emergency.

Another reason the potential threat from a volcanic disaster should not be ignored, despite the statistics, is the ability of a volcanic disaster to last for months, even years, leaving cities and towns completely destroyed and uninhabitable for years after activity has ceased. This presents unique challenges for disaster management in terms of long term evacuation and resettlement. During the 1990s two important towns (one provincial capital, one country capital) were completely destroyed by volcanic eruptions – Rabaul (Papua New Guinea) and Plymouth (Montserrat) (Annen and Wagner, 2003). On the Caribbean island of Montserrat, for example, the capital town Plymouth was destroyed by pyroclastic flows and lahars during the activity of Soufrière Hills volcano that began in 1995. More than 10 years later the activity is still ongoing and the population has nearly halved as a result of the southern half of the island remaining an exclusion zone (Haynes, 2006).

Furthermore, volcanic hazards can occur without an eruption and therefore the threat from living on the slopes of a volcano is increased. On Casita volcano in Nicaragua, intense rainfall associated with Hurricane Mitch in October 1998 produced a lahar that flowed down the slopes of the volcano and completely destroyed two towns, killing over 2,500 people. After the event the towns could only be located using the Global Positioning System (GPS) as all but one house was destroyed (Kerle et al., 2003). Lahars on the slopes of Mount Pinatubo also continue to impact the population, more than a decade after the 1991 eruption (Gaillard et al., 2001; Annen and Wagner, 2003; Baxter, 2005). Wallenstein et al. (2005) emphasise that on Fogo volcano (Azores) the volcanic edifice is unstable particularly after heavy rainfall, and therefore the volcano poses a threat during periods of quiescence and this should be included in comprehensive risk assessments.

An additional consideration is the number of volcanoes globally that have no record of a historical eruption. The Soufrière Hills volcano had been dormant for centuries with no historical record of an eruption. Mount Pinatubo in the Philippines had not erupted for 500 years and was not monitored (Annen and Wagner, 2003). The Global Volcanism Program[5] database compiled by the Smithsonian Institute lists over 1500 sub-aerial

[5] http://www.volcano.si.edu/world/

volcanoes that have not erupted in historical times (since 1700) but are still nevertheless considered active. Of these, 643 are thought to have erupted during the Holocene (approximately the last 10,000 years). Scores of major cities are located close to such Holocene volcanoes, including Honolulu (within 10km of Kooloui volcano), Rome (within 25km of Monte Albano caldera), Seoul (within 100km of Ch'uga-nyong volcano) and San Diego (within 150km of Cerro Prieto lava dome). Volcanic hazards can stretch for hundreds even thousands of kilometres and can therefore impact even distant populations (see Table 2.13 in Blong, 1984).

So even though at face value the statistics seem comforting, volcanoes have the potential to impact millions of people globally, and therefore studying the vulnerability of these people will better enable disaster managers to mitigate against and prepare for the threat. Although the IDNDR had its critics for being focused heavily on physical science and technology at the outset, the emphasis did begin to shift towards focusing on the people exposed to the hazards. *"Accordingly, much greater emphasis is now placed on the particularities of the societies living on volcanoes and how they will react to damaging eruptions."* (Chester et al., 2001, p.100).

1.3. Revealing past vulnerabilities

In the paper 'Living with volcanoes', Rymer (2000, p.27) defines vulnerability to volcanic hazards as *"a measure of the number of people in the affected area and the local infrastructure"*. The explanation given for increasing volcanic risk globally is because more people live near active volcanoes. This is a simplistic explanation that fails to take into account the fact that not all people who live near active volcanoes are impacted equally. In addition, Wisner et al. (2004, p.304) suggest that vulnerability analysis in volcanic regions is of limited value as *"income levels, the quality of house construction and the type of occupation all seem to have* *little bearing on people's differential capacity to resist the volcanic arsenal of hot gas emissions, blast impact, lava flows, projectiles, volcanic mudslides (lahars) and the deposit of ash"*. Again, this is a simplistic point of view. It is correct in that if a wealthy lawyer and a poor farmer are equally exposed to a pyroclastic flow, both will likely be killed. What it ignores are the characteristics of people that might make them more likely to be exposed to the hazard in the first place, plus the demographic, cultural, psychological or economic factors that might make them less likely to evacuate, or be able to recover after a volcanic eruption.

Dibben and Chester (1999, p.135) advocate the use of vulnerability analysis for volcanic hazards and state that *"vulnerability is identified through the study of past events"*. If you look at past volcanic disasters they clearly reveal how the 'particularities of societies' that Chester et al. (2001) mention, shape who are most affected by an eruption. The following section reviews a number of well documented volcanic eruptions in the 20th Century to demonstrate the impact pre-disaster vulnerabilities had on the resulting disaster.

1.3.1. Mount Pelée, Martinique

On Martinique, Mount Pelée erupted on the morning of May 8th, 1902. This was the deadliest eruption of the 20th Century, killing over 28,000 people and completely destroying the town of St. Pierre (Scarth, 2002). All classes of society and races were killed; *"masters and maids, teachers and tradesmen, intellectuals and ignorant, black and white died together in a few awful moments"* (Scarth, 1999, p.159). Some people did leave before the eruption, however, and the reasons behind why people were still in the town itself reveal vulnerable characteristics. Activity at the volcano had increased in the months before the eruption prompting some people to evacuate St. Pierre. According to Scarth (2002) those people that had families elsewhere, such as St. Lucia and those who had money to rent houses in 'safer' areas did evacuate. Others had less choice; for example *"unless the authorities took charge of them, the poor had nowhere to go and no means of getting there."* (Scarth, 2002 p.104). Scarth (2002) also tells the story of a family who evacuated, but were forced to leave their elderly, disabled relative behind in St. Pierre because she would slow them down, and would not be able to camp in the primitive dormitory conditions provided. The population was actually encouraged to stay in St. Pierre by the government as it was believed to be the safest place within the vicinity of the volcano.

1.3.2. Parícutin

A very different type of volcanic eruption impacted an area 300km west of Mexico City in 1943. Parícutin – a cinder cone – erupted from a fissure in the middle of a corn field and provided valuable insight into the cultural impacts of a volcanic eruption. Two of the existing settlements around the new volcano were destroyed and 6,000 people were evacuated. Although the eruption itself only caused three direct deaths, more than 100 people died in new settlements established as a consequence of the eruption, from violence, disease and the loss of will to live (Scarth, 1999). Nolan (1979) discusses the impact of the eruption on five communities. It reveals the differences in culture, family ties, skills, education and resources as being key to how the different villages were impacted and how they adapted. As on Martinique, those people who had family ties elsewhere, or the resources to liquidate and relocate, moved away. Wealthier farmers could afford to buy steel ploughs and were able to cultivate the land covered in ash by the volcano, whereas others had to wait for the rain to wash away the ash (Scarth, 1999). Culture also played an important role. Parícutin volcano erupted in Michoacán state where the traditional Tarascan people still remained. The extent to which the Tarascan culture was alive in each of the villages affected the response. Some of the first people to leave the area were Spanish-speaking whereas in the traditional Tarascan villages of Parícutin and Angahuan, few non

Spanish-speaking people left initially. In addition, many elderly people refused to leave as they were emotionally attached to their land.

1.3.3. Mount St. Helens

Mount St. Helens is a stratovolcano located in southwest Washington State in the US. Activity began in March 1980 prompting the evacuation of hundreds of residents within a 24km radius, including loggers on the north side of the volcano (Perry and Lindell, 1990). The initial activity brought excitement from residents and an increase in tourist traffic; however those people who were evacuated, especially the loggers, begged to return as it appeared there was little threat with activity remaining low. Some residents refused to evacuate as activity ceased for two weeks at the end of April 1980. The most notorious of the residents was eighty-three year old Harry Truman who lived in a lodge on Spirit Lake north of the volcano. Through a mixture of stubbornness and attachment to the land, Harry refused to leave (Scarth, 1999).

The climatic eruption began on Sunday May 18th, 1980. Fifty-eight people were killed (Witham, 2005) with damages totalling more than US$1.8 billion in property and crops (Perry and Lindell, 1990). Some of those killed were loggers who had returned to their livelihoods, and Harry Truman who had refused to leave his property. The total death toll could have been much higher had the area been more densely populated or an evacuation not ordered: however the impacts demonstrate how certain vulnerabilities led to fatalities.

1.3.4. Mount Pinatubo

The response to the 1991 volcanic crisis at Mount Pinatubo in the Philippines is generally regarded as a success, as tens of thousands of people were evacuated before the main eruption on June 15th, 1991 (Scarth, 1999). In total between 200 and 300 fatalities occurred as a direct result of the eruptions, however with succeeding events, in particular lahars, the number rose to 1,202 (Scarth, 1999; Witham, 2005). Around 58,000 residents were evacuated from within a 30km radius of the volcano, in addition to 14,500 US military personnel and families from Clark Air Force Base. Prior to the eruption Mount Pinatubo was home to the Aetas – a semi-nomadic people who had lived on the volcano for 400 years. Although Aeta families only accounted for two percent of the total affected, they are regarded as having suffered the most (Mercado et al., 1996; Scarth, 1999). Thirty thousand Aetas were housed in refugee camps, where many died as they succumbed to diseases from which they had been previously isolated (Mercado et al., 1996; Scarth, 1999). Many did not leave as they were attached to their land, it was the source of their livelihoods and they had a religious affiliation with the volcano. Others who had tried to evacuate, got on the wrong buses as they could not read the signs and were so embarrassed they returned home (Scarth, 1999).

Further consequences of the eruption came from roof collapse and secondary lahars. The eruption coincided with a tropical storm that caused wet tephra to collect on roofs. Public buildings such as schools and hospitals suffered the most damage as their large roof spans were unable to withstand the dense wet tephra. Secondary lahars were also a persistent hazard, causing over 100 deaths by 1993 and the evacuation of thousands of people on numerous occasions. Families with disabled members, young children or the elderly often found it hard to evacuate, and many people wanted to bring livestock with them to the refugee camps (Scarth, 1999).

1.3.5. Montserrat

Lastly, the continual eruption on the island of Montserrat in the Eastern Caribbean is addressed. The Soufrière Hills volcano began erupting in 1995 and continues to this date. More than half the island's population of 10,500 has left and the southern half of the island, including the capital Plymouth, has been destroyed. Discussions continue regarding the management of the crisis by the British government on the island (see Clay et al., 1999; Haynes, 2006); what is interesting here, however, is consideration of why the 19 people who were killed on June 25th, 1997, were in the exclusion zone.

Pattullo (2000) reports on the social aspects of the crisis and provides details as to who was killed in the only fatal eruption and the possible explanations as to why these people might have been in the exclusion zone. The volcano threatened the fertile south of the island, where many people had their crops and livestock. When residents were ordered to evacuate no crop insurance scheme compensated them for their loss of livelihoods and therefore some farmers returned to tend their land and livestock. Some of these farmers were even contracted by the island's Ministry of Agriculture and Emergency Operations Centre to provide crops for the island. Those residents who had transferable skills such as teaching or nursing were able to evacuate the island and find work elsewhere. Wealth was also a factor for Montserratians in deciding upon whether to evacuate. Pattullo (2000) describes one family living in the exclusion zone that did not have the money to leave and had nowhere to go; therefore they remained in their house. Furthermore, the conditions in the evacuation shelters prompted some people to return to their homes, either for privacy, as the shelters were overcrowded, or to cook to bring hot food back to the shelters which lacked facilities. Finally, there was confusion as to the threat the volcano posed within the exclusion zones. Many essential services such as the airport and facilities in the capital Plymouth were still running despite either being in the exclusion zone or on the outskirts. One lady and her daughter drove from the airport into the exclusion zone the day before the fatal eruption, and passed no signs or checkpoints warning her of the dangers.

1.3.6. Common vulnerability characteristics

These five 20th Century volcanic disasters serve to illustrate how the particularities of the society before the disaster led to disproportionate impacts or fatalities. In addition they highlight how the management of the different disasters led to either increased or decreased vulnerability of the population. Although the details of how each disaster progressed are specific to the local politics, culture, economy and society of that country or region, common characteristics can be identified, which are summarised in Table 1.1.

Vulnerable characteristic	Increase/decrease vulnerability	Example of where this impacted disaster losses
Transferable assets (skills, education)	Decrease	Parícutin, Montserrat
Economic resources	Decrease	Mount Pelée, Parícutin, Montserrat
Vulnerable livelihood (agriculture, forestry)	Increase	Parícutin, Mount St. Helens, Mount Pinatubo, Montserrat
Cultural, religious ties, attachment to land	Increase	Parícutin, Mount St. Helens, Mount Pinatubo
Extended family	Decrease	Mount Pelée, Parícutin, Montserrat
Elderly, disabled, poor health	Increase	Mount Pelée, Parícutin, Mount Pinatubo, Montserrat
Poor shelters	Increase	Mount Pinatubo, Montserrat
Disaster management	Increase Decrease	Mount Pelée, Parícutin, Montserrat Mount St. Helens, Mount Pinatubo

Table 1.1: Vulnerability characteristics.

In all these examples a strong vulnerability component is revealed therefore more research needs to be conducted to better understand current vulnerability to volcanic hazards in order to analyse who may be vulnerable to future eruptions and why.

1.4. Aim and outline of thesis

With a strong vulnerability component in volcanic disasters identified, the aim of the work presented here is to investigate how one goes about analysing this concept to inform disaster management. Small and Naumann (2001, p.107) argue that *"understanding human vulnerability to natural hazards requires more than merely quantifying exposure. The social, cultural and economic dimensions are at least as important as the physical components"*. This requires an integrative approach to the research, where aspects of traditional scientific methods are incorporated with social science theories and methods (Haque et al., 2006).

A vulnerability analysis is often not completed, particularly in developing countries due to a lack of expertise, time, resources, and a focus on short term response. Furthermore, there is no agreed template or model to use and this may be an additional barrier to mainstreaming vulnerability analyses into disaster management. Consequently, the theoretical approach taken here is a problem solving one. It is acknowledged that there are other theories relating to vulnerability to natural hazards– for example, development (Anderson and Woodrow, 1989), political ecology (Wisner et al., 2004), and anthropology (Oliver-Smith, 1996). This research, however, is not grounded in any one of these theories as it takes a practical approach and aims to integrate, as advocated by Haque et al. (2006), ideas and methods from a wide range of research on vulnerability to natural hazards. The aim is to understand what characteristics of people and places make them vulnerable to volcanic hazards and practically, how does one go about measuring and analysing the concept.

In the literature there are a wide range of approaches to defining, modelling and measuring vulnerability. These different views originate from different concepts of the causes of a disaster. Research into vulnerability is often grounded in one of these views. The approach taken in this thesis, however, is a multi-disciplinary, multi-method one where stakeholders frame the problem and define vulnerability. Acknowledging that there are a variety of definitions, models and methods available to capture and analyse vulnerability, how do they compare and contrast and how do views of the stakeholders differ? To research these questions four different methods have been used to capture and analyse vulnerability to volcanic hazards on the island of St. Vincent in the Eastern Caribbean. The location was chosen as there is one active volcano that has erupted in historical times and is expected to erupt again in the future, and there is currently no volcanic vulnerability analysis being used by disaster managers. The four methods (Social Vulnerability Index, building vulnerability analysis, stakeholder mental mapping, and historical vulnerability analysis) were designed to complement each other and build on the limitations of each. They utilised both quantitative and qualitative techniques and originated from different academic disciplines.

The Social Vulnerability Index calculated for St. Vincent quantifies socio-economic and geographic vulnerability as identified by stakeholders during interviews. This method uses secondary census data and takes a geographic approach to analysing the results. Building vulnerability to tephra and pyroclastic flow/surge hazards is quantified using primary data from a field survey. These data are used to calculate the potential loss of residential buildings and life for the current St. Vincent volcanic hazard scenario and adopts the traditional volcanology and engineering approach. The third method, taking a social science approach, captures stakeholder perceptions of vulnerability to volcanic hazards through mental mapping. This enables a comparison of the results with those maps created in methods one and two. Finally, a historical vulnerability analysis utilises primary data from interviews and secondary data from historical documents to identify possible root causes of vulnerability to the volcano on St. Vincent. This historical geography method was completed last as it helps develop an understanding of why the vulnerabilities identified in methods one to three exist.

The following chapters present a review of the literature on vulnerability in natural hazards research which helped formulate the research questions (Chapter Two). The research design and description of the case study site is outlined in Chapter Three, followed by Chapters Four to Seven which describe each of the four methods adopted for vulnerability analysis. Chapter Eight discusses the four methods and compares and contrasts the results. Chapter Nine concludes the thesis and presents ideas for further work.

The structure of the thesis can be visualised with the following schematic (Figure 1.1):

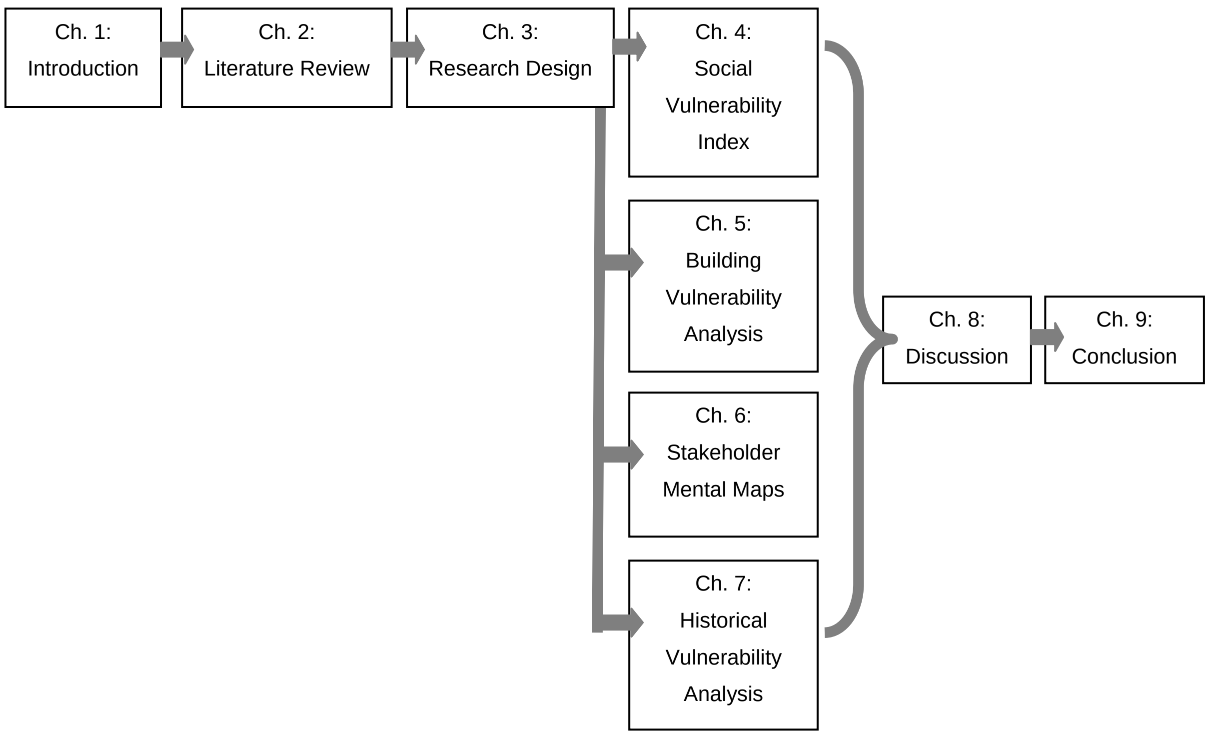

Figure 1.1: Thesis structure.

The originality of this thesis is that it utilises a range of theories, models and methods from the vulnerability literature to complete a holistic analysis. By completing these four methods for one area it enables a critique of the methods and the results to be compared and contrasted in order to answer whether or not the methods all capture the same elements of vulnerability, and practically which are the most useful and appropriate models and methods to adopt. The work also develops approaches for incorporating views of stakeholders into traditional quantitative vulnerability analyses.

1.5. Definitions used in this thesis

Throughout the thesis a number of terms are used that have a range of possible meanings. The following outlines the definitions of four key terms – natural hazard, vulnerability, risk and disaster – subscribed to by the researcher.

Natural hazard: a naturally occurring event (e.g. volcanic eruption, earthquake) that has the potential to cause harm.

Vulnerability: susceptibility to loss. Includes loss to individuals, communities, infrastructure, and/or economies. Vulnerability is often characterised using indicators that measure the degree to which an individual, for example, is threatened by a hazard event, and indicators that measure that individual's ability to respond to and cope with a hazard event (includes resilience and capacity).

Exposure: the number or value of assets in the area.

Risk: probability of loss. A function of hazard, vulnerability and exposure.

Disaster: occurs from the interaction of a natural hazard event with society, when the impacts outweigh the society's capacity to cope.

Chapter 2: Literature Review

2.1. Introduction

"Studying the interface between the natural environment and human activities has not proved easy and much of the history of geography has consisted of successful and unsuccessful attempts to devise frameworks in which the theme may be brought into focus" (Chester, 1993, p.228).

This review of relevant literature explores how different researchers have approached the problem of studying and conceptualising that interface between humans and their environment. The focus here is on hazardous environments and in particular what role the natural hazard and society play in causing a disaster event and how vulnerability has been conceptualised and measured. Chapters Four to Seven describe the four methods used in this research, and each contains a short review of relevant literature relating specifically to methods. This chapter, therefore, provides a broad overview of models and methods relating to vulnerability analysis in natural hazards research, and how vulnerability has been conceptualised and measured in volcanology.

First, a discussion of how different schools of thought within the natural hazards and disaster community conceptualise 'disaster' and people's response is presented, followed by how vulnerability is defined by international agencies. The review next explores different definitions of the term 'vulnerability' and the corresponding models and methods adopted to measure and analyse the term. The final section summarises how vulnerability is conceptualised today for natural hazards in general, and vulnerability research in volcanology.

2.2. What causes a disaster?

Social scientists from a range of disciplines including sociology, geography, and psychology have long been interested in human interaction with the environment. In particular, researchers have attempted to answer the question, what causes an extreme event such as a volcanic eruption or an industrial chemical spill, to become a disaster? Cutter (1994a) reviews work in three parallel streams of research that all attempted to answer the question of disaster causation, and how people respond. According to Cutter (1994a) the three streams of research evolved independently, with some overlap at times, and all had a slightly different focus. The fields of research are disaster studies, risk analysis and management, and natural hazards.

Disaster studies in sociology derived from efforts to support US civil defence during the Cold War. The aim was to understand how populations reacted to peacetime disasters in order to be better prepared for wartime disasters (Quarantelli, 1988). The main questions were to do with panic and fear and how people might react to the extreme event, and how that could be managed. Analogues for potential wartime disasters such as a bomb attack were found by studying natural hazards such as earthquakes and tornadoes. Disaster studies had an applied focus which influenced the methods adopted as well as what constituted a disaster. The majority of this early work was carried out in the US, funded by the US government and mainly looked at response and reaction to an extreme event as opposed to prevention and mitigation.

The second of the three streams of work was risk analysis and management. This shifted the nature of the risk to more technological sources such as industrial failures, and the focus here was really to develop analytical techniques and measures to quantify the risk, and to help governments regulate the risk. Covello and Mumpower (1985) discuss how risk analysis in its more primitive form was carried out by ancient Babylonian societies in order to make difficult decisions and that modern risk analysis has its roots in mathematical theories of probability from the 17th Century. The seminal work in this field, however, was that by Starr (1969). Starr argued that it was necessary to understand the relationship between the social benefit and cost of adopting a new technology, for example, and not just focusing on the performance and monetary benefits and costs. He offered an approach for quantifying social benefit and cost, and introduced the distinction between voluntary and involuntary risks. The initial study by Starr investigated a range of risks and concluded that society was more willing to accept risks from voluntary activities.

The last of the three streams of work discussed here – natural hazards – was actually the first to develop, and forms the focus of the remainder of this literature review. The evolution of the natural hazards discipline is described in the following section.

2.3. Natural hazards paradigm

The natural hazards field of research has its roots in geography and human ecology. Harlan Barrows is credited with being one of the first researchers to investigate the interaction between human systems and the physical environment, and introduce human ecology as the line of enquiry. Human ecology as defined by Barrows (1923, p.3) *"will aim to make clear the relationships existing between natural environments and the distribution and activities of man"*. The focus was on man's adjustment to the environment. Gilbert White was one of Barrow's students and continued this work by first looking at human occupation and adjustment to floods in the US (White, 1945). This research came about in response to trying to understand how man adjusted to risk and uncertainty with respect to the flood hazard in the US, and what did that understanding imply for public policy. In 1936 the US government had invested heavily in flood control works; however two decades later, when the affect of that investment was appraised it was discovered that flood losses had actually increased (White, 1974, citing White et al., 1958).

Out of this research came a new field of investigation into natural hazards; human occupation and adjustment. White was joined by colleagues such as Robert Kates, Ian Burton and Kenneth Hewitt, and together they were referred to as the 'Chicago School'. Their human ecology approach to floods, and later other geophysical events, centred around five main objectives:

1. To estimate the extent and nature of human occupancy in areas subject to extreme natural events;
2. To determine the range of possible adjustments by social groups to these extreme events;
3. To examine how people perceive extreme events and the hazards resulting from them;
4. To examine the processes by which damage-reducing adjustments are chosen; and
5. To estimate the effects of varying public policy upon the set of responses.

(Burton et al., 1968; Hewitt and Burton, 1971; White, 1973; White, 1974).

Objectives three and four *"represented at the time a major innovation, for White and his colleagues recognised that the processes by which individuals, cultural groups and societies choose adjustments when faced by hazards are extremely complex"* (Chester, 1993, p.232). The argument was that people did not always react in an economically rational manner – i.e. choosing an adjustment if the economic benefits outweighed the economic costs. Using evidence from a number of place-specific studies in the US the Chicago School sought to explain why humans chose to make the adjustments they did in the face of natural hazards and suggested a number of decision-making models (see Kates, 1971; White, 1973; Slovic et al., 1974). This thinking led to a whole field of studies on hazard and risk perception. The perception literature is not the focus of this review: for a summary see Slovic (2000).

This school of thought was referred to as the 'dominant' approach and although it *"accepts that no hazard can exist without human intervention, it argues that physical processes – in particular their magnitude and frequency – are first-order determinants of a disaster and that differences between societies are at a lower, albeit still significant, level of importance"* (Chester, 1993, p. 237). There is some mention, however, of the effect of society on disaster losses. For example, in reviewing damage from two storms in Bangladesh and the US, Burton et al. (1978, 1993) did recognise that the impacts were not distributed equitably. In Tropical Storm Agnes in the US in 1972 250,000 people were evacuated and a dozen people were killed. In contrast in the Bangladesh cyclone of November 1970 at least 225,000 people lost their lives. The authors' explanation for this disparity in deaths was *"to be poor as a nation or a person is to be particularly vulnerable"* (Burton et al., 1978, p.12) however they also state that individuals or public agencies had made the decision to locate in those areas exposed to cyclones. The connection between poverty and vulnerability is the only mention of vulnerability as a cause of disaster. In addition, their explanation for the recognised increase in the total number of disasters worldwide was threefold: an increase in population, increased occupancy of hazardous locations, and a greater reporting of disaster events (Burton et al., 1968; Burton et al., 1978; Burton et al., 1993). So even though the hazards paradigm recognises that society plays a role in disaster causation, the focus really is on how and why people choose to live in hazardous areas, and how they choose adjustments. There is little mention of vulnerability, other than being poor, and the implication is that people have the choice to live and work where they do and therefore could reduce their losses with better decision making. The people exposed to a hazard are considered in this discipline; however the approach to reduce their risk from a natural hazard event is through technocratic solutions. Technocracy refers to the control of society or industry by technical experts. Technocrats believe societal problems are solvable, often with engineering solutions. Although under the hazards paradigm White and his colleagues did not necessarily advocate engineering solutions such as flood levees, they did advocate better decision-making and adjustments to hazards as a way to reduce disaster losses, often with a top-down approach.

A very different approach to understanding the causes of disasters and why and how people adjust to hazards developed in critique of the work by White and his colleagues. This is discussed in the following section.

2.4. Critique of the hazards paradigm: vulnerability as a core concept

The hazards paradigm evolved from its roots in flood plain studies and progressed to look at a number of hazards worldwide, but it still had many critics. In particular, social scientists suggested that disasters had their root causes in society and not the hazard event. This group of researchers are often referred to as having the radical or vulnerability perspective; a number were from the newly-formed Disaster Research Unit at the University of Bradford. These researchers took a political economy view of disasters claiming that populations were made more vulnerable to hazards by social, political and economic constraints (Cutter, 1994b).

There are a number of particular arguments that the radical perspective established in its critique of the hazards paradigm. According to Chester (1993) the seminal work in this field was that edited by Hewitt (1983b) ‘Interpretations of Calamity’; however the concept of society as the root cause of disaster was first presented by O'Keefe et al. (1976). Critics' main arguments with the dominant hazards approach were that the extreme impacts of natural hazards could not be explained purely in physical terms, or as a consequence of the occupation of hazardous terrain. Disaster losses could not be mapped by tracing the hazard alone. It was differences in the societies that affected how a hazard impacted an area. O'Keefe et al. (1976, p.566) stated that *"disaster marks the interface between an extreme physical phenomenon and a vulnerable population. It is of paramount importance to recognise both of these elements. Without people there is no disaster"*. The natural hazards paradigm described above also specified that a hazard could not be a disaster without people, however they did not consider the vulnerability of that population explicitly. According to Hewitt (1983a) the direction of explanation was from the physical environment to its social impacts. In contrast, work under the radical perspective focused on society first.

The work of those from the radical perspective was at first very much focused in poor developing countries, addressing slow-onset hazards such as drought whereas the hazards paradigm focused initially on geophysical events. Instead of suggesting that the rise in disasters was a result of population growth, increased occupation of hazardous lands, and more complete reporting of disasters (as White and his colleagues initially argued), the researchers from the radical perspective sought an explanation in the growing *vulnerability* of the population (O'Keefe et al., 1976).

An additional argument from the radical perspective was that natural hazards should be viewed as a part of everyday life, and not as a one-off extreme random event. Much of the work in the hazards paradigm describes disasters as extreme, unscheduled and/or unpredicted events. Hewitt (1983a) argues that hazards should be viewed as a part of 'ordinary' life, and not as an extraordinary occurrence. People choose to adjust to a natural hazard when the hazard is viewed in context of other everyday pressures such as feeding a family or continuing work. Pressures of underdevelopment, and from some authors, the theory of marginalisation, are societal causes of disaster that far outweigh the importance of the hazard (Susman et al., 1983). In many cases people do not have the resources to provide themselves with modern adjustments to hazards as advocated by White and his colleagues. As a result they are often found to return to hazardous locations after a disaster has struck (O'Keefe et al., 1976; Susman et al., 1983).

The vulnerability paradigm, like the hazards paradigm, is also one-sided in some respects, in that it is focused on developing countries and hazards such as drought. It was very important that they recognised the need to consider people in the context of a disaster; however one cannot discard the value of technology as a way of monitoring and minimising hazard impacts. Sometimes the top down approach is appropriate as local people may not have the necessary expertise to reduce disaster losses.

What the work under the radical perspective did serve to do was shift the focus onto societal vulnerability and understanding the cause of a disaster from this viewpoint, rather than having the hazard event as the starting point. This shift in ideas is evident when reviewing international concepts and definitions of disaster risk. This is discussed in the following section.

2.5. International definitions of disaster risk and vulnerability

The dominant hazards view of disasters was that adopted by international agencies such as the United Nations (UN) and World Bank, and to some extent this view remains today (Bankoff, 2001), although there has been a move over the past decade or more towards considering vulnerability as a core concept.

Some of the first work on vulnerability to natural hazards arose out of the Office of the United Nations Disaster Relief Co-ordinator (UNDRO) Expert Group Meeting on Vulnerability Analysis (UNDRO, 1980). One aim of this meeting was to agree on the definitions of some widely used terms in disaster prevention and mitigation, including vulnerability. They proposed a definition of vulnerability as *"the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude on a scale from 0 (no damage) to 1 (total loss)"* (UNDRO, 1980, p.5). Elements at risk included populations, buildings, and economic activities in a given area. This was a very quantitative definition, which reflected the norm at the time.

On the understanding that the science and technology existed to reduce losses from disasters if applied effectively, the 1990's was declared by the UN as the IDNDR. This initiative was the work of natural scientists at the outset, who believed that greater application of scientific and technical knowledge should enable countries to reduce the loss of life and damage from natural disasters (Jeggle, 1999). This technocratic approach is evident in the five goals set out at the beginning of the decade, which focused on the transfer of knowledge and skills from developed to developing countries covering topics such as mitigation, early warning systems, technical assistance, technology transfer, education and training (Hewitt, 1997).

The IDNDR had many critics for its failure to take a more holistic approach to disaster management at the beginning of the decade. According to Varley (1994) this emphasised how unwilling policy makers were to look beyond the technical solutions. Indeed the term vulnerability or the role that social scientists could play in preparing for disasters was never mentioned in the UNDRO Resolution that established the IDNDR (Cannon, 1994).

Mid-decade, however, a number of costly disasters such as Hurricane Andrew highlighted that, on its own, science was insufficient to tackle disaster reduction. The IDNDR did subsequently begin to include the vulnerability, bottom-up approach into its strategies. In 1994 at the World Conference on Natural Disaster Reduction in Yokohama, Japan, the member states produced the 'Yokohama Strategy and Plan of Action for a Safer World', and affirmed that society in general had become more vulnerable to natural disasters, and that it was the poor and socially disadvantaged groups who were usually most affected[6]. At the end of the IDNDR the UN General Assembly founded the International Strategy for Disaster Reduction (ISDR). The aim was to continue the work in shifting the emphasis away from hazards research as traditionally conceived to *"incorporating physical and socio-economic dimensions of vulnerability into the wider understanding, assessment and management of disaster risk"* (ISDR, 2004, p.11).

Ten years after Yokohama the ISDR General Assembly convened a follow up meeting in January 2005: The World Conference on Disaster Reduction at Kobe (Hyogo, Japan). The objectives were to review the Yokohama Strategy and identify lessons learned and future challenges. The outcome of the meeting was the Hyogo Framework for Action 2005-2015 which outlined five priorities for action to continue the emphasis on disaster risk reduction at local and national levels. Vulnerability was now a recognised concept and considered an integral part of reducing losses from disasters. The definition of vulnerability had evolved in the decades since the UNDRO (1980) to *"the set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility of a community to the impact of hazards"* (ISDR, 2004, p.16).

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[6] Yokohama strategy and plan of action for a safer world: Guidelines for natural disaster prevention, preparedness and mitigation. [online]. Available from: http://www.undp.org/bcpr/disred/documents/miscellanous/yokohamastrategy.pdf#search=%22yokohama%20strategy%22. Accessed August 21st, 2006.

2.6. Definitions and models of vulnerability

Out of these various paradigms and approaches come different models and frameworks with which disasters and vulnerability can be conceptualised. The subsequent sections look first at definitions of vulnerability and models for conceptualising the term, followed by a review of some of the available methods to capture vulnerability.

Hilhorst and Bankoff (2004, p.1) when discussing the wide range of perspectives associated with vulnerability begin by saying *"the nature of this [vulnerability's] complexity dictates that there can be no general theory and therefore no simple solutions"*. Indeed, the more people that research vulnerability, and the more disciplines that grapple with the subject, the more perspectives, definitions and models arise.

Birkmann (2006d, p.11) in the UN University Institute for Environment and Human Security (UN-EHS) publication on measuring vulnerability states that *"it is evident that measuring vulnerability requires, first and foremost, a clear understanding and definition of the concept of vulnerability"*. Therefore this section will begin by discussing the problem of defining the term vulnerability, and then continue with a critique of some of the key models in the literature that attempt to represent the causes of vulnerability.

2.6.1. The problem with defining terms

The previous section demonstrated how the UN definition of vulnerability has evolved over the past 40 years from a purely quantitative term, to one that includes social, economic and environmental factors in addition to physical vulnerability. The UN ISDR definition is not, however, the only one used today. There are a multitude of different definitions in the literature. Cannon (2008, p.351) goes so far as to say that *"the term vulnerability has become so vague and abused that it is in danger of losing* *its analytical value. Like the term sustainability, it has become a buzz word lacking precision"*. Cutter (1996, p.530) provides one explanation for the abundance of the use of the word vulnerability and its various meanings: *"many of the discrepancies in the meanings of vulnerability arise from different epistemological orientations (political ecology, human ecology, physical science, spatial analysis) and subsequent methodological practices"*. An engineer will conceptualise, define and measure vulnerability in a very different way to a social scientist working with communities on drought hazard.

Cutter (1996) lists no less than 18 different definitions to illustrate her point that vulnerability means different things to different people. In a similar way, Weichselgartner (2001) lists 24 definitions mainly from the geography discipline. More recently, the UN-EHS published a comparative glossary of the various components of risk (Thywissen, 2006). Within the paper were 14 definitions of hazard, 14 of resilience, 23 definitions of risk and 36 of vulnerability. The paper concluded with a description of central characteristics for each term and the conceptual framework of risk as a function of hazard, vulnerability, resilience and exposure. Thywissen also noted that these terms can further be defined by individuals depending on the specific context of the research. McEntire (2005) lists 15 different disciplines, from geography to political science to homeland security, and outlines their relative views on vulnerability. Rashed and Weeks (2003a) describe vulnerability as an 'ill-structured' problem. They define ill-structured problems as ones *"which possess multiple solutions and contain uncertainty about the concepts, rules and principles involved to reach these solutions…such problems lack a single solution or algorithm and in many cases experts may not agree regarding whether a particular solution is appropriate"* (p.550). This certainly is the case when reviewing the vulnerability literature. The authors also argue that a major problem with the definition of vulnerability is that it is often confused with that of risk.

A number of these vulnerability definitions are similar, however, despite crossing disciplinary boundaries. When reviewing the 36 definitions in Thywissen (2006) certain words and phrases reappear. Vulnerability is defined as the characteristics of people, households or economies that increase the likelihood to suffer damage given a hazard event. It is considered a function of one or any number of the following: exposure, capacity to cope and adapt, resilience, livelihood stress, susceptibility, sensitivity and/or weakness.

There is, therefore, common ground on how to define vulnerability within and between disciplines. Models that conceptualise the term, however, can be very different. This is the topic of the following section.

2.6.2. Models to conceptualise vulnerability

With the recognition that trying to find one common definition of vulnerability might be inappropriate, Birkmann (2006d, p.16) provides an overview of the key *"spheres of the concept of vulnerability"* (Figure 2.1).

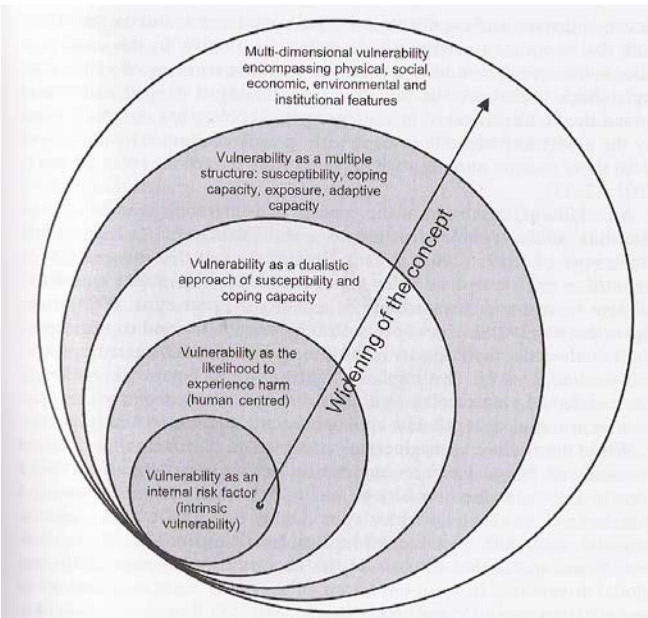

Figure 2.1: Key spheres of the concept of vulnerability (Birkmann, 2006d, p.17).

The common thread that runs through nearly all concepts of vulnerability is that it is an *"intrinsic characteristic of a system or element at risk"* (Birkmann, 2006d, p.16). This forms the inner circle. The concept widens in scope following the arrow in Figure 2.1 with the introduction of different elements such as human, physical and environmental. The second progression in Figure 2.1 is the inclusion of vulnerability as the likelihood to cause harm to people – the human centred approach. This widens further in the third circle to also include the concept of capacity to cope with disaster. As the circles widen, vulnerability is represented as a multi-dimensional concept that addresses aspects of coping, exposure, adaptive capacity, and finally in the outer circle, to encompass global economic and environmental factors.

These concepts illustrate the shift from a purely physical, technocratic approach to vulnerability and risk assessment, to more interdisciplinary, bottom-up research. There are a number of different conceptual frameworks that systemise vulnerability and that fall within various circles in Figure 2.1. It is acknowledged that there are different models from disciplines such as global environmental change, development, and sustainable livelihoods. The focus of this literature review, however, is vulnerability in relation to natural hazards; therefore the remaining discussion will review some of the models of vulnerability that are common in this discipline.

The vulnerability literature is wide-ranging and can be hard to make sense of. Within the natural hazards field Cutter (1996) describes three distinct themes that neatly categorise the different approaches. These are useful to consider and help frame the remaining literature review. These themes are:

- *Vulnerability as a pre-existing condition*. Considers the source of hazard and people's exposure to the hazard and potential loss of life and property given occupation and building stock;
- *Vulnerability as a social construct*. Focuses on the construction of vulnerability rooted in historical, cultural, social and economic processes, and society's ability to cope with and respond to a hazard; and
- *Vulnerability as hazard of place*. Combination of the two themes above, focusing on a specific geographic or social domain.

According to Cutter (1996, p.530) *"while not mutually exclusive nor exhaustive, this typology helps to distinguish between the theoretical and methodological orientations of the current [vulnerability] research"*. Although this typology was devised over 10 years ago, it is still relevant and a very useful way of making sense of the vulnerability literature and range of models and methods available. One model from each of the three themes is presented below. These were chosen to review as they commonly appear in the natural hazards literature and illustrate the varying approaches to conceptualising disaster risk and vulnerability.

2.6.3. Vulnerability as a pre-existing condition

Under this theme vulnerability is considered as an individual's or infrastructure's location with respect to a hazard event, and the potential economic loss or loss of life (exposure). This falls into the inner circle in Figure 2.1 above - vulnerability as an intrinsic factor of risk - and is often conceptualised as part of a pseudo risk equation. For example, the United Nations Educational, Scientific and Cultural Organisation (UNESCO), in a meeting on the statistical study of natural hazards and their consequences, defined risk as *"the possibility of loss"* (UNESCO, 1972, p.2). Fournier d'Albe, (1979, p.321) of UNESCO goes on to convert this definition into the pseudo equation:

Risk = (Value) x (Vulnerability) x (Hazard)

This approach to modelling vulnerability to natural hazards such as earthquakes, volcanoes, storms and floods formed the basis for the early work by UN organisations (UNESCO, 1972; UNDRO, 1980). Here vulnerability is *“a measure of the proportion of the value…which is likely to be lost as a result of a given event”* (Fournier d'Albe, 1979, p.321). Value is measured as either the number of human lives ‘at stake’, capital value (land, buildings, etc.) or productive capacity (factories, power plants, agricultural land). Fournier d’Albe (1979, p.322) comments that value and vulnerability *“are relatively easy to assess”* it is the hazard that he considers extremely difficult to quantify.

2.6.4. Vulnerability as a social construct

The second of the three themes is vulnerability as a social construct where the causes of vulnerability are understood to be rooted in historical, cultural, social and economic processes. One model which conceptualises this view of vulnerability is the Pressure and Release model (PAR) (Wisner et al., 2004) (Figure 2.2). This model is from authors associated with the radical critique of natural hazards research discussed in Section 2.4. The focus is placed on people, emphasising that it is the difference in society that leads to differentiating patterns of disaster losses within an affected area and aims to understand what forces and processes give rise to the marginalisation and vulnerability of people. Wisner and colleagues define vulnerability as *“the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard”* (Wisner et al., 2004, p.11). It is important to note that the term vulnerability as used here only refers to people. Buildings they consider to be susceptible or unsafe; economies fragile; landscapes such as unstable slopes are hazardous; and regions on the Earth’s surface are hazard prone.

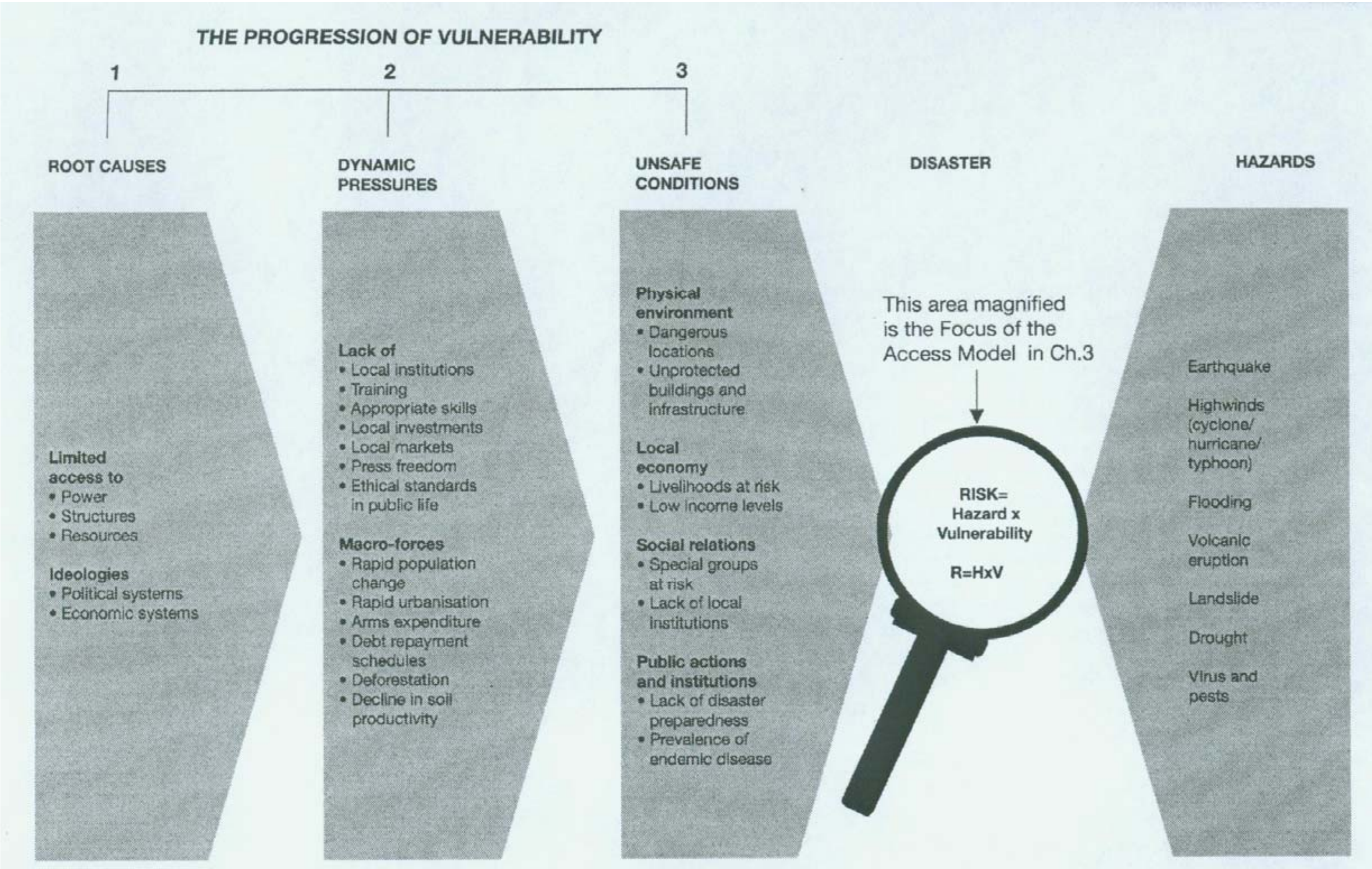

Figure 2.2: Pressure and Release model (Wisner et al., 2004, p.51).

A disaster is at the intersection of two opposing forces – hazard and vulnerability. Vulnerability is divided into three separate stages that model the progression of the concept as something that is distant in both time and space culminating in the conditions seen today. These three stages are termed ‘root causes’, ‘dynamic pressures’ and ‘unsafe conditions’. This forms the ‘pressure’ part of the model. The ‘release’ is viewed in what is effectively a reversal of Figure 2.2 where factors that cause risk are addressed through initiatives such as education, preparedness and mitigation on a local, national and international scale.

Within this model vulnerability is again seen as a part of the bigger picture of disaster risk and the hazard is also an important component as in the equation from Fournier d'Albe (1979). A second similarity between the two models is the inclusion of factors such as buildings, infrastructure and agriculture. The concept of vulnerability in the PAR model is greatly expanded upon, however, when compared with the more quantitative definitions. The characteristics of the population that make them more susceptible to loss such as education and income are included. In addition, the model can be used to trace how these vulnerable characteristics came to exist given the history and political structure of the study area.

2.6.5. Vulnerability as hazard of place

The final of the three themes is vulnerability as hazard of place whereby both the exposure component of vulnerability is combined with the social component focusing on a specific geographic domain. The model which conceptualises this theme is the Vulnerability of Place (VoP) model (Cutter, 1996) (Figure 2.3).

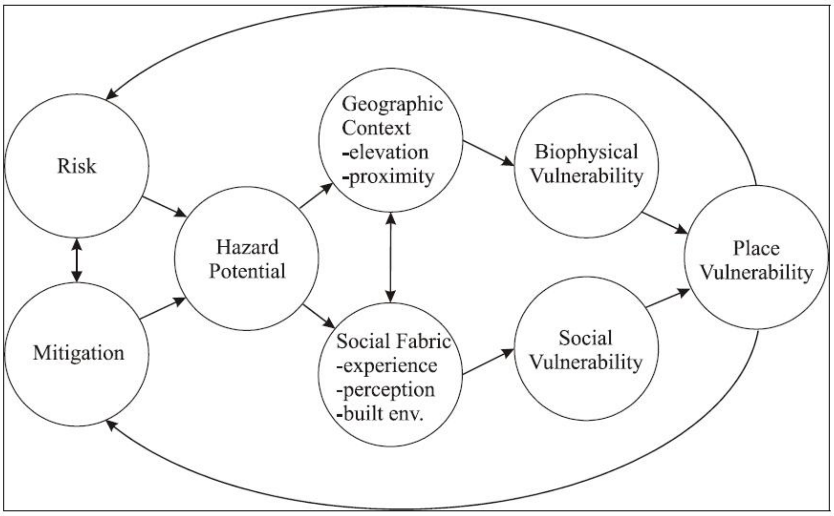

Figure 2.3: Vulnerability of Place model (Cutter, 1996, p.536).

In a 1989 paper on the hazard from airborne toxins Cutter revisited the work by Hewitt and Burton (1971) on 'hazardousness of place' where they attempted to map all hazards impacting London, Ontario, Canada, taking a geographic approach. Cutter and Solecki (1989) proposed the initial 'Hazards of Place' model based on the work by Hewitt and Burton (1971) where the 'hazard potential' is a combination of the magnitude and frequency of the physical event (risk), but also the adjustment and preparedness (mitigation) of the population. These form the first three parts of Figure 2.3. The second half of the model was constructed in response to Cutter's struggling with the issues of there being no synthesis in the vulnerability literature and according to Cutter (1996, p.529) the resulting VoP model *"clarifies many of the discrepancies found in the existing literature"*. The model is a complex interaction of the risk, vulnerability, hazard and value components of Fournier d'Albe (1979) equation with two feedback loops. Risk is the probability of the hazard occurring and combines with mitigation to create hazard potential. Hazard potential is then filtered through the social fabric to determine social vulnerability, in addition to being filtered through the geographic context to determine biophysical vulnerability. The intersection of the two creates place vulnerability. The dynamic nature of vulnerability is represented by Cutter in Figure 2.4 with change in time (T).

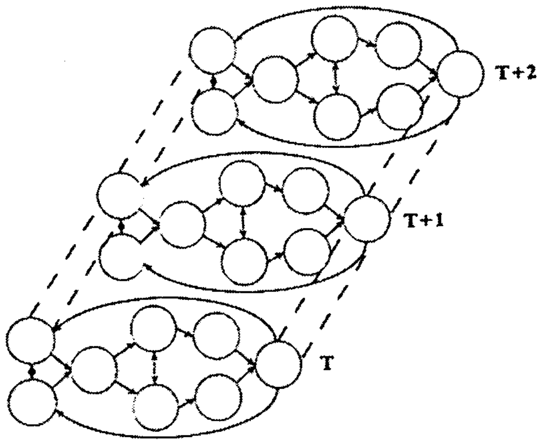

Figure 2.4: Vulnerability of Place model over time (Cutter, 1996, p.536).

2.6.6. Summary

The first model is quantitative with a narrow focus and does not allow for the inclusion of broader social or historical themes. Under this model, the approach to reduce risk is to reduce the value of the elements exposed to the hazard through either long term land-use planning and/or short term evacuation.

In contrast, the PAR model does not lend itself to quantifying vulnerability; rather it is used for conceptualising the processes involved in constructing vulnerability and disaster risk. It includes a wider range of factors but is very hard to practically measure some of these vulnerabilities such as ‘access to political power’.

The advantage of the VoP model is that it sets out to combine divergent concepts of vulnerability discussed throughout this chapter: that of people and buildings being vulnerable because of their location with respect to a hazard event, and vulnerability as a social construct. It acknowledges the role both parts play in constructing the vulnerability of place and how these vulnerabilities are determined by the existing geographic context and social fabric of the area. However, it can be a difficult model to follow with the numerous arrows and feedback loops. Furthermore, the definition of risk is not the one subscribed to in this thesis. Cutter defines risk as the probability of the hazard occurring, whereas here risk is understood as the intersection of hazard *and* vulnerability.

Models for conceptualising vulnerability are widespread in the literature from many disciplines. Three models representing the main concepts from natural hazards research have been critiqued here. Despite the differences, all these frameworks fit into Birkmann's key concepts of vulnerability in Figure 2.1. The common theme is that vulnerability is an intrinsic part of risk and the risk assessment process. The differences lie in how vulnerability is conceptualised and defined. This is dependent on the research community from which the framework originates, and the goal of the framework and vulnerability analysis itself.

Defining and conceptualising vulnerability within a risk framework are the first two processes required before a vulnerability analysis can be undertaken. The third step is to design suitable methods to capture the different concepts described above. The following section discusses some of the methods adopted for measuring and analysing vulnerability under each of the three themes outlined here.

2.7. Methods for vulnerability analysis

2.7.1. Vulnerability as a pre-existing condition

Under this conceptual framework vulnerability is viewed as the exposure of people or infrastructure to the hazard event. Three common methods for analysing vulnerability under this theme are: spatial analysis and overlay; fragility curves; and remote sensing.

2.7.1.1. Spatial analysis and overlay

Overlaying information on hazard and exposed elements was identified as a method with which to analyse risk and vulnerability as early as the 1970s. In the UNDRO (1980, p.25) publication on natural disasters and vulnerability analysis the authors state that:

> *"one method that has been found to be useful particularly for insurance purposes is based upon the utilisation of computer simulation techniques for approximating the overlapping and interaction of storm, flood and earthquake severity patterns with the spatial arrays of population and properties at risk."*

Nowadays, a common method for analysing vulnerability information and combining it with hazard data as a part of a risk assessment is with the use of a Geographic Information System (GIS). GIS are used to collect, store, analyse and display spatial data. Since the 1980s they have become a very efficient means of managing large data sets, and with the advance in technology and the increased availability of computers and software, GIS have become invaluable tools in the decision making process of many organisations (DeMers, 2000). Much data used in vulnerability analyses, such as population data and building inventories, are already in a spatial format that can easily be displayed, manipulated and analysed in a GIS. For example, Michael-Leiba et al. (2003) assess regional landslide risk in Cairns, Australia. The method involves creating a GIS database that can be searched in order to calculate landslide risk. The database consists of elements of the landslide hazard in addition to elements of vulnerability which includes residents, roads and buildings. Vulnerability is defined as *"the probability of death or destruction given that a landslide hit the residence or road"* (Michael-Leiba et al., 2003, p.239). A similar approach is taken to assessing vulnerability and risk from sea-level rise and flooding in Fiji. Gravelle and Mimura (2008) use a GIS and digital elevation model to identify areas of potential future flooding from sea-level rise on the main island of Viti Levu. Overlay analysis was then used to highlight vulnerable elements which fell within these flooded areas. Although not specifically defined, elements such as roads, infrastructure, settlements and agriculture were considered vulnerable if they were exposed to the flood hazard.

2.7.1.2. Fragility curves

A more detailed analysis of vulnerable elements exposed to a hazard takes into account the likelihood of damage given a certain hazard magnitude. Within earthquake and windstorm hazards in particular, fragility curves are used, *"which express the probable damage to an element at risk given a level of hazard"* (Douglas, 2007, p.284) – an example of a typical fragility or vulnerability curve is shown in Figure 2.5 below.

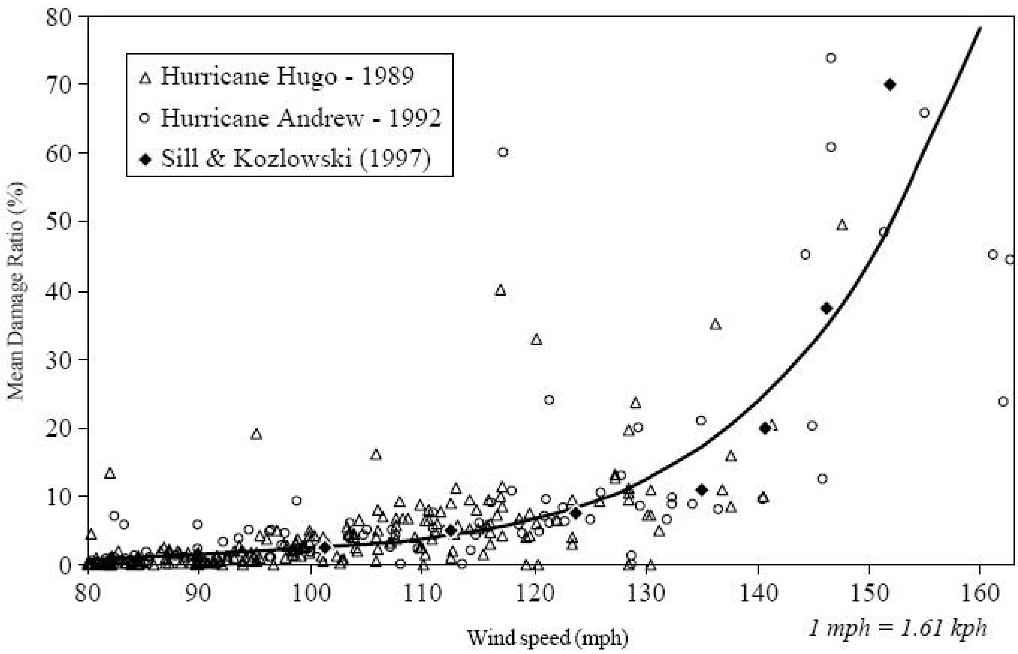

Figure 2.5: Typical hurricane vulnerability curve for wood frame buildings (Khanduri and Morrow, 2003, p.458)

Two examples of tools designed to conduct multi-risk assessments that Douglas (2007) uses as examples of those which utilise fragility curves are HAZUS-MH from the Federal Emergency Management Agency (FEMA) in the US and RiskScape in New Zealand. HAZUS-MH (Hazards US Multi

Hazards) is a loss estimation tool for floods, hurricanes and earthquakes, similar to the tools used in the insurance industry. The method to model loss is through a combination of the exposure of building inventory, essential facilities and population, and the intensity of the hazard, to produce direct economic loss, indirect economic loss and social loss (FEMA, 2003). The fragility curves are the method used to model the vulnerability of buildings.

A similar loss modelling tool called RiskScape is being developed in New Zealand as a joint venture between GNS Science (Institute of Geological and Nuclear Sciences) and NIWA (National Institute of Water and Atmospheric Research) (Reese et al., 2007). Again, fragility curves are used to estimate hazard-related damages to the building stock and infrastructure. Five hazards have been modelled to date: river floods, earthquakes, volcanic ash, tsunami and wind storms.

There are a number of reasons, however, why fragility curves are not prevalent in natural hazard risk assessments. Douglas (2007) suggests that a lack of observational data on damage, lack of structural input data, and the fact that fragility curves may not be appropriate for some risk assessments depending on the aim (e.g. pinpoint areas for evacuation) as reasons for the deficiency of fragility curves in hazards research outside of earthquakes and windstorms. Despite Douglas's (2007) argument, work has nonetheless focused upon development of fragility curves for some volcanic hazards; this work is described in Section 2.8.1.

2.7.1.3. Remote sensing

The final method discussed here to measure vulnerability as a pre-existing condition is through the use of remote sensing techniques. Aerial photographs, satellite or radar images can be used to collect information regarding the Earth's surface. Data on buildings, population estimation and quality of life indicators can be obtained from remotely sensed images (Jensen, 2000) and form part of a vulnerability analysis.

Barclay et al. (2008) briefly discuss the benefits of freely available remote sensing products such as Landsat[7] images that can be processed to produce maps of population distribution and terrain useful for vulnerability analysis. Mueller et al. (2006) address the use of high resolution satellite imagery such as IKONOS and QuickBird[8] to analyse the vulnerability of buildings to earthquake. Data on three parameters can be captured using this technique: building type, morphological structures such as faults and landslides, and contextual information (e.g. the spatial position of a house in relation to other buildings). The advantage of these methods is that they can be used to conduct large-scale vulnerability analyses however, a disadvantage is that at these scales (1:50,000, 1: 25,000) one cannot gather information on the characteristics of the people on the ground.

2.7.2. Vulnerability as a social construct

Within this concept, vulnerability is viewed as a social construct, where the focus is on people and how vulnerability has been constructed over time. Frameworks, such as the PAR model, that conceptualise this social vulnerability, include elements that are hard to quantify (such as limited access to power, or lack of disaster preparedness). Consequently, qualitative, participatory techniques are required to gather data, rather than the quantitative techniques discussed above.

In a review of the role of vulnerability in the IDNDR and identifying challenges ahead Maskrey (1999, p.86) stated that *"only by harnessing the huge and largely untapped potential of vulnerable communities to manage and reduce risks at the local level…will it be possible to look*

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[7] Landsat (land satellite) jointly run by NASA and the United States Geological Service has been capturing multi-spectral images of the Earth's surface since 1972.
[8] IKONOS and QuickBird are commercial earth observation satellites that collect multi-spectral and panchromatic imagery.

forward to a more sustainable future in the next century and beyond". Much vulnerability analysis was initially conducted by policy-*makers "far removed from the realities facing people who are most vulnerable to disasters"* (Davis and Hall, 1999, p.87). As a result there has been a surge in the number of community based vulnerability and capacity assessments which aim to tap into local knowledge and allow individuals exposed to hazards to identify their own vulnerabilities and risks. The PAR model is commonly used as a tool for these assessments. As Wisner et al. (2004, p.83) state *"several NGOs have made use of the PAR model as the basis for community-based self study of vulnerability and capability"*. Therefore this section will briefly review some of the community-based methods that analyse vulnerability as a social construct.

An example of a method that explicitly uses the PAR model as a framework for vulnerability analysis is that by the non-governmental organisation Tearfund (Venton and Hansford, 2006). Referred to as the Participatory Assessment of Disaster Risk (PADR), the aim is to engage locals in identifying their own vulnerabilities and capacities in order to design and implement development plans which reduce their risk to future disasters. The PAR or 'crunch' model is used to illustrate how disasters are constructed, and how working against the components of the crunch model and utilising a community's strengths can lead to a reduction of disaster risk. The components of the model (hazards, element at risk, vulnerable conditions, dynamic pressures and root causes) are used to form stages in the PADR process. Methods that are used to gather data on vulnerabilities and capacities include: timelines to gather data on what has happened in the past; mapping to draw an area's main features and landmarks; ranking of risk and priorities in a community; and transect walks to explore the local area and take photographs and notes.

Another, more practical analytical framework that is often used for participatory work, is the Capacities and Vulnerabilities Analysis (CVA)

Matrix from Anderson and Woodrow (1989) (Figure 2.6). The CVA matrix is divided into three areas of vulnerability and capacities: physical/material, social/organisational and motivational/attitudinal. In this framework disasters are viewed in a development context with the aim of the matrix to help relief agencies understand the pre-existing vulnerabilities and capacities prior to designing aid programs.

	Vulnerabilities	**Capacities**
Physical/material (What productive resources, skills, and hazards exist?)	e.g. coastal houses exposed to hurricanes	e.g. emergency shelters for use during hurricanes
Social/organisational (What are the relations and organisation among people?)	e.g. schools close during evacuations	e.g. local community disaster groups
Motivational/attitudinal (How does the community view its ability to create change?)	e.g. dependence on emergency management office	e.g. religion provides strength within community

Figure 2.6: CVA Matrix. Adapted from Anderson and Woodrow (1989, p.12). Examples researchers own.

Oxfam use the CVA matrix to guide their work in communities (De Bois, 2002). They further disaggregate the CVA matrix by gender and social groups within a community as they recognise that women, for example, have different capacities to men and different roles within a community. The matrix is also completed over time to assess changes before and after a disaster event, and at different spatial scales. Using the CVA matrix as a framework Oxfam adopt different methods to capture community knowledge similar to those described by Tearfund (Venton and Hansford,

2006) such as transect walks, community mapping and seasonal calendars.

2.7.3. Vulnerability as hazard of place

The third way of conceptualising vulnerability involves combining exposure and social vulnerability. As in the 'vulnerability as a pre-existing condition' approach, this framework lends itself to spatial analysis as methods overlay data on exposure to a hazard with the vulnerability of the population and buildings. Consequently GIS software is commonly the tool used. Spatial data are required in order for overlay analysis to be performed. Hazard maps may be available and for social information, census data or remotely sensed images are commonly used as they provide information about the population and infrastructure in a format that is already spatially referenced. There exist a number of studies wherein GIS software, spatial analysis and remote sensing have been adopted to create maps of vulnerability which include data on both the exposure and social factors.

2.7.3.1. Spatial analysis and overlay

A method developed for use in the US is the Community Vulnerability Assessment Tool (CVAT). CVAT was developed by the National Oceanic and Atmospheric Administration to help emergency managers and planners reduce vulnerabilities to hazards in collaboration with FEMA (Flax et al., 2002). Utilising datasets from the US Census for indicators of social vulnerability, and government hazard maps, CVAT analyses physical, social, economic and environmental vulnerability at the community level. Societal vulnerability is assessed by identifying areas with high levels of special consideration groups such as the elderly, minority groups, low-income, single-parent households etc.. These data are then overlain with data on hazards in that area to identify groups that are vulnerable and exposed. CVAT provides guidance in relation to how to go about conducting a vulnerability analysis; however, the details of how to decide upon which factors to include are not specified. The authors do, however, recommend stakeholder engagement and acknowledge that a vulnerability analysis requires participation from many disciplines.

Adopting a similar method to the CVAT, Wood (2007a) and Wood et al. (2007) mapped community exposure and sensitivity to tsunami hazards in Hawai'i and Oregon using spatial analysis, GIS software and government datasets on land cover and census information. The framework for the study is similar to Cutter's (1996) VoP model, where vulnerability is a combination of exposure and sensitivity. Exposure is defined as *"the amount of an asset (for example, the number of residents of a town) within a tsunami evacuation zone"* (Wood et al., 2007, p.3). Sensitivity is *"the relative impact of losses to an entire community (for example, the percentage of a community's workforce in a tsunami zone)"* (Wood et al., 2007, p.3). The authors use statistical methods to develop composite indices of exposure and sensitivity in order to make comparisons between different areas on Hawai'i and Oregon.

2.7.3.2. Remote sensing

Research is now being conducted into the use of remote sensing data as proxies for social vulnerability. A disadvantage of the methods described in Section 2.7.1.3, is that very little detail about the characteristics of the population are captured. Lo and Faber (1998) address this issue by integrating Landsat Thematic Mapper (TM) data with socio-economic census variables for Athens-Clarke County, Georgia, US, to assess the quality of life of residents. Statistical correlations were found between vegetation indices derived from the remotely sensed images and population density, median home value, and per capita income. Although not explicitly analysing vulnerability to natural hazards, these 'quality of life' type indicators are often included in a vulnerability analysis, and researchers are now applying these methods to study natural hazard vulnerability. For example, Rashed and Weeks (2003a; 2003b) ran five scenarios for losses from earthquakes in Los Angeles County using HAZUS software to define ‘hot spots’ of vulnerability (exposure). An index of social vulnerability was created using census data on wealth, age and race, and images from Landsat TM used to assess urban characteristics of land cover, vegetation, soil, impervious surface and shade. Statistical models tested the correlations between the three variables. Areas with lots of impervious surfaces were strong predictors of areas of high social vulnerability as were areas with little vegetation. The authors argue that the advantage of using remote sensing data for vulnerability analysis is that it can be used to gather data that might be difficult to measure using other techniques. These data can in turn be used as indicators of social vulnerability, although they acknowledge that the relationship between social vulnerability and the urban environment will be different from place to place, especially in developing countries.

Ebert et al. (2009) continue this work and present an innovative method of using remote sensing data to define proxies of social vulnerability for urban areas. They argue that the conceptual basis and measures for physical vulnerability are well established when compared with social vulnerability and consequently physical vulnerability is often used synonymously for social vulnerability. Common methods for analysing social vulnerability are those discussed above: use of census data and community-based methods. The disadvantages they identify with these methods are the applicability of census data which has been collected for another purpose, and the timeliness of data sets often collected once every five to 10 years. In addition, census data are not always available for many countries. Community-based methods are detailed and specific to the purpose, however timely to collect, subjective and difficult to scale up. As a result of these limitations, the authors build on work using remote sensing for measuring physical vulnerability and use QuickBird images to define proxies for social vulnerability. They found that slope position and the proportion of built-up areas in a neighbourhood were the most useful proxies for social vulnerability. The authors acknowledge that this method alone cannot provide a complete analysis of social vulnerability as there is no way to gather data on age, gender and other parameters. However, they argue that it can help overcome the low-spatial detail of census data based methods.

The advantage of the 'vulnerability as hazard of place' approach taken by each of these methods is that in contrast to the models and methods described above, vulnerability is conceptualised as a combination of exposure, physical and social factors, allowing for a more complete analysis.

2.7.4. Summary

The limitations of the different methods lie in part in the narrow focus of the underlying model of vulnerability. In addition, methods adopting spatial analysis and overlay are data intensive and require data in a spatial format. Equally, fragility curves are data intensive and remotely sensed images at a fine resolution such as those from IKONOS and QuickBird satellites are expensive. In contrast, methods such as those adopting the CVA matrix are time-intensive and require the participation and cooperation of vulnerable communities.

2.8. Models and methods for the analysis of vulnerability to volcanic hazards

Volcanology has traditionally focused on analysing risk as the potential for loss of life. This focus has determined that the models and methods used in the analysis of vulnerability to volcanic hazards tend to be those which quantify vulnerability as the exposure of people and buildings. Although this is still a focus, recent work over the past decade has begun to include the 'vulnerability as a social construct' and 'vulnerability as hazard of place' approaches into volcanology. This section outlines those models and methods used for research into vulnerability in relation to volcanic hazards.

2.8.1. Vulnerability as exposure

The most common model of vulnerability seen in the volcanic literature takes the 'vulnerability as a pre-existing condition' approach, where people and buildings are considered vulnerable if they are exposed to volcanic hazard events. The pseudo-equation by Fournier d'Albe (1979) has been applied to a number of volcanic vulnerability studies and spatial analysis and overlay are often the tools used for analysis. For example, Robertson (1995) describes a method for conducting a volcanic risk assessment on St. Vincent using the Fournier d'Albe (1979) equation as a guide. Vulnerability is defined as the proportion of value likely to be lost. Robertson overlays hazard data with infrastructure and population centres to determine the possible vulnerability in a future eruption. Work by Paleo and Trusdell (2002) on the island of Hawai'i calculates the total population exposed to lava flow hazards using GIS overlay. Pareschi et al. (2000) and Pareschi (2002) evaluate the impact of volcanic hazards in Italy and define vulnerability as the probability of roof collapse. GIS is used to overlay building vulnerability with hazard and population data to calculate the number of inhabitants affected. Lirer and Vitelli (1998) assess the risk to people and property from lava flow hazard around Vesuvius and use the UNDRO (1980) definition of vulnerability and the Fournier d'Albe (1979) equation as their conceptual framework. The elements at risk considered are people, property and economic activity of the area. Vulnerability is the percentage of value of the elements at risk likely to be lost given a specific hazard event. The authors use GIS to map the land use type exposed to lava flow for a VEI (volcanic explosivity index) 3 size eruption and calculate the economic value of exposed buildings. Alberico et al. (2002) use the same definition of vulnerability and associated risk equation as Lirer and Vitelli (1998), and calculate the risk to people and property of pyroclastic flows and surges at Campi Flegrei in Italy using digital elevation models and overlay in a GIS.

Douglas (2007) in an article on physical vulnerability modelling in natural hazard risk assessment, argues that the assessment of the physical vulnerability to volcanoes lags behind other natural hazard research, specifically that of earthquakes. He argues that volcanology should adopt the use of fragility curves to quantify vulnerability. Recently, work has begun to adopt this approach. For example, Spence et al. (2004a; 2004b; 2007) developed fragility curves of window failure under pressure from experimental studies and used them to estimate the resistance of buildings and human casualties from pyroclastic flows. In a similar way, Spence et al. (2005b) model the failure of masonry walls to the dynamic pressure from pyroclastic flows, and Spence et al. (2005a) model the vulnerability of four roof types to tephra fall. Leone (2002) uses GIS and spatial analysis to quantify risk and vulnerability to volcanic and seismic hazards on Martinique. Here vulnerability is defined as the level of damage of a given exposed element acted on by a given hazard. Damage functions are used to calculate losses of housing stock per 500m grid cell across the island. In addition, recent work in New Zealand is using fragility curves to estimate damage to agriculture from volcanic ash hazards (Wilson et al., 2007).

A different approach to quantifying vulnerability as exposure is presented by Lesales (2004) for Dominica. Vulnerability in relation to volcanic hazards is quantified on a national scale in order to compare the situation in Dominica with other countries. Exposure is calculated as the number of active volcanoes per square km (Dominica has one volcano for every 94km^2) and correlated with three indicators of socio-economic vulnerability (population density, Gross Domestic Product (GDP) and Human Development Index). Lesales concludes that with the exception of population density, volcanic vulnerability on Dominica is high when compared with other Caribbean islands, the Philippines, Indonesia and Japan.

2.8.2. Modified approach to vulnerability to volcanic hazards

Recognising that volcanic disasters were not exclusively the product of the physical event, and that previous work on disasters and vulnerability was very polarised in one camp or the other (dominant versus radical views) Dibben and Chester (1999) and Dibben (1999) present a vulnerability framework that integrates the macro or societal analysis of the radical approach and the micro, behavioural perspective of the dominant school of human ecology (Figure 2.7). Vulnerability is conceived in terms of 'universal needs' (food, water, health care, education, etc.) and the susceptibility to be deprived of those needs. The susceptibilities listed in Figure 2.7 below include a range of factors from the 'vulnerability as a pre-existing condition' approach (i.e. location of activities and home) and the 'vulnerability as a social construct' viewpoint (i.e. resilience and livelihoods). The model was tested on two case studies, Mount Etna in Italy and Furnas volcano in the Azores using interviews, analysis of census data and examination of historical documents (Dibben and Chester, 1999; Dibben, 1999). The authors do critique the vulnerability approach in general, suggesting that it requires extensive cross-disciplinary work; is complex in that it involves exploring both natural and human domains of hazards; and requires a mixed-method approach, however they do not specifically critique the integrative framework on how practical it is for capturing vulnerability to volcanic hazards.

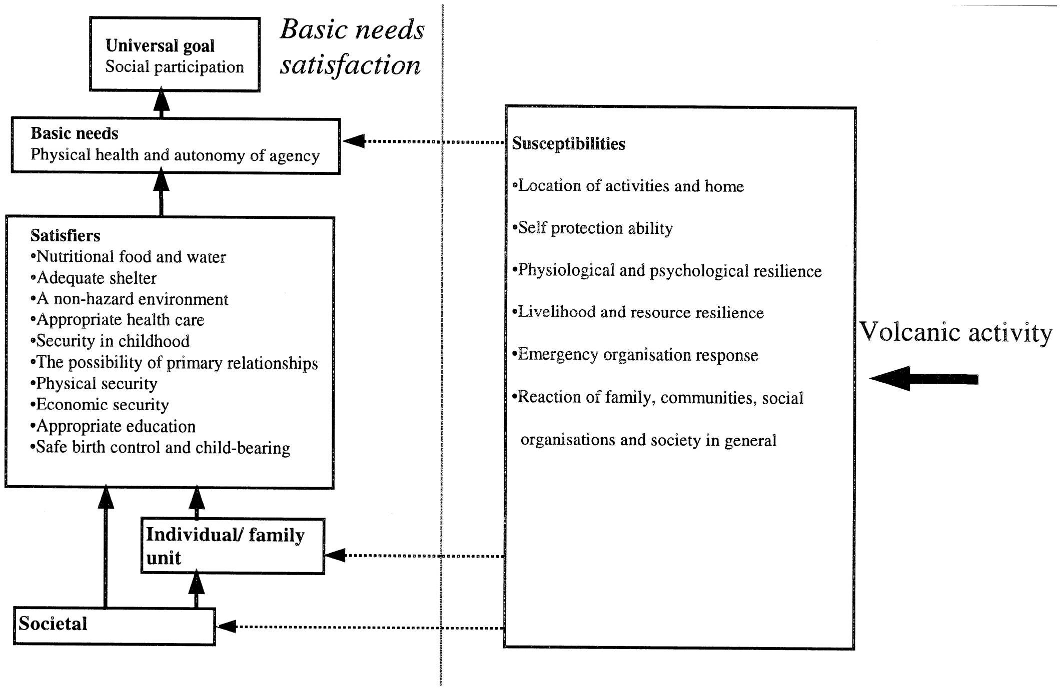

Figure 2.7: Framework of vulnerability to volcanic hazards (Dibben, 1999, p.51, citing Doyal and Gough 1991, p.170).

Wallenstein et al. (2005) also take this modified approach to vulnerability and risk assessment in relation to volcanic hazards, working on Fogo volcano in the Azores. In this example there is a particular focus on socio-economic vulnerability factors that affect the ability of an individual to evacuate. Tourist numbers, literacy, mobility, assets, family members elsewhere and livestock are highlighted as important considerations in addition to the vulnerability of buildings and infrastructure. The authors also discuss the limitations of census data to capture all these vulnerability factors.

Other research into vulnerability to volcanic hazards takes a 'vulnerability as hazard of place' approach and often utilises GIS and spatial analysis. These studies are described in more detail in Chapter Four.

2.9. Summary

Vulnerability as a concept initially took a while to catch on. Ten years after the work by Hewitt (1983b) Varley (1994, p.2) stated that *"vulnerability* *analysis has failed to make significant inroads into the dominant paradigm in disaster management. This is demonstrated by the approach of the United Nations IDNDR".* She suggested two reasons why this might be so. First, that the main contributors to the development of vulnerability analysis came from a very Marxist perspective, stating that the only approach to reduce vulnerability was a socialist one, and effectively required political revolution. White et al. (2001) further state that the arguments regarding the social causation of disasters are numerous and not easily corrected or removed. The second reason Varley suggests as to why the vulnerability perspective had not caught on was its focus on poverty. Although researchers made very clear that vulnerability does not equal poverty, it is clear in practice that the poor often suffer most. Consequently, reducing vulnerability requires the reduction of poverty which might, in the short term at least, discourage researchers from taking this approach as it is a huge undertaking.

More recently, however, vulnerability has become an established concept in hazards and disaster research, with numerous books being published on all aspects of the subject (e.g. Hewitt, 1997; Bankoff et al., 2004; Birkmann, 2006c). Vulnerability to volcanic hazards is becoming a focus at traditional physical science conferences. For example, sessions at the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) General Assembly and Cities on Volcanoes conferences frequently address interactions between volcanoes, people and the environment, including aspects of vulnerability.

Today, there is a modified approach to understanding the cause of disasters, such as that represented in the integrative framework in Figure. 2.7. Hewitt (1997) in particular maintains the need for a more balanced view which considers both the hazard and vulnerability perspectives. He suggests that there are four elements of a disaster – hazards, vulnerability and adaptability, intervening conditions of danger, and human coping and adjustments. Vulnerability comprises of six basic components: exposure, weaknesses, lack of protection, disadvantage, lack of resilience, and powerlessness. These six components neatly combine a number of factors which are discussed in the literature. The critique of many perspectives on disasters and hazards is that the views are often very one sided. Hewitt's approach is to find a balance that does not exclude any single perspective. He argues that there is still the need for dominant approach type research as for some hazards warnings, forecasts, etc. are always going to be useful. Vulnerability must also be considered, however, to truly understand the uneven distribution of disaster losses.

Although there is now this balanced approach to looking at disasters and vulnerability, the field still lacks a consensus as to definitions of key terms, and methods of analysis. A particular problem highlighted by Villagran De Leon (2006) is that models of vulnerability provide no guidelines on how to assess the different vulnerability components, and in some cases the topics covered in a model are too broad to be assessed effectively. He goes onto argue that with the number of researchers using the term vulnerability in many different ways, and the wide range of sectors adopting it as a concept, *"it is difficult to come up with a single means to asses it [vulnerability]"* (Villagran De Leon, 2006, p.52).

The following chapter describes the research design, methods and case study used in this research. The methods have been designed to address some of the problems identified by Villagran De Leon (2006) on the lack of consensus regarding vulnerability and the gaps found in the literature.

Chapter 3: Research Design

This chapter describes the gaps that have been identified in the literature, and the research goal and questions that were formulated to address some of these gaps. The methods chosen to investigate the research questions are also outlined and the chapter concludes with a justification and description of the case study site chosen.

3.1. Gaps in the literature

Historical data on the impact of volcanic eruptions emphasises that people still die and suffer loss in volcanic eruptions despite advances in monitoring, prediction and hazard assessment. Peer reviewed literature suggests there is a strong social vulnerability component to disaster losses in addition to the physical vulnerability that is often the focus of traditional vulnerability assessments. Both these types of vulnerability now need to be investigated to assess risk and to inform disaster preparedness and response plans. There are a number of gaps in the volcanic vulnerability literature in particular that this research aims to address. These are outlined below.

3.1.1. The complexity of vulnerability to volcanic hazards

Volcanology and volcanic risk assessment has in the past been dominated by pure physical science in an attempt to better understand the volcanic hazards such as pyroclastic flows and lahars, and in order to improve the forecasting of eruptions. The nature of the hazards (location, frequency, magnitude) however, does not fully explain losses from historical volcanic eruptions. There is a strong vulnerability component to volcanic disasters such as political influences, wealth and the ability of the population to cope and respond to volcanic hazards, as demonstrated by the review in Chapter One of 20th Century volcanic eruptions. In addition, it is evident in the literature that vulnerability to natural hazards is multifaceted (Cutter et al., 2003; Thywissen, 2006). It is complex and diverse with different stakeholder groups having different views of vulnerability and different needs with respect to conducting vulnerability analyses. Despite this diversity, traditional volcanic vulnerability analyses have focused on the physical vulnerability of buildings to collapse and the likelihood of death given exposure to a volcanic hazard (e.g. Pomonis et al., 1999 ; Spence et al., 2004a ; Spence et al., 2004b ; Spence et al., 2005a ; Spence et al., 2005b). There is a limit to this traditional, quantitative approach and the socio-economic, cultural, historical and political factors evident in the literature have to date been under-researched in volcanology.

It is important to investigate the needs of users of vulnerability analyses in order for the results to include relevant information and be presented appropriately. In addition, it is necessary to not only focus on the physical vulnerability of buildings or people's exposure to volcanic hazards, but also include the particularities of society that will help inform disaster management and reduce disaster risk.

3.1.2. Only one aspect of vulnerability analysed for an area

In the vulnerability literature in general, many assessments for an area tend to focus on just one aspect of vulnerability (i.e. socio-economic or physical). Very few look at a range of vulnerabilities in order to see how they compare. Exceptions include the studies by Boruff and Cutter (Boruff, 2005; Boruff et al., 2005; Boruff and Cutter, 2007). They use the 'Vulnerability of Place' model as the basis for the research that includes both socio-economic and physical vulnerabilities (see Figure 2.3). The advantage of this is that the influence on a region of different types of vulnerability can be analysed and inform planning. This is still a very limited view, however, and a quantitative one. An aspect of vulnerability that is often overlooked is the historical component. Bankoff (2003) argues that vulnerability is constructed by the interplay of history, nature and society. Wisner et al. (2004) state that researchers need to look at *why* and *how* people are vulnerable, and not just use standard indicators such as age and wealth to measure vulnerability (as in the work by Boruff et al., 2005).

Consequently it is important to include all these aspects - social, physical, economic, cultural, historical, and political - in a vulnerability analysis. Furthermore, without studying different aspects of vulnerability for one area it is not possible to fully understand how they compare and contrast. For example, are the same areas of a country that are highlighted as being highly vulnerable in terms of economics, vulnerable culturally as well? Understanding the geography of different vulnerabilities can inform preparedness and response measures required to reduce disaster risk.

3.1.3. Appraisal of models and methods of vulnerability analysis

There are many different theoretical models of vulnerability in the literature and a wide range of quantitative and qualitative methods to follow (see Sections 2.6 and 2.7). Very few studies analyse vulnerability of a place using more than one model and method. The work on Furnas volcano in the Azores is one exception. Pomonis et al. (1999) conducted a building survey and estimated the vulnerability of the buildings to various volcanic hazards, together with the likely scale of human casualties. Dibben and Chester (1999) complemented the building vulnerability assessment with a human vulnerability evaluation. The results of the two surveys, however, were not compared and discussed in the relevant papers. There was no discussion, for example, of whether the same people experienced both high levels of building and social vulnerability and how the methods for vulnerability analysis compared.

Therefore, as no single model and method may be able to capture the diversity and complex nature of vulnerability, it is desirable to conduct multiple analyses of one place to see how the models and methods compare, and the appropriateness of each. Birkmann (2006b, p.56) states that *"we often know too little about the advantages of the different approaches and methodologies [for measuring vulnerability], their applicability in different areas and their limitations"*. For the field of vulnerability research to progress it is necessary to appraise the different models and methods available so that researchers and practitioners can apply the most appropriate methods in the field.

3.2. Research goal and questions

Acknowledging that there are different views of vulnerability (engineering, social, political, etc.) and that a single method of analysis may not be appropriate, the goal of this thesis is to take a mixed method approach – incorporating both quantitative and qualitative elements - to investigate the spatial and temporal aspects of vulnerability to volcanic hazards on the Caribbean island of St. Vincent, and to evaluate the range of methods that can be adopted. A number of vulnerability maps will be produced that will enable a comparison of the methods used.

The following research questions have been formulated:

1. How does the shape of vulnerability change when different aspects (social, physical, economic, etc.) are mapped?
2. How do stakeholder views of vulnerability compare?
3. Do different models and methods for vulnerability analysis capture the same thing and what are the limitations associated with each?
4. Is there a minimum threshold that can capture the vulnerability of a place, using a single model or method?

Question one addresses the first two gaps identified in the literature - that of there being a limited focus on social vulnerability to volcanic hazards, and the fact that a range of vulnerability factors are rarely analysed simultaneously for one area. By analysing social vulnerability to volcanic hazards it will then be possible to compare it to physical building vulnerability measures and see whether or not areas of high social vulnerability occur in areas with vulnerable buildings. Question two addresses an aspect of the first gap in the literature regarding the complexity of the term vulnerability, and the fact that stakeholders may understand the term differently and have specific needs with regards to vulnerability analyses. Chapter Two discusses the range of definitions of vulnerability, and how this poses challenges when conducting vulnerability research. In order to design vulnerability analyses that meet user needs, their views will be obtained and incorporated into the analysis. Question three addresses the fact that in the literature models and methods for vulnerability analyses are rarely appraised. Deciding upon what model and method to adopt requires an understanding of how different approaches compare and contrast and the limitations of each. The final question is designed to answer whether or not it is necessary to conduct a range of vulnerability analyses for one area, using different models and methods, or if in fact it is possible to capture useful information on vulnerability with a single approach.

3.3. Research design and methods

In order to answer the research questions, four methods have been chosen which encompass a range of current methods described in the literature and aim to give a holistic view of vulnerability. The research methods – Social Vulnerability Index determination, building vulnerability analysis, stakeholder mental mapping and historical vulnerability analysis - are designed to complement each other, compensating for the limitations of each. They are briefly described below.

3.3.1. Social Vulnerability Index

Initially an index of social vulnerability to volcanic hazards is created using GIS as a tool to map the results. This adopts a method utilised in the US and New Zealand that use census data as proxies for vulnerability variables (Cutter et al., 2003; Boruff et al., 2005; Finnis and Johnston, 2007). The method analyses pre-disaster vulnerability as a snap-shot in time, effectively creating a checklist of vulnerable characteristics that can be mapped. The aim is to show how these vulnerability variables vary across the island. In order to create an index that reflects local stakeholder views, interviews were carried out with decision makers on the island to ascertain their views on what makes people vulnerable to the volcanic hazard on St. Vincent.

The justifications for creating a Social Vulnerability Index are two-fold: first, the index provides a method to incorporate stakeholder views into a quantitative analysis, and includes social vulnerability variables often left out of volcanic vulnerability analyses. Second, an index provides a quantification of vulnerability that can be easily mapped and compared with the building vulnerability maps and mental mapping that are described below.

3.3.2. Building vulnerability analysis

Methods for structural surveys of buildings exposed to volcanic hazards are available in the literature on volcanic hazards and their impacts, and this is the form that the majority of current volcanic vulnerability analyses take. To provide this research with as complete a view of vulnerability on St. Vincent as possible, a survey of residential settlements on the island was undertaken. The aim is to give an overview of the types of structures across the island and their potential vulnerability (i.e. flat roof vs. pitched roof for tephra loading, wood vs. brick or concrete construction for the potential to ignite) and see whether there is a spatial distribution of vulnerable buildings that can be compared with the social vulnerability maps. Data in the literature on the probability of building damage in relation to specific volcanic hazards can be used to create a building vulnerability rank and to quantify the number of buildings expected to collapse, and the number of deaths given the current volcanic hazard scenario for St. Vincent.

A building vulnerability analysis is important for a number of reasons. Building collapse from volcanic hazards is a common cause of fatalities in an eruption. According to Simkin et al. (2001, p.256) *"the most common killer in fatal eruptions is tephra…killing mainly by collapse of ash-covered roofs"*. Although pyroclastic flows and surges have killed the greatest number of people in the historical record, fatalities from tephra-induced roof collapse have occurred in over 20 percent of fatal eruptions (pyroclastic flow fatalities occurred in less than 15 percent of fatal eruptions). Consequently, understanding how a building is damaged by volcanic hazards, and by tephra in particular, is an important consideration when analysing a population's vulnerability.

3.3.3. Stakeholder mental mapping

Recognising that different stakeholder groups may have different views as to the meaning of vulnerability, and that they may possess local knowledge that is not sampled by inventory data such as a census, a mental mapping exercise was undertaken on St. Vincent. Soliciting the views of national level decision makers such as emergency managers and planners, in addition to local community disaster group members, participants drew their own mental maps of vulnerability to volcanic hazards on a topographic map of St. Vincent. These maps were used to assess whether stakeholders held different views on vulnerability and were combined to produce a composite mental map that can be compared with the social and building vulnerability maps.

A mental or cognitive map is a person's representation of the spatial environment, answering the 'what', 'where' and 'when' questions about that environment. It effectively looks at an individual's perception of the environment, with a focus on the spatial element. The research described here is designed to analyse vulnerability to volcanic hazards, in particular looking at *what* people and places are vulnerable and *where* they are located. Therefore, mental mapping, which uncovers the 'what', 'where' and 'when' of an environment, is a suitable technique with which to investigate vulnerability in relation to volcanic hazards.

3.3.4. Historical vulnerability analysis

Finally, there are a number of conceptual models of vulnerability in the literature that highlight factors such as livelihoods and access to power as important components of vulnerability. Factors such as these are difficult to analyse spatially, and many have a temporal component that the previous methods fail to capture. Document analysis was conducted, therefore, to research the history and development of St. Vincent and the impacts of previous volcanic eruptions on the island. The interviews conducted with decision makers are analysed, along with texts on the history of St. Vincent, to add a temporal dimension to the vulnerability analysis and investigate to what extent this adds value to the spatial vulnerability analyses described above.

Bankoff (2003, p.106) states that:

> *"a fuller appreciation of the nature of vulnerability is still often hampered by the lack of an adequate historical perspective from which to understand the contexts and roots of disaster causality...Without proper consideration of the temporal dimension, hazards remain random, disasters unaccountable and societies simply exposed."*

Vulnerability is complex – the interplay of the hazard, society and physical infrastructure. In addition, vulnerability is a dynamic process which has its roots in the historical development of a place and its population. The previous three methods adopted in this research look at the *spatial* component of vulnerability on St. Vincent identifying vulnerability variables and where vulnerable people and places are located. In addition the methods investigate how some stakeholders perceive the island's vulnerability. Looking at historical vulnerability allows one to research the *temporal* aspect of the phenomenon. Qualitative analysis such as this helps answer the how and why questions which cannot be understood using quantitative techniques alone.

3.3.5. Fieldwork design

The fieldwork consisted of two trips covering a total of five weeks on St. Vincent, two weeks in Trinidad and two weeks in Dominica. During the first trip interviews for the SVI were conducted in addition to gathering data such as the census. The building survey and mental mapping exercise were completed during the second trip, 15 months later. A number of difficulties were encountered throughout the fieldwork. First, it was often difficult to engage with the stakeholders on St. Vincent. Few had time to dedicate to the research and often a personal introduction from Dr. Robertson was required in order to get cooperation. The second difficulty was around the availability of data. Census data, for example, do exist for St. Vincent; however the Statistics Office was unable to allow access to the fine resolution data sets. In part because no one was available to compile the datasets from the Statistics Office computers, in addition there were confidentiality issues. Finally, the fieldwork was limited by the budget and time available, and therefore only two relatively short trips were feasible.

3.4. Case study: St. Vincent

This section provides the justification for choosing St. Vincent (Figure 3.1) as a case study. It describes the nature of volcanic hazards in the Eastern Caribbean, outlines the history of volcanic activity on St. Vincent and examines how the government has developed a disaster management agency and preparedness and response plan.

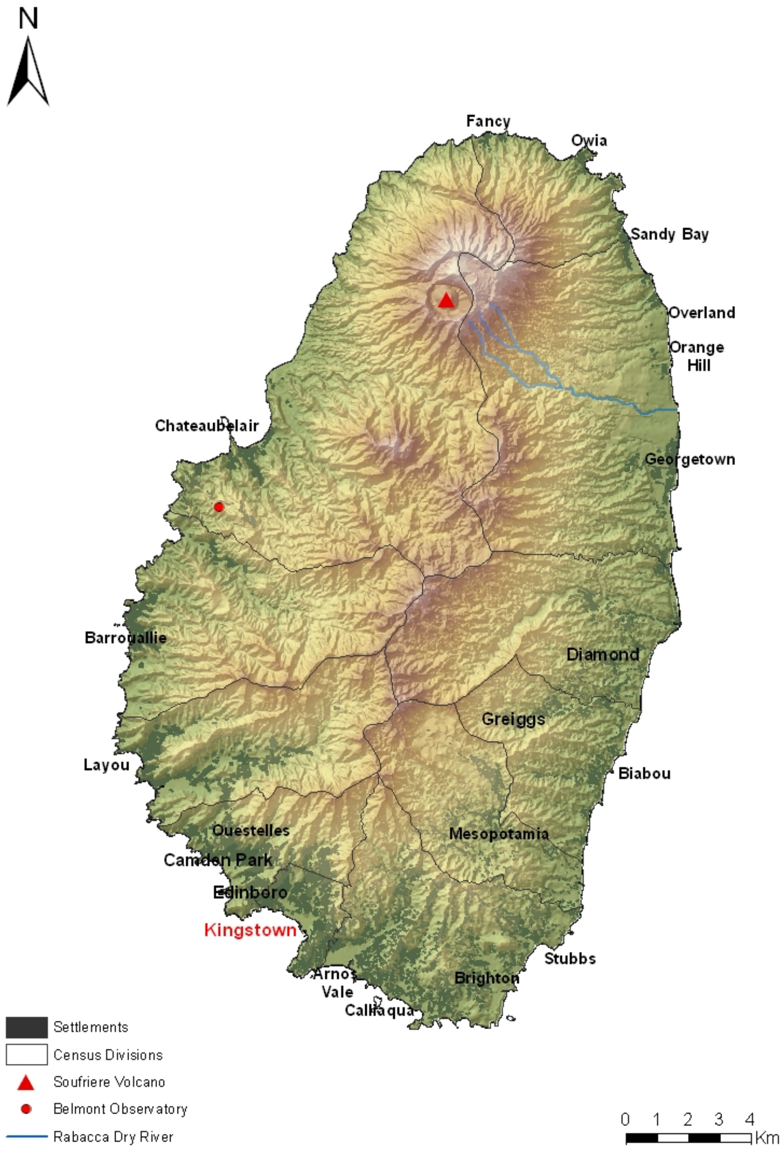

Figure 3.1: Map of St. Vincent showing main settlements, census division boundaries, Soufrière volcano, Belmont Observatory and the Rabacca Dry River.

3.4.1. Case study justification

St. Vincent provided a suitable case study for a number of reasons. As a small island developing state (SIDS) it has special circumstances that increase its vulnerability to disasters. SIDS have long been recognised as being especially vulnerable to disasters (see Briguglio, 1995; Pelling and Uitto, 2001; Méheux et al., 2007). Economically their small size leads to limited natural resources, dependence on export market, and a limited ability to exploit economies of scale (Briguglio, 1995). In addition, the geography of where SIDS are often located (along plate boundaries and within the tropical cyclone belt between five and 20 degrees north and south of the equator) results in high exposure to volcanic activity, earthquakes, tsunami, storms and landslides (Méheux et al., 2007). Pelling and Uitto (2001) calculated a vulnerability index for SIDS combining data on five factors – Human Development Index, debt, health expenditure, adult literacy, and GDP per capita. Out of the nine Eastern Caribbean islands included, St. Vincent was one of the most vulnerable, with only Grenada calculated as being more vulnerable.

A further consideration is how SIDS are especially vulnerable to volcanic activity in particular. Many islands have been forced to completely evacuate with the onset of volcanic activity. Examples include the island of Niuafo'ou, Tonga (1946), Maat, Vanuatu (1951), Tristan de Cunha (1961/62), and Nila, Indonesia (1968) (see discussions in Méheux et al., 2007 and Gaillard, 2007). Inadequate air and sea transport links can often render evacuation difficult, and the cost of total evacuation may lead governments to risk keeping citizens on the island (McGuire et al., 2009b).

An additional reason St. Vincent provides a suitable case study is that the research focuses on the vulnerability in relation to volcanic hazards, consequently the study site needed to have an active volcano which could be a threat in the future, but not one that is currently erupting and therefore having a direct impact on how and where people live and work at the present time. As interviews were planned with stakeholders on their views on the population's vulnerability to volcanic hazards, the volcano had to be a *known* threat, and not a mountain that had yet to be identified as an active volcano.

St. Vincent was also suitable amongst the Eastern Caribbean volcanoes as it is an English speaking island. Additionally, in contrast to St. Lucia and Dominica for example, it only has one active volcano, which meant the focus of the threat was simplified. In future studies more complex examples could be used to test the methods adopted in this research.

3.4.2. Volcanic hazards in the Eastern Caribbean

The Eastern Caribbean is exposed to a range of natural hazards that include hurricanes, earthquakes, tsunami, floods, landslides, and volcanic eruptions. The most frequent hazard is hurricanes which can occur annually, traditionally during the months of June to November. The threat posed by volcanic eruptions, however, is very different in nature due to the long repose intervals and their potential to completely destroy towns and render land uninhabitable for years after the event. For example, the Seismic Research Centre (SRC) website[9] (the organisation responsible for the seismic and volcanic monitoring of the Eastern Caribbean) states that property destruction levels from severe hurricanes generally range from 10 to 20 percent. However, damage (and by extension, causalities) caused by volcanic eruptions in the region approach one hundred percent in the most severely affected cases.

St. Vincent is one of a chain of islands known as the Lesser Antilles volcanic island arc (Figure 3.2) that hosts 19 'live' volcanoes (likely to erupt again), five of which have been active in the 20th Century (Table 3.1). Although the region only accounts for one percent of the world population exposed to volcanic hazards, it is responsible for over 13 percent of total deaths (Lewis, 1997). St. Vincent's Soufrière volcano is one of the most active in the region (Robertson, 1995).

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[9] www.uwiseismic.com

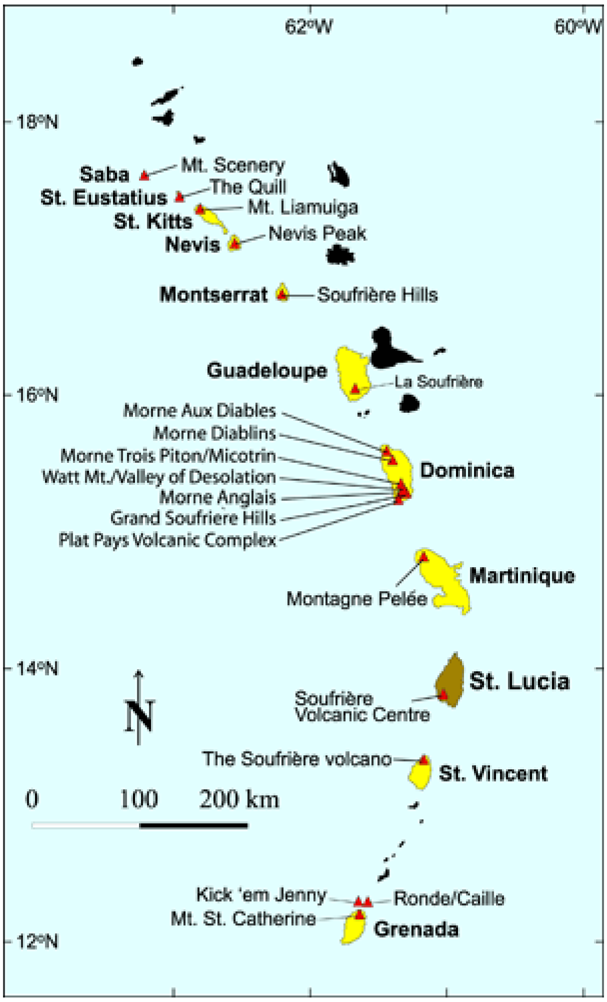

Figure 3.2: 'Live' volcanoes in the Eastern Caribbean (from SRC).

3.4.2.1. Twentieth Century volcanic crises

Witham (2005) determined a best-estimate death toll from volcanic phenomena during the 20th Century of 91,724. Nearly one-third occurred in the Caribbean region (30,584) dominated by two explosive eruptions in 1902 (Mount Pelée, Martinique and Soufrière, St. Vincent). Table 3.1 summarises volcanic activity in the Lesser Antilles during the 20th Century.

Volcano	Year of start of eruption or activity	Nature of eruption or activity	Deaths (Witham 2005)	Volcanic Explosivity Index (VEI)
Soufrière (St. Vincent)	1902	Explosive magmatic;	1565	4
Mount Pelée (Martinique)	1902	Dome-forming and explosive;	29,000	4
	1929	Dome-forming and explosive	0	3
Soufrière (Guadeloupe)	1956	Phreatic	0	1
Soufrière (St. Vincent)	1971	Dome-forming	0	0
Soufrière (Guadeloupe)	1976	Phreatic	0	2
Soufrière (St. Vincent)	1979	Dome-forming and phreatomagmatic	0	3
Soufrière Hills (Montserrat)	1995	Dome-forming	19	4
Valley of Desolation (Dominica)	1997	Phreatic	0	?

Table 3.1: 20th Century volcanic activity in the Lesser Antilles. Adapted from McGuire et al. (2009) citing Simkin and Siebert (1994), Lindsay et al. (2005), and Witham (2005).

The deadliest volcanic eruption in the world during this time occurred on the French colonial island of Martinique in 1902 (Witham, 2005). Activity from the island's Mount Pelée had increased during February and March of 1902, with reports of strong sulphur smells, light ash fall and earthquakes. These were followed by two lahars in the first week of May, however, no evacuations were ordered. Some authors suggest that evacuations were not ordered because government elections were planned for May 9th to May 11th and an evacuation at this point would have adversely effected the elections (Ferguson, 2002). Scarth (2002) however dismisses this claim and states that the second round of elections would not have made any notable difference in the balance of power and therefore there was no reason for the government to keep people in town. He suggests the reason an evacuation of the town of St. Pierre was not ordered was because previous eruptions in 1792 and 1851 had been relatively small and confined to the crater. It was thought that the 1902 activity would be similar. When, on May 5th, large lahars washed a factory away and killed 25 people, villagers from the slopes of Mount Pelée actually took refuge in St. Pierre as it was believed to be the safest place. Tragically, on May 8th, the volcano erupted and produced pyroclastic flows that completely destroyed St. Pierre killing over 28,000 – only two people survived in the city itself (Scarth, 2002). Over 100 years later, the population of St. Pierre is only one-fifth of the number who lived there at the beginning of the 20th Century (Ferguson, 2002).

May 1902 also saw the eruption of Soufrière volcano on St. Vincent, the day before Mount Pelée destroyed St. Pierre. Witham (2005) lists this eruption ninth worldwide in terms of the number of people killed during the 20th Century. The eruption was preceded by 14 months of earthquakes which had caused the indigenous Carib population of Morne Ronde and Sandy Bay in the north to petition to have their settlements moved. Their concerns were ignored and so with preliminary activity of steam and glowing emissions in the crater early on Tuesday May 6th, 1902, the Caribs in the north evacuated themselves further south to the village of Chateaubelair (Anderson et al., 1903). Throughout the day of May 6th the plantation villages of Richmond and Wallibou evacuated to Chateaubelair on the western slopes of the volcano, but those villages in the east were oblivious to the activity as the volcano was covered in cloud and they believed the noises from the crater to be thunder. At 2pm on Wednesday May 7th the eruption culminated in an explosion, producing ash, mudflows and pyroclastic flows down valleys in the east and west of the island, killing 1,565 people. A map produced by the British Ordnance Survey in Southampton in 1902 shows the areas in the north of the island that were devastated and the estimated population of the villages affected (Figure 3.3).

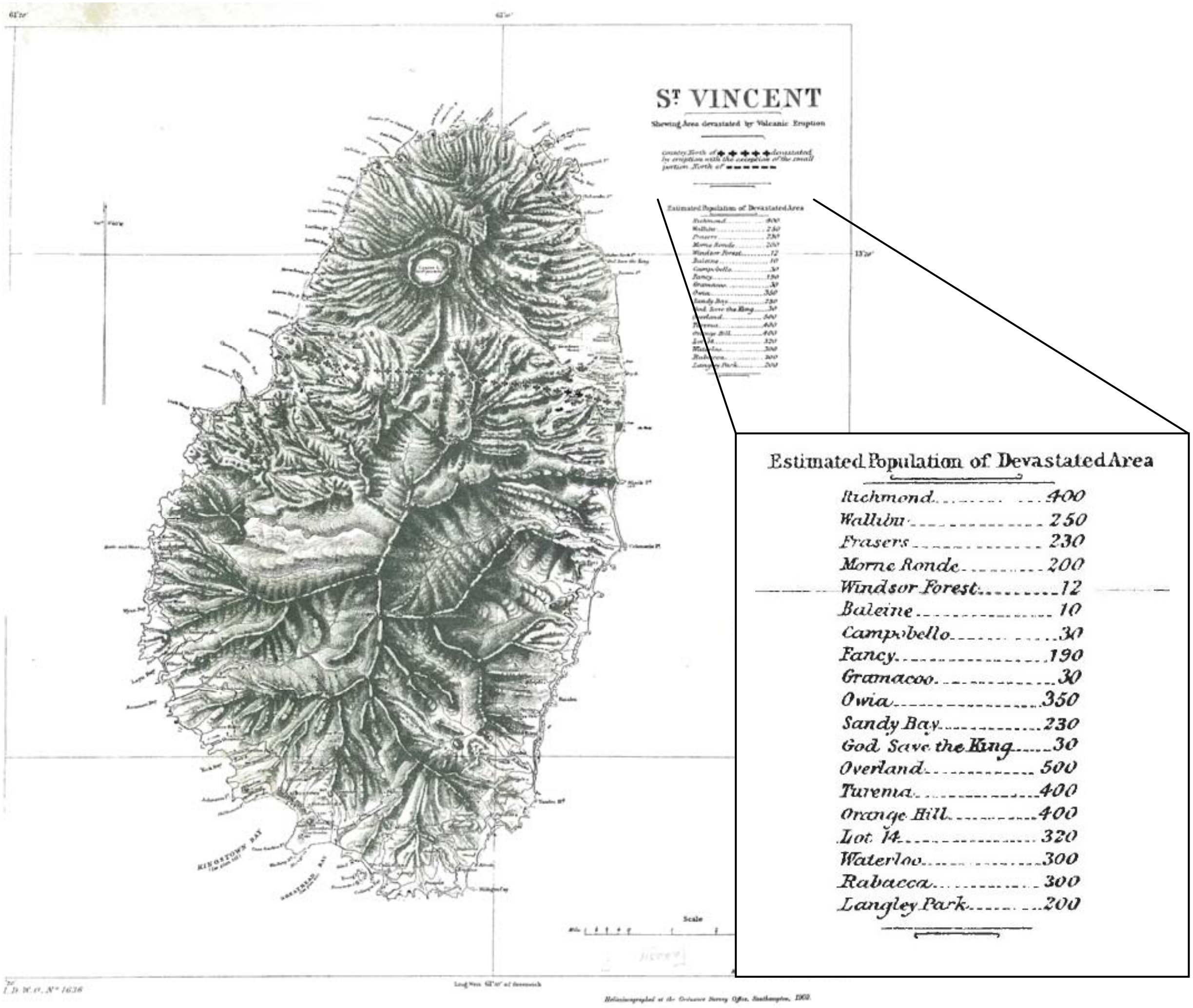

Figure 3.3: British Ordnance Survey map of St. Vincent after the 1902 eruption.

Soufrière volcano erupted explosively again on Friday April 13th, 1979, this time with no loss of life. Although there was heightened activity at the volcano from 1976 (increases in lake temperature, apparent inflation of the volcano and seismicity), none of the precursors were felt by the residents living on the flanks of the volcano (Shepherd et al., 1979). The population in the north woke at dawn on Friday 13th to a fine coat of grey dust and thunder-like rumbles coming from the crater (Tomblin, 1979). They were also able to see large eruption plumes which were being generated by explosions at the time (Robertson, pers. comm.). By midday almost all of the 22,000 people living on the slopes of the volcano voluntarily evacuated before official orders were given (Tomblin, 1979; Fiske, 1984). The explosive activity continued in phases until April 26th and was followed in May by the growth of a new lava dome in the crater (Shepherd et al., 1979). Despite no loss of life, property damage and economic losses were estimated to have exceeded US$5.2 million, and the social impact from the eruption included prolonged evacuation for up to three months, family disruption, extended period of school closures used for emergency shelters and larceny (Robertson, 1995). Although there were numerous social and economic costs of this eruption, it is widely accepted that the event was well managed (Tomblin, 1979). This contrasted completely with the events on Guadeloupe three years earlier. In 1976 Guadeloupe's Soufrière volcano erupted steam and ash and the evacuation of 72,000 people - one quarter of the island's population - was ordered with people relocating to safe areas on other parts of the island. The situation worsened when scientists disagreed over the threat the volcano posed, and these disputes were played out in the media for all to observe. As a result, authorities in Paris arranged for a group of impartial, foreign scientists to review the science, and after concluding that the volcano no longer posed a major threat, the evacuation was ended after almost four months (Fiske, 1984). Although the volcanic activity settled, the economy, and public trust in scientists, was severely affected.

The region's most recent volcanic crisis has been ongoing since 1995. An eruption of the Soufrière Hills volcano on the island of Montserrat began in July 1995 and has devastated the southern portion of the island. Prior to this Montserrat enjoyed some of the highest levels of health, education and housing standards in the region (Clay et al., 1999). Phreatic activity began in July 1995; for the first three months of the crisis there were temporary evacuations of the southern portion of the island and population and administration were moved from the capital. By September 1995 the population and administration returned and there was a period of 'waiting on the volcano', during which activity increased gradually (Clay et al., 1999). Voluntary relocation schemes were set up for people to move abroad and resettlement in the north of the island began. By early 1996 permanent evacuation of the south was ordered (Clay et al., 1999; Kokelaar, 2002; Haynes, 2006). Activity escalated when on June 25th, 1997 a lava dome collapse created pyroclastic flows that killed 19 people - aged from 3 months to 73 years - who were in the exclusion zone (Pattullo, 2000).

The activity continues to date, and has caused the relocation of approximately 90 percent of the 10,500 population with two thirds leaving the island; and destroyed virtually all the important infrastructure including the capital Plymouth, hospital and airport (Clay et al., 1999; Kokelaar, 2002). The eruption has consisted of phases of explosive activity and periods of relative quiet associated with dome-building.

These volcanic crises in the Eastern Caribbean, in particular the drawn out situation on Montserrat, highlight just how important it is for islands with potentially active volcanoes to be prepared for a possible eruption. Despite the Montserrat crisis being played out on their doorsteps, many islands in the region still do not have comprehensive vulnerability and risk assessments in place.

3.4.2.2. St. Vincent

St Vincent is the largest of a multi-island chain called St Vincent and Grenadines that is located within the southern part of the Lesser Antilles Volcanic Island Arc. The Grenadine islands do not have any active volcanism and therefore only the island of St Vincent is included in this research. The small, mountainous island has an area of 344km^2, and is roughly 29km long and 17.5km wide. There is a backbone of stratovolcanic centres ranging from south to north in age. The only active volcano, Soufrière, is the northernmost peak, reaching 1,178m high with an age of 0.6Ma to Recent (Robertson, 2005, citing Rowley, 1978 and Heath et al., 1978).

St. Vincent and the Grenadines gained independence from the UK in 1979, having been under colonial rule since the 1700s. The total population for the islands is estimated to be 104,574 in July 2009[10] with the majority of the population - over 90 percent - residing on St Vincent. Traditional industries such as agriculture, fishing and manufacturing are in decline. As a result development of the island has increasingly turned towards the tourism and financial sectors. Education and job creation are key focuses for the government to increase development in addition to attracting new investment and visitors to the island. As a consequence, a new 'international' airport is being built to aid in this. Despite these efforts, the island suffers from high unemployment rates (over 20 percent) and emigration of young people to neighbouring Caribbean islands, the US, Canada and the UK for education and employment.

3.4.2.3. Soufrière volcano and its monitoring

Soufrière has erupted explosively roughly once every 100 years during the past 4000 years (Robertson, 2005). Recent explosive eruptions occurred in 1718, 1812, 1902-1903, and 1979 (Shepherd et al., 1979; Robertson, 2005). There is also evidence that the volcano experiences periodic aseismic effusive activity such as in 1971-72 (Aspinall et al., 1973). The explosive eruptions are of the type typically experienced in the Eastern Caribbean region and were responsible for the Martinique and St. Vincent disasters in 1902 and the most recent St. Vincent eruption in 1979. According to Aspinall et al. (1973, p.123) the 1971-72 effusive eruption that resulted in the extrusion of a viscous lava dome in the crater *"was of a type [of eruption] different from any which had previously been described in the West Indies".*

[10] https://www.cia.gov/library/publications/the-world-factbook/geos/vc.html
Accessed November 11th, 2009

There is evidence of one period of ‘cataclysmic’ Plinian-type volcanic activity. Although there is no historical (post 1700) record, the presence of thick ash deposits over most of the island demonstrates that the Soufrière volcano has the potential capacity for large events (Robertson, 2005). A geological map of St. Vincent (Figure 3.4) shows volcanic deposits from Soufrière volcano along with pre- Soufrière volcanic centres. Although the geology demonstrates that there is the potential for a large event on St. Vincent, the 1902 VEI 4 eruption and 1979 VEI 3 eruption are used as the basis on which to model future activity in the short term (less than 100 years) (Robertson, 2005). The volcanic hazard map for this short term scenario is shown in Figure 3.5.

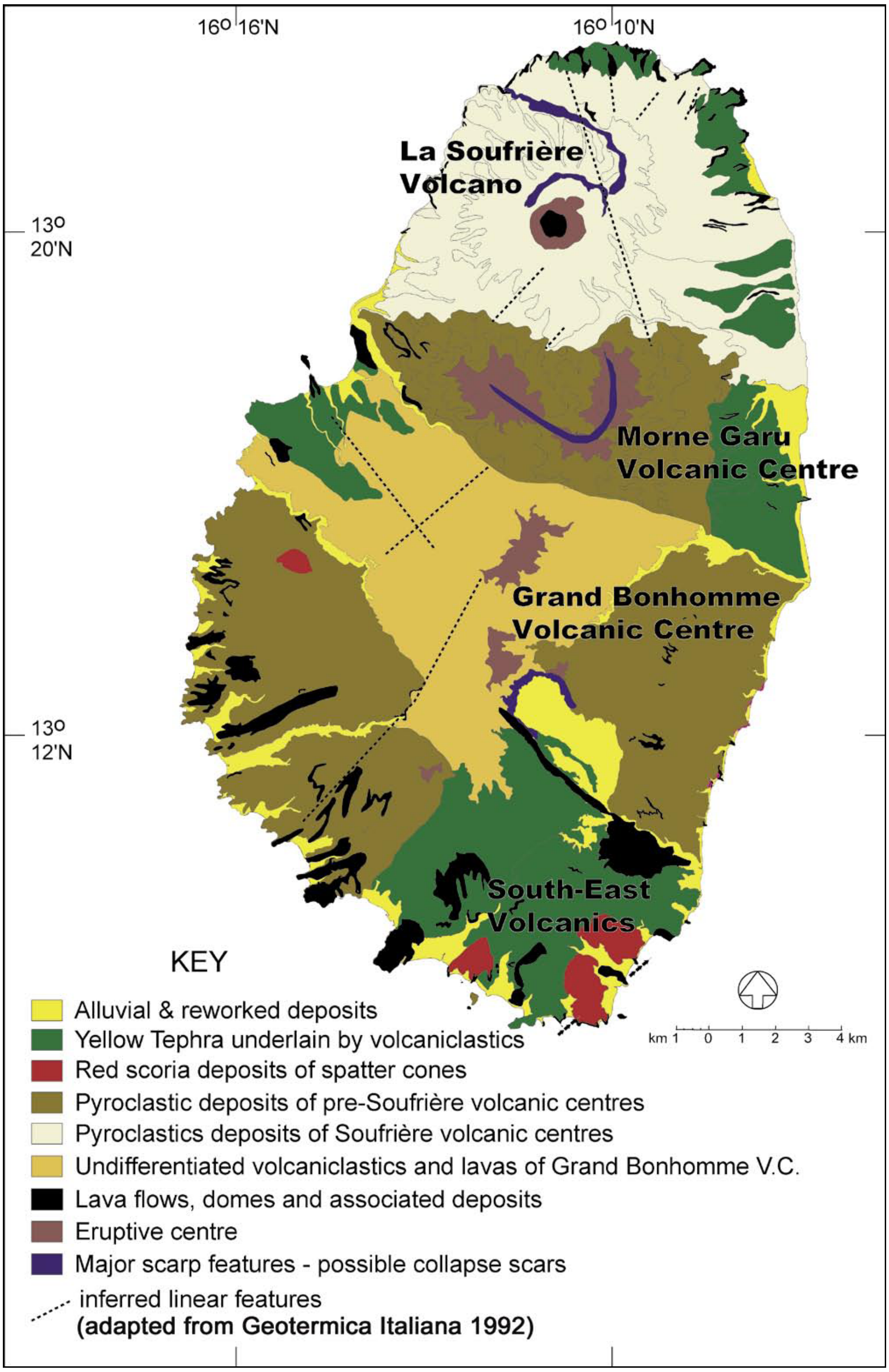

Figure 3.4: Geological map of St. Vincent (Robertson, 2005, p.242).

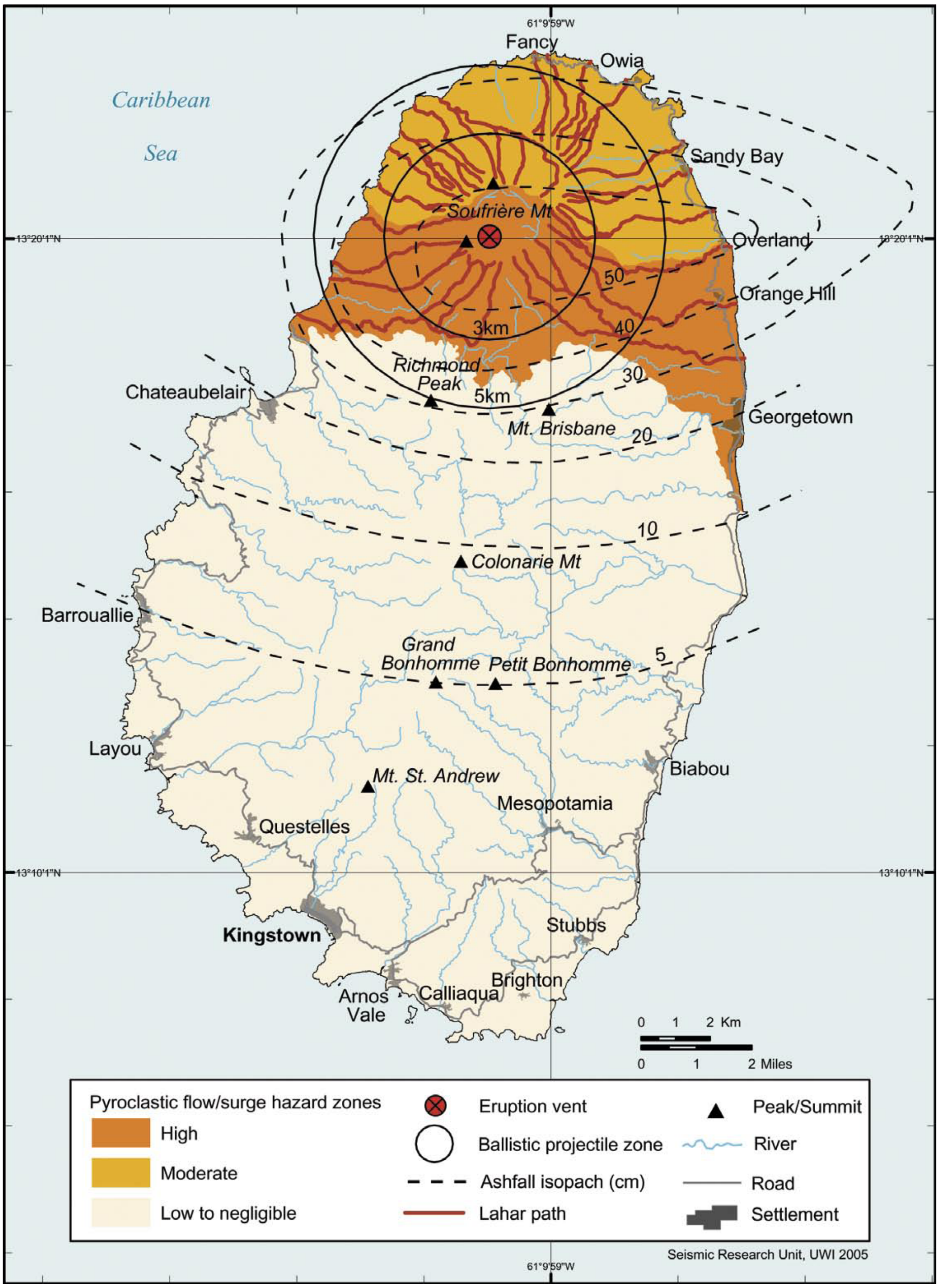

Figure 3.5: Volcanic hazard map for St. Vincent (Robertson, 2005, p.254). For definitions of the volcanic hazards see Appendix A.

This hazard assessment and map are based on evidence from past eruptions as the knowledge of Soufriere Volcano is fairly detailed. The following description is taken from Robertson (2005). The most hazardous events expected in a future eruption are pyroclastic flows and surges, lahars, ash fall and ballistic projectiles. The boundaries of the zones in Figure 3.5 are based on a number of factors: past incidence of the hazards and areas of maximum projected extent, in addition experience of these hazards at similar volcanoes is combined with theoretical considerations of mass discharge rates of magma, wind direction and morphology.

The ‘high’ pyroclastic flow boundary is based on the 1979 and 1902 pyroclastic flows. The ‘moderate’ zone is considered less likely to be impacted by pyroclastic flows and surges unless there is an eruption column height greater than 20km. Dark circles define areas likely to experience damage from ballistic projectiles with the largest projectiles expected within the 3km zone. Lahars extend up to 7km from the crater and are projected to follow rivers. Ash fall isopachs are based on the 1979 pattern of deposition and scaled upwards to take into account a 1902 magnitude eruption. At around 8-16km the westerly trade winds are dominant and this is the expected height of an eruption column from future explosive activity at Soufriere Volcano, therefore the isopachs extend to the east of the volcano.

There are some limitations associated with the hazard map in Figure 3.5. First, pyroclastic surges are not well represented as they have been combined with the pyroclastic flow zone. Surges are less constrained by topography, and Robertson (2005) states that with larger eruptions they may reach up to 5km from the crater. Therefore the pyroclastic flow/surge zone could be extended further south to take this into account. Lahars are also poorly represented as they are confined to the paths of the main rivers radiating out from the crater. Secondary lahars from a combination of rainfall and ash on the flanks of the volcano are a possibility and require consideration. In addition, Anderson et al. (1903) describe houses being destroyed by lahars in Georgetown, and the current map does not indicate this as a possibility. These lahar zones could be improved upon with output from lahar models such as LAHARZ (Iverson et al., 1998). Finally, the ash fall isopachs are drawn to represent the prevailing wind direction, but no indication is given on the map as to what time of year these westerly trade winds are dominant. Below 5km and above 16km the prevailing winds are easterlies (see Figure 3.6), therefore if the column height fell within these ranges it is possible that ash could be deposited in the opposite direction to that indicated in Figure 3.5.

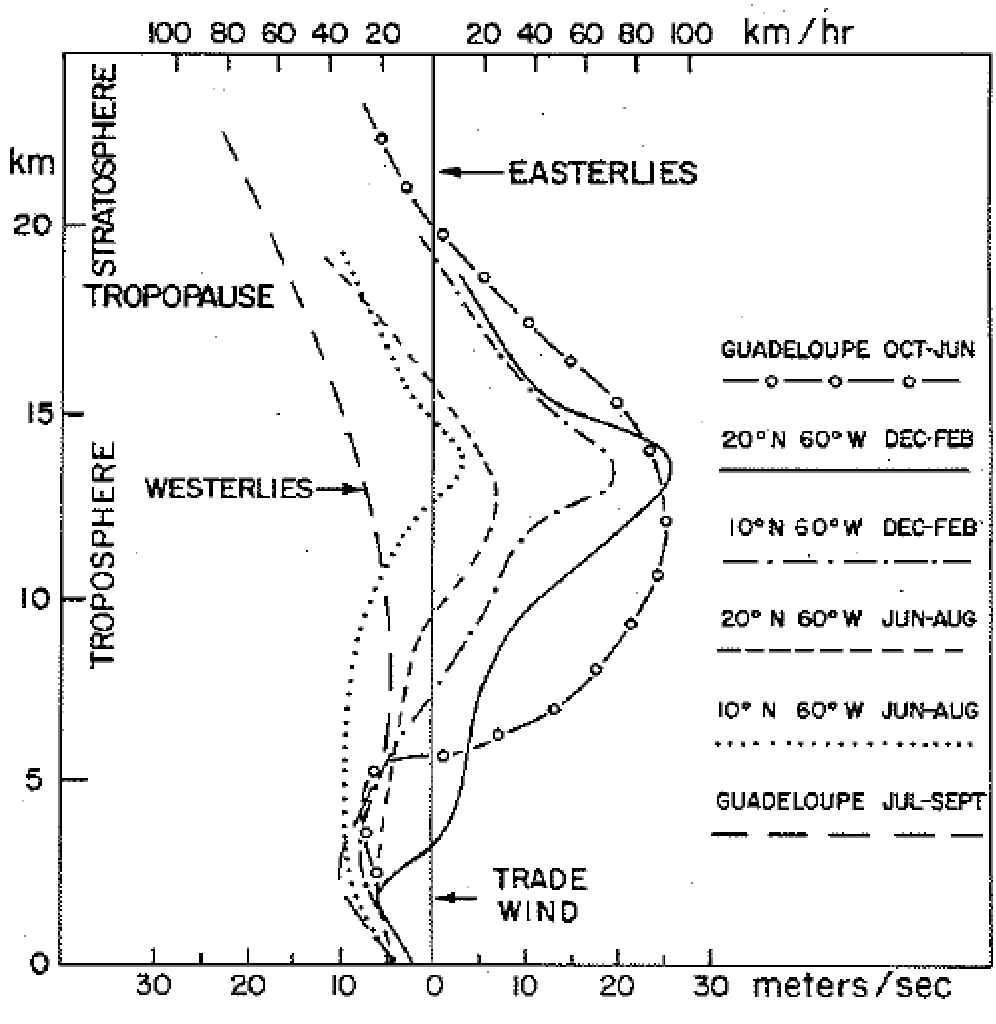

Figure 3.6: Seasonal and height variation in wind circulation above the Lesser Antilles arc. From Sigurdsson and Carey (1981, p.269) based on data from Newell et al. (1972) and Westercamp (pers. comm.).

Despite these limitations, Figure 3.5 represents the best available hazard assessment and map for Soufriere Volcano and is therefore the one used throughout this research.

Monitoring of Soufrière volcano is the responsibility of the SRC at the University of the West Indies in Trinidad, with the help of a local Soufrière Monitoring Unit (SMU) based at the Ministry of Agriculture on St. Vincent. The main monitoring techniques used are seismology (seismograph network), geodesy (ground deformation network), geochemistry (sampling fumaroles), and visual observations (monthly visits). A new broadband seismic station with continuous links to SRC in Trinidad was installed at the custom built Belmont Observatory in 2007 with funds from USAID (Figure 3.7) (see Figure 3.1 for location of observatory).

Figure 3.7: New seismometers after installation at the Belmont Observatory, St. Vincent.

3.4.2.4. Disaster management on St. Vincent

A summary of disaster management in the Caribbean is provided by Poncelet (1997) and outlined here. Throughout the 1960s and 1970s disaster management in the region was based on *ad hoc* response to disasters. This changed, however, after a number of destructive hazard events in 1979. First, the costly volcanic eruption on St. Vincent, in addition to Hurricane David which devastated Dominica and the Dominican Republic resulting in over 200,000 people being made homeless and more than US$1 billion in damage. On Dominica 88 percent of roofs and 56 percent of structures were damaged. These disasters led to a more regional approach to disaster management and the creation of the Pan Caribbean Disaster Preparedness Program in 1981 (later called the Pan Caribbean Disaster Preparedness and Prevention Program PCDPPP). The initiative lasted around 10 years under the guidance of a number of regional and international organisations including the Pan American Health Organisation (PAHO), the Red Cross, UNDRO, and the Secretariat of the Caribbean Community (CARICOM). However, the limited success of the PCDPPP became evident at the end of the decade when in 1988 Hurricane Gilbert devastated Jamaica and in 1989 Hurricane Hugo severely damaged Montserrat. In 1991 CARICOM states replaced the PCDPPP with CDERA – the Caribbean Disaster Emergency Response Agency - which has a stronger institutional position than the PCDPPP.

At a recent conference on Caribbean Disaster Management it was noted that:

> *"Caribbean disaster management has undergone a paradigm shift over the past few years, with the discipline changing from a single person or unit dealing with the response to a single hurricane hazard to a more multi-hazard approach involving the coordinated action of numerous private and civil society personnel in all stages of the disaster management cycle, from prevention and preparedness response and recovery." (Downer, 2008)*

Each island now has a disaster management agency. Initially the role of disaster manager was a part time job undertaken by someone with additional duties in the government. On St. Vincent the disaster agency is called NEMO – National Emergency Management Organisation. It was established in 2002, and with a loan from the World Bank, on the understanding that the role of Director would be made full time, a new office was built in Kingstown, the capital of St. Vincent (Figure 3.8).

Figure 3.8: NEMO headquarters, Kingstown, St. Vincent (M. Duncan, 2007).

NEMO personnel comprises of a Director, Deputy Director and Education Officer, plus around 10 clerical staff. It is part of the Office of the Prime Minister with the Director reporting directly to the Prime Minister. Other ministries such as transport and works, and telecommunications, are theoretically involved in national level disaster planning and management through several subcommittees, however, according to officials at NEMO they do not all recognize the importance of disaster planning and are not as active in the subcommittees as NEMO would like. At the local level disaster management is coordinated through community disaster groups across the island, of which there are over 20. These comprise of members of the community who hold jobs such as farmers, teachers, etc., that meet to assess the hazards specific to their community. In response to the risk from these hazards the groups create plans to respond to a hazard should it occur. These local groups are supported by NEMO, however in the same way as government ministries are not all active in disaster management; some community disaster groups are more active than others. Formally, the roles and responsibilities of the government ministries and community disaster groups and the structure for preparedness and response to disasters are outlined in the National Emergency and Disaster Management Act 2006, and the National Disaster Plan (NEMO, 2004).

3.4.2.5. Future volcanic threat

The volcanic hazards likely to be associated with a future eruption of the Soufrière volcano are outlined in the Volcanic Hazards Atlas of the Lesser Antilles (Lindsay et al., 2005). The Atlas covers 12 volcanic islands in the Eastern Caribbean and documents the geological history of each island, previous work carried out on assessing the volcanic hazards and current state of monitoring. Each island chapter concludes with two types of hazard map for the most likely future eruption scenario or scenarios – one showing the likely areas to be affected by the individual hazards (Figure 3.5) – the second map is an ‘integrated’ hazard map zoning these hazards into areas of high (red) to low hazard (green).

The most likely scenario in the short term (less than 100 years) is either an explosive eruption in the range between a 1979-style event (VEI 3) and a 1902-style event (VEI 4) or an effusive eruption similar to 1971-72 (Robertson, 2005). The hazards associated with an effusive eruption would most likely be confined to the crater and consequently no hazard map has been produced for this. The most hazardous events expected to occur in an explosive eruption include pyroclastic flows and surges, lahars, tephra fall and ballistic projectiles. The integrated hazard map for such an eruption is shown below (Figure 3.9).

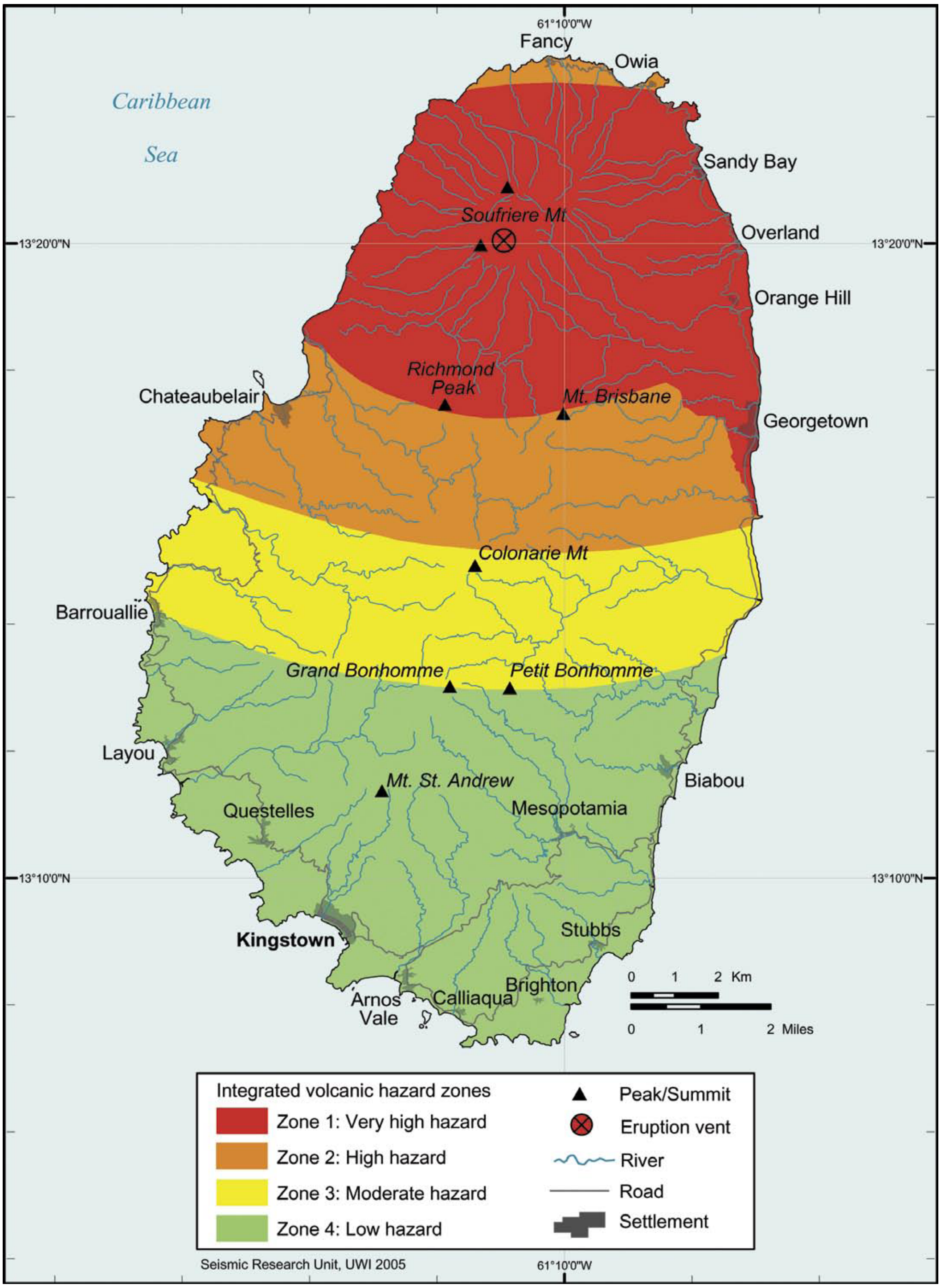

Figure 3.9: St. Vincent integrated volcanic hazard map (Robertson, 2005, p.258). For an explanation of the hazard zones see Appendix B.

3.4.2.6. Hazard communication and education

The Atlas was formally launched on only two islands in the region - St. Vincent and Dominica. On St. Vincent this involved distribution of the

Atlas to libraries and bookshops, and an official launch supported by NEMO. The integrated hazard map is also displayed at educational events across the island including the annual commemoration of the April 1979 eruption where there are stalls in the capital, Kingstown, and exhibitions at venues across the island, in addition to public education events throughout the year (Figure 3.10). Two local newspapers also reproduced the integrated hazard map and alert level table that were published on Friday April 13th, 2007 (see Appendix C).

Figure 3.10: Public educational event, Kingstown, St. Vincent. The integrated volcanic hazard map is displayed alongside the alert level table (top left of photograph).

Prior to the Atlas being produced, St. Vincent had a volcanic ‘risk’ map that was very similar to the current integrated hazard map. On the ‘Volcanoes of St. Vincent’ leaflet produced by the SRC in 2001 it is described as a ‘hazard’ map, but the arrow shows increasing *risk* (Figure 3.11).

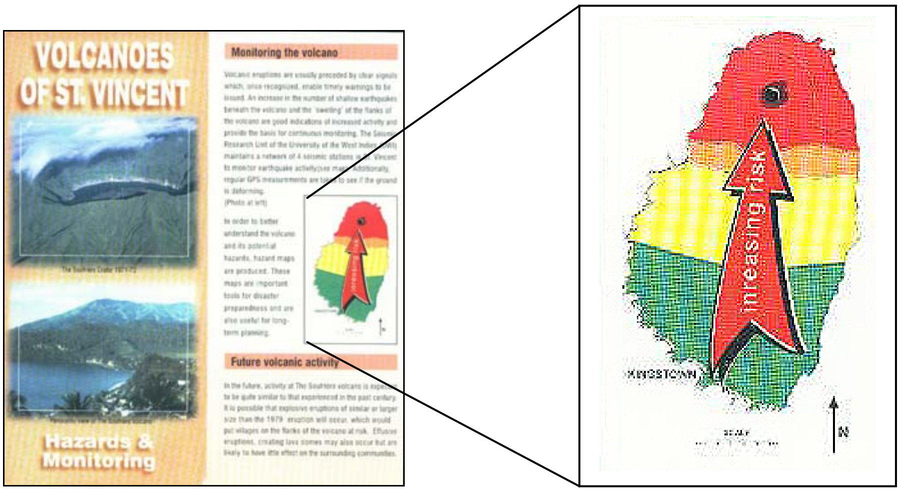

Figure 3.11: SRC leaflet on volcanic risk in St. Vincent. The new integrated volcanic hazard map has replaced the ‘risk’ map displayed here.

This change in terminology, from ‘risk’ to ‘hazard’ highlights how the field of volcanology and natural hazards in general has progressed recently. The leaflet in Figure 3.11 was used prior to the launch of the Atlas in 2005, and although the label on the map says ‘risk’, only hazard information is included. The Atlas specifically addressed this terminology issue by labelling the new maps ‘integrated hazard maps’. In order to produce a true assessment of volcanic risk on the island, first vulnerability needs to be investigated and mapped. This is a current aim of the SRC and one reason why St. Vincent was chosen as the case study for this research.

3.5. Summary

Gaps in the literature on vulnerability to volcanic hazards exist that the research has been designed to address. To accomplish this St. Vincent has been selected as a suitable case study. Vulnerability is a complex concept to quantify and analyse with no single model or method able to capture its complexity. Research into vulnerability can be broader in its approach, blending contemporary knowledge from various disciplines and comparing and contrasting the results. In this way measures to reduce risk to future disasters will incorporate information on various social, physical, economic, cultural and political aspects of vulnerability. This approach is taken here using the four methods previously described and which are individually addressed in the following four chapters.

Chapter 4: Social Vulnerability Index

Here, the first of the four research methods – a Social Vulnerability Index (SVI) – is described in detail. It begins with a review of current methods in the literature, followed by a description of the methods adopted for data collection. The results obtained and analyses are presented along with a critique of this method for analysing vulnerability to volcanic hazards.

The aim of completing a SVI is to capture data on vulnerability to volcanic hazards that are often left out of traditional physical-oriented volcanic vulnerability work. Stakeholder views are sought to help tap into local knowledge and create a vulnerability analysis that is appropriate to user needs and understanding.

4.1. Review of current methods

In the literature there are a large number of quantitative and qualitative methods used to analyse vulnerability (see Section 2.7). Here, quantifying vulnerability using an index is specifically addressed, and the results mapped to examine the spatial nature of the vulnerability on St. Vincent.

With an increasing awareness of disaster impacts attempts are being made to measure aspects of disasters such as preparedness, resilience, mitigation, social vulnerability and hazard exposure (Simpson and Katirai, 2006). One form these measurements are taking is the creation of an index whereby a number of indicators are combined mathematically to produce a value that measures the relative state of a concept (i.e. vulnerability). These indices can be calculated for different areas and the status of that concept compared. The scale at which these indicators are calculated varies from global to local. The following paragraphs outline some of the most recent methods currently described in the literature; the first two are global in scale, followed by national level index, and local indices at county and census tract scale. These were chosen to review in order to provide examples of indices at different scales and using different data sets. The second section reviews the literature describing the spatial analysis of vulnerability to natural hazards and a small number of studies on volcanoes specifically. These are reviewed to provide examples of various methods of data collection and analysis available to incorporate into the research presented here. For a comprehensive review of index methods and indicators of vulnerability and risk see Pelling (2004), Birkmann (2006c), Simpson and Katirai (2006), and Villagran De Leon (2006).

4.1.1. Global, national and sub-national vulnerability indices

The Disaster Risk Index (DRI) from the United Nations Development Program (UNDP, 2004) provides a global view of vulnerability at national resolution targeted at national and international policy makers. It aims to link development with disaster risk and vulnerability through two measures: relative vulnerability that calculates numbers killed divided by numbers exposed; and socio-economic vulnerability indicators such as population density and GDP per capita that best explain recorded mortality for specific hazards. The EM-DAT database from CRED is used for data on mortality from earthquakes, tropical cyclones, droughts and floods. Vulnerability is calculated separately for each hazard.

The Hotspots model from the World Bank and ProVention Consortium (World Bank, 2005) aims to identify and map grid cells (around 21km^2 area) - rather than countries - with the greatest risk to individual hazards in terms of three indices: risk of mortality, risk of economic loss and risk of economic loss as a percentage of GDP. Hazards include cyclones, drought, earthquakes, floods, landslides and volcanic eruptions. The vulnerability from each hazard is calculated using historical loss data from the EM-DAT database. These vulnerability values are used to weight the hazard exposure of the population or GDP for each grid cell, determining overall risk.

Indicators of Disaster Risk and Risk Management from the Inter-American Development Bank (IADB) and the Economic Committee for Latin American and the Caribbean (ECLAC) (Cardona, 2006) differs in that it aims to aid national decision-makers and therefore the scale of the analysis is more detailed at national and sub-national level. It also takes an inductive approach rather than deductive as in the previous two examples. Four indices were produced for 12 Latin American and Caribbean countries. These are the Disaster Deficit Index that considers financial exposure, the Local Disaster Index that measures a country's proneness to disaster, the Prevalent Vulnerability Index that calculates conditions of human vulnerability, and the Risk Management Index that assesses a country's disaster risk management performance. The indices include data on a wider range of factors than the DRI or Hotspots model such as resilience and capacity to cope. Data are from country surveys, expert opinion and the DesInventar database[11] (Villagran De Leon, 2006).

There are a range of other national level vulnerability indicators that address different aspects of vulnerability, with a particular focus on SIDS. Examples include the Economic Vulnerability Index (Briguglio, 1995), the Environmental Vulnerability Index (UNEP and SOPAC, 2000) and the recent Social Vulnerability Index (St. Bernard, 2007). The aim for the Caribbean region, through work undertaken by ECLAC, is to combine these indices to produce a composite vulnerability index. The scale of the assessments is still at the national level, and although reports highlight the need to look at local and household level vulnerability, work to date has not addressed this (ECLAC Social Affairs Officer, pers. comm.).

[11] DesInventar is a Latin American database of loss, damage or effects caused by emergencies and disasters: www.desinventar.org.

What is clear from reviewing different indices is that there is no common method available for a researcher to follow. In addition there is no consensus as to what to include in an index of vulnerability, and mathematically, how to combine the datasets. The indices reviewed here calculate vulnerability as mortality rate, economic loss, or through social indicators. Different data sets are used that either measure historical vulnerability or the current situation of a country or region. The scales of the indices also vary depending on the aims and scope of the research. Two of the three examples use EM-DAT data that has limitations. Witham (2005) discusses problems with the EM-DAT database, specifically with respect to volcanic information, and suggests the figures would be incorrect by up to 30 percent. Issues include events missing, events listed twice, and inaccurate dates and details (e.g. the wrong volcano name attributed to a disaster).

Despite this lack of consensus around how to measure vulnerability with an index, one method of visualising and interpreting the results of vulnerability assessments that is becoming more prevalent is through spatial analysis and the application of GIS. The DRI and Hotspots indices discussed above both create maps as an output. Research into social vulnerability to natural hazards at a local scale also utilise spatial analysis and visualise results using GIS; this is discussed further in the following section.

4.1.2. Spatial analysis of social vulnerability at the local scale

A review of the literature on the spatial analysis of social vulnerability to natural hazards reveals a number of pertinent studies, a handful of which apply to volcanic hazards specifically. The following section outlines the studies applied to natural hazards such as flooding, earthquakes and tsunami. Section 4.1.3 discusses research into the spatial analysis of social vulnerability in relation to volcanic hazards.

One of the first studies to analyse social vulnerability using GIS was undertaken by Emani et al. (1993) who illustrated how GIS could be used to assess vulnerability to extreme storm events and sea-level rise of a coastal community in Massachusetts, US. Vulnerability is defined by the authors as the 'differential susceptibility' of social groups and locations to suffer loss, and includes an exposure factor (the location of people, the built environment and land use); resistance (the ability to withstand the impacts); and resilience (the ability to recover from the impacts). Census data were used to represent social vulnerability factors such as age, ethnicity and income. Digital elevation models and land use data were used to capture the hazard and exposure. Using overlay techniques in the GIS the authors were able to map the distribution of overall vulnerability across the study area.

Substantial recent work on the spatial analysis of social vulnerability has been led by Susan Cutter at the University of South Carolina Hazards and Vulnerability Research Institute. Cutter (1996) proposed the VoP model (Figure 2.3) and this has been advanced by the development of indices of social vulnerability that help analyse the spatial variation of vulnerability across regions and between countries. Cutter et al. (2000) used the VoP model in a multi hazard assessment of Georgetown County, South Carolina using a number of census variables to measure social and biophysical vulnerability. Following this work, Cutter et al. (2003) developed the Social Vulnerability Index (SoVI) for use in the US. The index is a combination of US Census data. Originally 250 variables were selected that broadly characterized social vulnerability. After testing, normalisation and factor analysis on the data, the variables were reduced to 11 factors – personal wealth, age, density of the built environment, single sector economic dependence, housing stock and tenancy, African American race, Asian race, ethnicity (Hispanic, Native American), occupation and infrastructure dependence. A SoVI was calculated based on 1990 census data and mapped for each of the 3,141 US counties with the most vulnerable counties shown to be in the south of the country (Cutter et al., 2003).

After developing the SoVI, Boruff et al. (2005) integrated the index with a measure of physical vulnerability of coastal communities in the US. The physical variables used to create the Coastal Vulnerability Index were adapted from a United States Geological Survey study and included mean tidal range, coastal slope, rate of relative sea-level rise, shoreline erosion and accretion rates, mean wave height and geomorphology. The two indices were added together to produce so-called 'place vulnerability'. In addition to calculating place vulnerability, the authors determined which vulnerability (social or physical) had the greatest influence on the overall place vulnerability. They found that for the Pacific and Atlantic coasts physical variables had the greatest influence, however for the Gulf Coast counties they found that social vulnerability had the greatest influence on place vulnerability.

Boruff (2005) and Boruff and Cutter (2007) conducted a comparative study of two small island states in the Caribbean – St. Vincent and Barbados – in part to determine the applicability of the SoVI method and VoP model to regions outside of the US. This multi-hazard assessment used data for flood, fire, landslide, storm surge, tsunami and volcanic hazards. Using census data from each island a social vulnerability index similar to the SoVI was created and integrated with data for the various hazards. Data included information on age, gender, disability, employment, number of persons per household, household density, infrastructure, and rural versus urban areas. The authors found that Barbados had the greatest percentage of its population living in risky areas, with over half residing in areas vulnerable primarily to fire. Biophysical vulnerability (i.e. the exposure to hazards) was determined to have the greatest influence on overall place vulnerability. On St. Vincent the population exposure was greatest for landslide and volcanic hazards, while social vulnerability factors, such as age and access to resources, had the greatest influence on overall place vulnerability.

Other researchers have taken similar approaches to analysing the spatial variation of social vulnerability. For example, Wu et al. (2002) adopt Cutter's VoP model for their study of the physical and social vulnerability of Cape May County in New Jersey, US, to flooding. For the physical vulnerability or exposure, they use the National Hurricane Center's SLOSH model (Sea, Lake and Overland Surges from Hurricanes) and compare the results with a 30m digital elevation model of the county to evaluate potential areas of inundation from sea-level rise flooding. In addition, they use river flood zone data from FEMA and combine the two datasets to produce four zones of total flood hazard. The social vulnerability measure is calculated using US Census Block statistics. The authors base their social vulnerability factors on existing literature. They use nine measures in total: population, housing units, number of females, number of non-white residents, number of people under 18 years of age, number of people over 60 years of age, number of female headed single parent households, number of renter occupied housing units and median house value.

Wood and Good (2004) evaluated the vulnerability of port and harbour communities in Oregon, US, to earthquake and tsunami hazards. The assessment utilised readily available data on four themes: study area data such as elevation models, digital photographs, and bathymetry data; hazard potential from a Cascadia Subduction Zone earthquake scenario including ground shaking data, liquefaction, landslides and tsunami inundation; and community assets for resiliency such as population, occupancy and infrastructures. The fourth theme, community vulnerability, was an aggregation of the hazards and assets data to produce 'hot spot' maps of relative vulnerability across the study area.

4.1.3. Spatial analysis of social vulnerability to volcanic hazards

The majority of studies that have used GIS to study volcanic risk (e.g. Lirer and Vitelli, 1998; Gómez-Fernández, 2000) have included vulnerability as a measure of potential property losses or loss of life. More recently, however, researchers have begun to specifically study the social vulnerability of populations living close to volcanic regions, often adopting social science methods to survey the population exposed to the hazards.

Lavigne (1999b) presents a method of volcanic risk zoning using GIS and overlay analysis for Merapi volcano, Indonesia. Volcanic hazard maps for four eruption scenarios are overlain with vulnerability data derived from census-type datasets. Vulnerability factors include population density, age, literacy, infrastructure and medical facilities. The zoning method identified that the vulnerability of individuals is unequally distributed across the flanks of Merapi.

Finnis and Johnston (2007) assessed the vulnerability of two communities in New Zealand to volcanic hazards. Vulnerability was represented as a combination of three measures: social vulnerability, socio-cognitive factors and preparedness. Social vulnerability is represented using the New Zealand Index of Deprivation (a combination of census data reflecting dimensions of socio-economic deprivation). Socio-cognitive factors such as self-efficacy, action-coping, sense of community and previous experience of hazards is measured using survey data. The final measure is of preparedness, again using survey data. These three indices of vulnerability are combined with a volcanic hazard map which is ranked into six categories of low-to-high hazard, to produce risk.

Hayes (2007) conducted a similar study comparing the vulnerability of two volcanic regions, Mount Rainier in the US and Volcan Tungurahua in Ecuador. Using a combination of semi-structured interviews with stakeholders and public questionnaires she explores the cultural, behavioural and social characteristics that shape human vulnerability of these two contrasting regions.

Wood (2007b) and Wood and Soulard (2009) study community vulnerability to lahar hazards from Mount Rainier, Washington in the US, and describe the vulnerable system as exposure, sensitivity and resilience of the population, economy, land use, infrastructure, cultural assets and natural resources. This method of analysis had previously been applied to the vulnerability to tsunami hazards in Hawaii and Oregon (Wood, 2007a; Wood et al., 2007). Using GIS and statistical analyses Wood identified a large variation in community exposure and sensitivity to volcanic hazards across the 18 cities of Pierce County, Washington. Some communities had high exposure (i.e. numbers of people or assets within a hazard zone) but low sensitivity, in that the assets exposed represented a small percentage of the community total. Other communities were calculated as having high sensitivity, potentially suffering total devastation in that although total numbers exposed were low, that number represented over 95 percent of community assets.

4.2. Method

Although there has already been a vulnerability assessment for St. Vincent (Boruff, 2005; Boruff and Cutter, 2007) there are three key reasons why more research is warranted. First, the study conducted previously looked at multi-hazard vulnerability, whereas this research focuses on vulnerability to volcanic hazards exclusively, and therefore provides a more focused assessment. Second, this research engages stakeholders to decide on the vulnerability variables used, as opposed to statistical methods, which may alter the results. Finally, more recent data (the 2001 Census) are available to provide up-to-date results and maps.

In describing the method used in this study for researching and creating a SVI to volcanic hazards, it is useful to follow the 'basic steps for vulnerability and capacity analysis (VCA)' from Twigg (2007) (Figure 4.1).

Figure 4.1: Basic steps for conducting a VCA (Twigg, 2007, p.4).

This describes the steps which are used here, although not necessarily in the order listed. The following section addresses each of these steps in turn.

4.2.1. Selecting a framework for analysis

Before an index can be created, it is first necessary to decide upon the framework for analysis. As Twigg (2007) states the selection of a framework is the starting point of any vulnerability analysis as it establishes what is to be analysed and how. There are many model frameworks in the literature (see Chapter Two). The one adopted in this portion of the research is the VoP model by Cutter (1996) (Figure 2.3). This was chosen for the following reasons:

- Many models in the literature focus on one aspect of vulnerability, such as physical exposure (e.g. Fournier d'Albe, 1979) or social and historical construction (e.g. Wisner et al., 2004);
- The VoP model aims to combine these divergent themes together; the overall 'place vulnerability' is a combination of both biophysical vulnerability (physical factors common in volcanic literature such as building type, plus a proximity factor) and social vulnerability (characteristics of the population exposed to the hazards);
- The focus is on analysing vulnerability spatially, and the model has been applied to studies that have quantified and mapped vulnerability in a GIS; and
- There is a clear method to follow in relation to the combination of the factors chosen and calculation of the final metric (see Cutter et al., 1997 and Cutter et al., 2003).

4.2.2. Selecting an approach for data collection and analysis

Vulnerability is dynamic and constantly changing, therefore once a method is designed for creating a vulnerability index stakeholders can take up-to-date data and produce new maps for mitigation and communication. It was therefore decided to use secondary data sources as proxies for vulnerability factors that did not require any primary data collection on the part of the researcher. Secondary data sources such as a population and household census or development agency assessments are available in many countries and can be adapted for use in a vulnerability analysis. This is the approach taken by a number of studies in the literature (e.g. Cutter et al., 2003; Wood, 2007b; Finnis and Johnston, 2007; and Hayes 2007).

The data used in this research are taken from the 2001 Population and Household Census Report (Statistics Office, 2001) provided by the St. Vincent Statistics Office which compiles information on migration, housing, crime, demographics, health, education and training. Owing to the spatial nature of vulnerability, volcanic hazard and risk, it was decided to use GIS as a tool for analysing these data. GIS has been applied to a variety of vulnerability research as it provides a tool for the spatial analysis and visualisation of the results.

4.2.3. Selecting a unit of analysis

This step is dependent on the secondary data available in the case study area. Censuses are collected at a range of scales from large census divisions, to small enumeration districts. Development data may be collected at household level. The aim of the vulnerability analysis and index creation in this study is to analyse vulnerability spatially across the chosen island and identify areas that have a higher or lower vulnerability relative to an island average. Therefore, the finer the resolution of data available the more comprehensive the analysis can be.

The unit of analysis for the vulnerability index here is the census division of which there are 11 on the island of St. Vincent (Figure 3.1). The population of an individual unit ranges from 2716 (Sandy Bay) to 22095 (Calliaqua), with an average of 8876 (2001 figures). This unit was chosen because it was the only level at which census data were available. St. Vincent has over 200 enumeration districts, and although access was given to population and household totals for this unit confidentiality meant that more detailed data were unavailable.

4.2.4. Identifying stakeholders and collecting data

The secondary data chosen as proxies for vulnerability variables are available in text or tabular format included in the 2001 Population and Housing Census Report (Statistics Office, 2001). The report is not a complete catalogue of the 2001 Census; rather it contains tables and text relating to some of the key themes (migration, housing, crime, demographics, health, education and training). As a result, any data used in this research were restricted to those census data that were tabulated in this report, and aggregated by census division.

The main task under this step was to collect data relating to those variables that render people vulnerable to volcanic hazards. There are a large number of vulnerability variables in the literature. Cutter et al. (2003) list 17. Different vulnerability studies utilise different variables depending on the scope of the research and the data available.

Statistical approaches such as principal components analysis are sometimes adopted when deciding upon which variables best explain vulnerability (e.g. SoVI methodology from Cutter et al., 2003). Boruff (2005) and Boruff and Cutter (2007) in the studies of St. Vincent and Barbados calculated both an empirical ranking using principal components analysis and compared the results with stakeholder rankings. There were many differences between the results of the two approaches, with some census divisions ranked as highly vulnerable using statistical methods but considered to have low vulnerability by the stakeholders, and vice versa. Therefore, although useful, empirical methods do not necessarily capture what is perceived as important to stakeholders and if they are going to use the results it helps if the results of the analysis reflect their own views. Indeed, Schmidtlein et al. (2008) present a sensitivity analysis of the SoVI methodology and conclude that it is sensitive to changes in the quantitative construction (component selection and method of weighting). As a result they recommend expert guidance when constructing an index of vulnerability. The approach adopted in this research is to gain local stakeholder input about what *they* felt makes people on their island vulnerable to volcanic hazards. This enables the researcher to tap into local knowledge and let the stakeholders define the variables of vulnerability depending on their views and needs. This provides an alternative to statistical approaches from outside researchers. Maps of the output index (SVI) will visualise the spatial distribution of those stakeholder defined variables. The stakeholders chosen were decision makers on the island; people who are involved in planning for volcanic hazards, mitigation measures, evacuation plans and communication. This group was chosen over the general public for a number of reasons. First, decision makers are involved in producing national level assessments. Second, it is the responsibility of the officials on St. Vincent to communicate volcanic hazards to the public, and therefore they are the users of hazard and risk maps. In addition, officials have access to secondary data sources such as a census that can be utilised in the future for updating of the vulnerability and risk assessments.

Data collection for gathering variables of vulnerability from decision makers included semi-structured interviews. A semi-structured interview is more flexible than a formal interview in that instead of a limited set of questions, the interviewer has a framework of themes to be explored that can be adapted depending on what topics come up during the interview.

There are a number of strengths and weaknesses in this approach for data collection. Hughes (2002, p.209) lists the strengths as including:

- Face to face encounter with informants;
- Large amounts of expansive and contextual data quickly obtained;
- Facilitates cooperation from research subject; and
- Useful for discovering complex interconnections in social relationships.

In contrast, weaknesses include:

- Data are open to misinterpretation due to cultural differences;
- Depends on cooperation of a small group of key informants; and
- Difficult to replicate (p.210).

An additional factor to consider when deciding to use this method for data collection is time available. Even if interviewees are cooperative, they may be very limited in time to dedicate to the researcher.

This method was chosen over closed-quantitative interviews or questionnaires for the following reasons. First, it encourages cooperation from the stakeholders, and gives them some ownership of the research and emphasises the importance of their opinions to the researcher. Second, a semi-structured interview allows for expansion on the basic themes chosen by the researcher, and insight can be gained into complex issues that were not necessarily apparent at the outset. In addition, with respect to gathering data on variables of vulnerability, a questionnaire type checklist would allow the participants to select variables that they had not necessarily considered before. With an open interview insight can be gained from what came to the participants' minds first, and how many times certain variables were mentioned throughout the interview.

Interviews were conducted on two Caribbean islands, St. Vincent and Dominica. In part to increase the sample size and also to get a broader view of vulnerability to volcanic hazards in the Caribbean. Interestingly, the same vulnerability variables were identified on both islands and therefore the results of all the interviews are used in the St. Vincent analysis. *Purposive sampling* was the first method used to target stakeholders. This involves deliberately selecting stakeholders who are thought to be relevant (Sarantakos, 1998). Participants were selected through consultation with Dr. Richard Robertson at the SRC, University of the West Indies, who knows the islands and the national decision makers well. In addition, each island has an emergency plan, and the list of those involved in the development of these was used. Initially interviews were arranged with the emergency manager, town planner, and Red Cross representative on each island. The second sampling method was a *snow-balling* technique whereby initial interviewees suggested other participants who may be suitable and available to help with the research (Sarantakos, 1998). Therefore the initial list expanded once on each island to include the Local Government Commissioner and District Development Officers and Assistants on Dominica, and the local scientist and community disaster group members on St. Vincent. In total, 18 people were interviewed (Table 4.1).

Engaging stakeholders to define vulnerability variables is an original approach. However, the researcher recognises that by only interviewing national level decision makers from key groups involved in disaster management produces a small sample size when working on SIDS. Further work could follow the same methods presented here with other individuals such as community or religious leaders, teachers, etc..

Position	Organisation
St. Vincent	
Director	National Emergency Management Office
Deputy Director	National Emergency Management Office
Local Scientist	Soufrière Monitoring Unit
President	St Vincent Red Cross
Town Planner	Physical Planning Office
Head	Community Disaster Groups
Head	Community Disaster Groups
Former Head	Community Disaster Groups
Former Head	Community Disaster Groups
Dominica	
Director	Office of Disaster Management
Director	Ministry of Lands and Surveys
Director	Red Cross
Commissioner	Local Government
Town Planner	Physical Planning Office
District Development Officer	Local Government
District Development Officer	Local Government
District Development Officer	Local Government
District Development Assistant	Local Government

Table 4.1: List of interviewees.

An interview guide was produced that consisted of a number of themes and sub-questions that the researcher wanted to cover during the interview (Table 4.2).

Interview section	Topics covered
Introduction	Aims of research project and purpose of interview
General opening questions	General role of interviewee and departments they worked with
Emergency planning	Interviewee's role in planning for and responding to volcanic eruptions
Maps and GIS	Use of maps, familiarity with Volcanic Hazard Atlas, availability and use of digital maps and data, use and training in relation to GIS
Definitions and understanding of hazard, vulnerability and risk	Familiarity with words, definitions, vulnerable areas and groups on island and reasons why
Future planning	Volcanoes in relation to other hazards on island, other Caribbean volcanic eruptions
Conclusion	Cover any other important topics missed, suggestions for who else to contact on island

Table 4.2: Outline of topics covered during semi-structured interviews with stakeholders. For a copy of the interview guide see Appendix D.

The interview was designed to last around one hour in length. It began with an introduction to the research and some general opening questions that would encourage the interviewee to feel at ease and not under pressure from difficult questions. The researcher only had a basic understanding of the role of each interviewee, so these questions were designed to gather some insight into what their day-to-day activities were, and how this related to planning for volcanic hazards. The third section related to emergency planning and specifically what role the interviewee had before, during and after a volcanic eruption. Additional questions were asked relating to the emergency plan if this was relevant. The fourth section covered the use of maps and GIS by the interviewee and their office. Specifically the researcher wanted to gain insight into whether maps were used on a regular basis, and for what purpose. The fifth section, definitions and understanding of hazard, vulnerability and risk, was felt to be the most difficult to discuss, and was therefore left until this stage of the interview where a conversation had been going for some time, and hopefully the interviewee would be comfortable. Questions were asked in order to understand how the interviewee thought about hazard, vulnerability and risk, and in particular, which areas of their island and groups of people they felt were most vulnerable to volcanic hazards, and why. The final section covered development planning, and whether volcanic hazards were considered. Questions were also asked about the frequency of volcanic eruptions as the interviewee understood it on their island, and whether they were familiar with the situation on Montserrat, and whether this had altered their perceptions of volcanic risk on their island. A hazard ranking exercise was also conducted that asked the interviewee to list the natural hazards faced by the island, and how they compared these with volcanic hazards in terms of how concerned they were about them. To conclude the researcher asked if there was anything else the participant wanted to discuss, and whether there was anyone else they thought the researcher should contact.

The majority of interviews lasted the full one hour, however time was restricted with some participants. In these cases, the focus was first on their role related to volcanic hazards and planning, whether they used maps and their thoughts on the terms, hazard, risk and vulnerability and vulnerability variables. If possible, the hazard ranking exercise was also carried out.

Part six of Figure 4.1, ‘Analyse data’ is discussed below. Part seven, ‘Decision making and action’ is outside the scope of the research presented here.

4.3. Interview analysis and results

This section describes the analysis undertaken to create the SVI and map the results. First the interviews were transcribed and analysed. From these transcripts variables that describe vulnerability were determined and either census data used as proxies for that variable or, where census data were not available, metrics were calculated using spatial analysis techniques in a GIS. Finally, a SVI was calculated using the method by Cutter et al. (1997) and the results mapped in a GIS.

4.3.1. Interview analysis

In total 18 interviews were undertaken on the two islands. These were transcribed in full including pauses, laughs, emphasis, etc.. Transcribing helps the researcher become more familiar with the data and form an understanding of what is being said. Five of the 18 interviews were not recorded due to the circumstances of the interview, therefore detailed notes were taken, and these were analysed along with the remaining interview transcripts. The next step was to analyse the transcripts to gather information on what the interviewees felt made people on their islands vulnerable to volcanic hazards. Given the nature of the data (interview transcripts) it was decided to use qualitative analysis techniques. Therefore thematic content analysis software was used to code the data. This software is a tool for the qualitative analysis of textual, graphical, video and audio data. It allows digital ‘highlighting’ of sections of the transcripts that discuss specific themes or codes. Codes can then be merged, and data sorted either by individual interviewee or by code.

Prior to analysis an initial list of codes that the researcher believed would describe the different themes in the interviews was drawn up:

- Hazards – different hazards faced by island;
- Risk – definitions;

- Vulnerability – location, vulnerable groups, other words;
- Past events;
- Using maps;
- Evacuation, planning;
- Training, education; and
- Community disaster groups.

Each transcript was read through and coded using the initial list, more codes came to light throughout the process and these were noted down (including Montserrat, positives of the volcano, development and trust in scientists). The transcripts were re-read a second time and the new codes were added where appropriate. Three main topics were covered in the interviews: use of maps, attitudes towards the volcano, and terminology. The terminology category was the first to be analysed in detail as it contained the information relating to vulnerability factors, and is the only one discussed in this chapter. All the text coded as describing a different vulnerability variable was grouped together. There were 15 in total. Figure 4.2 shows the different vulnerability variables mentioned throughout the interviews, and the number of interviewees that mentioned each variable.

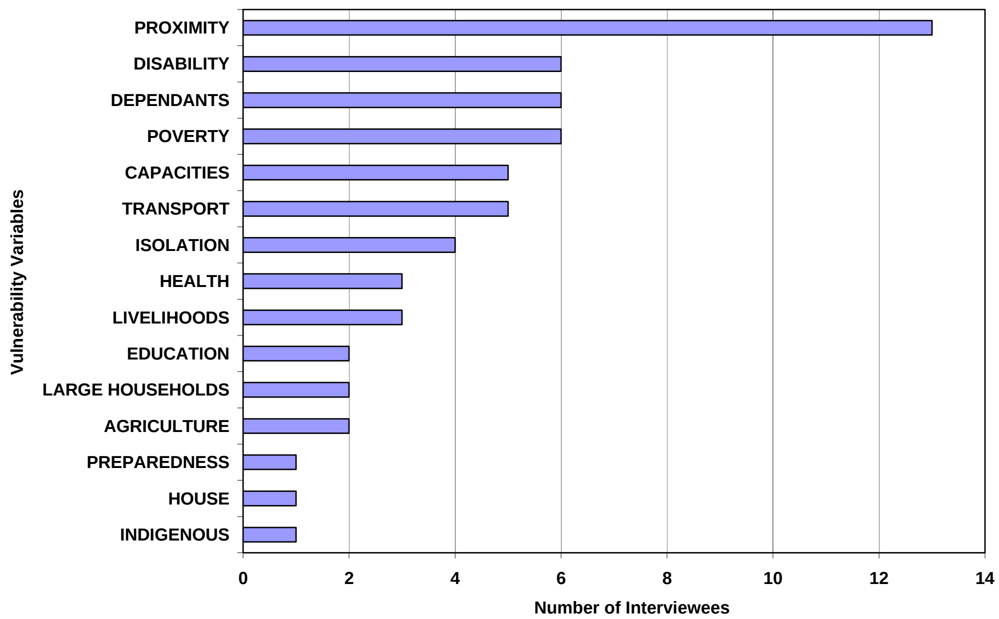

Figure 4.2: Initial list of vulnerability variables and the number of interviewees who mentioned each variable.

At this point a number of problems emerged:

- Some codes are very similar therefore could be merged;
- Some codes are hard to measure – e.g. preparedness; and
- Capacities to cope with the hazard are mentioned, however, sometimes as the opposite of vulnerability such as wealth versus poverty, whereas other people spoke about how a person's skills and knowledge increase their capacity to cope – how to measure these?

As some of the codes referred to similar topics each occurrence of a vulnerability variable in the transcripts were re-read and some codes were merged:

- *Indigenous* merged with *proximity*

  The interviewee who spoke about the indigenous population on St. Vincent being vulnerable said that they are vulnerable because they live near the volcano;

- *Agriculture* merged with *livelihood*

  Agriculture was mentioned as a particularly vulnerable livelihood;
- *Large households* merged with *dependants*

  The interviewees who spoke about large households focused on whether there were a lot of dependants in those households.

In addition, preparedness and capacities were omitted due in part to the fact that the interviewees' definitions of the words were ambiguous. Sometimes people spoke about capacity as the opposite of vulnerability, other times not. Lack of available data was also an issue. There is now more work being done on quantifying capacities and resilience using a census (see Finnis and Johnston, 2007; Cutter et al., 2008) and further work should explore this.

The final list of ten vulnerability variables is shown in Figure 4.3 and quotations or notes from the interviews that describe each variable are in Table 4.3.

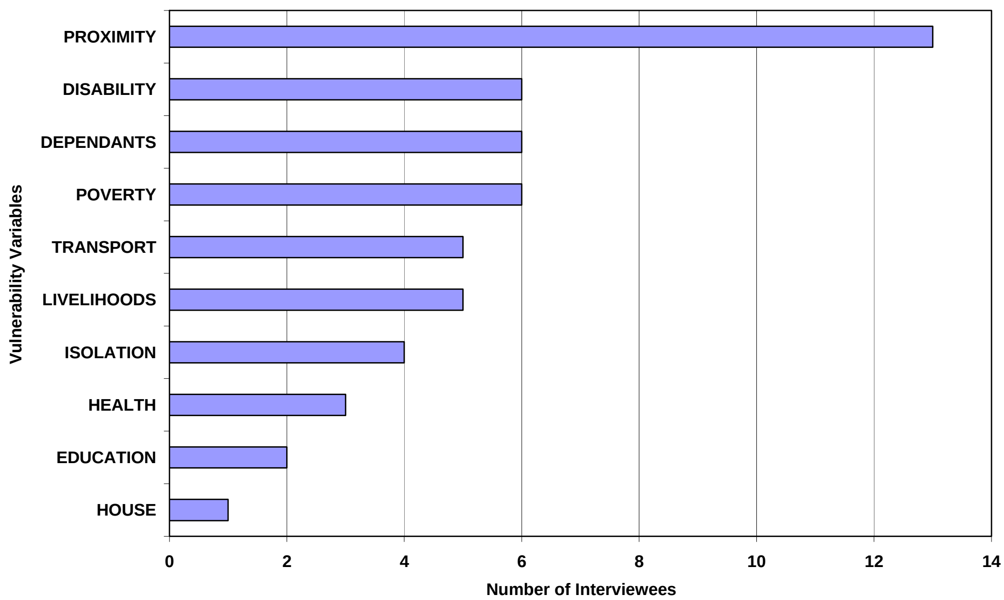

Figure 4.3: Final list of vulnerability variables.

Vulnerability variable	Sample quotes
Proximity	*"well as I say, the closer you are to the volcano, the more vulnerable you are"* *"so on that basis the closer you are to the foothills of the volcano the more vulnerable you are, the more risk that you are exposed to"*
Disability	*"so you have to look at your physically challenged"* *"the persons who are older, who may be disabled in any way, they are vulnerable persons too"*
Dependants	*"very often you could look for persons who are elderly"* *"the younger persons who have nobody to.....persons of a certain age who have to depend on somebody to look after them are persons who are more vulnerable also"*
Poverty	*"obviously the poor are always the most vulnerable to any form of hazard"* *"okay, for instance, a lot of persons who are maybe below the poverty line are living closest to the volcano with a lot of children, or something, will make them more vulnerable"*
Transport	People without transport and those with limited mobility would be a priority (notes from interview) *"and then of course your poor persons who maybe would not have any way of getting out unless you assist them"*

Table 4.3: Interviewee quotes on vulnerability variables.

Vulnerability variables cont.	**Sample quotes cont.**
Livelihoods	*"to me the most vulnerable ones would be those who depend on the farming in those areas"* *"livelihoods would be totally disrupted. So they are the vulnerable ones. That's the volcano…"*
Isolation	*"it's perhaps more of a question that those who would be indirectly affected would be isolated because of the road network"* *"so yes they will be very vulnerable because of the topographic divide, because of the river that was there, and that made them even more vulnerable"*
Health	*"anybody with respiratory problems"* *"it [ash from the volcano] made asthmatic and people with bronchial disease particularly vulnerable and uncomfortable in that situation"*
Education	The uneducated – there was a lack of organisation during 1979 [St. Vincent eruption] and panic for some people (notes from interview) *"low education, what have you. They're vulnerable for various reasons"*
House	*"We like to talk about vulnerability as level of exposure. What really makes you likely to be a target of a particular hazard? Is it because your house is old?"*

Table 4.3: continued - Interviewee quotes on vulnerability variables.

4.3.2. Creation of the SVI

Once the vulnerability variables had been gathered from the interview data, the next task was to find census data to use as a proxy for each. Table 4.4 shows the results of this with an explanation as to what that vulnerability variable describes.

Vulnerability variable	Explanation	Data used
Proximity	More vulnerable if you live near the volcano	GIS Analysis
Disability	Lack of mobility, reliance on care	Percent of census division population who are disabled
Dependants	The elderly and very young are more vulnerable due to reduced mobility, and need for care.	Percent of over 65s and under 4s in census division (note that these formed separate inputs into the index)
Poverty	Less ability to absorb losses and cope after an eruption	Percent of households that do not have utilities
Transport	Less able to evacuate	Percent of households that do not have access to a private vehicle
Livelihoods	Reliance on resource based livelihoods such as agriculture or fishing increases vulnerability when means of production is lost	*Not available*
Isolation	Some areas of St. Vincent are isolated geographically which makes it difficult to evacuate	GIS analysis
Health	People with health problems are less likely to be able to work, rely on social services, increase dependency ratio	*Not available*
Education	Linked to socio-economic status and ability to understand warning information	Percent of census division population under 19 years old that are not at school
House	Poorly built or old house may be more vulnerable to particular hazards	Covered in Chapter Five

Table 4.4: Vulnerability variables, explanation, and data used.

A problem encountered at this stage was that for two variables, health and livelihoods, no data were available to use as proxies from either the census or other sources. For livelihoods there were no data included in the census report aggregated by census division that indicated which areas of St. Vincent might have a higher proportion of adults employed in agriculture or fishing, for example. The number of hospitals or clinics in each census division was considered as a proxy for health, however the map from which this information could be gathered was created in 1983, and therefore the dataset was a minimum of 26 years old, and given the changes in development on the island, in particular in the north, it was felt that this was not an accurate measure of current access to health facilities. Therefore these two variables had to be excluded from the index. The house variable had to be excluded from this index as no census data were available; however building vulnerability has been assessed separately in Chapter Five. The proximity and access variables required spatial analysis to quantify vulnerability of each census division rather than use census data. The methods used to determine these are described below along with the method to calculate vulnerability from the remaining variables.

4.3.2.1. Proximity

The most common variable mentioned, and often the first thing interviewees replied when asked ‘what makes people vulnerable to the volcano on St. Vincent’ was if you live near the volcano you are vulnerable. To quantify this proximity variable in a way that could be added to the SVI, the study area was divided into 100m cells, and the Euclidean (straight line) distance from each cell to the volcano was calculated in a GIS. For each census division the average distance of all its cells was calculated.

4.3.2.2. Isolation

This variable describes a geographic barrier that inhibits people's evacuation. On St. Vincent it was used to refer to those villages in the north of the island that have only one road suitable for evacuation. If this road is cut by volcanic hazards such as lahars or pyroclastic flows and surges, as happened in the 1902 eruption, then people who had not evacuated prior to these hazards would be stuck. Exercises have been undertaken to practice evacuating people from the village of Fancy in the north by sea. Along the Atlantic coast of St. Vincent, however, this is very treacherous and emergency managers will not rely on this method for a successful evacuation of the area.

To quantify this geographic barrier, network analysis was undertaken using a GIS. Network analysis is used to analyse flows along a network, such as calculating the shortest path between two points. The aim was to calculate how long it would take people to travel from a village to the capital Kingstown. Villages would not necessarily evacuate to Kingstown during a volcanic eruption as there are shelters designated in more central locations, however, without information on the emergency shelters assigned to each village, Kingstown was chosen as it is the capital, and is relatively remote from the volcano located in the green low hazard zone. A network was created in a GIS for St. Vincent that consisted of footpaths, minor roads and major roads. As the analysis aimed to quantify travel time as opposed to distance, a travel speed was assigned to each of the three layers that was a reasonable estimation. From experience in the field of having driven along both main and minor roads, a speed of 30mph was assigned to main roads, 20mph to minor roads, and 5mph walking speed for footpaths. The assumption was made that only those villages north of the 1979 evacuation line would be evacuated again in a future eruption, as the current volcanic hazard scenario assumes an eruption similar to that of 1979. Therefore a travel time was calculated from 14 of the main villages north of the 1979 evacuation line to Kingstown (Table

4.5, Figure 4.4). This accounted for five of the 11 census divisions. The worst case travel time was used for each of the five census divisions (Table 4.6), a value of zero was assigned to those divisions what would not be evacuated, and these numbers were used in the SVI (Table 4.7).

Settlement	Census division	Travel time (minutes)
Fancy	Sandy Bay	118
Owia	Sandy Bay	105
Sandy Bay	Sandy Bay	95
Overland	Georgetown	82
Orange Hill	Georgetown	74
Fitz-Hughes	Chateaubelair	71
Rose Hall	Chateaubelair	70
Chateaubelair	Chateaubelair	69
Georgetown	Georgetown	64
Rose Bank	Chateaubelair	63
South Rivers	Colonaire	59
Byera	Colonaire	56
Spring Village	Barrouallie	54
Friendly	Colonaire	51

Table 4.5: Evacuation travel time for 14 of the main St. Vincent settlements that might be evacuated in a future eruption similar to 1979.

Census division	Worst-case travel time (minutes) used for SVI
Sandy Bay	118
Georgetown	82
Chateaubelair	71
Colonaire	59
Barrouallie	54
Bridgetown	0
Marriaqua	0
Layou	0
Suburbs	0
Kingstown	0
Calliaqua	0

Table 4.6: Worst case evacuation travel time for each census division.

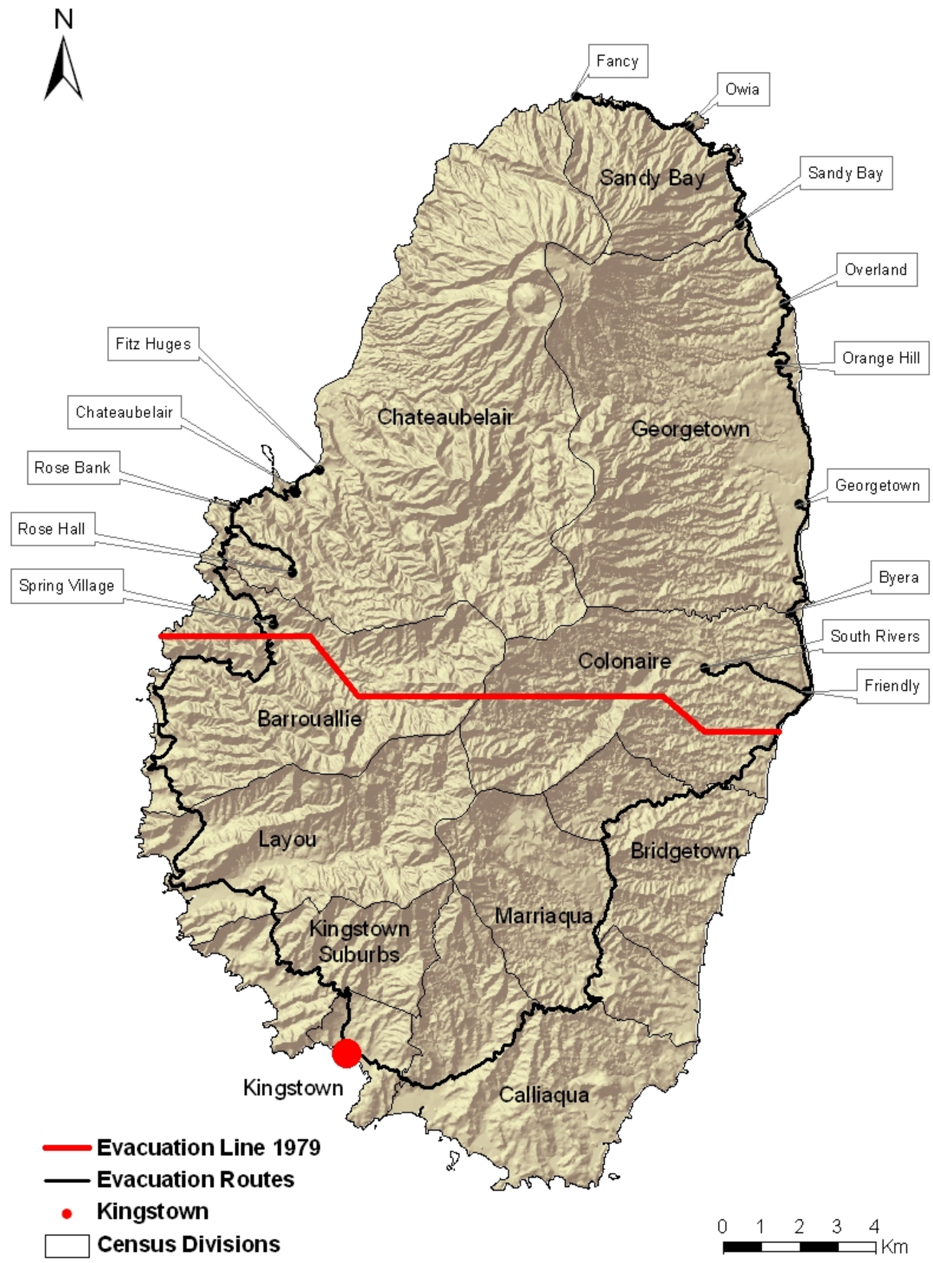

Figure 4.4: Evacuation routes from 14 settlements to the capital, Kingstown.

This is a very basic method and takes no account of the number of people that might be trying to evacuate at the same time, nor how the network could get clogged with vehicles and pedestrians, or if the road were cut by hazards. For the purpose of the SVI, however, it was sufficient to illustrate which census divisions were more vulnerable due to limited geographic access.

4.3.2.3. SVI calculations

The method for calculating the SVI is taken from Cutter et al. (1997). Vulnerability is calculated for each census division as this is the scale at which data are available. For each census division, the individual vulnerability variable is calculated as a proportion, and then normalised to a number between zero and one for comparison with other variables. The variables are manipulated so that the higher the value, the higher the vulnerability. All but one variable used in this research *increase* vulnerability and are therefore all positive values. The exception is the proximity variable which describes distance from the volcano. For this variable a large number (i.e. distance) *decreases* vulnerability and is given a negative value in Table 4.7.

The method for calculating each variable score is as follows:

For example - calculate percentage of elderly in each census division

$$X = \frac{\text{Number of over 65s in census division}}{\text{Total population of census division}}$$

Calculate the most vulnerable census division for that variable

$$\text{Vulnerability score} = \frac{X}{\text{Maximum } X}$$

For each variable, every census division is given a score of between zero and one where one represents the most vulnerable for that variable. Each vulnerability variable can be calculated using the same method and all the variable scores can be added to produce composite vulnerability (Table 4.7).

	Vulnerability variables								
Division	**Proximity**	**Isolation**	**Under 4s**	**Over 65s**	**Disability**	**Poverty**	**No private transport**	**Popn. not attending school**	**Composite vulnerability (sum of 8 variables normalised)**
Kingstown	**-1.00**	**0.00**	**0.81**	0.98	0.68	**0.78**	0.80	**0.63**	0.57
Suburbs	-0.90	**0.00**	0.92	**0.55**	**0.53**	0.85	0.87	0.80	0.56
Calliaqua	-1.00	**0.00**	0.83	0.88	0.62	**0.78**	**0.75**	0.64	**0.54**
Marriaqua	-0.81	**0.00**	0.93	0.90	0.83	0.90	0.87	0.73	0.68
Bridgetown	-0.74	**0.00**	0.90	0.97	0.62	0.92	0.91	0.86	0.69
Colonaire	-0.55	0.47	**0.81**	0.97	**1.00**	0.93	0.95	0.84	0.84
Georgetown	-0.29	0.70	0.85	0.95	0.71	0.96	0.97	0.81	0.88
Sandy Bay	**-0.23**	**1.00**	0.96	0.89	0.83	**1.00**	**1.00**	**1.00**	**1.00**
Layou	-0.76	**0.00**	0.89	**1.00**	0.55	0.88	0.91	0.85	0.67
Barrouallie	-0.60	0.46	0.93	0.87	**0.53**	0.95	0.98	0.91	0.78
Chateaubelair	-0.25	0.60	**1.00**	0.80	0.74	0.96	0.99	0.87	0.89

Table 4.7: Vulnerability scores. Red numbers show the census division(s) that were calculated as the most vulnerable for each variable, green numbers show the census division(s) calculated as the least vulnerable.

Variables were not weighted as there was no defensible method for assigning a value. Therefore, each variable was assumed to have an equal contribution to the census division's overall vulnerability.

4.3.2.4. Composite SVI

With the eight vulnerability variables all in a common numerical format, they were added together for each census division and, following the method in Cutter et al. (1997), the 'z' score was calculated. A 'z' score, or standard score, is a dimensionless quantity that indicates how many standard deviations an observation is above or below the mean. Using this 'z' score the average vulnerability across the island as a whole is calculated, and then the relative vulnerability of each census division to the island average is determined. The results show which divisions are more or less vulnerable to volcanic hazards on St. Vincent, considering the variables deemed important by the interviewees. The 'z' scores could then be mapped to show relative vulnerability across the island (Figure 4.5 and Figure 4.6)

4.3.3. Vulnerability maps

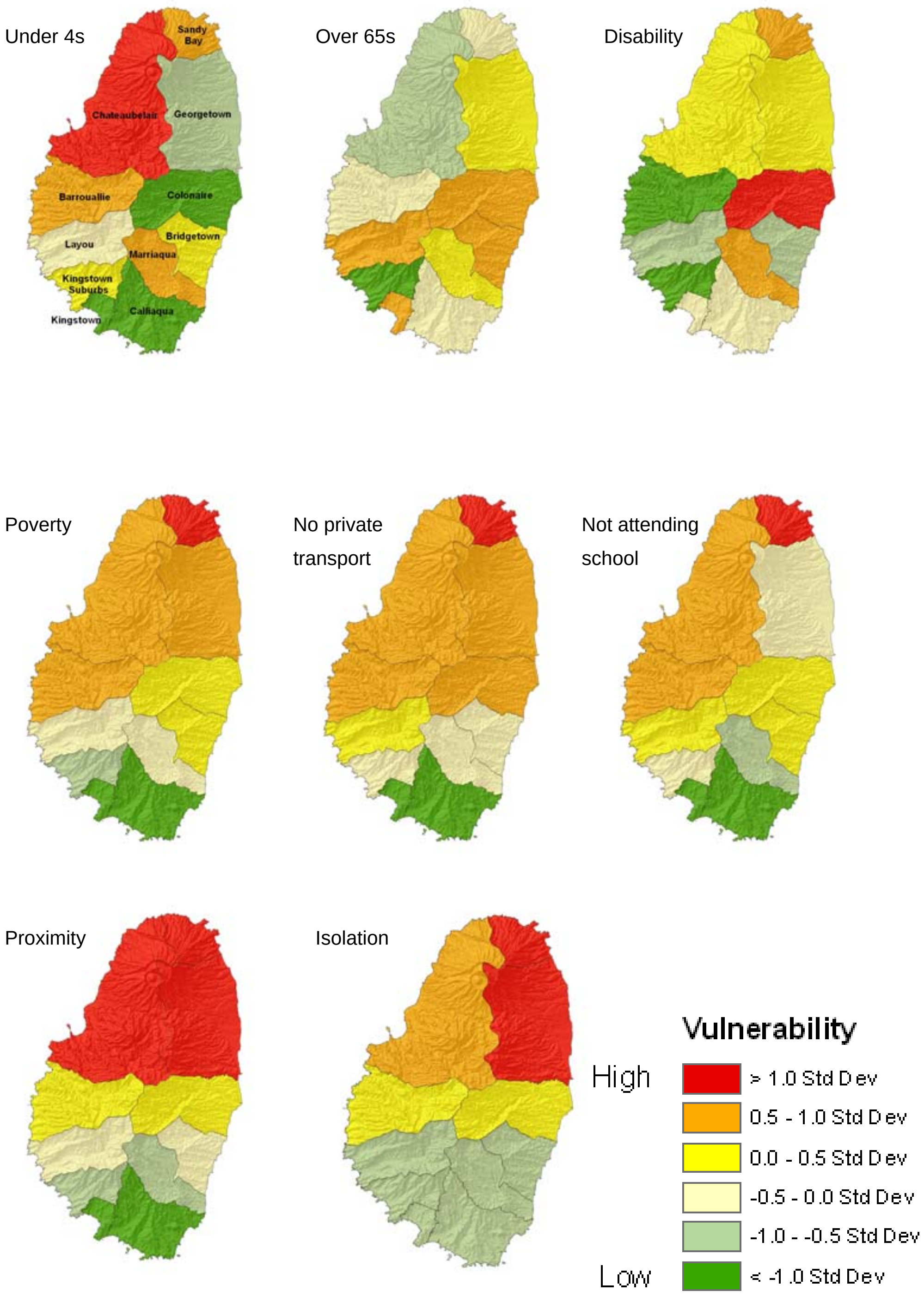

Figure 4.5: Individual vulnerability maps for each of the eight vulnerability variables.

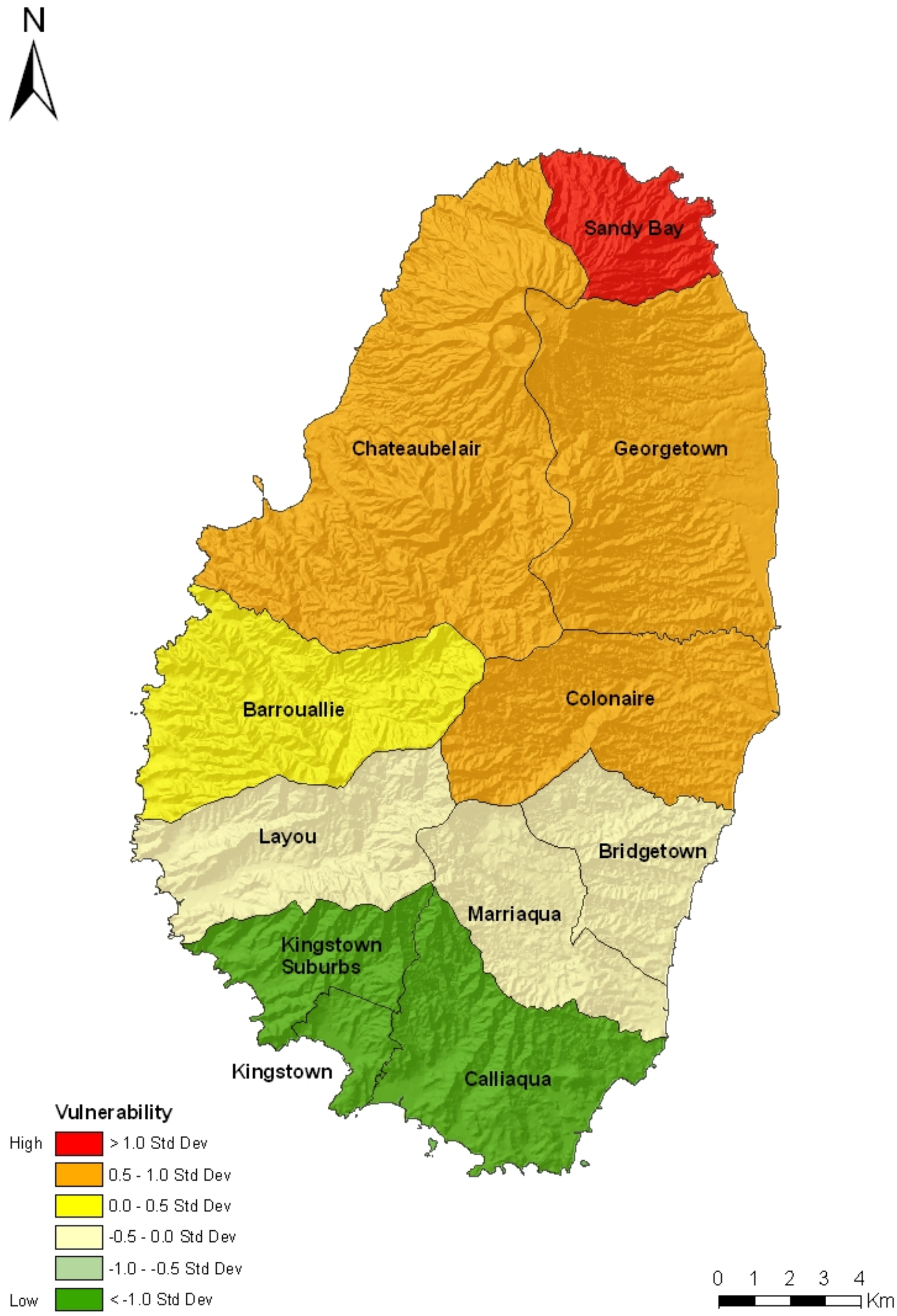

Figure 4.6: Composite social vulnerability map of St. Vincent.

4.4. Analysis and interpretation of index and maps

Here, the analysis of the vulnerability variables used in this research and the index and maps created are examined. Outputs of this element of the research are compared with what is currently in the literature and the vulnerability maps are discussed including how they change with a different method of calculation.

4.4.1. Vulnerability variables

According to Cutter et al. (2003, p.245) *"there is a general consensus within the social science community about some of the major factors that influence social vulnerability"*. These include lack of access to resources; limited access to political power and representation; social capital; physically limited individuals; and infrastructure and lifelines. The problems arise when trying to decide on what specific characteristics of a population or place represent these factors (Cutter et al., 2003). This was one justification for getting stakeholder input on what to include in a vulnerability analysis.

Of those variables that the interviewees identified as making populations vulnerable, a number are common in the literature. Table 4.8 compares the list in Cutter et al. (2003) of characteristics most often found in the literature with those used in this research.

Table 1 from Cutter et al. (2003, pp.246-249)	Vulnerability variables identified by interviewees (x denotes variables not identified)
Socioeconomic status (incl. income)	Poverty
Gender	x
Race and ethnicity	Indigenous population was mentioned by one interviewee but merged with ‘proximity’ variable as the reason for saying indigenous population was vulnerable, was because they lived near the volcano
Age	Over 65s and under 4s
Commercial and industrial development	x
Employment loss	x
Rural/urban	x
Residential property	Quality of a person’s house was mentioned by one interviewee – building vulnerability is considered separately in Chapter Five
Infrastructure and lifelines	x
Renters	x
Occupation	Livelihoods were mentioned (but no data available)
Family structure	Large single parent households was mentioned and this was merged with ‘dependants’ variable
Education	Population not attending school
Population growth	x
Medical services	x
Social dependence	x
Special needs populations	Disabled (health was also mentioned by interviewees but no data available)

Table 4.8: Comparison of social vulnerability variables.

Of the five broad factors discussed in Cutter et al. (2003) and listed at the beginning of this section, social capital, access to political power and prestige, and infrastructure and lifelines are missing from this vulnerability analysis. Social capital could be considered a capacity to cope, and therefore might reduce a person's or community's vulnerability to a hazard. Capacities were mentioned in the interviews, although no specifics as to what might be included under this theme were given. People's preparedness was also mentioned. Further work should look at what to include under this broad 'social capital' theme, and how to assess it.

Access to political power and prestige was another broad theme not covered in this analysis. In Table 4.8 the factors that might be used to represent this are race, ethnicity and gender. In some disasters, indigenous populations suffer greater loss due to where they live, reluctance to leave their spiritual homes, or their lack of access to power (for example the Aetas on Mount Pinatubo in the Philippines). On St. Vincent, the indigenous Carib population mostly live in the Sandy Bay census division which is close to the volcano. Although this in itself increases their likelihood to suffer loss in an eruption, it was not thought by those interviewed that the Carib population would be reluctant to leave as they are not attached to the land as other indigenous populations are in other countries. In fact, in the 1902 eruption the Caribs who lived in reserves in the north of the island petitioned the government to resettle them when they first felt volcanic activity increasing. They were the first to leave their homes in 1902, and it is not thought they would be reluctant to evacuate again in a future eruption. The 'access to power' factor and the situation of the Carib population on St. Vincent are discussed in more detail in Chapter Seven.

In a similar way to indigenous populations being more vulnerable owing to lack of access to power, racial minorities often suffer greater losses due to language barriers and exclusion from politics. This is not thought to be a factor relevant to St. Vincent despite its racial mix. The population is mostly of African descent, with the next largest group being 'mixed race'. There are small percentages of White, Indian and Portuguese descent and this is a result of the colonial history and indentured labour. From experience on the island it appears that society is fairly integrated, with the current Prime Minister being of Portuguese descent.

Gender is also an issue that is commonly seen in vulnerability analyses but was not included in this research. No interviewee mentioned gender specifically as a variable that might increase a person's vulnerability; however it may have been implied when speaking about single-parent households. On St. Vincent the impression is that there are a large number of single parents, in particular single mothers. Migration of adult males to work or be educated abroad may exacerbate this. Adult females also leave the island to work or be educated abroad and a number of children are brought up by their grandparents on St. Vincent. It is thought, however, that the inclusion of this variable would have little overall effect on the outcome of the index and maps, as there is only a small variation in the proportion of females residing in each census division (from 47 percent in Sandy Bay to 51 percent in Calliaqua).

Characteristics of the population were covered by the interviewees (e.g. age, poverty, education); however variables that referred to the built environment and services within a community were only mentioned by one interviewee. This may have been a result of the interview question which asked people to tell the interviewer what areas or groups of people they felt were vulnerable to volcanic hazards as opposed to specific communities, or the built environment. There were no data available in the census to measure this vulnerability variable therefore the built environment on St. Vincent was assessed and is covered in Chapter Five.

The variables included in this vulnerability analysis which are not discussed explicitly in Cutter et al. (2003) are 'no private transport', 'proximity' and 'geographic isolation'. Access to private transport describes a person's ability to evacuate and is an important consideration when formulating evacuation plans. It is covered in the current St. Vincent National Disaster Plan (NEMO, 2004) and local community hazard assessments also take into account those who have transport and how it could be utilised in an evacuation. The second two – isolation and proximity – fall into the category 'geographic context' in Cutter's (1996) VoP model which determines the biophysical vulnerability of a place. The geographic isolation variable in this research describes a person's ability to evacuate and the geographic characteristics of the location. It may be more prevalent in the literature on emergency management and included in detailed models of transport routes and evacuation.

Finally, the proximity variable is not often found in the literature focusing on social vulnerability reviewed for this research. Many authors from the radical perspective of disasters may argue it does not describe vulnerability at all, but rather a person's location with respect to a hazard and forms a part of the more traditional hazard and engineering approach to analysing vulnerability. The nature of the volcanic hazard, however, may help explain why proximity was mentioned by 13 of the 18 interviewees as a vulnerability variable. Unlike some hazards considered in the vulnerability literature, such as drought, the location of the volcanic threat can in many cases be accurately determined prior to an eruption. Therefore people are aware of where the threat is located and whether or not they live within harm's way. Perry and Lindell (1990) discuss a range of factors that explain people's perception of volcanic vulnerability on Mount St. Helens and proximity is one of these. These are discussed further in Chapter Six.

4.4.2. Interpretation of maps

The composite social vulnerability map (Figure 4.6) shows that relative vulnerability is highest in the north of the island with vulnerability decreasing as you move south being lowest in the census divisions of Kingstown, Kingstown Suburbs and Calliaqua. Of the eight individual vulnerability variables (Figure 4.5) Sandy Bay scores high or very high (orange or red) in seven, with the ‘over 65s’ being the only variable in which the census division has average, or below average vulnerability.

The three census divisions in the south of the island, Kingstown, Kingstown Suburbs and Calliaqua, are the wealthier, more developed areas, with more vehicle ownership and population under 19 years old attending school. They are also furthest from the volcano.

The middle census divisions of Barrouallie, Layou, Marriaqua and Bridgetown have average vulnerability, visualised by yellow or cream in Figure 4.6. They score average, or below average, in the majority of the eight individual variables, with a high score (orange) in the dependants and disability variables.

The three census divisions in the north, Chateaubelair, Colonaire and Georgetown, have high (orange) or very high (red) vulnerability overall. Their scores vary across the eight individual variables, with high vulnerability in poverty, no access to transport, geographic isolation and proximity.

Interpreting these maps raises the question of what is actually being measured with the SVI created in this research. The eight individual variables can be grouped into three broader categories that explain a different component of vulnerability. These are a *dependants* component (over 65s, under 4s and disability), a *poverty* component (no private transport, poverty and population not attending school), and a *geography* component (isolation and proximity). Each of these broad categories is discussed below.

4.4.2.1. Dependants

The *dependants* component maps show no similarities between them, however they all measure factors which would increase the burden on individual households during and after a volcanic eruption. Both the elderly, very young and disabled would need extra help if evacuating. In addition they may not be able to work or support the household during the recovery phase of a volcanic disaster. Dependants put pressure on the household, and if the households are also poor and lack resources, this pressure is increased. There is no similarity, however, between the dependant's maps, and that of poverty in this case.

4.4.2.2. Poverty

Although none of the individual variables in Figure 4.5 are the same, three maps – no private transport, poverty and population not attending school – are similar, with a clear north-south divide. These are grouped under the *poverty* component. A lack of monetary resources at the household level could prohibit the ownership of a vehicle and household goods (stove, washing machine, computer, etc.). The population not attending school map shows a similar north-south divide. In the Caribbean context education is perceived as a mechanism for social mobility and hence movement out of poverty (Robertson, pers. comm.), however, in these maps a low percentage of children attending school coincides with areas of fewer household resources. This suggests that a greater focus on education is needed to increase social mobility and hence reduce vulnerability in these areas. In terms of preparedness, response and recovery from a volcanic eruption the census divisions that have high vulnerability due to poverty may need special consideration for evacuation with the provision of buses and insurance schemes to cover property and livelihoods such as agriculture. With the percentage of children attending schools being lower in these areas a focused effort for education campaigns and the giving of hazard warnings to the populations in the north may be required.

4.4.2.3. Geography

The final *geography* component encompasses the isolation and proximity variables. The isolation variable is an interesting consideration for evacuation, i.e. where are the areas which might not be able to evacuate in a timely manner, or more specifically, only have one option for doing so (one route) which if blocked during the early stages of an eruption would render the population trapped. It is intuitive that those areas closest to the volcano will score highest in both these categories, and therefore their vulnerability scores give more weight to the north-south divide seen in the overall vulnerability map.

4.4.3. Sensitivity testing: alternative methods of calculating the SVI

To test the sensitivity of calculating the SVI a number of alternative methods are explored here. These include calculating the SVI without the proximity and isolation variables; calculating absolute vulnerability as opposed to relative vulnerability; and weighting the variables.

To reveal the social, economic and demographic vulnerability that is measured by the remaining six variables, the index was re-calculated without the proximity and isolation variables, the results of which are mapped in Figure 4.7.

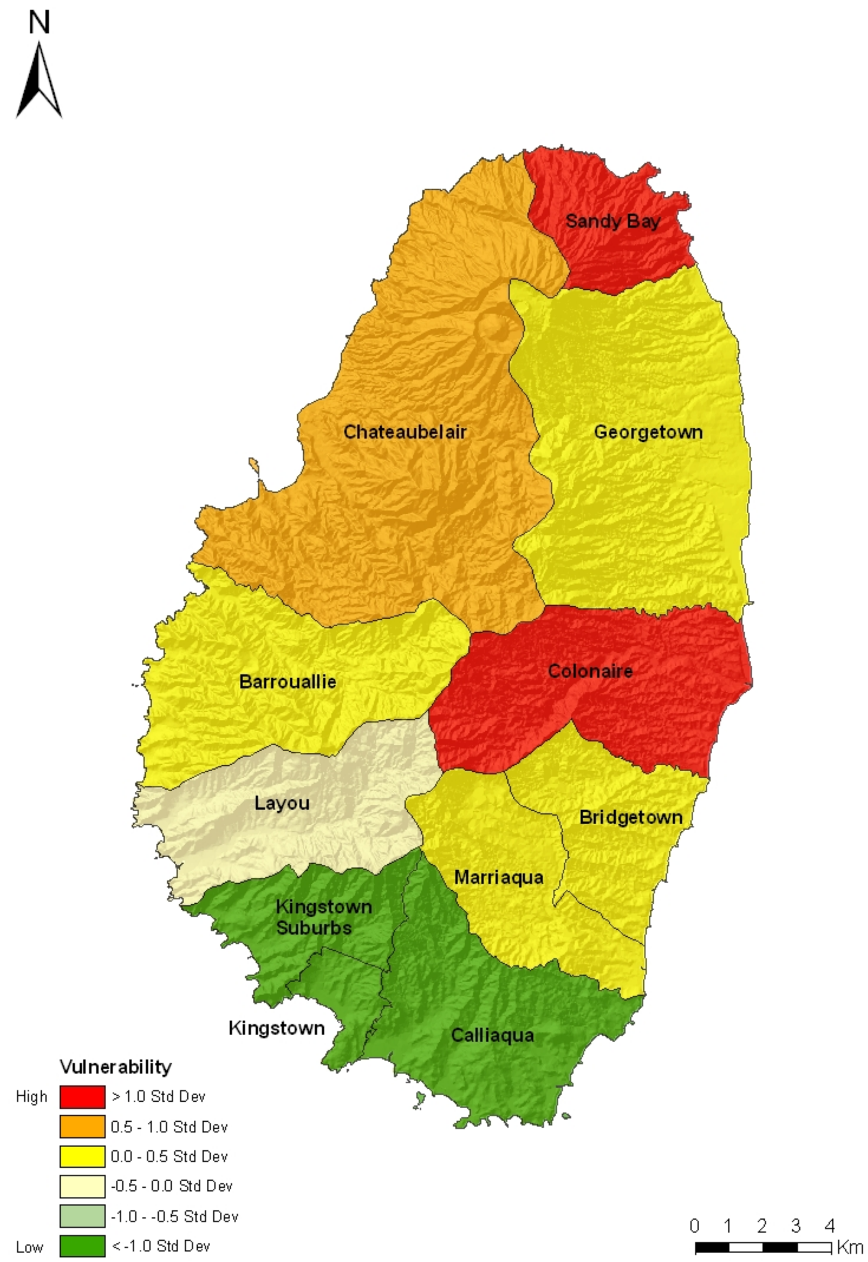

Figure 4.7: Composite social vulnerability without the proximity and isolation variables.

The north-south divide in vulnerability is no longer as evident as before; however Sandy Bay remains as the most vulnerable census division. This is because even with the isolation and proximity variables removed, the northernmost census division scores very highly and high in five of the remaining six variables. In particular, in the poverty variable, Sandy Bay has the highest score. With this new index, Colonaire is also revealed as having very high vulnerability. It has the highest proportion of its population registered as disabled, in addition to a high proportion of over 65s and households without access to a private vehicle. Georgetown's and Chateaubelair's vulnerability relative to the island average are lowered slightly with the removal of the isolation and proximity variables. The vulnerability of the southern census divisions, however, remains very similar to that in Figure 4.6. Figure 4.7 effectively shows the *hazard independent* vulnerability.

It is worth noting again that the index and maps calculate vulnerability as a proportion of each census division population or number of households – i.e. which census division has the highest proportion of elderly people given its population total. The index does not illustrate which areas have the highest *total* number of elderly people. The reason this method of calculation was followed was because it is the method described in Cutter et al. (1997) and Cutter et al. (2003). It might be more useful, however, to know which areas have the highest number of vulnerable people or vulnerable households. Therefore the index using only the six *hazard independent* social, economic and demographic variables was recalculated for each census division as a proportion of the island population and household totals, as opposed to the totals of the individual census divisions. The results of this are shown in Table 4.9 and mapped in Figure 4.8 and Figure 4.9 below.

	Vulnerability variables						
Divisions	**Under 4s**	**Over 65s**	**Disability**	**Poverty**	**No private transport**	**Popn. not attending school**	**Composite vulnerability (sum of 6 variables normalised)**
Kingstown	0.58	0.67	0.65	0.60	0.65	0.58	0.62
Kingstown Suburbs	0.63	0.35	0.48	0.56	0.60	0.80	0.57
Calliaqua	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Marriaqua	0.41	0.38	0.49	0.38	0.39	0.46	0.42
Bridgetown	0.33	0.33	0.30	0.33	0.34	0.45	0.35
Colonaire	0.33	0.37	0.54	0.36	0.39	0.49	0.41
Georgetown	0.32	0.34	0.36	0.36	0.38	0.45	0.37
Sandy Bay	**0.14**	**0.12**	**0.16**	**0.12**	**0.13**	**0.20**	**0.15**
Layou	0.31	0.32	0.25	0.32	0.35	0.40	0.33
Barrouallie	0.27	0.24	0.21	0.29	0.32	0.41	0.29
Chateaubelair	0.33	0.25	0.33	0.30	0.32	0.44	0.33

Table 4.9: Absolute vulnerability. Red numbers show the census division that was calculated as the most vulnerable for each variable, green numbers show the census division calculated as the least vulnerable.

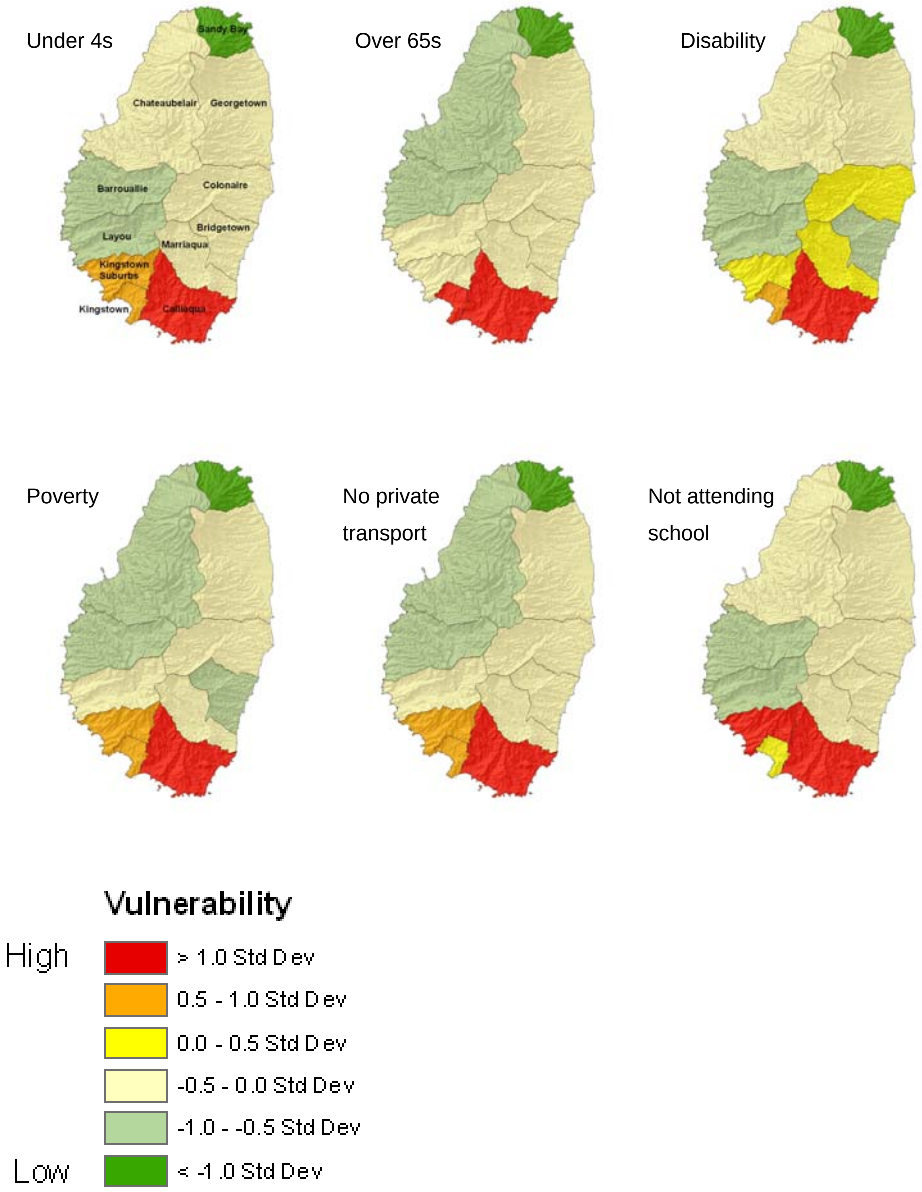

Figure 4.8: Individual absolute vulnerability maps for each of the six hazard independent vulnerability variables.

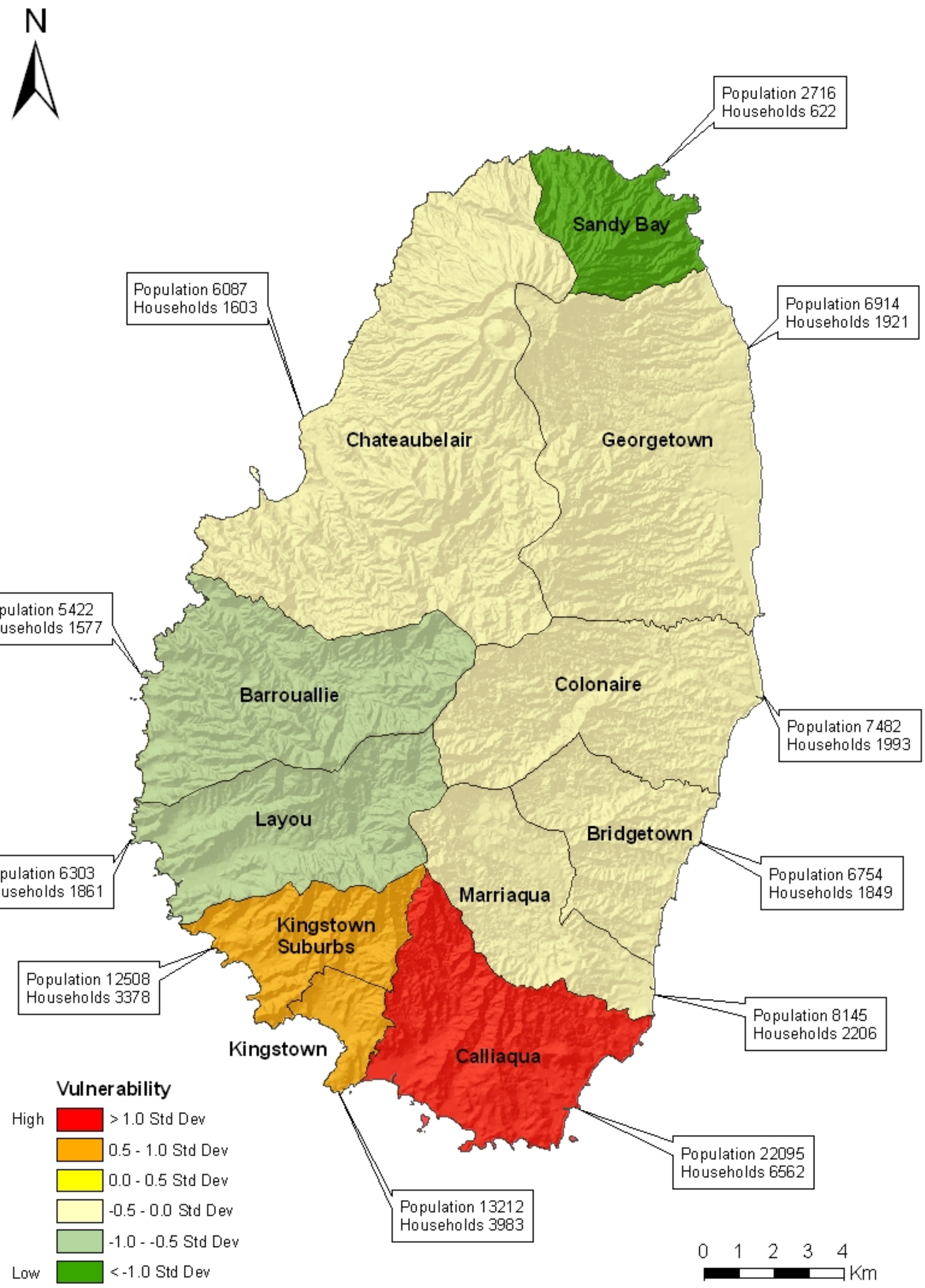

Figure 4.9: Overall absolute vulnerability with population totals and number of households per census division.

This new hazard independent absolute vulnerability map effectively flips vulnerability to the highly populated south of St. Vincent. Sandy Bay now has the lowest vulnerability in all of the remaining six factors as it has the lowest population total. These maps show where the highest numbers of vulnerable people or households are located for each of the variables which could be useful information for emergency managers, and help them allocate resources to assist the greatest number of people (King, 2001).

It is worth reiterating, however, that Calliaqua census division in the south, although having the highest population (and therefore mapped as red, high vulnerability in Figure 4.9), is still the wealthiest area on the island, with the highest proportion of children attending school. Sandy Bay is a relatively poor area with some communities only receiving electricity in the 1990s.

Finally, the overall vulnerability map is altered considerably when the variables are weighted by the number of times each variable was mentioned. In this case, the proximity variable has a stronger influence on the overall map, and a greater proportion of the north of St. Vincent is red, very high vulnerability (Figure 4.10).

These different methods of index calculation raise the question of how to measure and visualise vulnerability. What is the index trying to capture and for what purpose? The preferred representation of vulnerability in this research is that in Figure 4.7 which captures aspects of social, economic and demographic vulnerability. The proximity and isolation variables measure aspects of the hazard, not vulnerability, and it was decided not to weight the variables so as to give equal influence to each variable in the overall representation.

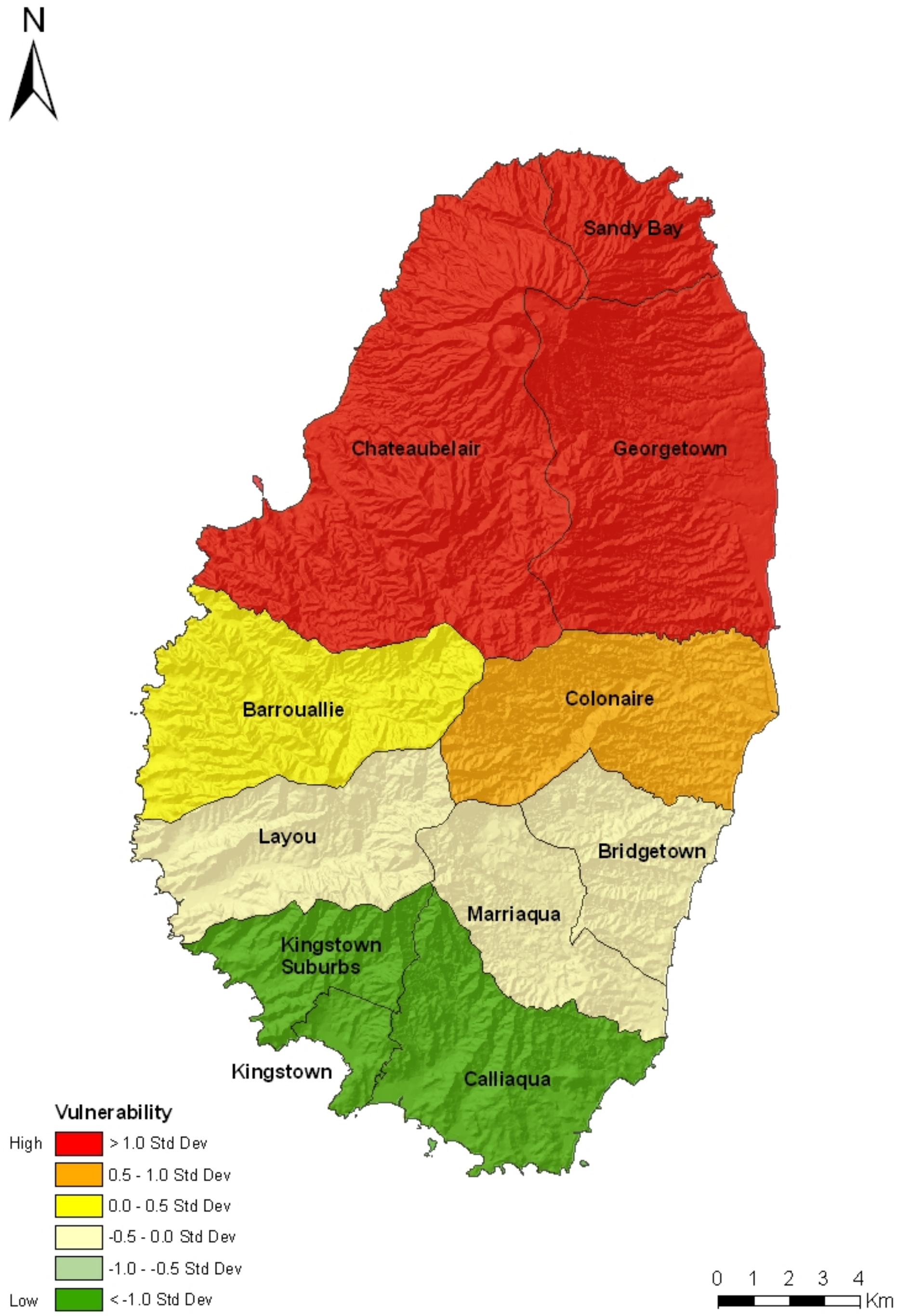

Figure 4.10: Weighted social vulnerability map. The eight variables are weighted by the number of interviewees who mentioned that variable.

4.5. Critique of method and outputs

4.5.1. Advantages

Indices have been used by a number of organisations wishing to capture and visualise vulnerability, as outlined in Section 4.1. This is because there are a number of advantages to the method. First, it is quick and can be calculated using standard statistical procedures and software. Simpson and Katirai (2006), in their working paper on issues of indicators, suggest that indices are attractive because they are able to summarise a lot of data in an understandable way. As they include more than one variable they provide a dynamic picture and a wider perspective. Cutter et al. (2003) also state that they are attractive to the policy community as they provide a metric that allows comparison between different communities and areas.

In the context of this research in particular it was determined to be a useful method as it utilises secondary data sources. An advantage of creating an index based on secondary data such as a census is that it can be updated as new data become available. This enables the capture of the time series element of vulnerability (Simpson and Katirai, 2006).

An additional advantage to the method presented here is that it provides a technique with which to include local views into quantitative analyses. Variables of vulnerability specific to St. Vincent such as geographic access and proximity were highlighted in the interviews and included in the SVI. These would have been excluded had standard vulnerability variables been used. However, by asking local stakeholders to define indicators of vulnerability it is possible that only a narrow view of the situation is being represented with a focus on local, not necessarily broader issues that might be important.

4.5.2. Limitations

Despite these advantages, there are a number of limitations to capturing vulnerability with an index which are discussed in the literature, and found during this research.

The first step of the process – that of choosing indicators of vulnerability – raises questions of who decides and why. The subjectivity and potential bias of the process is the first limitation encountered. Some studies use theory and statistical procedures to determine indicators of vulnerability (Cutter et al., 2003; Boruff, 2005; Boruff and Cutter, 2007). In contrast work by Tapsell et al. (2002) used focus groups to determine vulnerability indicators for a social flood vulnerability index, and the research presented here used interviews with stakeholders. When deciding upon a method for choosing indicators it is important to consider who is going to use the index and what they consider vulnerability to be. More often, however, the choice of indicators is determined by data availability, and this is a second limitation. The index created in this research was not complete as data on health, livelihoods, capacities and preparedness were not available. Another limitation is that of how to combine the data mathematically. Does one calculate vulnerability as a relative measure or consider total numbers of vulnerable people? In addition, a decision needs to be made on whether to weight different factors or not.

Although using secondary data sources such as a census brings advantages, it also produces limitations. When using census data to capture vulnerability the research needs to take into account what information is and is not collected. For example, the census on St. Vincent provides two different population totals depending on what was included. The one chosen to calculate the index was the enumerated population as other data such as ‘total number of households without a private vehicle’ was recorded using this method. A number of groups of people are excluded in this total and include those which might be considered to be particularly vulnerable. For example: homes for the physically and mentally handicapped; leprosaria and nursing homes with more than six beds; almshouses; poor houses; homes for the aged; prisons, reformatories and detention camps (Statistics Office, 2001). Hospital and prison populations would need special consideration for evacuation and health concerns. Another population group that is not included are tourists in hotels and guesthouses, a limitation highlighted by Wallenstein et al. (2005) on methodological issues related to using census data for vulnerability and risk assessment. These people will need providing for in a disaster especially as they are less likely to be aware of and prepared for the risk from a volcanic eruption. In addition, St. Vincent has a particular problem with illegal settlements. There are a large number of marijuana farms and settlements on the flanks of the Soufrière volcano. Although the location of these settlements is well known, they are not included in the census or the resulting SVI. In addition, the secondary data availability meant that the unit of analysis (census division) was very coarse and did not allow for a detailed picture of the distribution of vulnerability across the island.

Another limitation of the spatial analysis is the boundaries within which people actually work may not necessarily be the same as the census boundaries. As King (2001, p.153) states *"a collection [census] district is not necessarily a community"*. For example on St. Vincent there are over 20 community disaster groups distributed across the island. Each group is responsible for hazard assessment and preparedness for their locality. It may be more appropriate to calculate a vulnerability index at this geographic level. In addition, census boundaries are often modified over time. Therefore research that is capturing the change in vulnerability over a number of years may find boundaries to be inconsistent.

4.6. Conclusion

The aim of creating a SVI was to capture data that are often excluded from traditional vulnerability analyses for volcanoes, and to tap into local stakeholder knowledge. The SVI and maps present indicators of vulnerability perceived as important to some local stakeholders. Despite some limitations, the creation of a vulnerability index is a useful starting point when trying to capture vulnerability. It enables the inclusion of factors on social aspects of vulnerability that are often excluded from traditional volcanic vulnerability analyses. Vulnerability captured here, using stakeholder interviews to define variables, reveals three core components: poverty, dependants and geography. A method is presented to enable researchers to include stakeholder views in a traditional quantitative index. The results of the analyses change, however, when the index is calculated using either *relative* or *absolute* vulnerability metrics and when one includes *hazard dependent* variables (proximity and access).

When *relative* vulnerability is considered the results show that the areas in the north of St. Vincent are the most vulnerable due to proximity to the volcano, and also the fact that these areas are less developed than the south, have less access to facilities and poorer living conditions. When *hazard independent absolute* vulnerability is considered measuring total numbers of vulnerable people, the densely populated southern census divisions score highest.

A general limitation of using variables as a proxy for vulnerability is that a personal characteristic, such as age, may increase or decrease vulnerability. For example an elderly person could be vulnerable because they are less mobile or unwilling to leave their home. On the other hand they could have experience of an eruption and this might make them more prepared for future scenarios. An elderly person classified as ‘vulnerable’ in the index in this research may also be wealthy and therefore have more resources to cope during and after an event. An index cannot capture these nuances; all it can do is provide a representation of 'indicators'.

In researching vulnerability one has to make an informed decision about what to include and how to capture it. King (2001, p.153) argues in his paper on the uses and limitations of socioeconomic indicators of vulnerability to natural hazards that there is *"a need to be wary of making absolute and finite classifications of communities on the basis of quantifiable vulnerability alone"*. The complexity of vulnerability lends itself to more qualitative techniques as it is not possible to get a holistic analysis of vulnerability with one indicator or method (Dwyer et al., 2004). An index is a useful starting point, especially when calculated with stakeholder input, but to address its limitations and understand the patterns of vulnerability revealed, other more qualitative methods are required. For this reason other methods for capturing vulnerability to volcanic hazards have been explored and are described in the following chapters.

Chapter 5: Building Vulnerability Analysis

The second of the four research methods is described here, that of analysing building vulnerability to volcanic hazards. A review of current methods in the literature for analysing building vulnerability is presented along with the methods adopted for the building survey. Results obtained, analysis and a critique of this method for analysing vulnerability to volcanic hazards concludes the chapter.

Cutter et al. (2003, p.255) state that the type, quality and construction of the built environment are important for understanding social vulnerability, *"especially as these characteristics influence potential economic losses, injuries and fatalities from natural hazards"*. A survey was designed to gather residential building data for St. Vincent. The results are analysed and mapped to provide a comparison of whether high levels of social and building vulnerability occur in the same areas, and the building vulnerability data are used to calculate the potential losses given the current volcanic hazard scenario.

5.1. Review of current methods

Before research paradigms shifted to look at the social aspects of disasters, vulnerability was often quantified as potential loss in terms of building damage and loss of life. Even though building damage has in the past been studied more than social vulnerability, there is still only a limited literature on volcanic hazards and building damage. This section reviews this literature, with a focus on identifying characteristics of buildings that make them vulnerable to damage from different volcanic hazards, and identifying methods to quantify this potential damage.

5.1.1. Damage mechanisms

Blong (1984) published the book 'Volcanic hazards: a sourcebook on the effects of eruptions'. It compiled chapters not just on volcanic eruptions themselves, but the effects of these eruptions on people, property, and the environment. One chapter is dedicated to volcanic hazards and buildings. As Blong (1984, p.187) states in the first sentence of this chapter *"volcanic eruptions effect buildings through a variety of damage mechanisms"*. Table 5.1 below is reproduced from Blong (1984) and summarises the different types of damage that buildings can experience given possible volcanic hazards.

		Volcanic hazards							
Damage	**Damage mechanism**	**Lava flows**	**Tephra falls**	**Pyroclastic flows**	**Lahars**	**Seismic activity**	**Tsunami**	**Atmospheric effects**	**Acid rain and gases**
Total destruction	Collapse/overturning	3	2	3	2	2	3	1	-
	Burial/inundation/flooding	4	2	3	4	1	4	-	-
	Ignition	3	1	3	1	2	1	2	1
Severe damage	Uplift/transport	1	-	3	3	-	3	2	-
	Foundation failure/deformation	1	-	1	1	3	2	1	-
	Racking	-	-	3	2	3	3	2	-
	Wall loads	4	1	4	4	-	4	3	-
	Undermining/erosion	-	-	1	2	-	2	-	-
Minor damage	Roof loads	-	4	-	-	1	-	2	-
	Projectile impacts	2	4	2	2	2	2	-	-
Negligible damage	Corrosion/discoloration	-	2	1	3	-	2	-	2

Table 5.1: Damage mechanisms to buildings by volcanic hazards and their relative likelihood of occurrence (1 to 4 increasing likelihood of occurrence). Reproduced from Blong (1984, p188).

The summary suggests that pyroclastic flows, lahars and tsunami are associated with the most damage mechanisms; whereas ignition and building collapse are associated with the greatest number of hazards. The most likely damage states to occur are wall loads and burial or flooding. The usefulness of this table is that the relative likelihood of occurrence values assigned to each hazard provides a starting point from which to assess the potential effect of different hazards on buildings.

5.1.2. Relative Risk Index and Volcanic Risk Rank

Blong continued the work on building damage from volcanic hazards and produced the Relative Risk Index for Papua New Guinea volcanoes at VEI 4 (Blong, 2000). The index is a product of the frequency of each hazard occurring, area affected and building damage. Progressing on from the summary in Table 5.1 building damage is now calculated as a proportion of replacement costs. It is still a subjective measure but gives an idea of how buildings are vulnerable to different volcanic hazards.

An improvement on this method was proposed by Magill and Blong (2005a; 2005b) with the Volcanic Risk Rank. Volcanic risk is calculated individually for each hazard as the product of likelihood, extent and effect. Likelihood is defined as the probability of the hazard given a volcanic eruption; extent is the spatial proportion of the study area affected by the hazard; and effect is the proportion of loss in the given area (both buildings and lives). In a similar way to the Relative Risk Index building damage here is calculated as a proportion of replacement costs, however the Volcanic Risk Rank is more detailed in that it assigns hazards on an order of magnitude scale. This makes it easier to determine which hazard should belong in which category as opposed to whether a hazard is a six or a seven in a one to 10 rank.

The categories of building damage assigned to each hazard were based on evidence from the literature on damage assessments from a number of recent volcanic eruptions and analytical and experimental work. These assessments are described below.

5.1.3. Post-disaster damage assessments

Spence et al. (1996) conducted a building damage assessment after the Mount Pinatubo eruption in the Philippines in June 1991. They surveyed 51 houses recording principal construction materials used; number of storeys; roof structure, shape and pitch; and building usage. They concluded that *"the nature of the roof supporting structure was the principal factor influencing the level of damage sustained"* (Spence et al., 1996, p.1055) as long span roofs were found to be nearly five times more likely to suffer damage. Other significant factors were construction type (timber buildings suffered more damage than concrete framed buildings) and roof pitch (steeper roof pitch suffered more damage than shallow pitch).

A similar damage assessment was carried out by Blong (2003) at the town of Rabaul after the September 1994 eruption of Rabaul volcano. Here, 173 buildings were surveyed identifying characteristics such as construction material, roof type and material, number of storeys and type of foundation. The survey considered damage from tephra loading with the failure mode of the roofs identified as being from both purlin and rafter damage. In addition, the survey results showed that concrete block buildings suffered less damage than timber framed buildings and in a similar way to the damage from Mount Pinatubo described above, shorter span roofs faired better. There was insufficient evidence, however, to identify the effect of roof pitch on tephra load induced roof failure. One other damage characteristic highlighted was the potential for corrosion of steel roofs that did not fail during or after the eruption.

A building damage assessment was also conducted on Montserrat after three eruptions in June, September and December 1997 (the June 25th

eruption being the only fatal event to date on Montserrat) (Baxter et al., 2005). In this example the damage to buildings from pyroclastic flows was evaluated. The authors found that the vulnerability of the buildings was due to openings such as windows, flammable contents and type of building construction. They stated that *"the most resistant buildings to damage were single storey and reinforced concrete construction"* (Baxter et al., 2005, p.293). In addition, they noted that there was a great deal of variability in the damage across the impact area which was attributed to the effects of topography, projectile impacts, and localised variants in the pyroclastic current velocity and density.

5.1.4. Potential damage assessments

In addition to post-disaster damage assessments of areas affected by volcanic eruptions, there is some literature describing research where the potential damage to buildings has been assessed pre-disaster as well as calculations of the potential loss of life if an eruption were to occur.

Pomonis et al. (1999) conducted a comprehensive building survey of four towns around Furnas volcano in the Azores. They surveyed 1,911 buildings and identified building use; structural type, age and condition; number of storeys; size; roof type, cover, condition and pitch; wall condition; availability of vents; and availability of window shutters. The vulnerability of the buildings was assessed for volcanic earthquakes, projectiles, pyroclastic flows and surges, and tephra. For earthquakes the authors used the damage to similar building types from past earthquakes to calculate the proportion of each building type to partial or complete collapse given different seismic intensities. Again, based on past activity, the possible damage from ballistic projectiles was described, but not quantified. For pyroclastic flows and surges the authors assumed that all houses within the path of a flow or surge will either suffer severe damage or collapse. Finally, for tephra, roof types on the island were grouped into four categories based on material, roof span and condition. Purlin failure was assumed to be the damage mechanism therefore the strength of timber for each roof type was tested in a laboratory and the expected failure loads determined. The associated loss of life from earthquakes and tephra was calculated by comparing building collapse from each hazard with mean occupancy for both night and day scenarios. For earthquakes it was assumed that one third of occupants would be trapped, of which 25 percent would die, 35 percent suffer severe injuries (15 percent of whom would later die) and 40 percent would suffer light injuries and survive. For tephra-induced roof collapse in single storey houses, one third of occupants are assumed to be trapped, of which 50 percent die. In two or more storey houses, 10 percent of occupants are assumed to be trapped, of which 50 percent die.

Spence et al. (2004a; 2004b), conduct an assessment of the potential building damage on Vesuvius, focusing on the impact of pyroclastic flows. They surveyed the buildings and urban environment in four villages thought to be most at risk around Vesuvius with a particular focus on the number, location and type of openings characteristic of each of the building classes defined in the survey, as these provide *"a weak point in a building envelope in the event of a pyroclastic flow"* (Spence et al., 2004b, p.327). Analytical and experimental studies on the resistance of the building envelope to pyroclastic flows were conducted and the proportions of occupants who would be killed or seriously injured given a pyroclastic flow modelled roughly on the 1631 eruption were estimated. The authors discuss three casualty types: dwelling invaded by flow through failure of an opening; infiltration of hot gases into dwelling; and people outside dwelling. The percentage of people killed varies considerably by casualty type and the distance of the dwelling from the vent. The survey also assessed the urban environment noting the urban density, vegetation and other combustibles and potential missiles, as these factors might influence the damage in the towns.

This work by Spence et al. (2004a; 2004b) for Vesuvius was expanded upon in the European Union funded EXPLORIS project (explosive eruption risk and decision support for EU populations threatened by volcanoes). EXPLORIS is a multi-disciplinary project which has developed quantitative methods for assessing risk and informing disaster management at explosive-erupting volcanoes (Baxter et al., 2008). Part of the project was to develop a multi-hazard, multi-vulnerability impact model which could be applied to four European volcanoes (Vesuvius, Italy; Teide, Tenerife; Soufrière, Guadeloupe; and Sete Citades, the Azores). In a similar way to the assessments described above, a building stock classification was defined which could be applied to the diverse conditions on all four volcanoes. Over 20 classes were defined for each volcano, collecting information on material for construction; number of storeys; age; density of the urban environment; openings and building use (Spence et al., 2005b). Vulnerability functions were calculated for tephra fall, pyroclastic density currents and earthquakes (Spence et al., 2005a; Spence et al., 2007) and used to estimate the number of buildings that would collapse and potential loss of life. Using this model, potential damage scenarios have been run for Vesuvius (Zuccaro et al., 2008), Teide (Marti et al., 2008) and Soufrière (Spence et al., 2008).

5.2. Method

5.2.1. Framework of analysis

Having researched the literature described in Section 5.1 a framework for analysis was developed which could be used for a building vulnerability survey on St. Vincent. A range of characteristics were identified which could help describe how a building might be impacted by volcanic hazards. These are listed below.

- Building material;
- Building condition;

- Age;
- Number of storeys;
- Foundations;
- Roof material, condition and pitch;
- Openings – doors, windows, vents;
- Window shutters;
- Building use; and
- Urban environment – density, availability of missiles, combustible material.

The hazards focused on in this analysis are pyroclastic flows/surges and tephra. Lahars were excluded as the volcanic hazard map for St. Vincent shows lahars travelling along rivers and streams on the flanks of the volcano and there are no buildings overlapping these areas. The only other hazard which has been analysed in the literature with respect to building vulnerability is that of volcanic earthquakes (Pomonis et al., 1999; Spence et al., 2005b). This has been omitted from this research for two reasons. First, there is no isoseismic map for St. Vincent with respect to possible volcanic earthquakes. Second, the likelihood of building damage from a volcanic earthquake is much less than that for pyroclastic flows and tephra. In Spence et al. (2005b) the authors assign a two percent probability of collapse or partial collapse of concrete or timber buildings in an intensity IX[12] earthquake. In addition, Blong (1984) could only attribute 79 out of a total 238,867 fatalities between 1600 and 1982 to volcanic earthquakes.

An additional parameter, External Heat Flux (EHF) has been used as a predictor of casualty rates for people in buildings during a volcanic eruption (see Spence et al., 2005b). EHF could not be used in this

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[12] European macroseismic scale: I to XII (*not felt* to *completely devastating*). IX = *destructive*. Monuments and columns fall or are twisted. Many ordinary buildings collapse and few collapse completely.

research, however, as there are no data on ventilation, temperature, and time of exposure in the building.

5.2.2. Data collection and level of analysis

It was not possible to do a complete survey of the building stock on St. Vincent, therefore a method was designed to collect a sample of data within the time and facility limits of the research. To collect as much information as possible on buildings in a short space of time it was decided to take a digital survey of the building stock that could be analysed at a later date in the UK.

Over four days approximately 10 hours of video data were collected whilst driving around St. Vincent along major and minor roads. The route taken across the island was chosen to cover as large an area as possible in the four days, using the knowledge of the local driver and volcanologist. A GPS track was collected in addition to the video data so as to be able to map the building survey. The GPS track was set to take one point every 100m. This scale was chosen in order to collect as detailed a track as possible, whilst ensuring enough battery and memory for a day's survey. The time on the GPS and video were synchronised so the data could be collated. As a result of a GPS point not being taken for every house surveyed, it was decided to use the enumeration districts as the unit of analysis. This is the smallest unit at which the census data are aggregated. There are 213 enumeration districts on St. Vincent. The survey covered 118 of these (Figure 5.1).

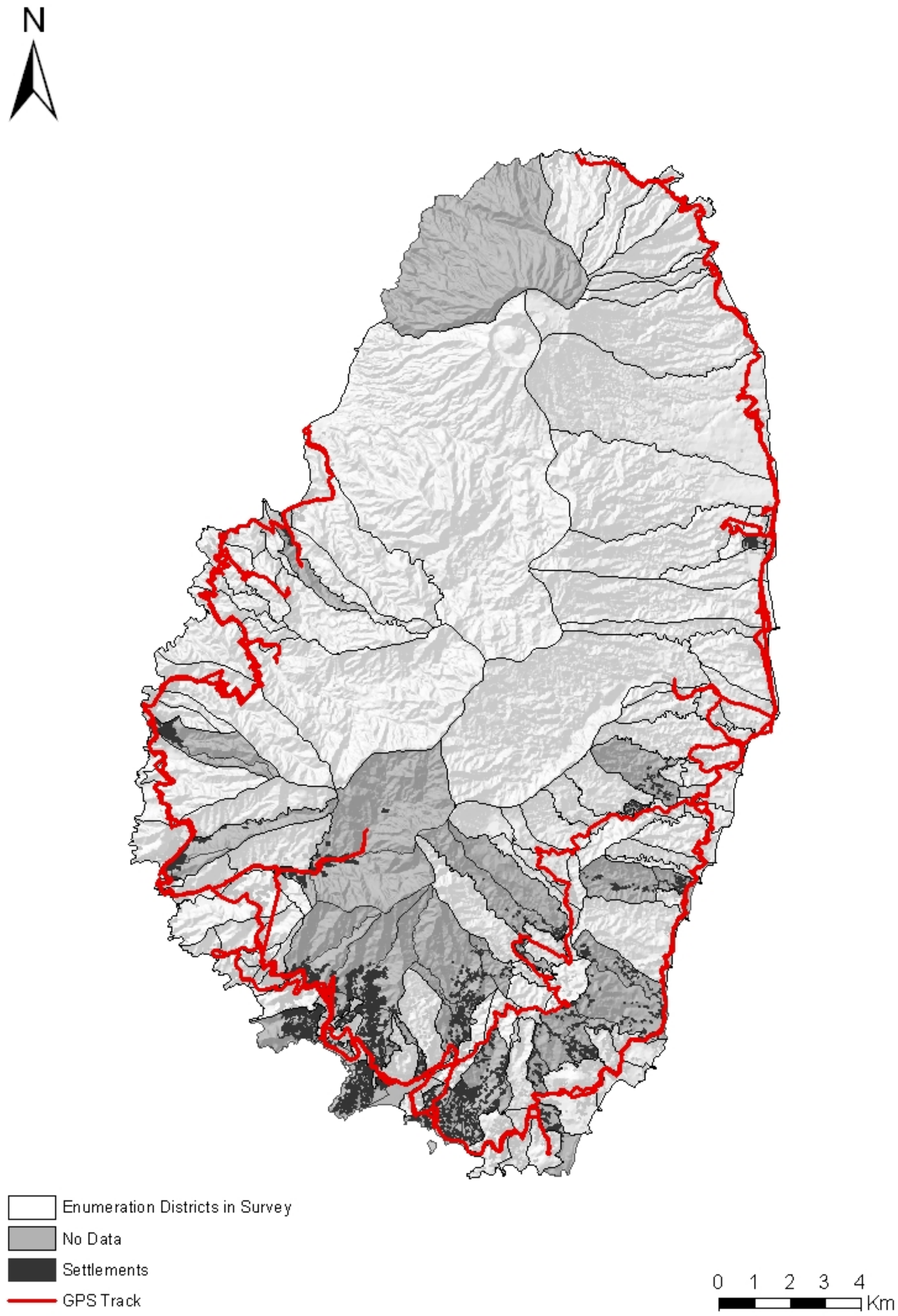


Figure 5.1: Enumeration districts and route taken in building survey.

5.2.3. Residential building database

The next step was to build a database of the building survey results. In order to do this, categories were defined into which buildings on St. Vincent could be placed. These categories were based on the characteristics identified in the literature which could affect the way a building might be impacted by the different volcanic hazards. In addition factors were chosen which could be identified from the video. The characteristics used in this research were wall material (concrete or wood); roof type and material (flat or pitched, concrete or galvanised steel/tile sheets); condition of building and roof (good or bad); and number of storeys (one or two plus).

Wall material was recorded as this is included in all the damage assessments reviewed in the literature. Wooden buildings will be weaker than concrete, and more likely to be ignited by tephra and/or ballistics. The material of the roof affects its resistance to tephra loading. Spence et al. (2005a) classified flat reinforced concrete roofs as the strongest, with sheet metal and tiled roofs as the weakest. The authors also recorded the condition of the roof. Therefore, in this research the general condition of the roof and the building as a whole were noted as this may affect how it is impacted by volcanic hazards. Finally, according to Spence et al. (2005b, p.1006) *"the height of a building is significant for its response to pyroclastic flow pressure and for the impact of roof failure"*; therefore the number of storeys was recorded. Using these parameters, twelve categories were created listed in Table 5.2. Photographs of typical building types are shown in Figure 5.2 to Figure 5.6.

Wall material	Roof	Condition	Number of storeys	Category
Concrete	Pitch steel/tiles	Good	One	CPG1
Concrete	Pitch steel/tiles	Bad	One	CPB1
Concrete	Pitch steel/tiles	Good	Two or more	CPG2+
Concrete	Pitch steel/tiles	Bad	Two or more	CPB2+
Concrete	Flat concrete	Good	One	CFG1
Concrete	Flat concrete	Bad	One	CFB1
Concrete	Flat concrete	Good	Two or more	CFG2+
Concrete	Flat concrete	Bad	Two or more	CFB2+
Wood	Pitch steel	Good	One	WPG1
Wood	Pitch steel	Bad	One	WPB1
Wood	Pitch steel	Good	Two or more	WPG2+
Wood	Pitch steel	Bad	Two or more	WPB2+

Table 5.2: Twelve building categories defined for St. Vincent.

Figure 5.2: Example of building category CPG1.

Figure 5.3: Example of building category CPB1.

Figure 5.4: Example of building category CPG2+.

Figure 5.5: Example of building category CFB1.

Figure 5.6: Example of building category WPB1.

Characteristics such as type and size of openings and the urban environment were not identifiable for individual buildings from the video alone. Therefore these were not integrated into the building categories. Generalisations about some of these characteristics can be made for the typical building types seen on St. Vincent and this will be discussed in later sections.

With the 12 categories defined, the DVDs recorded in the building survey were watched twice, and for every minute of data, the number of each residential building type was tallied. Commercial buildings, churches and schools were not included as no data were available on the occupation of these buildings. DVDs were watched twice as this is a subjective exercise - in particular deciding whether a building was good or bad condition. By watching the DVDs twice, and comparing the tally sheets, the consistency of the researcher’s judgement could be internally validated. The two tally sheets varied only slightly. Around 85 percent of the second tally sheet corresponded to the categories in the first tally sheet. The second tally sheet was used as by this time the researcher has watched all the DVDs and was more familiar with the building stock on St. Vincent. A database was created that integrated the GPS track data by minute with the number of each building category seen for the corresponding minute. With the coordinates from the GPS track, the data were mapped in a GIS and aggregated by enumeration district.

5.2.4. Vulnerability rank

One of the aims of analysing building vulnerability was to be able to compare it to the social vulnerability mapped in the previous chapter. In order to map overall building vulnerability it was decided to assign a number to each of the 12 building categories that described how vulnerable it might be in a volcanic eruption to both pyroclastic flows and tephra, relative to the other building categories.

The two ranks are based on the literature on how buildings are impacted by these hazards; however there is still a subjective element as the researcher has to choose what rank to give each building category. It was decided to use a rank of one to four with one being the least vulnerable, four the most. This was chosen instead of 12 individual ranks as it is hard to decide whether a building category is a six or a seven for example. It is easier to decide if the building's vulnerability is very high, high, medium or low.

For pyroclastic flow vulnerability the two important considerations were building material and number of storeys. In line with evidence of building damage from pyroclastic flows and surges on Montserrat (Baxter et al., 2005), concrete buildings of one storey were considered the least vulnerable on St. Vincent. For tephra vulnerability, the material, condition and pitch of roof were important. Spence et al. (2005a) defined four roof classes for the EXPLORIS project – weak, medium weak, medium strong, and strong. The roofs observed on St. Vincent fitted into the descriptions of these four classes, therefore 'weak' roofs were ranked four (most vulnerable), 'medium weak' ranked three and so on. The two ranks were added together for overall building vulnerability, with equal weighting assumed. The ranks are displayed in Table 5.3.

Category	Pyroclastic flow/surge rank	Tephra rank	Composite building vulnerability rank
CPG1	1	2	3
CPB1	1	3	4
CPG2+	2	2	4
CPB2+	2	3	5
CFG1	1	1	2
CFB1	1	2	3
CFG2+	2	1	3
CFB2+	2	2	4
WPG1	3	3	6
WPB1	3	4	7
WPG2+	4	3	7
WPB2+	4	4	8

Table 5.3: Building vulnerability ranks for pyroclastic flow/surge and tephra hazards.

5.2.5. Potential loss calculations

In addition to comparing building vulnerability with social vulnerability, it was decided to use the data collected in the building survey to calculate the potential loss of buildings and life, in a similar way to studies on the Azores and Vesuvius (Pomonis et al., 1999; Spence et al., 2005b). This was completed using the current volcanic hazard map (Figure 3.5) which defines the extent of pyroclastic flows/surges, tephra, lahars and ballistics, and household and population totals from the 2001 Census.

Data were manipulated in a GIS to assign the number of each building category recorded in the survey to one of the residential settlements (Figure 3.1). These were used instead of the enumeration districts as it gave a more accurate picture of where households and people would be located. A large area of St. Vincent is rural farmland and forest, in particular on the flanks of the volcano. Keeping the data aggregated at enumeration district level would give a false sense of the picture, calculating more household collapses and deaths than might actually occur as in reality, very few people are located within 4km of the volcano.

Assuming that the building survey was a representative sample of the residential building stock on St. Vincent, the percentage of each of the 12 building categories in an enumeration district was multiplied by the total number of households in that district. The number of households in each enumeration district was assigned to the residential settlements in that district based on the area of each settlement polygon. As a result, household density within an enumeration district was assumed to be constant. Population totals were assigned to each settlement by dividing the population in each district by the total number of households in that district to give an average household size. This was then multiplied by the number of households in each residential settlement to give the population in that settlement. Consequently, population density was also assumed to be constant within an enumeration district. Finally, using overlay analysis in a GIS the type and intensity of hazard that would occur at each residential settlement was recorded.

For the pyroclastic flow/surge hazard, it was assumed that all buildings in the ‘high’ (red) zone would collapse (in line with assumptions in Pomonis et al., 1999), and all occupants killed. These assumptions were made due to a lack of data on the dynamic pressure of the pyroclastic flow/surges. Evidence from Montserrat (Baxter et al., 2005) suggests that not all buildings collapse in a pyroclastic flow due to the effects of sheltering and lower pressures on the edges of the flow, however data would be required to calculate these effects. It was assumed that flows would not reach the ‘moderate’ and ‘low/negligible’ zones as the description of the hazard map states that flows would reach these areas during eruptions of magnitudes greater than 1902 and 1979 (greater than 20km eruptive column height) (Robertson, 2005).

To calculate potential roof collapse it was necessary to convert tephra depth into load (kilopascals kPa). The following equation was used:

$$TephraLoad = \rho gh$$

ρ = tephra density (kg/m^3)

g = gravitational acceleration $(9.80665 m/s^2)$

h = tephra thickness (m)

(Spence et al., 2005a, p.480)

Tephra thickness was taken from the isopachs in Figure 3.5. Two tephra densities were used to account for the possibility of dry or wet tephra. For dry tephra a value of 1000 kg/m^3 was used; wet tephra 1500 kg/m^3. These values were chosen as they are those used in Spence et al. (2008) in their modelling of a hypothetical explosive eruption of Soufrière volcano in Guadeloupe.

The vulnerability curve for roof collapse in Spence et al. (2005a) (reproduced in Figure 5.7) was used to assign a probability of collapse to each tephra load calculated for each of the four roof classes.

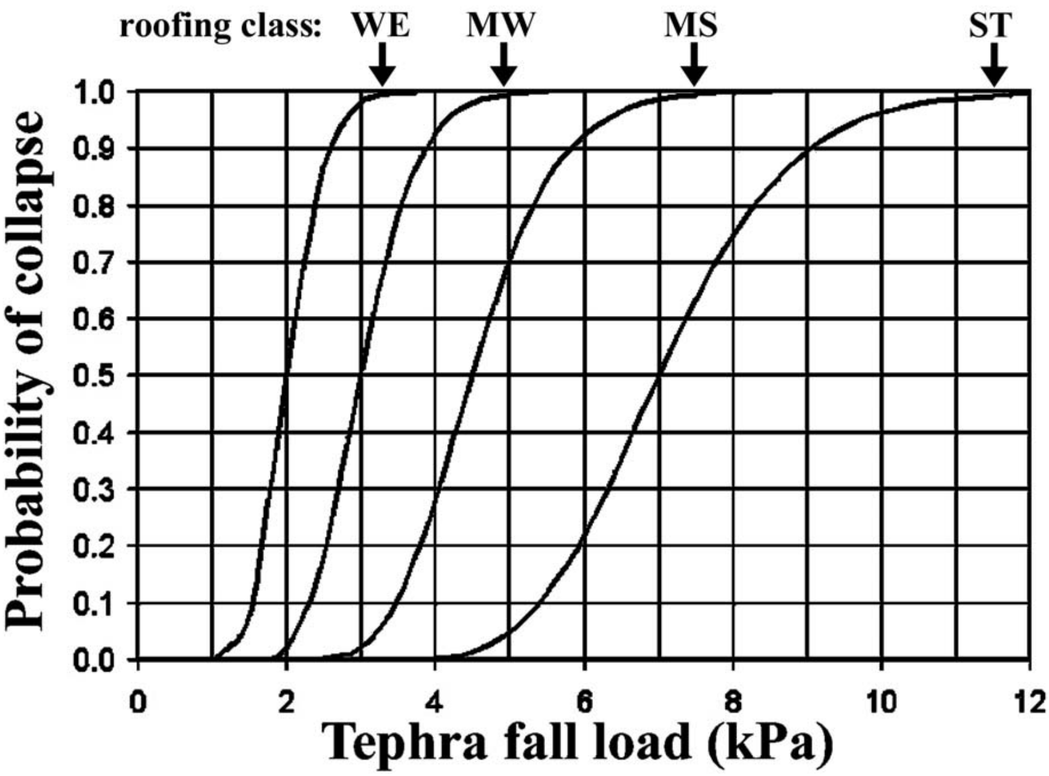


Figure 5.7: Tephra fall roof vulnerability curve (Spence et al., 2005a, p.1009). WE weak roofs, MW medium weak, MS medium strong, ST strong.

The tables below show the tephra loads calculated for each isopach (Table 5.4); the St. Vincent building categories grouped into weak, medium weak, medium strong and strong classes (Table 5.5); and the probability of collapse estimated for each roof class at the seven different tephra depths for dry and wet tephra (Table 5.6).

Isopach (cm)	Load dry tephra (kPa)	Load wet tephra (kPa)
50	4.90	7.35
40	3.92	5.88
30	2.94	4.41
20	1.96	2.94
10	0.98	1.47
5	0.49	0.74
<5 (0.25 used)	0.25	0.37

Table 5.4: Calculated tephra loads for St. Vincent using isopachs from the volcanic hazard map (Figure 3.5).

Roof class (Spence et al., 2005a)	St. Vincent building category
Weak	WPB1, WPB2+
Medium Weak	CPB1, CPB2+, WPG1, WPG2+
Medium Strong	CPG1, CPG2+, CFB1, CFB2+
Strong	CFG1, CFG2+

Table 5.5: St. Vincent building codes and roof class.

	Probability of roof collapse													
	Dry tephra (depth cm)							Wet tephra (depth cm)						
Roof class	**50**	**40**	**30**	**20**	**10**	**5**	**<5**	**50**	**40**	**30**	**20**	**10**	**5**	**<5**
Weak	1	1	0.97	0.4	0	0	0	1	1	1	0.97	0.04	0	0
Medium Weak	0.98	0.9	0.42	0.02	0	0	0	1	1	0.96	0.42	0	0	0
Medium Strong	0.65	0.24	0.02	0	0	0	0	0.98	0.9	0.45	0.02	0	0	0
Strong	0.04	0	0	0	0	0	0	0.55	0.18	0.02	0	0	0	0

Table 5.6: Probability of roof collapse for St. Vincent buildings using Figure 5.7.

These data were used to calculate the number of household roofs that would collapse on St. Vincent given dry tephra and wet tephra. In addition, the potential loss of life given this roof collapse was calculated for both scenarios. The results of the building survey, vulnerability rank and potential loss calculations are presented in Section 5.3 below.

5.3. Results

5.3.1. Individual categories

Table 5.7 below shows the number of each building category recorded in the survey. Table 5.8 shows the percentage of buildings surveyed by census division. The total number of households in the 2001 Census is 27,981. Therefore the survey recorded over 18.5 percent of the 2001 total. The 2001 Population and Housing Census Report (Statistics Office, 2001) states that 71.6 percent of the buildings in 2001 were concrete construction and 19.3 percent were wooden (the remainder were a mix of wood and concrete or makeshift materials). The percent of wooden buildings had decreased from 31.3 percent in 1991. The number of buildings recorded as concrete in this survey was 87 percent, with 13 percent wood. Therefore wooden buildings have been under sampled in this survey, although it is possible that the proportion of wooden buildings may still be in decline from the 2001 totals.

Building category	**Number of buildings**	**Percent of survey total**
CPG1	1673	32.21
CPB1	1472	28.34
CPG2+	917	17.65
CPB2+	246	4.74
CFG1	81	1.56
CFB1	92	1.77
CFG2+	26	0.50
CFB2+	12	0.23
WPG1	55	1.06
WPB1	529	10.18
WPG2+	7	0.13
WPB2+	84	1.62
TOTAL	**5194**	**100**

Table 5.7: Number of each building category recorded in survey.

Census division	**Percentage of 2001 household totals covered in survey**
Barrouallie	16.49
Bridgetown	9.14
Calliaqua	6.31
Chateaubelair	15.53
Colonaire	16.21
Georgetown	23.22
Kingstown	2.44
Kingstown Suburbs	6.96
Layou	8.76
Marriaqua	13.28
Sandy Bay	31.51

Table 5.8: Percentage of 2001 household totals covered in survey for each of the eleven census divisions.

Figure 5.8 maps the proportion of each building category by census division, and Figure 5.9 maps the proportion and distribution of building vulnerability variables recorded in the survey.

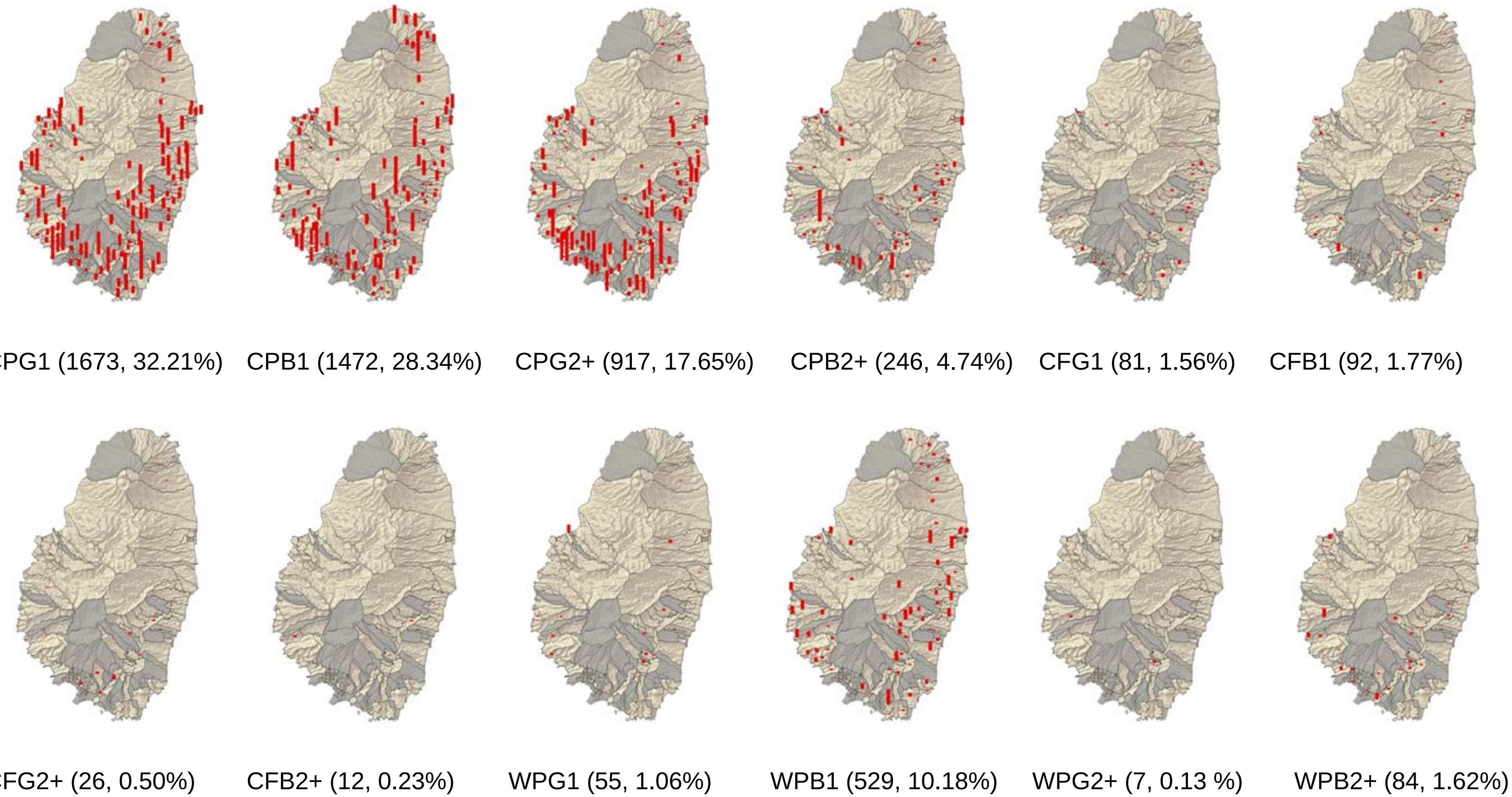


Figure 5.8: Proportion of building category by enumeration district. The number of each building category and percentage of the survey total are shown in brackets. The size of the red bars is proportional to the number of households in that enumeration district.

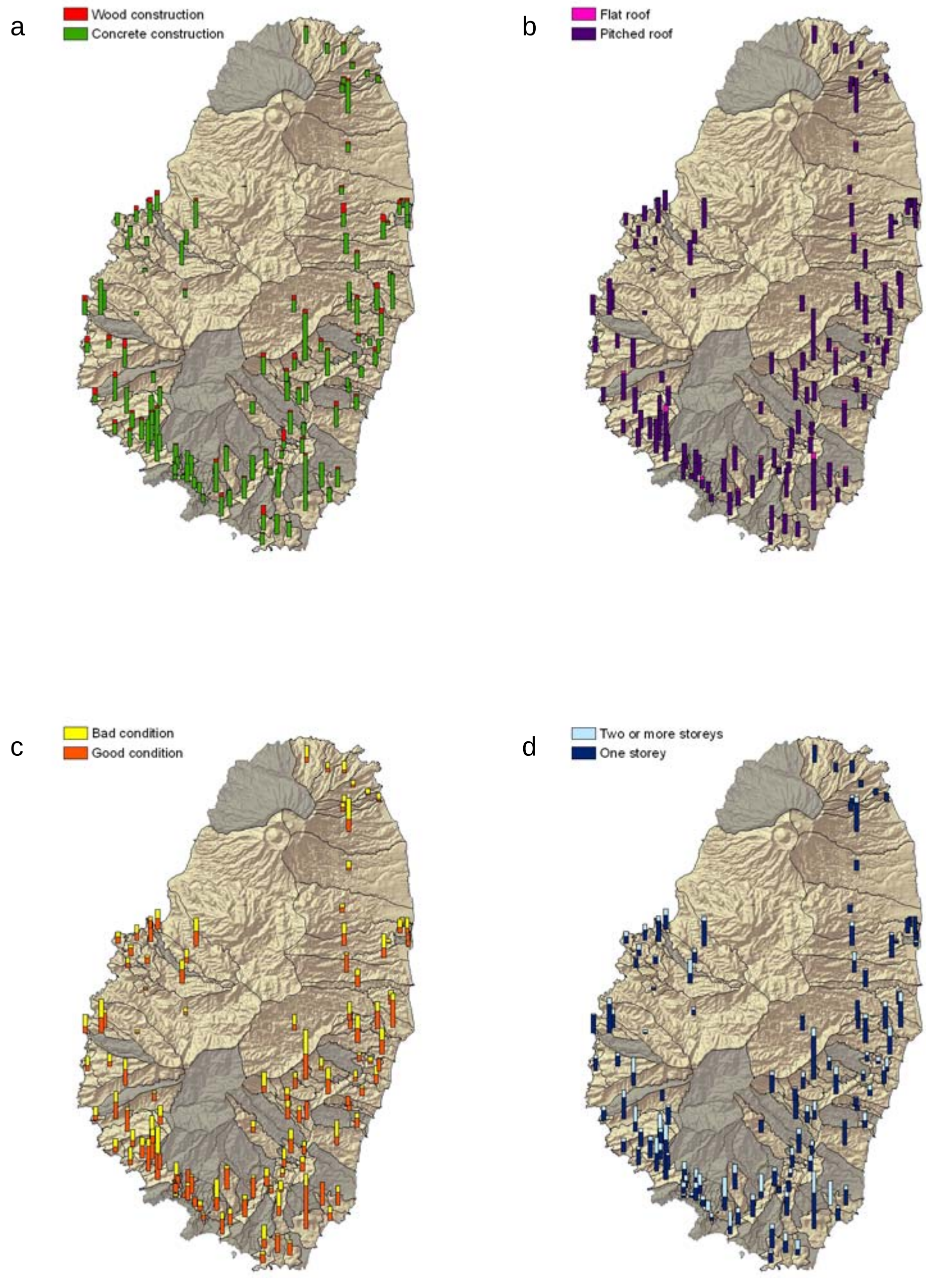


Figure 5.9: Comparison of building vulnerability variables. (a) wall material; (b) roof pitch; (c) building condition; and (d) number of storeys. The size of the bars is proportional to the number of households in that enumeration district.

5.3.2. Building vulnerability rank

Figure 5.10 maps the results of the building vulnerability rank. The ranks in Table 5.3 were multiplied by the proportion of each building category in each enumeration district and the 'z' score was calculated. This produces relative vulnerability which can be compared with the social vulnerability maps produced in the previous chapter. The data are mapped as the number of standard deviations from the island average.

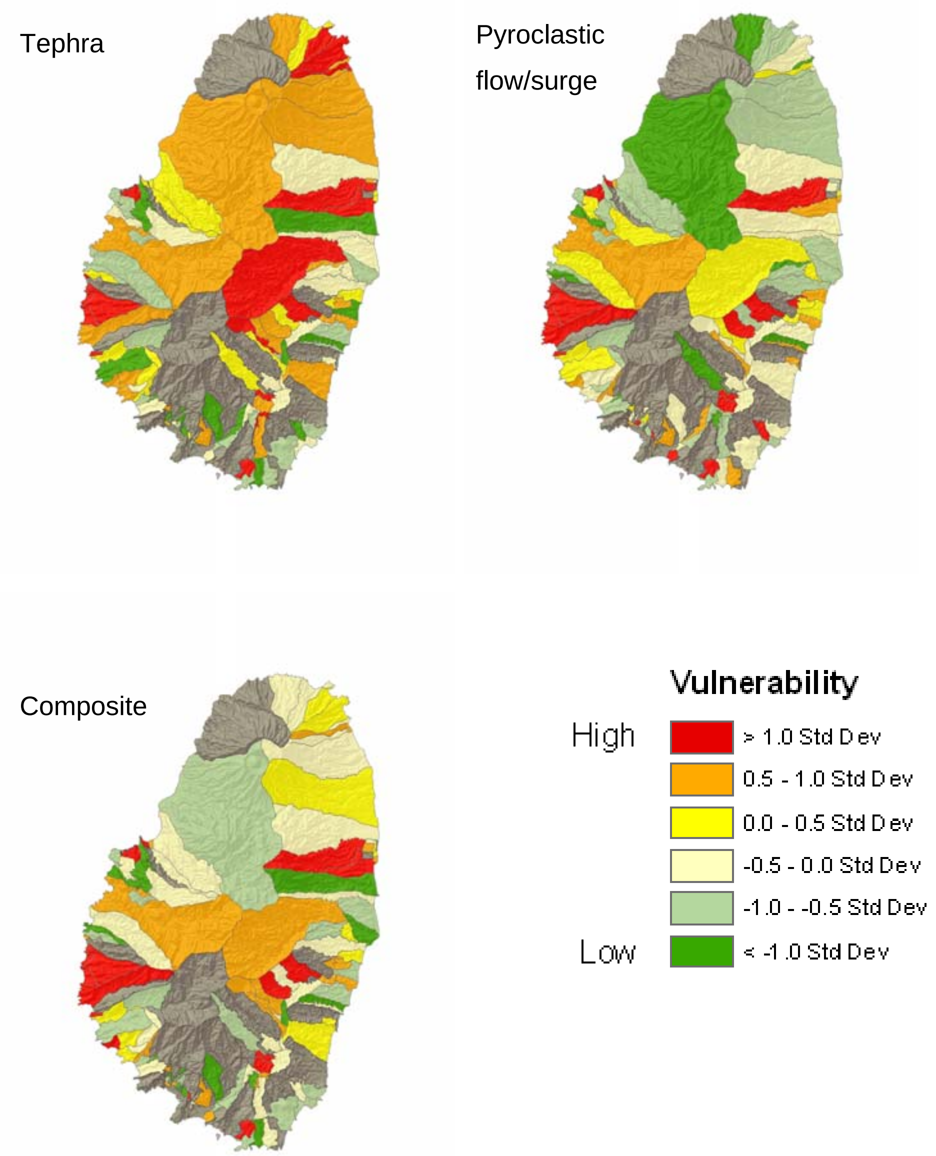


Figure 5.10: Relative building vulnerability (grey areas have no data).

Absolute building vulnerability is shown in Figure 5.11. The ranks in Table 5.3 were multiplied by the number of each building category in each enumeration district as a proportion of the island household totals and the 'z' score was calculated. These maps are comparable to the absolute social vulnerability maps produced in the previous chapter.

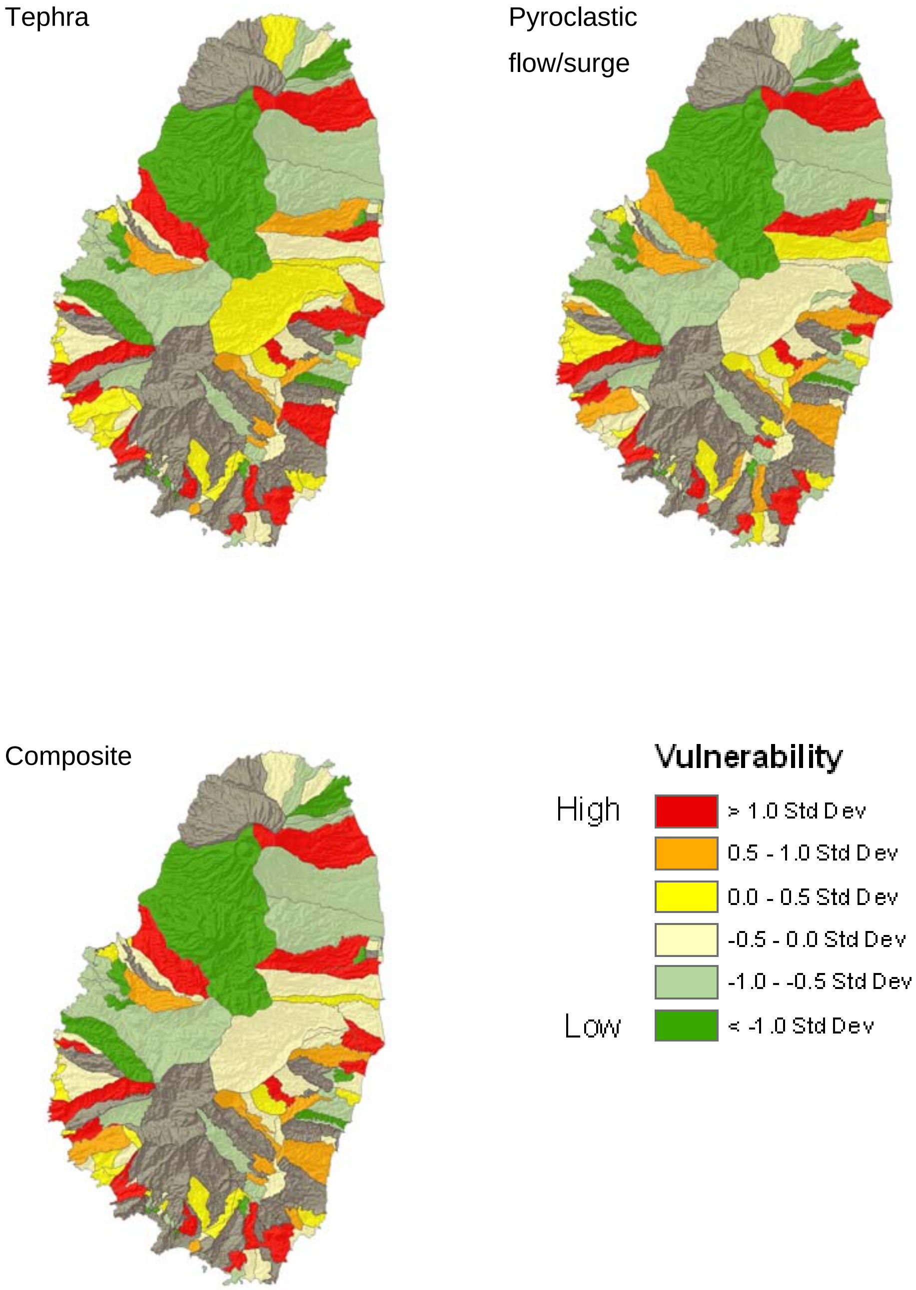


Figure 5.11: Absolute building vulnerability (grey areas have no data).

5.3.3. Potential loss

Potential loss of lives and households could only be calculated for the 118 enumeration districts that were surveyed. When calculating loss as a percentage of the island population, however, the population and household totals on St. Vincent were used as the majority of loss will occur in the north where only six enumeration districts were un-surveyed.

To calculate the number of households expected to collapse given two eruption scenarios (dry or wet tephra plus pyroclastic flows) overlay analysis in a GIS was used. The number of households within the pyroclastic flow/surge zone was calculated as these were assumed to all collapse. Next, of the remaining households, the number within each tephra isopach was calculated and multiplied by the data in Table 5.6 on roof type and probability of collapse. The results are show in Table 5.9.

	Number of collapsed households	
Pyroclastic flow/surge household collapse	929	
As a % of total number of households on St. Vincent (2001 census)	3.32%	
	Number of remaining households (after pyroclastic flow/surge hazard) which will collapse	
Isopach (cm)	**Dry tephra**	**Wet tephra**
50	107	125
40	225	315
30	69	145
20	43	206
10	0	4
5	0	0
<5	0	0
Total	445	796
As a percentage of total number of households on St. Vincent (2001 census)	1.59%	2.84%
Total number of household collapse	1374	1725
As a percentage of total number of households on St. Vincent (2001 census)	4.91%	6.16%

Table 5.9: Projected number of households to collapse given two hazard scenarios (dry and wet tephra).

To estimate the potential loss of life, the number of people in a household with roof collapse or collapse from pyroclastic flow/surges was calculated. It was assumed that the whole population was indoors, with no evacuation, and that 100 percent of the building occupants will be killed with complete collapse from pyroclastic flows. Pomonis et al. (1999) and Spence et al. (2005b) both assume that 50 percent of the building occupants on the top floor will be killed if the roof collapses from tephra. They assume, however, that the households are only partially occupied – two thirds of occupants escape in a single storey house, and one third are trapped of which 50 percent die. In two or more storey houses they assume ten percent of occupants are trapped of which 50 percent die. These assumptions are based on casualty statistics mainly from earthquakes (Spence, pers. comm.) and are used here for the potential loss calculations on St. Vincent. Table 5.10 shows the calculations for loss of life, and Figure 5.12 maps the results of the worst case scenario (wet tephra).

	Loss of life	
Pyroclastic flow/surge	3237	
As a percentage of population on St. Vincent (2001 census)	3.28%	
	Loss of life from roof collapse of remaining households	
	Dry tephra	**Wet tephra**
Single storey house	308	529
Two or more storey house	9	19
Total	316	548
As a percentage of population on St. Vincent (2001 census)	0.32%	0.55%
Total loss of life	3553	3785
As a percentage of population on St. Vincent (2001 census)	3.60%	3.83%

Table 5.10: Projected loss of life for two hazard scenarios (dry and wet tephra).

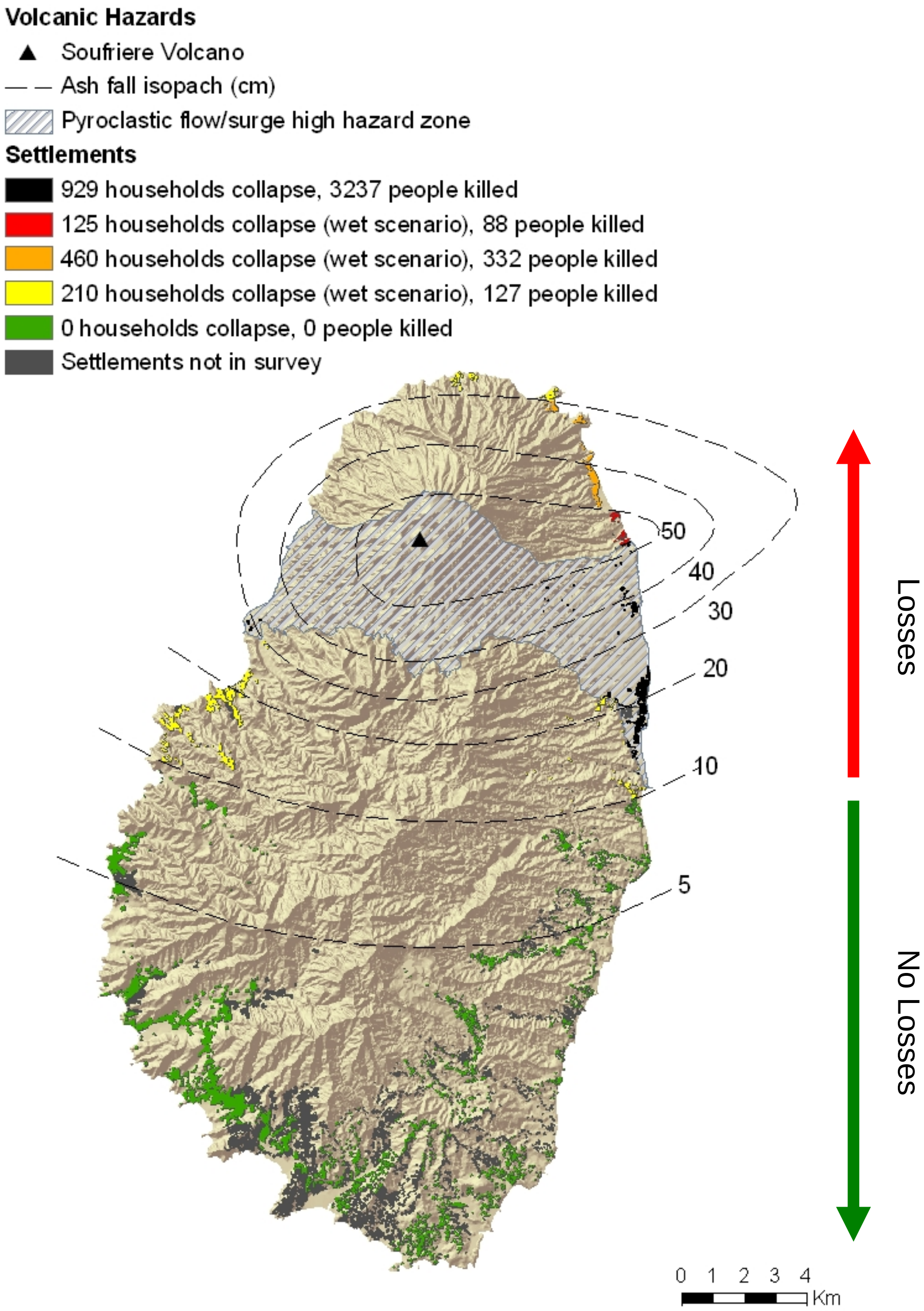


Figure 5.12: Potential losses for future eruption scenario (wet tephra).

5.4. Interpretation of building vulnerability

This section discusses the maps in Section 5.3 and offers an interpretation of the results shown. First the distribution of building types across St. Vincent is discussed, followed by the vulnerability ranking and maps. Building codes and other hazards are examined, along with additional factors relating to building and urban vulnerability to volcanic hazards discussed in the literature.

5.4.1. What do the maps show?

The maps in Figure 5.8 show that the majority of buildings on St. Vincent are located in the south of the island and along the coast. The building type that was observed the most was CPG1, one storey concrete building with a pitched roof all in good condition which accounted for over 30 percent of the survey total. This building type occurs all over the island, particularly in the south east around Calliaqua and Diamond; the south west in Camden Park; and the east near Greiggs and Bellevue. The next two most common building types are CPB1 and CPG2+ at 28.34 and 17.65 percent respectively. One storey concrete buildings with pitched roof but in bad condition are also located across the island; however there is more of this type in the north in Sandy Bay, Owia and Fancy, and again in the east near Greiggs. Two storey concrete buildings with a pitched roof in good condition are located in large numbers along the south east coast around Brighton. This is the wealthier area with lots of villa style accommodation.

Wooden buildings in bad condition are the next most common building type, with 10.18 percent of the survey total. These are located around the island, with pockets of high numbers in Barrouallie in the west, Georgetown area in the east and Arnos Vale in the south. None of the remaining building types occupy more than six percent of the survey total.

The building ranked the most resistant to volcanic hazards was CFG1: one storey concrete building with flat roof in good condition. This type represents only 1.56 percent of the survey total and is found in the south and along the east coast. Building practices on St. Vincent, however, means that many of these buildings will be converted into two storey concrete houses with pitched roofs. Families often build a one storey house at first, keeping a flat roof, and then when finances allow, a second storey will be added with the commonly seen pitched roof. This means that the building's vulnerability will be increased from the best rank to the third best. The most vulnerable building type is a two storey wooden house in bad condition. Very few of these were observed in the survey, 1.62 percent, mostly in Layou and Chateaubelair in the west.

Figure 5.9 maps the distribution and proportion of each of the building variables recorded in the survey. These maps show that overall most buildings are concrete construction (87 percent); however there are pockets of wooden buildings in the west around Layou and Barrouallie, and in the east at Georgetown. Buildings commonly have pitched roofs (96 percent), though some flat roofs were seen particularly in the south east. Building condition varied considerably, although the majority were recorded as being in good condition (53 percent). Those buildings in bad condition are located throughout the island; however they are in the majority in the north and around Georgetown in the east. Finally, the majority of the buildings in the survey were one storey high (75.12 percent). Two storey buildings were more common in the wealthier southern suburbs of Calliaqua and Edinboro.

Figure 5.10 shows relative building vulnerability mapped using the vulnerability rank in Table 5.3. The shape of the areas is dictated by the enumeration district boundaries which are defined in part by the topography of the island. The tephra map highlights areas of high vulnerability where there are a large proportion of buildings classified as having ‘weak’ roofs, and buildings made of wood. The pyroclastic map contrasts in that the north is now predominantly green with lower than average vulnerability. Although this area is considered poorer than the south, the houses are mainly concrete and single storey. Vulnerability to pyroclastic flows and surges is greater for two storey buildings due to the dynamic pressure of the flow. If the dynamic pressure is considered constant with height higher buildings are likely to attract higher lateral forces and therefore more prone to fail. Research suggests however, that pressure actually increases with height therefore higher buildings are even more likely to fail (Spence, pers. comm.). Thus, the higher proportion of two storey buildings partly explains the high vulnerability seen in the south of St. Vincent. In addition, wooden buildings and buildings in bad condition rank high on pyroclastic flow/surge vulnerability. When the two ranks are combined to produce a composite vulnerability map a lot of the island is calculated as having average or close to average vulnerability. There are still pockets of red (high vulnerability) that maps areas with a greater proportion of wooden buildings that score highly on both tephra and pyroclastic vulnerability ranks.

The maps in Figure 5.11 show a very different picture, effectively highlighting highly populated areas. These maps show absolute building vulnerability where the number (not proportion) of each building type in an enumeration district is considered. The tephra, pyroclastic and total vulnerability maps look a lot more alike than when relative building vulnerability was mapped. The pockets of red, high vulnerability are showing areas where there are a high number of households, particularly of wooden construction. The sparsely populated north of the island on the whole is below average vulnerability. The one exception is the area around Sandy Bay and Overland Village where population and household totals are greater. Georgetown still scores high vulnerability as it too has a large population and number of households, many of which are wooden or in bad condition.

In a similar way to the social vulnerability maps discussed in the previous chapter, the relative and absolute building vulnerability maps in Figure 5.10 and Figure 5.11 raise the question of what are the most useful measurements and representations of vulnerability. If one wants information to target the greatest number of vulnerable buildings with a limited retrofitting budget, for example, then the absolute vulnerability maps may be appropriate. If the aim is to increase the levels of development and household standards in an area then the relative vulnerability maps may be more suitable. This highlights the importance of engaging stakeholders when analysing and mapping vulnerability, so the needs of the user are taken into consideration.

5.4.2. Other factors in the literature

In addition to the factors recorded in this building survey, literature on building vulnerability highlights a number of other important considerations such as size and type of openings, roof span, and the urban environment (Spence et al., 2004b ; Spence et al., 2005b ; Baxter et al., 2005; Spence et al., 2007). Although these aspects could not be quantified using the video data, some general comments can be made regarding the building types and environment on St. Vincent.

According to Spence et al. (2004b) openings such as windows and doors form a weak point in the building envelope which allows for pyroclastic flows and surges to infiltrate and damage the building. Evidence from Montserrat showed that building vulnerability to pyroclastic surges lay in the window openings in particular and that wooden shutters if closed could act like hurricane boards and protect a window from infiltration of hot ash and gases (Baxter et al., 2005). The building survey on St. Vincent suggests that very few buildings have wooden shutters that were visible. Those that did tended to be the wooden buildings, although often in the absence of a glass window. Wooden buildings also appeared to have fewer and smaller window and door openings than concrete buildings, though overall openings were generally small.

The other important consideration for vulnerability to pyroclastic flows and surges is the urban environment. Spence et al. (2004b) discuss the importance of the density of the built environment, in that closely spaced buildings can provide protection for one another from pyroclastic flows and surges, thus lowering the vulnerability of the area. In contrast, characteristics of the urban environment that can increase a building's vulnerability are presence of combustible material such as vegetation and fuel cylinders, and the availability of missiles (bins, road signs, etc.). Outside of the zone of total destruction from pyroclastic flows and surges on Montserrat there was variation in impact which the authors partly attributed to the effects of sheltering and missiles (Baxter et al., 2005). On St. Vincent the density of the built environment varies considerably. Some towns and villages have buildings spaced very closely together, for example the town of Layou (Figure 5.13). This could act as shelter from a pyroclastic flow or surge therefore reducing building vulnerability.

Figure 5.13: View over Layou, St. Vincent, showing the density of the built environment in some settlements.

In contrast, some areas, in particular the more rural locations in the north are sparsely populated and buildings are situated along a road or track. There are no other buildings or infrastructure to act as a shelter from pyroclastics and this would make these areas more vulnerable to flows and surges.

In addition, it is clear from Figure 5.13 that much of St. Vincent is very densely vegetated thereby providing combustible material and increasing the buildings' vulnerability to volcanic hazards. It is also possible for households to have fuel cylinders nearby if there is no mains gas to the area, thereby providing even more combustible and explosive material. St. Vincent also has plenty of debris along the streets that could be entrained in a pyroclastic flow or surge and act as a missile, causing more damage to buildings. Although there are few road signs, there are shop signs, lampposts, wheelbarrows and tools, and general debris, particularly from construction.

Roof span was highlighted as an important characteristic to consider with respect to vulnerability to tephra (Spence et al., 1996; Blong, 2003). Evidence from Rabaul and Pinatubo showed that shorter roof spans (less than five metres) fared better under tephra load than longer roof spans. On Pinatubo long roof spans were nearly five times more likely to suffer damage (Spence et al., 1996). On St. Vincent concrete buildings tended to have longer roof spans than wooden buildings (see Figure 5.2 to Figure 5.6), therefore increasing their vulnerability to collapse from tephra.

A factor that is not discussed in the literature relating to building vulnerability, but which commonly occurs on St. Vincent, is houses built on stilts (Figure 5.14). Owing to the topography of the island, and the lack of flat land to build on, many houses are built on slopes using stilts. Over time some of these houses will have a ground floor built, in a similar way to flat roofed buildings having a second floor added. When considering building vulnerability however, it is necessary to take this into consideration. This building type has not been considered in previous volcanic vulnerability analyses. According to Spence (pers. comm.) depending on how well the structure was built, stilts could act either to increase or decrease the building's resistance to volcanic hazards. Further studies should consider this building type and conduct engineering assessments to determine resistance to volcanic hazards.

Figure 5.14: Example of a house built on stilts.

5.4.3. Building codes and practices on St. Vincent

Currently there are no volcanic building codes in the Caribbean. Information on building codes for other natural hazards such as hurricanes and earthquakes is spread across a wide range of websites including CDERA, the Caribbean Development Bank (CDB), the United States Agency for International Development (USAID), the Organisation of American States (OAS), the Association of Caribbean States, the Organisation of Eastern Caribbean States, and the UNDRO. The sheer number of organisations and websites which hold information on building codes and practices in the region, and have conducted studies to improve building practices and update codes, makes getting any up-to-date information confusing and difficult. There are efforts to change this with a new CARICOM/CDB project on the preparation of regional building standards[13]. What is clear is that there is a uniform code developed in

[13] www.crosq.org

1985 called CUBiC (Caribbean Uniform Building Code). This covers wind and seismic hazards and the objective is that it forms the basis for national building codes to be developed and implemented. Despite these codes existing (albeit difficult to find), it is widely acknowledged by agencies working in this field that a lot of construction is done by builders without any formal training. Therefore, even if codes are in existence they are not necessarily adhered to or followed to suitable standards. Newer buildings on St. Vincent may be built to wind and seismic code standards, however much construction is still conducted in an informal manner with many people helping each other build houses in a community. During one of the interviews conducted in this research the President of the Red Cross on St. Vincent explained how people build houses on the island:

> *"For those persons with steady income, you can borrow money, and you can build a house to a certain specification. But there are people who do not have the wherefore to borrow monies from banks so they have to build a house in accordance of what comes in their pockets. Now, how would they do that? I have my piece of land, I may go to the Rabacca Dry River and may buy a truck load of Rabacca sand, and borrow a block mould, and during the day in the afternoons I come from the mountains from the lands and me and me children, we mix up the concrete and we make blocks. But you could only build a house in accordance with what your ability, your financial ability, your financial resources to do so. You may not be able to build it to put in the hurricane straps or the other things that will withstand even a forty mile per hour wind. Okay. So you understand the economics of it?"*

In addition to informal building of concrete houses described in this quote, many wooden houses are built to be mobile. Their foundations consist of a concrete block in the ground with the house on short, wooden stilts. According to Robertson (pers. comm.) these houses are made to be mobile so owners can move them if necessary (Figure 5.15).

Figure 5.15: Wooden house on stilts.

5.4.4. Potential loss

Overall a maximum of 6.2 percent of households on St. Vincent are projected to collapse given the current hazard scenario with wet tephra. This number reduces to 4.9 percent of households if tephra is dry (Table 5.9). The majority of household collapse is from pyroclastic flows and surges (67.6 percent of total if dry tephra, 53.9 percent of total if wet tephra). This is partly because the pyroclastic flows and surges are projected to cover a large area (roughly 48km^2), but also because in this research it was assumed that all buildings within this zone will collapse. Evidence from Montserrat suggests that this is not the case, as some buildings, in particular on the fringes of the flows may survive with minimal damage, even wooden buildings if they have been boarded up (Baxter et al., 2005).

Data not included in these calculations need to be considered. In total there were 95 enumeration districts that were not surveyed. Only six of these, however, are in the loss zone of 10cm tephra and above. Within these six enumeration districts there are 454 households with a population of 1654 which accounts for 11.2 percent and 10.7 percent of the total households and population in the loss zone.

Other considerations may also alter the loss calculations. One factor that this analysis does not take into account relates to the illegal settlements which are located on the flanks of the volcano. These settlements are not included in the census and therefore are excluded from these projected losses. Illegal settlements are located on the flanks of the volcano, in particular around the western slopes down towards Chateaubelair. Pyroclastic flows and surges have occurred on the western flanks in both the 1902 and 1979 eruptions and it could be expected that flows will follow a similar path in a future eruption. This could add to the total losses calculated.

A factor that may reduce the loss calculations is the extent of future pyroclastic flows. The potential loss map in Figure 5.12 shows pyroclastic flows possibly reaching Georgetown in the east of the island and this is where a large number of households are likely to collapse. The geology map of St. Vincent (Figure 3.4) also shows pyroclastic deposits from Soufrière volcano covering the Georgetown area. In the 1902 and 1979 eruptions, however, flows or surges did not reach this area. Anderson et al. (1903, p.399) in their report of the 1902 eruption stated that *"at Georgetown no lives were lost, and it seems certain that the deadly black cloud did not pass over the town"*. Therefore, in a future eruption, actual losses could be less than calculated here, if the pyroclastic flows and surges are similar in extent to those witnessed in historical times.

Nearly 50 percent of households that collapse from tephra are within the projected area to be covered by 40cm of tephra. This is because there are not many households in the 50cm tephra zone and the 40cm zone covers the town of Sandy Bay. Wet tephra increases the number of household collapses by almost 80 percent overall. The largest increase occurs in the 20cm tephra zone where nearly five times the number of households are projected to collapse given wet tephra versus dry. Very few households collapse with less than 20cm of tephra therefore authorities on St. Vincent could concentrate on strengthening roofs in those areas which will receive greater than 20cm of tephra for maximum benefit. Anderson et al. (1903) reported that in the 1812 eruption on St. Vincent, roofs collapsed with tephra of 15 to 25cm, and in 1902, 7.5 to 12.5cm, with houses collapsing with 46cm depth. Given that roof strength could be greater today, the numbers calculated in this analysis appear reasonable.

If the population were all in their homes, it is projected that between 3553 and 3785 people might be killed in a future eruption on St. Vincent (Table 5.10). The majority of deaths occur from pyroclastic flows and surges (91 percent of total if dry tephra, 85 percent if wet tephra). This is because all households were assumed to have collapsed in areas covered by pyroclastic flows and 100 percent of the population in the household to be killed.

It is useful to compare these loss calculations, and locations of damage, to the eruption in 1902.   The total loss of life recorded varies between reports; however a figure of 1565 is often used (Robertson, 1995; Robertson, 2005; Witham, 2005). This may be an underestimate, however, as the census at the time was not very good and most of the people killed may not have been ‘valuable’ enough to be counted (Robertson, pers. comm.). The reported figure was around four percent of the population at the time (Anderson et al. (1903) reported that the population of St. Vincent in 1902 was around 40,000). Deaths occurred mostly in the northwest and northeast of the island. Anderson et al. (1903) describe the loss of life found at Langley Park, Lot 14, Rabaka, Orange Hill, Turema and Overland village (see Figure 3.3). Some of these villages do not exist anymore, however they are all located within the high pyroclastic hazard zone in Figure 5.12 and suffocation from a pyroclastic flow appears to have been the major cause of death in most of these areas. Loss of life was also reported to have occurred from roof collapse of buildings. At Orange Hill *"many shut themselves up in a store with a galvanized iron roof. All died, and were found buried in sand with the roof collapsed and fallen upon them"* (Anderson et al., 1903, p.396). There were also reports of devastation at Fancy and other villages in the north of the island, though *"much less considerable than in the valleys on the south of the mountain"* (Anderson et al., 1903, p.398). In particular at Owia the damage was reported to be comparatively light, with crops only partially buried and no one killed.

The area of damage calculated in this research stretches farther south than that reported in 1902. This is due to the extent of the current high pyroclastic hazard zone in Figure 3.5. The percentage of the population calculated to be killed is in the same range as that of 1902, however in 1902 many people had already evacuated. It is understood that the population in the north of St. Vincent was proportionally greater in 1902 than it is today as this was where a number of the colonial plantations were located. This might explain why so many people were killed despite evacuations.

Another consideration is that this analysis has calculated potential loss of life assuming people are inside buildings and that the agents of death were pyroclastic flows or surges and tephra. A large number of people in 1902 were killed outside in the fields, and not just from the effects of a pyroclastic flow or tephra fall. Anderson et al. (1903, p.399) reported that *"there can be no doubt that the lightnings were the cause of many fatalities"*. Lightning was also thought to have killed many animals in the fields. In addition, the impact of lahars and tsunami on buildings and people should also be analysed to update these loss calculations. Blong (1984) suggested that lahars and tsunami were associated with a number of building damage mechanisms such as flooding, uplift and transport (Table 5.1). The lahars depicted on the hazard map for St. Vincent (Figure 3.5) follow rivers and streams and therefore do not overlap with any buildings. A more detailed lahar hazard map showing possible areas of flooding would allow for an analysis of the number of buildings, farmland and people exposed to this hazard. Tsunami as a result of a volcanic eruption may also pose a threat, especially as the settlements on St. Vincent are largely congregated along the coast. The Global Volcanism Programme database[14] has record of a tsunami occurring as a result of the 1902 eruption.

To take into account the possibility of a different wind direction (as discussed in Section 3.4.2.3 and shown in Figure 3.6) the isopachs from Figure 3.5 were rotated 180°. This maps a scenario where there are easterly winds at either below 5km or above 16km (Figure 5.16). Potential losses were calculated using the same assumptions described above given this new wind direction. The total loss of life reduces slightly to 3.33 percent in a dry tephra scenario, or 3.61 percent if wet tephra (down from 3.6 percent and 3.83 percent respectively). The majority of deaths still occur from pyroclastic flows and surges, however if the wind direction is the opposite to that in Figure 3.5 then fewer houses collapse and fewer people are killed as the north west of the island is less inhabited than the north east around the volcano.

[14] www.volcano.si.edu

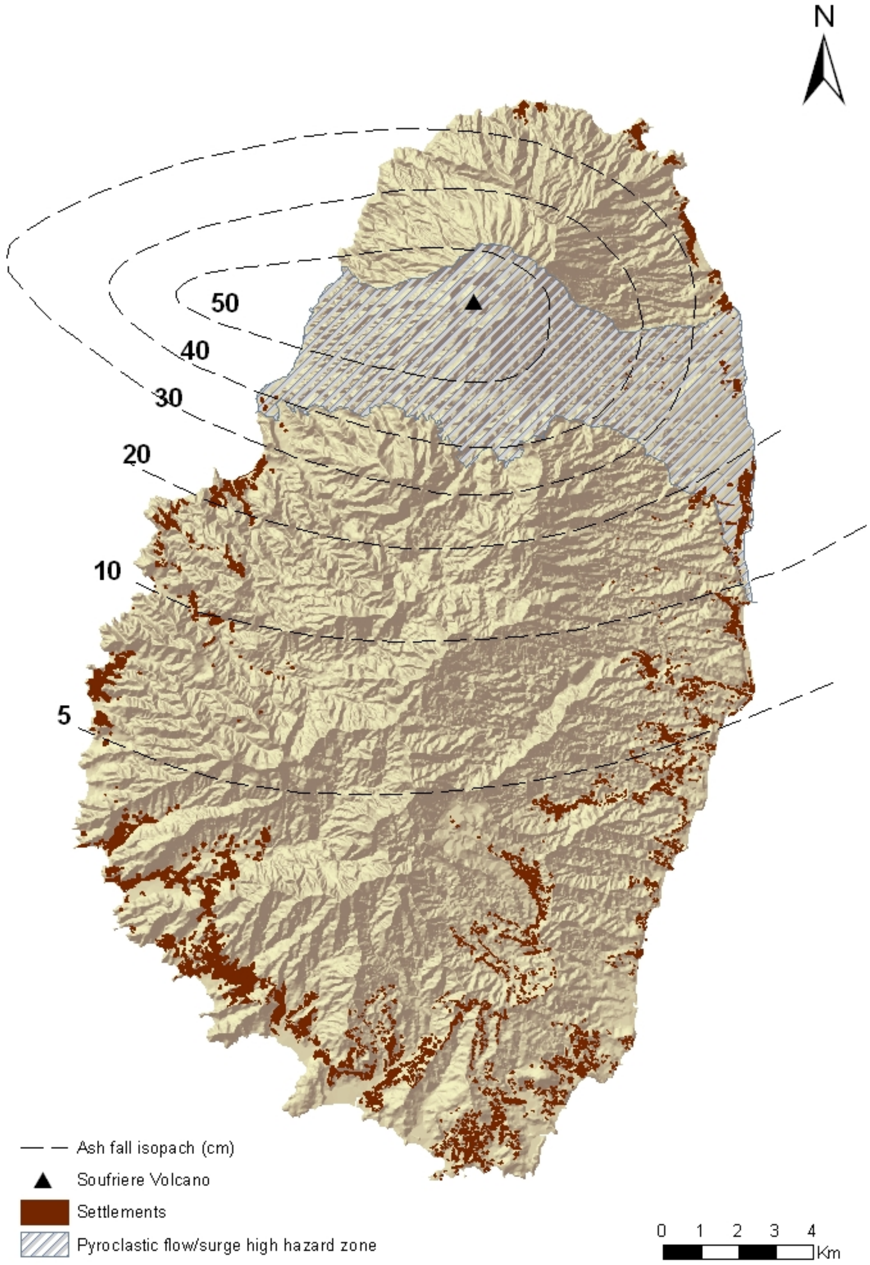


Figure 5.16: Alternative isopach map given easterly wind direction.

It is reasonable to assume that in a future eruption of St. Vincent much of the population in the high hazard zones would be evacuated, either of their own accord or on order from the government. Both the eruptions in 1902 and 1979 gave little warning; with the explosive phase of the activity in

1979 occurring around 24 hours after felt activity began. The population living around the volcano self-evacuated in both cases, and it is thought that this would happen again. In 1979 there was no loss of life; people were evacuated from everywhere north of roughly the 5cm isopach in Figure 5.12. This analysis shows that no buildings are expected to collapse until 10cm of tephra is reached, therefore if a similar evacuation were to be carried out in the future, including those residing in illegal settlements, it would mean that given the hazard scenario no one would be left in areas at risk of building and roof collapse.

5.5. Critique of method

5.5.1. Advantages

When vulnerability has been analysed for volcanic hazards, the emphasis has often been upon the physical vulnerability of the buildings and infrastructure, and the probability of loss of life given this vulnerability. Understanding the characteristics of the built environment of hazardous areas is important for mitigation, preparedness, response and recovery from a volcanic eruption. The method described in this chapter to capture and analyse building vulnerability is an excellent starting point to gain an understanding of the local infrastructure and how it might be impacted by a future volcanic eruption. Use of video for data collection allows capture of up-to-date information. Data and subsequent maps represent the current situation and not data that were collected at the time of the last census (in St. Vincent's case, from 2001).

The methods for data collection and analysis are easy to replicate. All that is required is a video camera and a GPS. Data collection is quick and as detailed as time allows. Videoing the buildings also provides information on the urban environment allowing other factors affecting physical vulnerability, such as density of the built environment, combustible material, availability of missiles, to be observed, if not quantified. The video is also an excellent resource that can be kept and compared to damaged areas if there were to be an eruption in the future. Given modern technology, the cost of tools such as a GPS and video camera are low; consequently this method can be completed with limited resources. Leone and Lesales (2009) present a volcanic vulnerability analysis for Martinique, however, they were unable to analyse the differential performance of the building stock to volcanic hazards as statistical data were unavailable. The method presented here provides a simple, relatively cheap alternative to statistical data for gathering and analysing data on the built environment.

Grouping the building categories and ranking them based on their vulnerability to volcanic hazards is a useful way of summarising a large amount of data and enables the vulnerability of different areas to be compared. These building vulnerability maps can also be compared with the social vulnerability maps discussed in the previous chapter and gives insight into whether or not high social and building vulnerability occur in similar areas. Identifying areas of high building vulnerability can also inform mitigation and preparedness measures.

Finally, the potential loss calculations provide a useful yardstick for emergency managers to see where the greatest building damage and loss of life might occur. Again, this can inform mitigation and preparedness measures. In addition these data might prove useful for the insurance sector should they wish to provide coverage for the area.

5.5.2. Limitations

Limitations with this method and output fall into two main categories: the sampling method; and the subsequent ranking and loss calculations.

5.5.2.1. Limitations in method of sampling

The video survey only collected data on a sample of buildings on St. Vincent. Although a large portion of the island was covered, and over 18.5 percent of the 2001 total households were surveyed, there is a bias towards buildings along the major roads. Owing to time restrictions, smaller roads leading through villages and into more rural areas were not surveyed.

In addition, the survey only looked at residential buildings. This was for two main reasons. First, the census data that were used to calculate the number of households that might collapse and population in these households only included residential households, and not commercial buildings. There were no data available on the numbers of people in office blocks, factories, shops, etc.. Second, it was not possible within the time limitations of this research to survey commercial buildings, schools and churches. A more detailed analysis should look at buildings that would be occupied during the day such as schools, offices, shops and factories. An idea of the occupation of these buildings would also allow for more detailed casualty estimates, and economic data would enable an estimate of economic losses and business downtime. In addition, buildings that are used as emergency shelters such as schools and churches should be a particular priority as during an eruption these would accommodate large numbers of people.

Another limitation with the sampling was that it was only possible to make a subjective assessment as to which buildings fell into each of the 12 categories. In particular, deciding upon whether a building was in good or bad condition required the researcher to make a judgement. The method was internally validated by watching the videos a second time and comparing the tally sheets, however, the method is still not as precise as a more detailed survey would allow. It is also not always possible to identify the wall material from the video if the building has rendering.

Finally, there is additional bias in the number of one storey buildings categorised as many of the buildings were viewed from the road and appear to be one storey high. A lower level, however, is sometimes out of view down a slope and therefore the actual number of two or more storey buildings may be higher than recorded in this survey, and this would increase the vulnerability of the building.

5.5.2.2. Limitations in vulnerability ranks and potential loss calculations

When designing the building vulnerability rank subjective decisions had to be made as to which buildings would suffer most damage from tephra and pyroclastic flows and surges. The rank was kept to four categories so as to not try and be too detailed in the absence of precise data on the performance of each building type to different hazards. In order to improve on the vulnerability rank and resulting maps a detailed engineering survey of a typical building from each of the 12 categories would be desirable, allowing for precise roof and wall strength data to be obtained, and an assessment of openings, vents, etc.. These data would also allow for a more accurate calculation of potential losses.

The potential loss calculations required a number of assumptions which if refined could improve on the output. First, it was assumed that all buildings will collapse in a pyroclastic flow or surge and that all occupants would be killed. It has been demonstrated with evidence from the 1902 eruption of St. Vincent and damage assessments from Montserrat that this is not the case. Buildings and people can survive in a pyroclastic flow or surge and therefore the numbers calculated here are a worst case scenario.

It was possible to assign a probability of roof collapse given a certain load of tephra because of vulnerability curves in the literature and the isopachs in Figure 3.5. The tephra loads, however, were calculated using average values. Spence et al. (2005a) discuss the variation in tephra densities and suggest dry tephra densities can range from 400 kg/m^3 to 1600 kg/m^3, and wet tephra densities from 800 kg/m^3 to 2000 kg/m^3. The values used in this analysis were 1000 kg/m^3 for dry tephra and 1500 kg/m^3 for wet tephra. For more precise calculations, tephra from Soufrière volcano should be analysed.

Calculations of loss of life are estimates. A number of factors would need to be considered to improve on these in addition to those mentioned already. First, population totals were assigned evenly across the enumeration districts' residential areas. In reality larger towns or villages might be more densely populated and this should be taken into account. Second, the linked issue of time of day of the eruption and building use would alter the calculations. It was assumed that everyone would be inside a residential building. However, as mentioned previously, people might evacuate or be located inside office buildings, schools or in fields and this would alter the projected loss of life. The number would decrease in the event of a successful evacuation, or could potentially increase if there was no evacuation during the night, for example, or if the eruption occurred during the day when large groups of people would be occupying schools, churches and places of work in addition to numbers being outside working on farms. If data on illegal settlements were included it would increase the population inside the most hazardous areas and would increase the potential loss of life.

There is also a limitation posed by the volcanic hazard map (Figure 3.5) used to calculate potential losses. The map represents one scenario and is based on a particular set of parameters. If the eruption were to be larger, for example, then the scenario in Figure 3.5, or if the hazards such as tephra altered with the wind direction to the populated south, then losses could increase.

5.6. Conclusion

The aim of surveying residential buildings and analysing their vulnerability with respect to two volcanic hazards was to capture important information excluded from the SVI, and allow for a comparison of the geography of social and building vulnerability. Looking at building vulnerability and the potential loss of households and lives is key to having a holistic analysis of the vulnerability to volcanic hazards on St. Vincent, and allows for focused mitigation methods to be developed. Fatalities from roof collapse occur in the greatest number of volcanic eruptions, and pyroclastic flows have killed the greatest number of people in the historic record. Therefore analysing vulnerability to these two hazards is an excellent starting point to gain an understanding of potential losses in future eruptions.

The results from this analysis suggest that relative and absolute building vulnerability is high in small pockets across the whole of the island. These tend to be areas that have a high proportion of wooden buildings, or buildings in poor condition. The potential loss calculations show that building damage and loss of life will occur in the north of the island, above the 10cm tephra isopach. If these areas are evacuated, however, as they were in 1902 and 1979, it is possible that there will be no loss of life from the direct impact of volcanic hazards in a future eruption. The calculations also show that the south of the island is not at risk from building damage as pyroclastic flows, surges and heavy tephra fall do not reach this far in the current scenario. If, however, the eruption were to be larger than the hazard map in Figure 3.5 shows, and the depth of tephra in particular were to be greater in the south, then the building vulnerability maps produced here will be useful for calculating potential loss in those areas that currently are considered safe. A critical depth of 10cm of tephra or more is needed for damage to roofs to occur, with greater than 20cm of tephra, particularly if wet, causing a large amount of damage to the building stock.

The methods of data collection and analysis used here are particularly useful when there are no readily available data on building stock, and the survey and analysis can be completed fairly quickly with limited resources. The next step should be to consider more volcanic hazards such as lahars, tsunami, and analyse the combined impact of these hazards on a building, and the progression of a possible future eruption (see Zuccaro et al., 2008, for work on Vesuvius).

Chapter 6: Stakeholder Mental Maps

The third of the four research methods is addressed here, that of using people's mental maps to capture their perceptions of vulnerability to volcanic hazards on St. Vincent. A review of the literature describes methods of capturing and analysing people's mental maps, followed by a description of the exercise conducted on St. Vincent and the resulting maps and an interpretation of the results. A discussion of the advantages and limitations of this method for data collection and analysis concludes the chapter.

The aim of this part of the research is to see whether or not a mental mapping technique could be applied to understanding vulnerability. The social and building vulnerability maps produced in the previous two chapters had very well defined boundaries as a product of the data used. These boundaries, however, are arbitrary. Another aim of adopting the mental mapping technique is to see how people defined communities on St. Vincent and what boundaries people drew. The technique also adds information to the interviews conducted during the initial field study where stakeholders identified variables of vulnerability. A mental mapping method allows stakeholders to highlight *where* they consider these vulnerable people and places to be.

6.1. Review of current methods

Research on mental or cognitive mapping was pioneered by Tolman (1948) who studied cognitive maps in rats and conducted spatial orientation experiments in mazes. Since then it is a subject area that has spanned a number of disciplines from urban planning and geography to psychology. As a technique it was argued that it had not taken off as rapidly as first expected and this may be due to the difficultly, in particular, of analysing the data (Downs and Stea, 1977). For this research the objective was to find a suitable method that could be adopted and used with stakeholders on St. Vincent and analysed to reveal views on vulnerability. With this in mind, this review of the literature is not a summary of work on mental mapping from across the disciplines, but more a review focusing on *methods* that have been used to capture people's mental maps.

6.1.1. Mental maps

Some of the earliest research recording and analysing people's mental maps is found in the urban planning literature from the 1960s. Lynch (1960), in his book 'Image of a City' investigated the 'imageability' of a city – *"that quality in a physical object which gives it a high probability of evoking a strong image in any given observer"* (p.9). The author was interested in uncovering the role of form in the urban environment, seeking to understand what paths, nodes, edges, districts, and landmarks were easily identifiable, and then use this information to aid decision making. To investigate this 'imageability' the work looked at Jersey City, Boston and Los Angeles in the US. The methods adopted were firstly interviews with residents during which they were asked to draw sketch maps of the city, describe their routes through the city and identify vivid or distinctive areas. In addition to these interviews and sketch maps, a team of trained observers mapped the city capturing an image of the urban environment. Although in this example the author was interested in the physical form of the urban environment, Lynch (1960, p.46) noted that *"there are other influences on imageability, such as the social meaning of an area"*.

Work by Al-Kodmany (1999; 2001) in engaging the community in urban planning and design in a neighbourhood of Chicago, US, adopts Lynch's concept of 'imageability'. The work began by using an artist to sketch residents' views on the design of their neighbourhood, thereby capturing their perceptions and ideas for future scenarios (Al-Kodmany, 1999). Further work in the same area of Chicago developed a website which visualised residents' mental maps. First interviews were conducted with residents to capture people's mental maps of their neighbourhood, identifying paths, nodes, edges, districts and landmarks. A website was then constructed that visualised people's perceptions using photographs and movies of the most common elements of the neighbourhood mentioned in the interviews (Al-Kodmany, 2001).

Another technique was used by Saarinen (1973) in capturing student's views of the world. Students from the US, Canada, Finland and Sierra Leone were given 30 minutes to draw a sketch map of the world, labelling places they considered to be important or interesting. The author analysed the data under the headings 'proximity', 'shape', 'size', 'current events' and 'cultural factors' looking at which regions or countries were included the most. This work by Saarinen and others on students' mental maps of the world has continued over the decades. Patterns that have emerged show that many of the maps are Euro-centric, and that Europe is enlarged compared to other continents – in particular Africa (Monastersky, 1992). A limit of this research is that the maps are not accompanied by any other research method such as interviews or questionnaires, and therefore the authors are left to speculate as to the reasons why these patterns emerge (Kong et al., 1994).

A statistical approach was used by Gould and White (1986) investigating spatial preferences. The authors asked people to rank their preferences of where they would most like to live and used principal components analysis to map the results as contours across the study area. This work was useful in that it provided a method to follow in constructing mental maps. It was not, however, without its critics. Questions were asked about the representativeness and reliability of the long ranking lists participants were presented with (Gold and Saarinen, 1995).

6.1.2. Social meaning of an area

Ley (1974) looked at the 'social meaning' of an area mentioned by Lynch (1960) when investigating the black inner city in Philadelphia. The author captured a 'stress surface' of a district in the city by asking interviewees which blocks had a bad reputation, and mapped the results using stress isolines. He sought to understand whether this perceived stress surface had an influence on the way people moved throughout the district.

A more recent study by Matei and Ball-Rokeach (2005) mapped a 'fear' surface of Los Angeles. A sample of 215 residents across the metropolitan area were given a black and white street map of Los Angeles with the street grid, main highways and established community names labelled. Using four crayons of different colours participants were asked to colour the map depicting feelings towards an area: red for fear, green for comfortable, orange for somewhat but not completely comfortable and blue for neutral feelings or an area the participant did not know well. The maps were digitized in a GIS and each colour was converted into a number where red areas had a score of negative one, blue equalled zero, orange one and green two. Using a technique called map algebra, the maps were combined mathematically and a composite fear surface of Los Angeles was produced.

6.1.3. Indigenous knowledge and volcanic risk mental maps

Indigenous communities often have their own mental maps of the world and their localities that may not conform to western cartographic standards. Feinberg et al. (2003) worked on the Polynesian island of Anuta and constructed a mental map of the ocean floor and reefs in conjunction with Anutan scholars. The authors state that *"their [indigenous people] mental maps are often impressive in sophistication and detailed"* (p.243).

Work on the volcanic islands of Ambae (Vanuatu), Savo (Solomon Islands) and Western Samoa by Cronin et al. (2004b; 2004c) and Németh and Cronin (2009) also studied indigenous knowledge through mapping. The authors sought to incorporate scientific and local knowledge on volcanic hazards and emergency management on the islands. They adopted participatory techniques based on participatory rural appraisal, which included mapping exercises with communities recording local geography, resources, and areas of high hazard exposure and interpretation of safe and dangerous regions. Although the authors do not use the words ‘cognitive’ or ‘mental’ maps, this is effectively what they were capturing, gathering information on a community’s perception of the hazards they faced.

On the volcanic island of Martinique research has been conducted to capture collective representations of the threat from Mont Pelée volcano (D'Ercole and Rançon, 1994; D'Ercole and Rançon, 1999; Leone and Lesales, 2004; Leone and Lesales, 2009). On a background map with landmarks of the island interviewees were asked to shade areas they considered to be at risk from a future volcanic eruption. These maps were combined in a GIS, in a similar way to the work by Matei and Ball-Rokeach (2005), to show the areas shaded by the most interviewees and compare them with risk maps established by volcanologists. Distortions were found between the public representation of the risk and the knowledge of the volcanologists. In particular, people under estimated the risk of the northeast of the island owing to memory of the 1902 eruption that devastated areas in the northwest. Leone and Lesales (2009) suggest that the impacts of the eruption in 1902 that destroyed the town of St. Pierre in the west of Martinique leads to an overestimation of the risk in that area by the public. A similar method has also been applied to collect people’s mental representations of places threatened by lahars around Pinatubo volcano in the Philippines (Gaillard et al., 2001).

6.2. Method

The initial idea behind capturing Lynch's 'imageability' of a city using mental mapping techniques was to improve urban planning and design through public participation, where *"if we are aware of people's perceptions of, and preferences for, different environments, then better matches between planning and policymaking and the perceived needs of the populations for whom plans are being made, can be achieved"* (Al-Kodmany, 2001, p.806). These methods, however, can equally be applied to understanding people's perceptions of their vulnerability to volcanic hazards in order to inform and improve disaster management – as demonstrated by the work on Martinique looking at volcanic risk (D'Ercole and Rançon, 1994; D'Ercole and Rançon, 1999; Leone and Lesales, 2004; Leone and Lesales, 2009). The methods adopted for this research are described in the following section.

6.2.1. Identifying stakeholders

The aim of this element of the research was to capture stakeholder views of vulnerability, specifically *where* vulnerable people and places were located. For consistency it was decided to work with the same stakeholders that were interviewed on St. Vincent during the first fieldwork. If the same person was not available, someone in the same role was sought. An objective was to talk to residents from across the island and not just in the populated south. Therefore, community disaster group members from the north, east and west of the island were interviewed.

6.2.2. Data collection and method of analysis

In light of the literature discussed in Section 6.1 the method for data collection and analysis chosen for this research is based on the study by Matei and Ball-Rokeach (2005) constructing a fear surface of Los Angeles, and the work on Martinique (D'Ercole and Rançon, 1994; D'Ercole and Rançon,1999; Leone and Lesales, 2004; Leone and Lesales, 2009).

These were chosen as the methods of data collection could easily be adapted to ask stakeholders to colour in areas of vulnerability, and they provide a suitable method for analysis using a GIS.

Investigating people's ability to draw an accurate map of St. Vincent was not an objective of this research, nor was assessing people's map skills of orientation and location. Work by Haynes et al. (2007) studied the efficacy of volcanic hazard maps on Montserrat. Initially interviewees were asked to draw their mental map of the area, highlighting safe and dangerous areas along a route. This exercise was abandoned, however, as after completing the survey part of the work respondents were tired and unhappy to cooperate. Consequently, it was decided in the research presented here to design the mental mapping exercise in a way that was hopefully as straightforward for participants as possible, and not too time consuming. Rather than get the stakeholders to draw their own sketch maps of St. Vincent a topographic map of the island was used so that the results were spatially accurate to a certain degree and could be compared with the social and building vulnerability maps produced in the previous two chapters. In a similar way to the street map of Los Angeles used by Matei and Ball-Rokeach (2005), the map of St. Vincent had some markers on it enabling the stakeholder to locate themselves. As the whole island was used, and a street network does not cover the whole area, a topographic background was added which showed clearly the volcano, valleys and ridges which determine to a large degree where settlements on St. Vincent are located. The major and minor roads were also added to help people locate specific towns and villages, and three of the main settlements, the capital Kingstown in the south, Georgetown in the east, and Chateaubelair in the west, were labelled (Figure 6.1). These decisions were made in consultation with Dr. Richard Robertson, a native of St. Vincent and Head of the SRC in Trinidad.

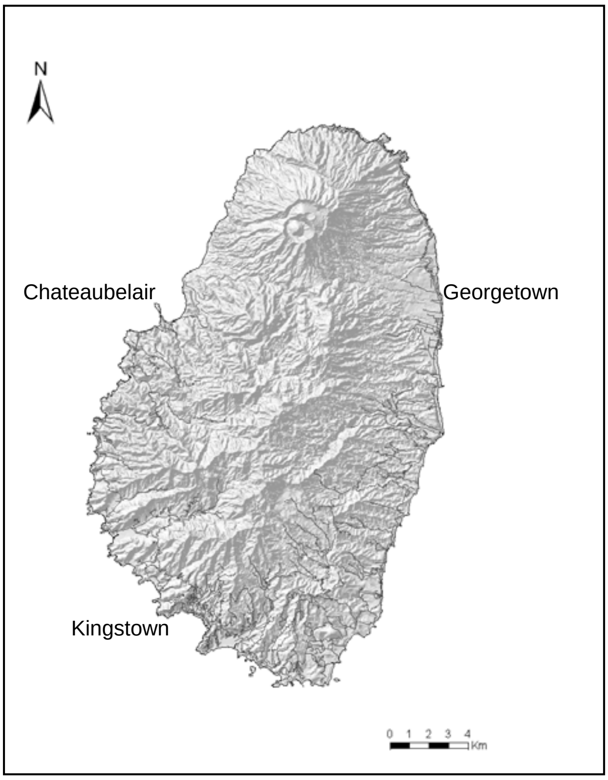


Figure 6.1: Background map of St. Vincent for mental mapping exercise.

The majority of the maps were A4 in size. It was felt that A3 was too large and was intimidating in providing such a large area to colour in. Indeed the first three exercises were conducted with an A3 map but comments on the size led the researcher to make A4 maps for the remaining interviews. A4 was also logistically easier to deal with as some of the exercises were carried out in the field where space was limited.

The exercise itself involved asking the participant to colour in areas of high vulnerability first with a red crayon, and annotate the map as they went along with reasons for their decisions. A yellow crayon was used for areas of medium vulnerability, and green for low. The participant was not required to colour in the whole map as they did not always have an opinion about an area, but they were asked to be as detailed as possible when colouring in. They were also asked to draw a dot roughly where they currently lived. This was to show the distribution of the participants' homes across the island, and to see if there was any link with how they depicted the vulnerability of their local area. Throughout the exercise all participants talked about what they were colouring in and why, and where possible, spoke about their experiences of the 1979 eruption.

Finally, it was decided to complete the exercise with individuals rather than get a group of stakeholders together to complete the exercise (as in the work by Cronin et al., 2004b; Cronin et al., 2004c). This was for a number of reasons. First, one aim of the research was to investigate differences between stakeholder views on volcanic vulnerability, therefore completing the mapping exercise with individuals allowed for this. Second, Donovan (pers. comm.) who completed participatory mapping with villagers on the flanks of Merapi volcano in Indonesia found that power relations between participants restricted the involvement of some members. Unequal power levels between participants and the issue of group work inhibiting outspoken speech are also limitations of participatory techniques discussed by Mercer et al. (2008). Logistically it was also difficult to get all the stakeholders on St. Vincent together to complete the exercise. In total, 13 mental maps were completed by 12 participants.

Composite maps were created from the 13 sketch maps. Each individual map was digitised in a GIS and attributes added to each zone: red areas were assigned a value of three, yellow areas two, green areas one and no data were assigned a value of zero. The individual maps were converted into raster (grid format) in order to sum the areas together using map algebra with equal weights assigned to each stakeholder map. The higher the number in each grid cell in the final composite maps, the higher the vulnerability. The composite maps were visualised in a GIS using a graduated scale (Figure 6.14, Figure 6.15). The highest value was 38, the lowest 12, although the numbers themselves are arbitrary, they only serve to represent which areas of St. Vincent are perceived to be more or less vulnerable relative to others.

6.3. Results

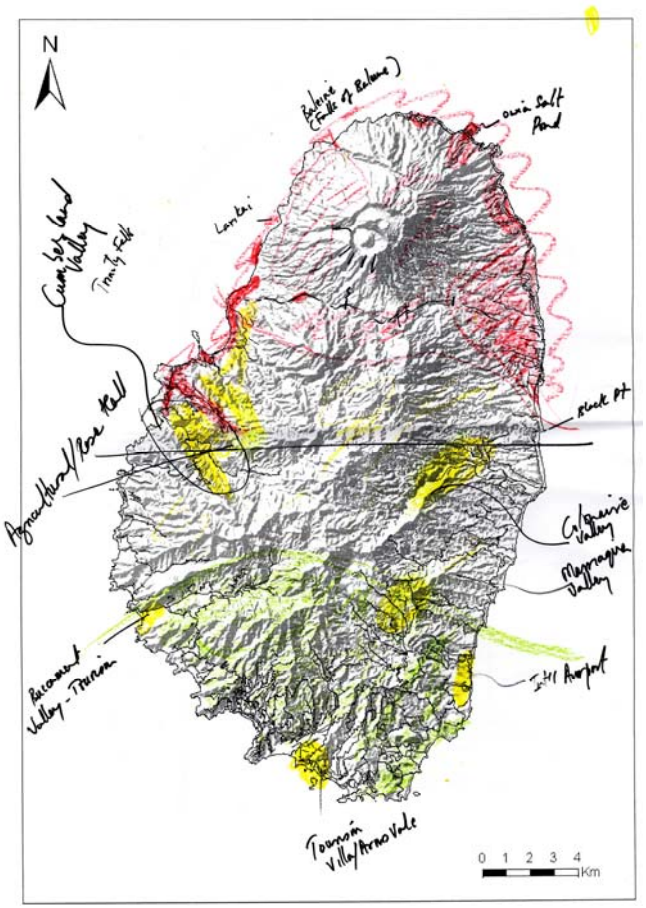


Figure 6.2: Scientist.

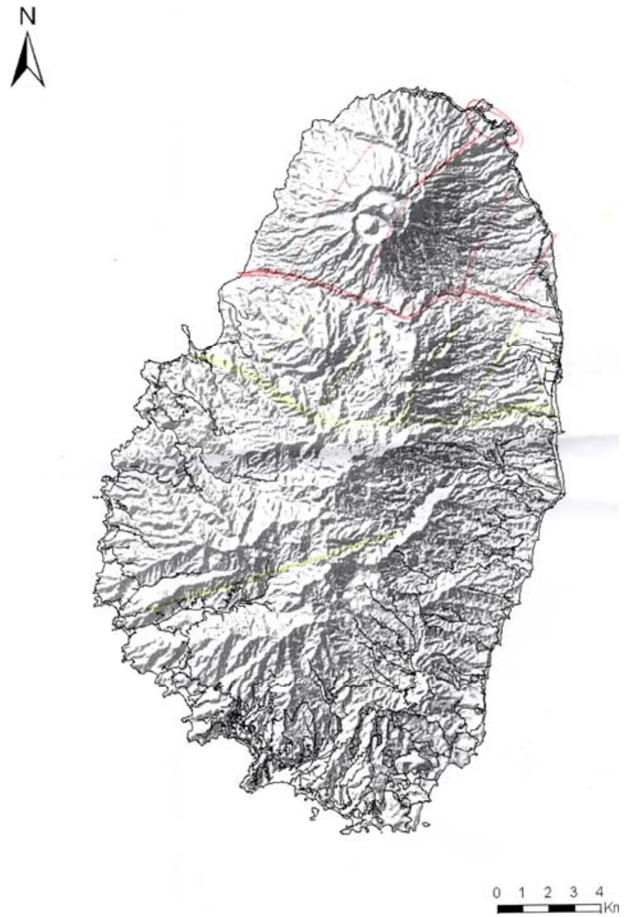


Figure 6.3: Scientist.

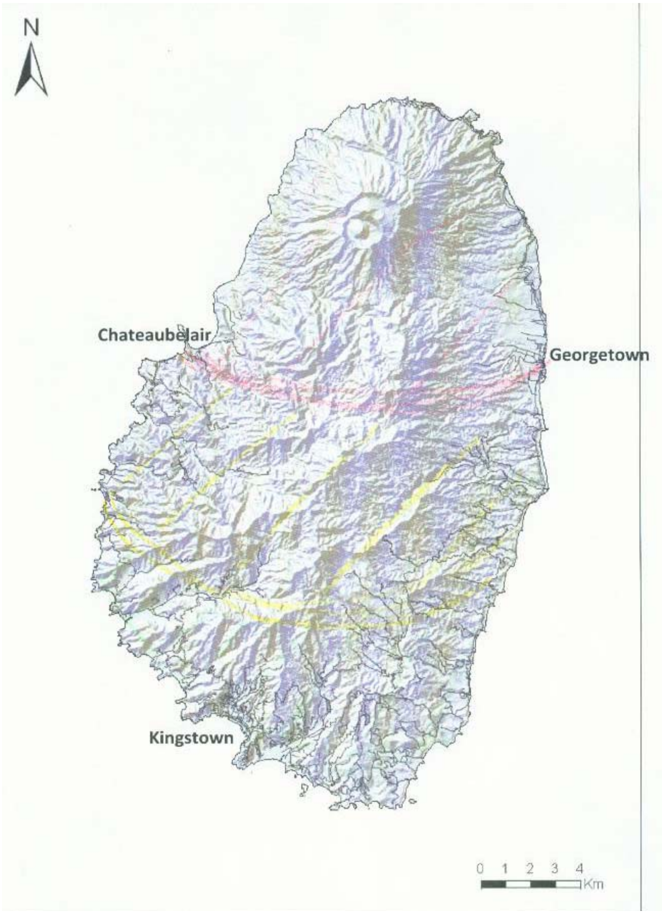


Figure 6.4: Scientist.

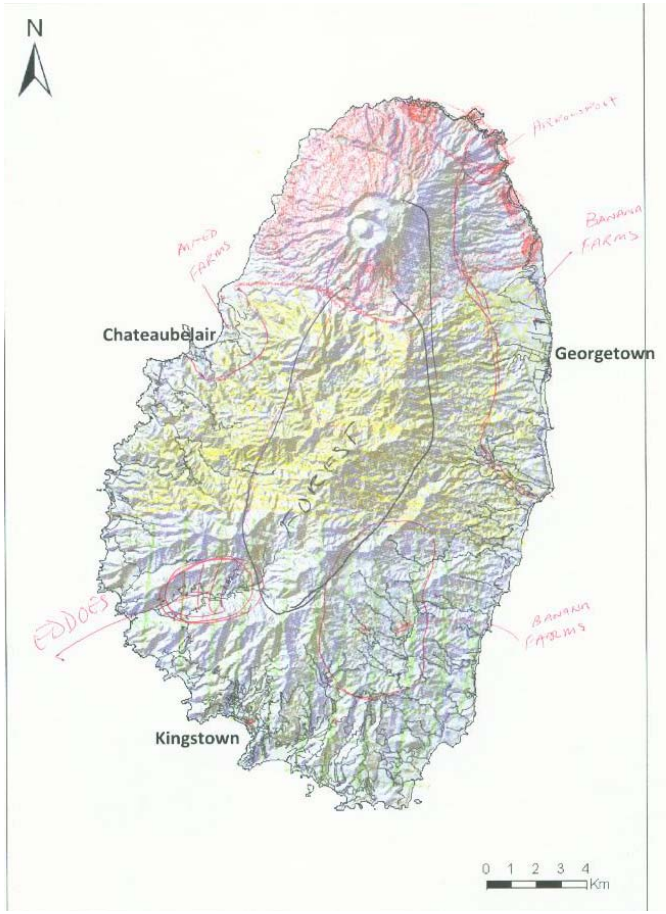


Figure 6.5: Town Planner (this map is a combination of two maps - social vulnerability and economic vulnerability).

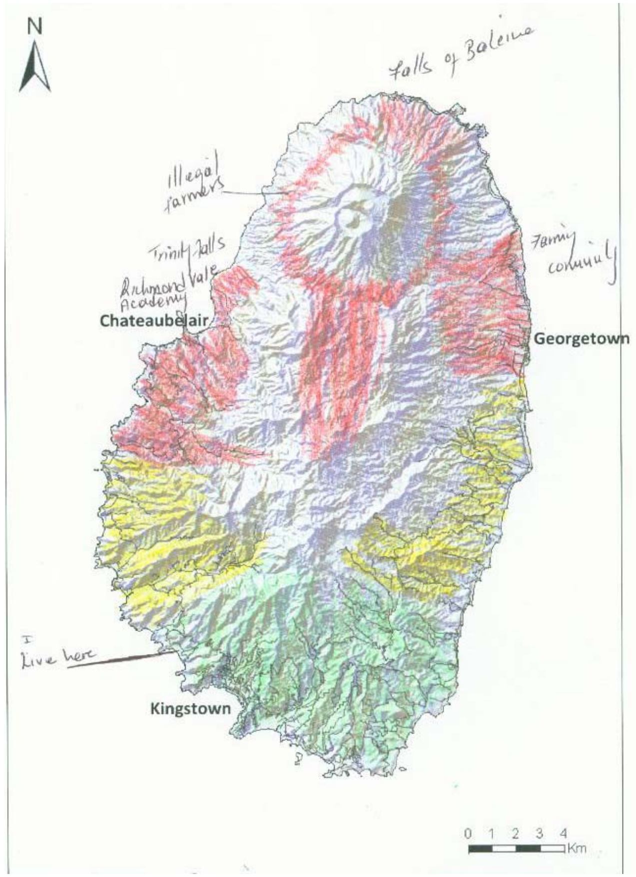


Figure 6.6: NEMO Staff.

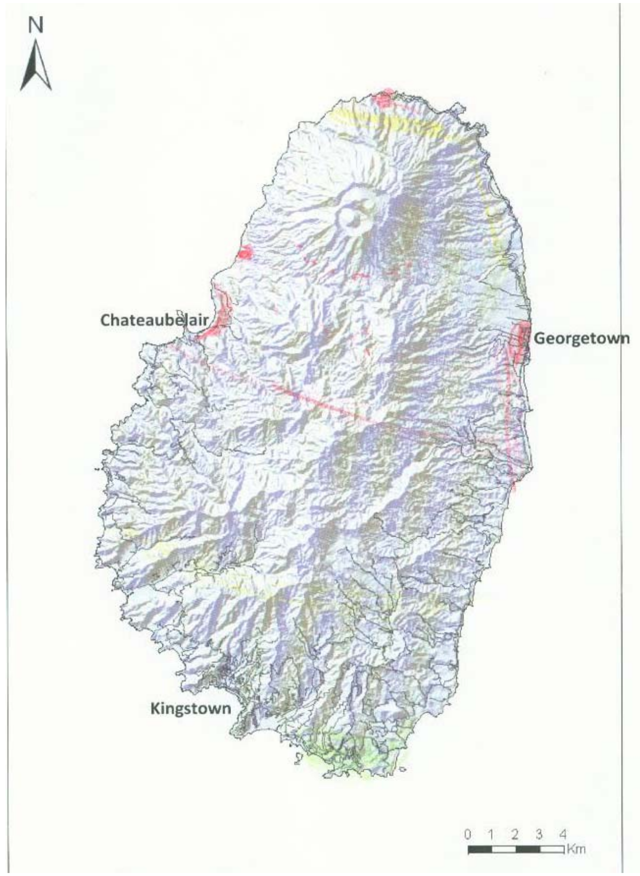


Figure 6.7: NEMO Staff.

A third member of the NEMO staff said the whole island would be red: this was excluded from the analysis as it will not change the overall maps.

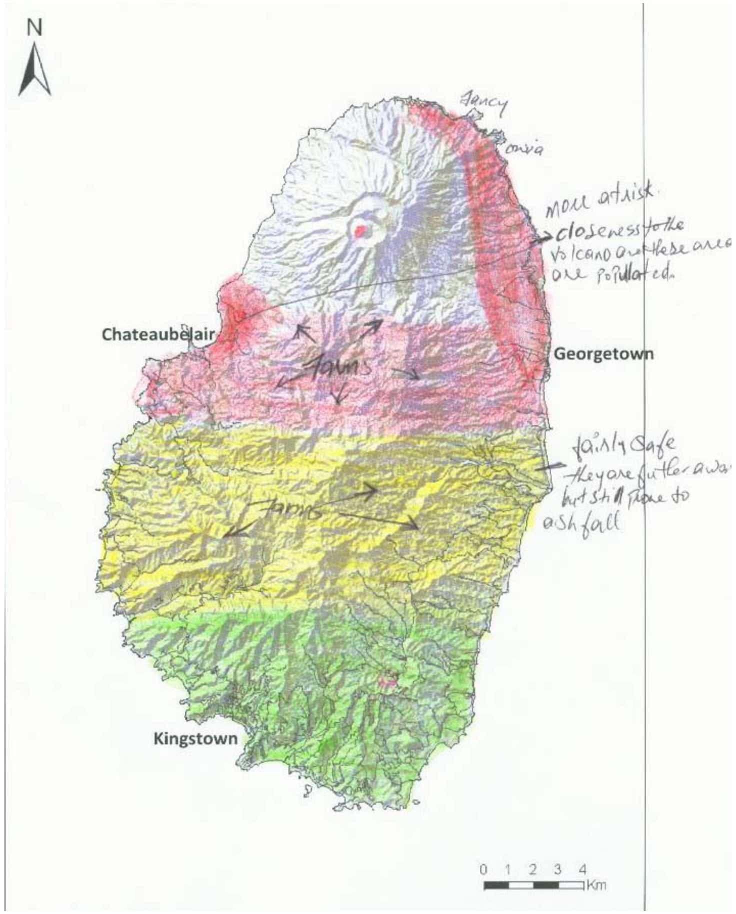


Figure 6.8: Soufrière Monitoring Unit Staff.

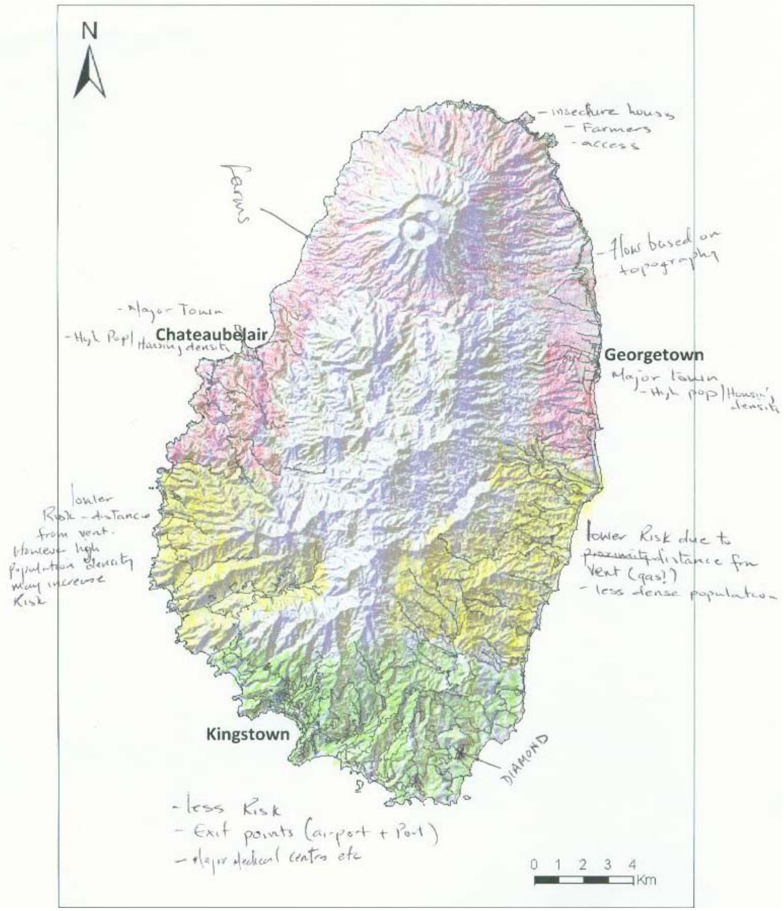


Figure 6.9: GIS Officer (Statistics Office) and local geologist.

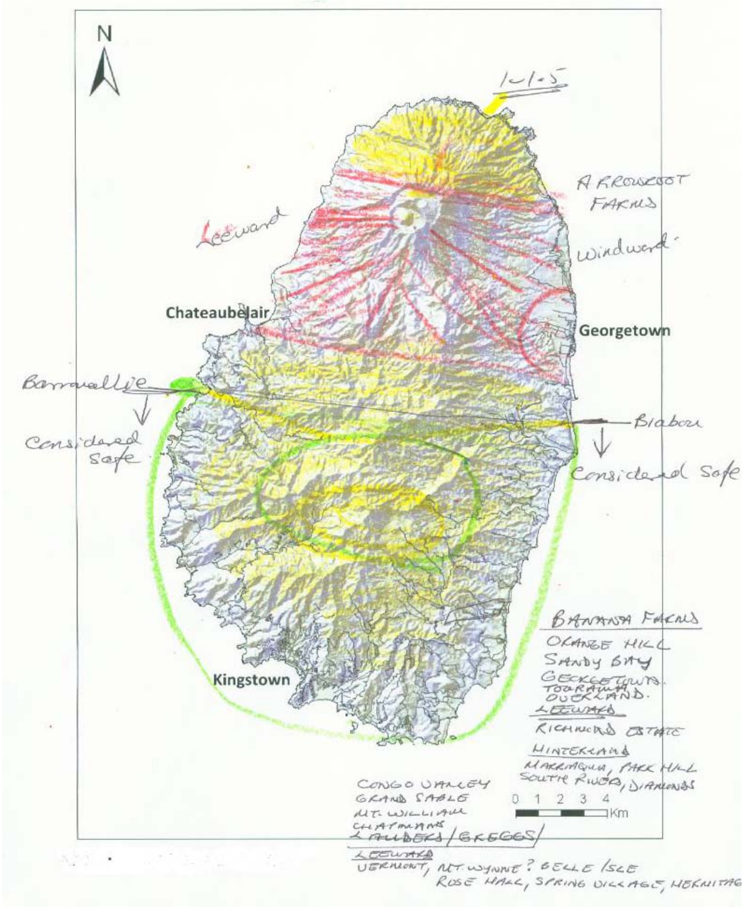


Figure 6.10: President, St. Vincent Red Cross.

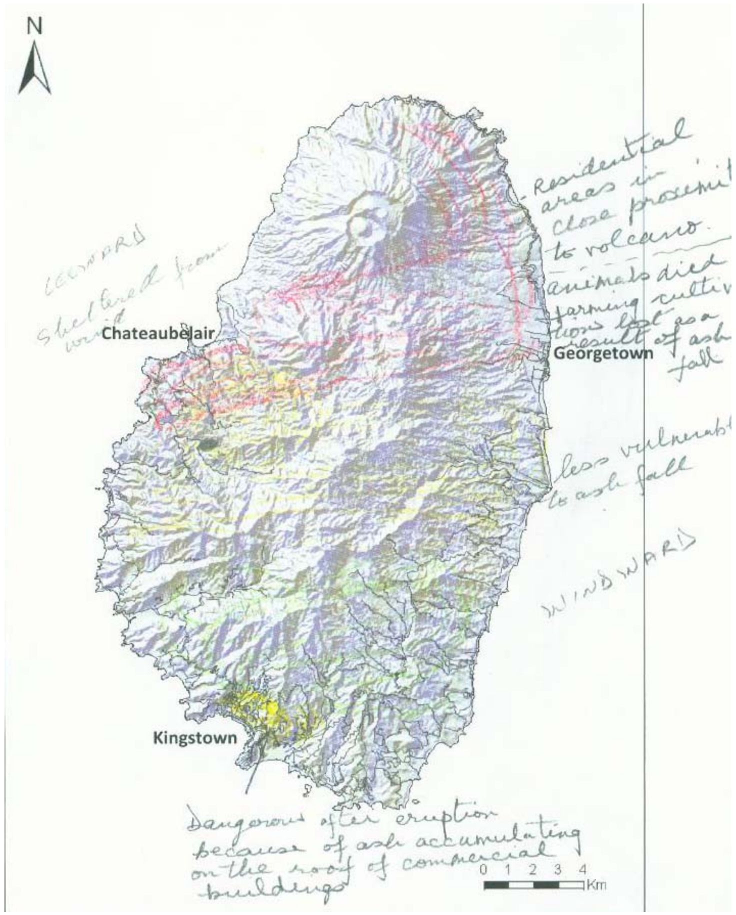


Figure 6.11: Community Disaster Group Member.

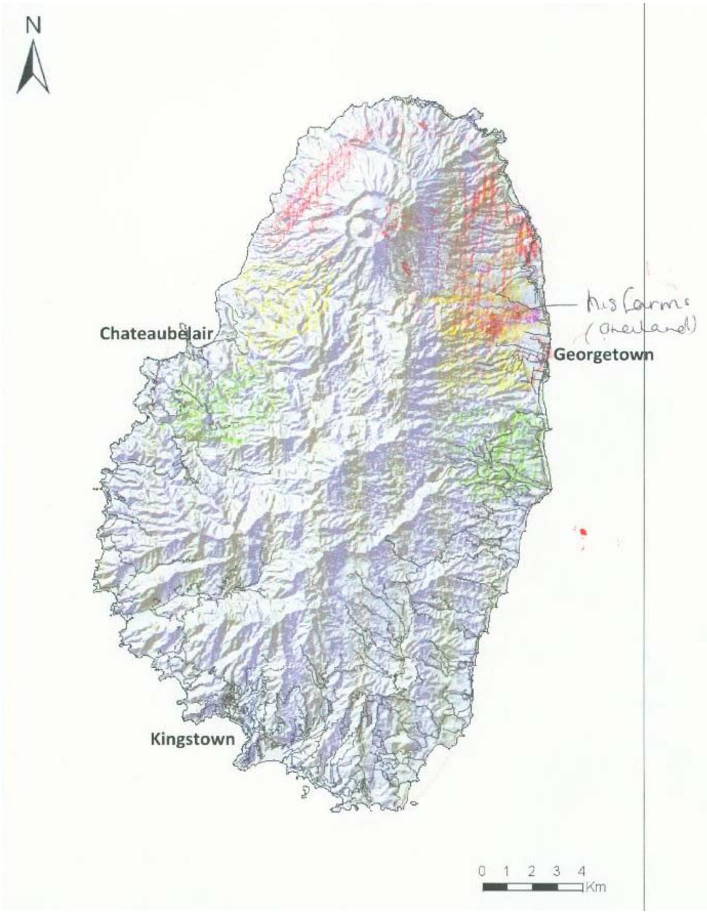


Figure 6.12: Community Disaster Group Member.

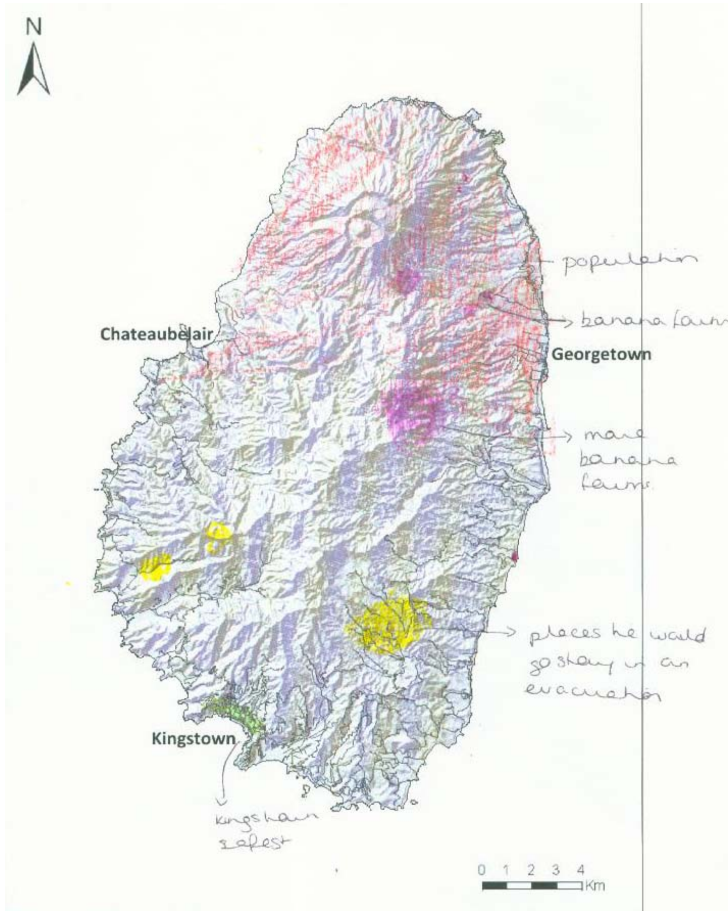


Figure 6.13: Community Disaster Group Member.

6.3.1. Composite mental maps of vulnerability

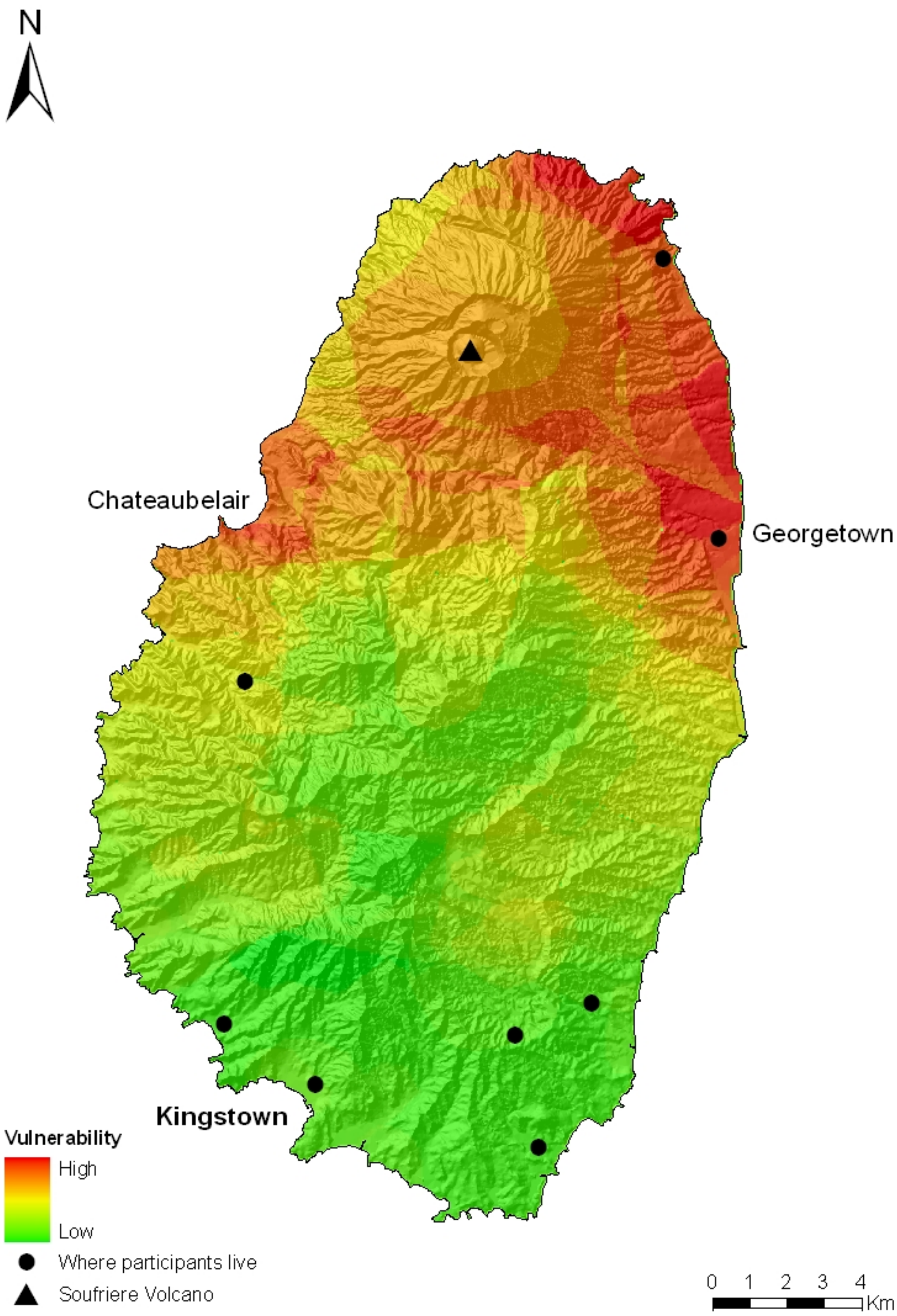


Figure 6.14: Composite mental map of vulnerability.

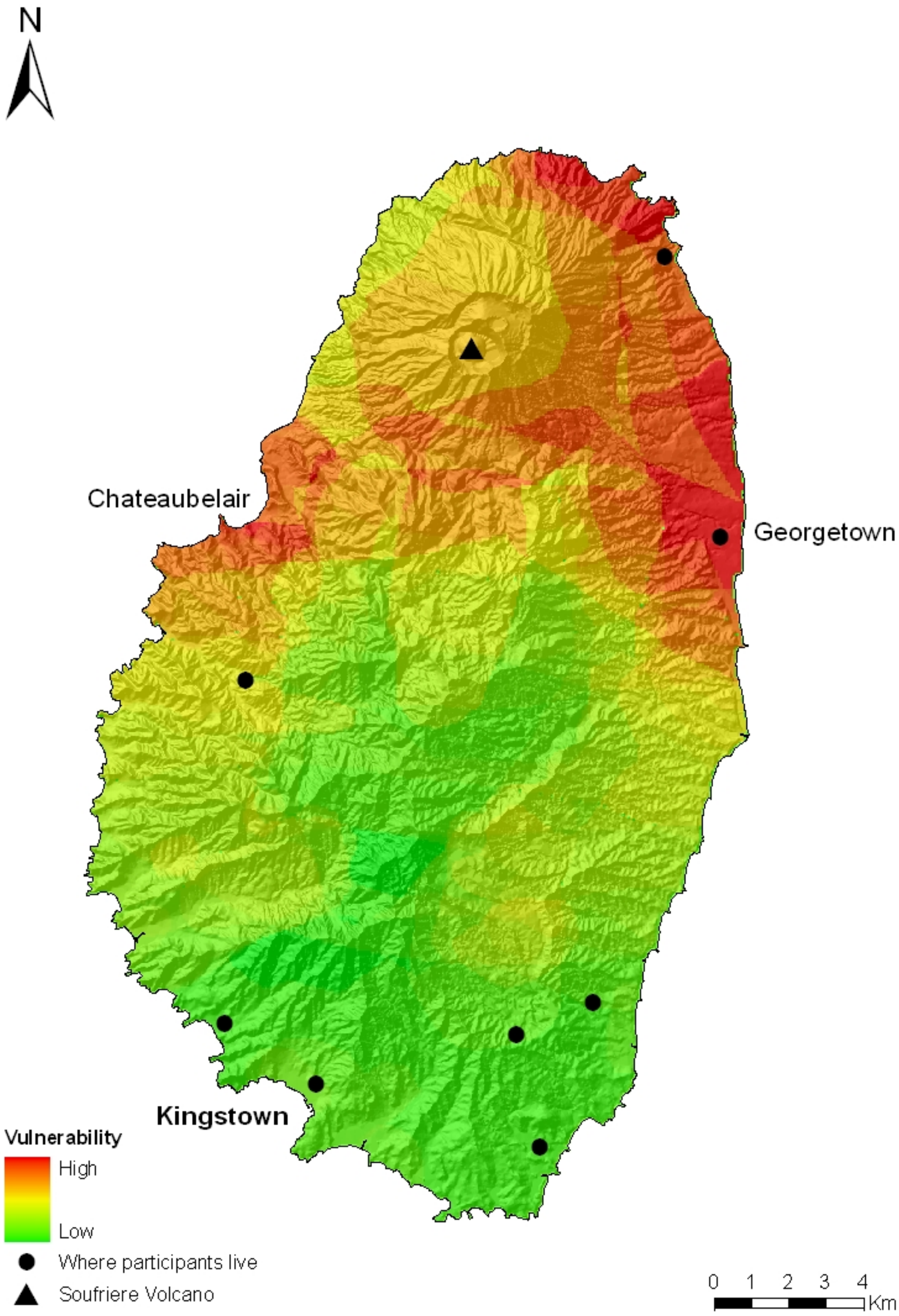


Figure 6.15: Composite mental map of vulnerability (St. Vincent nationals only).

6.4. Interpretation of maps

This section analyses the results of the mental mapping exercise. First the maps are compared and contrasted; in addition underlying explanations for the patterns observed are discussed. The analysis is grouped under the headings: common factors, extent of mental map, knowledge and personal experience, and proximity.

6.4.1. Common factors

The majority of the mental maps were similar in that the north of the island was coloured red (high vulnerability) with the south green (low vulnerability) and the middle was yellow. The boundaries between the three zones shifted with each individual map, but overall the picture was the same. The main exception was Figure 6.5 where the town planner drew two maps, one for social vulnerability and one for economic vulnerability which showed where the farms were located.

When specifying towns and villages which were in each zone, and when annotating the map with specific vulnerable places, a number of factors were evident in more than one mental map. The population centre that lies in the highest number of red zones is Overland, in 12 out of 13 mental maps. This village lies just north of the Rabacca Dry River, an area suffering lots of damage in the 1902 eruption and where lahars and pyroclastic flows are expected to run in a future eruption. The towns of Georgetown, Chateaubelair, Sandy Bay and Fancy are in the red zone of 11 of the 13 maps. Owia, although between Fancy and Sandy Bay is only in the red zone in 10 of the 13 maps. This may be because in the 1902 and 1979 eruptions the volcanic hazards were not as destructive in this area due to topographic barriers. The capital Kingstown in the south is in the green zone in 12 of the 13 maps. The one participant that put Kingstown in the yellow zone did so stating the vulnerability of large commercial buildings with flat roofs which accumulate ash during an eruption (Figure 6.11).

In addition to colouring in vulnerable areas with crayons, participants were asked to annotate the mental map with their reasons for choosing each colour. Not every mental map was annotated, and some had more annotations than others. Table 6.1 lists the annotations, and the number of mental maps that mentioned that factor.

Annotation	Number of mental maps
Farms/illegal farms	9
High population	7
Proximity to volcano	3
Tourist sites	2
Airport, port, new airport site	2
Insecure houses	1
Housing density	1
Hazards out to sea	1

Table 6.1: Annotations included in the stakeholder mental maps.

The most commonly mentioned factor in the mental maps was the location of farms and illegal farms. Some of the participants noted what crops were grown where and talked about how different crops were more or less vulnerable to volcanic hazards (Figure 6.5, Figure 6.10). This correlates with the fact that many of the stakeholders interviewed in the initial fieldwork (described in Chapter Four) stated that livelihoods, in particular agriculture, was a factor that increased vulnerability.

Where areas with large populations were annotated, such as Georgetown and Chateaubelair, participants made the point that these places were more vulnerable because of the number of people exposed to the volcanic hazards. High household density was another factor mentioned (Figure 6.9). In this case the participant was not taking into account the characteristics of the people that lived in these areas, just the fact that large numbers were exposed, and therefore vulnerable to the volcano. The same participant also noted that insecure housing in the north would increase vulnerability; this *is* considering the characteristics of the population and place. Three of the mental maps (Figure 6.8, Figure 6.9, Figure 6.11) mentioned proximity as a factor that increased vulnerability, which again correlates with the interviews conducted in the first field work, where 13 of the 18 people interviewed stated that you were vulnerable if you lived near the volcano. In addition to farms and large population centres located near the volcano, some mental maps noted tourist facilities as increasing vulnerability, such as waterfalls and areas with hotels (Figure 6.2, Figure 6.6). Infrastructure such as the port at Kingstown, the airport at Arnos Vale, and the new airport site were also specified as being vulnerable (Figure 6.2, Figure 6.9). The site of the new airport was mentioned as being vulnerable as it is closer to the volcano than the current airport. The port which is in Kingstown and the airport to the east of Kingstown are sites that need special consideration as they would be used for evacuation and for the import and export of goods during and after an eruption.

6.4.2. Extent of mental map

Another interesting point of comparison between the mental maps is the amount of the topographic map that was coloured in. Some maps are completely covered with red, yellow or green crayon, others have small areas left blank, while two are only partially coloured.

Two of the three scientists' maps are completely coloured in with just two lines drawn on the maps to demarcate the areas of high, medium and low vulnerability (Figure 6.3, Figure 6.4). These two scientists are not from St. Vincent although they have both worked there for short periods. Their mental maps traced the hazard map boundaries, and it became clear during the exercise that neither were particularly familiar with the population centres and places on the island. They were aware that there were people living in the red zones, and where the capital was, however that was the limit of their local knowledge. For the purpose of the rest of this analysis these two maps have been excluded as they did not have information to add other than the hazard boundaries.

Of the remaining maps, three of the 11 were completely coloured in; the two mental maps of the town planner, and the map from the President of the Red Cross (Figure 6.5, Figure 6.10). Two of the 11 were only partially coloured, with the remaining six having around three quarters of the area filled in. Common areas that were left blank were the centre of the island and around the volcano, in particular the northwest. These are unpopulated areas where there is little agriculture.

Does the detail and extent of the mental map reflect that individual's perception of vulnerability on St. Vincent? The three maps that were completely coloured were completed by two professionals who work throughout St. Vincent in either town planning or emergency management. From the exercise it was clear they had knowledge of areas across the whole island, and therefore the detail of their maps was greater. The two maps only partially coloured were by two of the three community disaster group members; both were farmers (Figure 6.12, Figure 6.13). The areas that they marked on the map were only areas that were relevant to them, i.e. their farms, their homes and where they might go in an evacuation. They did colour in the north of the island in the same red, high vulnerability colour which the majority of people used. There was less detail across the rest of the island, however, and they did not discuss other factors in Kingstown, or Chateaubelair or anywhere outside of their locality. It became clear throughout the exercise with each of the two farmers that one was a member of a community disaster group that was very inactive, and the other had not been actively involved recently. The third community disaster group member that completed a mental map was very active in emergency management and training locally as well as with

NEMO (Figure 6.11). The remaining participants coloured in around three quarters of the map, and gave more detail. These people all worked in national agencies where their roles exposed them to a greater portion of the island.

6.4.3. Knowledge and personal experience

Downs and Stea (1973, p.115) state that *"our knowledge of the spatial environment, the way in which we visualise and symbolize it, is a consequence of our experience in it and with it"*. It is hypothesised that the extent of the mental map is related to the participant's occupation on St. Vincent. In addition it may be related to their knowledge and personal experience of the volcano and its potential consequences.

For example in Figure 6.11 the area around Kingstown is coloured yellow. This is because the participant remembers that in 1979 the flat commercial roofs in the capital had ash accumulate on them and stay there for some considerable time. In addition, Figure 6.10 has the north of the island as yellow instead of the common red. This is because the participant remembers stories of a relative who experienced the 1902 eruption. They lived in Owia in the north and stayed there during the eruption. The volcanic hazards in that area were not as damaging as those to the east and west and this has altered the resulting mental map (see Figure 3.3, the 1902 Ordnance Survey map of St. Vincent after the volcanic eruption. Owia is outside the area of devastation). Although this is not direct personal experience with the impacts of the volcano, the mental map is altered through oral accounts. As Feinberg et al. (2003, p.249) state *"in addition to direct experience, one's mental map is shaped by descriptions and information gathered by others, whether compiled in books or passed on through oral traditions"*.

Another example is that of the local scientist's mental map in Figure 6.2. This has the area off the north coast coloured in red. This was on purpose to illustrate the fact that volcanic hazards, in particular pyroclastic flows, continue out to sea. No other mental map conveyed this fact, and this could be due to the extent of the scientist's knowledge of the volcano and past eruptions and work on Montserrat.

6.4.4. Personal proximity to the volcano

A final point of analysis is to consider whether a person's proximity to the volcano altered their mental maps; in particular how they coloured in their local area. Out of the 12 people who completed the exercise, 10 lived (or had lived) on St. Vincent. Of these 10, two people lived in their red zone of high vulnerability (Figure 6.12, Figure 6.13). One person lived in their yellow zone (Figure 6.11), and the remaining seven lived in their green zone.

These results are not surprising as the majority of those interviewed live in the south of the island which is in the green zone on the integrated hazard map (Figure 3.8). The results suggest that people consider vulnerable areas to be the same, if not very similar to the zones of integrated hazard advised by the government. The two people who live in their red zone live in the areas of the island which most people consider to be the most dangerous with respect to the volcano, so this is not surprising either. The person who coloured their home as yellow is close to the border with their red zone, however it is speculated that this is not to do with underestimating their proximity to the volcano. It was clear that the boundary between the red and yellow zone was drawn to reflect areas of high population (high vulnerability) versus lower population, with the participant living in a small village.

6.4.5. Composite mental map of vulnerability

The composite mental map of vulnerability (Figure 6.14) is a mathematical combination of all 13 mental maps using map algebra as in Matei and Ball-

Rokeach (2005). The green, low vulnerability area extends over half way up the island with little pockets of pale green/yellow around the Mesopotamia Valley and the populated west coast and farmland. The main population centres on the east and west coasts are average to high vulnerability (yellow to orange), with the areas of Georgetown, Chateaubelair, Fancy, Owia and Overland as very high, red vulnerability. There is also a stripe of red on the south flank of the volcano where there are illegal farms and settlements. The unpopulated northwest is yellow as a number of people left this area blank on their maps.

As the individual mental maps on the whole were very similar, this composite map serves only to reinforce the perception of vulnerability as being high in the northeast and west in particular, and low in the south. Small differences in the mental maps are evident such as the stripe of red showing the location of the illegal farms, and some areas in the south being a paler green to yellow colour. The middle of the island grades slowly from green to yellow to red as the boundaries between the low, medium and high vulnerable areas shifted within this region between individual mental maps.

A second composite map was calculated excluding the mental maps of the two scientists who had never lived on St. Vincent, and were not familiar with the island (Figure 6.15). There is very little difference between the map in Figure 6.14 and the map in Figure 6.15. The boundaries of vulnerability do not change; however, there is a greater contrast between the vulnerable red areas in the northeast and around Chateaubelair and Georgetown, and the yellow less vulnerable areas in the northwest in Figure 6.15.

A product of the method of creating the composite maps is that they give more weight to those stakeholders who coloured in larger areas of St. Vincent. Some maps only coloured in a very small area, therefore their influence on the overall map is much less than participants who coloured in the whole map. In future one could ask the participants to colour in the whole map; however in this exercise some people seemed reluctant to do so as they did not have opinions about many areas.

6.4.6. Similarity to hazard map: measuring hazard awareness?

The stakeholder mental maps drawn and the composite maps in Figure 6.14 and Figure 6.15 are very similar to the integrated hazard map produced by the SRC (Figure 3.8) in that vulnerability (or hazard) increases to the north of the island. Indeed two of the scientists effectively redrew the integrated hazard map. Work by Perry and Lindell (1990) on Mt. St. Helens in the US investigated human adjustment to the volcano throughout the activity beginning in 1980. The authors discuss 'hazard awareness' of which vulnerability awareness is just one part. Being aware of the hazard is the first stage, understanding how that hazard can impact on a person negatively leads to vulnerability perception. Their work also distinguishes between vulnerability of property and personal vulnerability. With the similarity between the mental maps in this research and the integrated hazard map used for education it is possible that what was being measured in this research was actually one element of 'hazard awareness'.

According to Perry and Lindell (1990, p.23) a general definition of hazard awareness is *"the understanding of a threat coupled with some subjective appreciation of its likely consequences"*. They continue to describe two parts of hazard awareness – an informational dimension and an evaluative dimension. From the mental maps drawn in this research which mirror the integrated hazard map it would seem that the information dimension has been successful in that everyone interviewed knew of the hazard map. It appears, however, that the evaluative dimension which would include the appreciation of the threat's consequences (i.e. vulnerability) is missing for some people. It is useful to consider why this might be so.

6.4.7. Perceived vulnerability

Perry and Lindell (1990) describe three classic determinants in the literature which can predict whether a person will perceive themselves or their property to be vulnerable. These are *proximity* to the threat, *certainty* that the threat will occur, and *severity* of the impacts. The work here differs in scale from Perry and Lindell's discussion, in that stakeholders in this exercise were asked about vulnerability of St. Vincent in general and not just their own vulnerability. However, personal vulnerability was covered as where the stakeholder lived was highlighted and therefore the three determinants of vulnerability perception from Perry and Lindell are still useful for discussing the results of the stakeholder mental maps. Although it is unclear whether personal proximity to the volcano affects a person's mental maps of vulnerability, the interviews conducted here suggest that proximity in general is an important factor for people when considering vulnerability. In the interviews conducted during the initial fieldwork proximity to the volcano was the most common vulnerability variable mentioned. The fact that the population centres near the Soufrière volcano are shaded red (high vulnerability) in these mental maps reinforces this. The impact of proximity to the threat on a person's perceived vulnerability and risk was highlighted by Peltre and D'Ercole (1992). The authors surveyed 2,200 families in four risk zones of Quito, Ecuador, exposed to volcanic hazards from Cotopaxi and Pichincha volcanoes. The investigation centred round the families' perception of their risk and three vulnerability factors: awareness of personal risk; knowledge of appropriate protective measures; and behaviour in case of an evacuation order. They found that the awareness of personal risk diminishes with distance from the volcanoes, especially when the volcanoes were not visible. Awareness was also lower for new inhabitants.

Whether certainty of the threat occurring and understanding the severity of the potential impacts has been evaluated by the people interviewed in this research is unclear as it was not specifically investigated. General observation and discussions with Vincentians suggests, however, that they are aware the volcano is active, and many know it erupts roughly once every one hundred years. In terms of evaluating the potential severity of the impacts, the past two eruptions have lasted a few months, and it appears people believe the volcano will behave in a similar fashion in the future. People did make the point that when the Soufrière Hills volcano on Montserrat began erupting in 1995 they expected the eruption to last a similar length of time to the two eruptions experienced on St. Vincent in the 20th Century. They were surprised that the activity continues to this date, and this has changed how they think of the potential threat from their volcano.

In addition to the classic determinants of perceived vulnerability, Perry and Lindell (1990) discuss three social psychological measures that are not directly related to the hazard: experience of the hazard; perceived efficacy of protective measures; and the impact of family responsibility. The mental maps, annotations and discussions in this research have suggested that experience with the volcano does alter a person's perception of vulnerability. Perceived efficacy of protective measures and family responsibility again were not investigated in this study. Discussions with some stakeholders, however, have shown that there is a lot of confidence in the scientists and their ability to predict and warn of impending eruptions. This may reduce people's perceptions of their own vulnerability. For example one interviewee described the scientists at work during the 1979 eruption:

> *"And they [the scientists] were timing the eruptions, and those men were accurate, they were good, they were somewhere across here [pointing to the map], in two boats. The men said it would erupt at six o'clock in the evening…five to six [it erupted]…those fellas were good! Fellas were good." (President, St. Vincent Red Cross)*

A distinction that was not made in this research was that between vulnerability to people and to property. The work on Mount St. Helens showed that people were more concerned with the vulnerability of their property than personal vulnerability. This was due to the nature of the threat and people's ability to evacuate, but not protect their property. It is possible that on St. Vincent people are also less concerned with personal vulnerability for two reasons. First, in 1979 no one was killed in the eruption. Second, if the perceived efficacy of official warnings and protective measures is high as speculated then people will believe they will be able to evacuate and be safe during an eruption. Further work could resolve this, although it is speculated that one reason the mental maps mirror the integrated hazard map is because people are more concerned with the proximity and therefore vulnerability of their property and farmland to the volcano.

6.5. Critique of method

6.5.1. Advantages

One of the aims of applying a mental mapping method to analyse vulnerability was to rid the maps of the arbitrary boundaries that are a product of census data mapping. People do not really think in relation to census division or enumeration district boundaries. This mental mapping method was successful in that it allowed people to draw their own boundaries and see how they grouped communities or areas on the island, although some maps were not as detailed as first hoped.

In addition it was an interactive method of data collection. The interviews undertaken during the initial fieldwork were successful, however it was found to be very beneficial to have a map in front of the interviewee during this second exercise so that they could annotate it as the interview progressed, and point out areas of specific interest that they were talking about.

Having the researcher present throughout this exercise was also an advantage over the method from which this exercise was adopted. The works by Matei and Ball-Rokeach (2005) and Saarinen (1973) were limited in that there was no researcher present while the participant drew their mental map. In this exercise the researcher was able to ask specific questions as areas were being coloured in, and ascertain detailed reasons for doing so, aiding interpretation of the results.

Finally, with respect to analysing the mental maps, digitising the data and combining them mathematically in a GIS is an excellent way to summarise the results. Although the individual mental maps in this research were all fairly similar, and there were a small number to compare and contrast, if this exercise was completed on a larger scale, creating a composite map using this method would be a useful technique for getting an overall view of people’s mental maps. However, one needs to consider that the composite map gives greater weight to those stakeholders who coloured in the whole map. As a result, the composite maps presented here do not necessarily reflect the views of those who only coloured in small areas.

6.5.2. Limitations

The biggest limitation in data collection involved the understanding of vulnerability and the different terminology used; many people thought it was the hazard map they were being asked to draw. Different words used to annotate the mental maps included *vulnerable*, *insecure*, *risk*, *dangerous* and *safe*, all in response to being asked to colour in areas of ‘vulnerability’. The problem of terminology will be discussed in more detail in Chapter Eight.

A second limitation is that only 12 people were interviewed in this section of the research, and people can be wrong. Terminology was a problem, and very often people identified proximity to the volcano as vulnerability, which in fact measures an aspect of hazard.

Initially it was hoped to gain more detail from these maps, however this was not achieved. Arbitrary boundaries that were a product of mapping social and building vulnerability were eliminated, but these maps still only give a very broad picture of vulnerability on St. Vincent. Perhaps additional colours would have given more detail, however it was felt best to keep the exercise as uncomplicated as possible and achievable in a short space of time. Future work adopting this method might ask people to draw vulnerable areas at a different scale; perhaps community level. This could lead to more detail, and interviewees would have a more in depth knowledge of the area. In addition, to ensure that all stakeholders have equal weight in the composite map, participants could be given an equal number of buttons or pins to place on the map assigning areas of relative vulnerability. More buttons or pins in one area would represent higher vulnerability.

The background map was kept free from most village names as the researcher did not want to influence what was annotated. However, this may have led to the areas coloured in not representing the areas people were talking about if they were unable to locate villages or towns on a relatively blank map. Adopting the method of Gould and White (1986) was considered where people could rank a list of villages as being more or less vulnerable; however it was not felt that the researcher would know which areas to list. The advantage of leaving the map relatively blank was that it allowed people to annotate it with whatever information they felt was pertinent.

A final limitation comes from targeting stakeholders who are decision makers on St. Vincent or involved in community-based disaster management. The composite map therefore reflects the views of a few experts. The exercise could be altered to ask people to focus on their own vulnerability and extend the stakeholder group to the general population. This may provide a localised view in contrast to the island-wide view obtained in this research. It is felt, however, that terminology would be an issue with members of the public.

6.6. Conclusion

Although the initial aim of this mental mapping method was not achieved (gaining more detail than previous socio-economic and building vulnerability maps, and ridding maps of arbitrary boundaries), the technique is an excellent way of capturing and comparing information on people's perceptions of vulnerability, and a useful tool to utilise throughout an interview.

The analysis of stakeholder's mental maps focused on: the different factors mentioned; the extent of the mental map; that person's experience and knowledge of the volcano and its impacts; and their proximity to the threat. Of these factors it is hypothesised that knowledge, experience and occupation in particular play an important part in determining a person's mental map of volcanic vulnerability. With only 10 residents of St. Vincent interviewed there were insufficient data to determine whether or not there was a relationship between the proximity of the person to the volcano and their mental map. On the whole, the mental maps resembled the integrated hazard map produced by the SRC which brings into question what was being measured during the exercise: hazard or vulnerability awareness.

Two parameters that were not recorded in this research were the participant's age and their gender. Age could be important as in this case it determines whether or not they had experienced previous volcanic activity. From the interviews it became clear that of the 10 people who were from St. Vincent, seven of them experienced the 1979 eruption. In addition, out of the 12 participants, three were female, and only one of the females was a resident of St. Vincent. It was not a goal of the research to sample an equal number of males and females and as the work is specifically interested in the views of the scientists and those involved in emergency management on St. Vincent the sample is determined more by role and availability than by gender. Attzs (2008, citing Enarson and Morrow, 1998) stated that women perceive natural disasters as more serious than men. In addition, the participatory hazard mapping completed by Cronin et al. (2004c) noted that the maps completed individually by men and women differed in the amount of detail and areas of greater geographical knowledge. Whether there are any differences between the mental maps and perception of vulnerability of males and females is something that could be investigated in future research, using a larger sample.

In conclusion, understanding how people perceive vulnerability of their community and island is an excellent first step towards the ultimate goal of reducing risk. In addition, gaining a better understanding of what people mean when they talk about vulnerability, and where they think vulnerable people and areas are located is important, especially when those people have roles in disaster management. Whether measuring that perception through interviews, questionnaires, observation or a mental mapping exercise as in this research, the goal must surely be to understand how that awareness influences a person’s adjustment to the hazard, and whether they actually perceive themselves to be vulnerable to that hazard in the first place. No amount of education campaigns, insurance schemes, or other measures aimed at reducing people’s vulnerability to a hazard will work unless that person first decides they, and their community, are vulnerable.

Chapter 7: Historical Vulnerability Analysis

Up until now this research has addressed the spatial component of vulnerability on St. Vincent identifying vulnerability variables and where vulnerable people and places are located. In addition it has investigated how stakeholders perceive the island's vulnerability. In order to understand how these vulnerabilities are constructed, however, it is necessary to explore the history of the island and research the temporal aspect of vulnerability.

The questions that this chapter aims to answer concern why people live where they do and how they came to be located in some of the most exposed areas on the island. How has the history of St. Vincent shaped the situation that is seen today in terms of demographics, economics and culture? The first three methods identified social, economic, building and spatial elements of volcanic vulnerability on St. Vincent. The addition of the historical analysis presented here can help to develop an understanding of how those vulnerabilities have evolved.

This chapter begins by discussing how volcanology research utilises historical data sources to better understand the potential impacts of future eruptions. Next, four examples of historical vulnerability analyses of natural hazards in general are outlined, along with the method and data used in this research. This is followed by a description of the historical development of St. Vincent and the current social and economic conditions with a view to identifying sources of vulnerability. The chapter concludes with a critique of this approach to understanding vulnerability.

7.1. 'The past is the key to the future'

The field of volcanology has long identified the contribution of studying 'the past as the key to the future'. Indeed, many volcanic hazard assessments are completed using evidence of past eruptions and deposits. More recently research has been conducted which investigates the application of oral histories and traditions in understanding the hazards from past eruptions and cultural adaptations (Cronin and Neall, 2000; Cronin et al., 2004a; Cronin et al., 2004c; Németh and Cronin, 2009). For example, Cronin and Neall (2000) investigate local stories on Taveuni, Fiji, that describe past eruptions and impacts and use this knowledge to inform disaster management. In addition, Cronin et al. (2004a) found that local legends describing catastrophic events from Nabukelevu volcano, Kadavu Island, Fiji, corresponded with geological findings and provided additional evidence of past volcanic hazards. Similar use of traditional knowledge of past impacts from volcanic hazards has been used to inform disaster management (e.g. Cronin et al., 2004c). As Cashman and Giordano (2008, p.325) state in the introduction to a special academic publication on 'Volcanoes and human history': *"the goal of evaluating the impact of past eruptions on human populations [is] to better prepare for future events"*. History and local knowledge can be used to reach this goal, in addition to traditional geological investigations and hazard mapping.

These studies demonstrate how volcanic research has used history to inform disaster management, however if vulnerability has been investigated these studies do not explicitly address how those vulnerabilities have emerged over time. The aim of this element of the research is to analyse the history of St. Vincent to develop an understanding of the construction of vulnerability to volcanic hazards. The following section reviews some examples in the literature of where this type of analysis has been conducted, and where possible, what methods have been adopted.

7.2. Review of current methods

Bankoff (2007) strongly advocates the need to understand the historical nature of disasters and construction of vulnerability. A large amount of his work has focused on the Philippines and its frequent exposure to natural hazards. Indeed *"the Philippines as a whole experiences more earthquakes, volcanic eruptions, and tsunamis than any other country on earth"* (Bankoff, 2007, p.26). Using Manila as an example he suggests that one of the principal human constructions of vulnerability arises through the increase in size and density of the population. This is due to rural-urban migration, mostly since the end of the Second World War, with rural populations attracted to the city for higher wages and greater livelihood opportunities (Bankoff, 2003). Many of these migrants were poor and could not afford the rising land prices. As a result they were forced to live in the informal housing sector, often located on the fringes of the city on poor quality, hazard-prone land, such as river banks. Researching the history of disasters in this area reveals not only the construction of vulnerability through population growth, urbanisation, agricultural practices, etc., but also coping mechanisms adopted by the population. For example in Manila that is exposed to frequent flooding, people in the past travelled around by canoe during floods, and workers in cigar factories wore high-heeled sandals in order to gain access to work (Bankoff, 2003).

Another study located in the Philippines is that by Gaillard et al. (2007) who trace the root causes of vulnerability (as defined by Wisner et al., 2004, in the PAR model) of the late-2004 typhoon disasters in Eastern Luzon that killed 1600 people. They argue that *"the catastrophe does not only lie in obvious triggering natural phenomena but is rather entangled in deeper demographic, socio-economic and political factors"* (Gaillard et al., 2007, p.258). Three root causes are identified. First, population growth led to increased occupation of hazardous lands such as the slopes of volcanoes and flood plains, particularly as the availability of suitable lowland areas decreased with population pressure. Many of the people who were killed by landslides during the typhoons were occupying mountain areas. The second root cause of vulnerability identified was access to land and resources. Landless farmers were increasingly moving to mountain areas in order to access larger parcels of land to farm and become food secure. In addition, fishing practices were destroying coral reefs and mangroves forcing people to migrate to less densely populated coastal zones, and it was these mountain and coastal zones that were most affected by the typhoons. The final root cause identified was that of corruption and elite power; in particular with regards to illegal logging which decreases forest cover. The authors acknowledge that these three root causes are intertwined and cannot be disassociated from each other. The result is the high vulnerability of the Philippine population to natural hazards.

Wisner et al. (2004) analysed the situation that led to the vulnerability of the population of Mexico City in the 1985 earthquake which killed up to 17,000 people. Using the PAR model as a framework they categorised the historical influences on different environments: physical, built, social and economic. One of the main reasons for the scale of the disaster in Mexico City was due to the fact that the city was sited on an old lake bed. The alluvial soil acted like a liquid during the earthquake and this caused the damage and collapse of many of the buildings. In addition to buildings being sited on the old lake bed, another factor which increased their vulnerability was the standard of building and the enforcement of building codes. Reinforced concrete buildings built between 1925 and 1942 were of a high standard, as were those built after 1964 when seismic building codes were introduced. Between 1942 and 1964 the standard of the building fell due to the construction boom and slackening of standards. In addition, social vulnerability arose out of the trends in population expansion and urbanisation, in particular the lack of access to resources of some low-income tenement residents in poorly maintained buildings.

A study which looks at historical vulnerability in a volcanic environment is that by Dibben and Chester (1999). The authors conducted a human vulnerability assessment on the volcanic island of São Miguel in the Azores. In addition to looking at the social, physiological and psychological context of the population, they argued that it is also necessary to investigate the history and development of society to understand the ‘root causes’ of vulnerability. The authors discuss a number of historical developments of the settlements which lead to the vulnerability seen today. The island of São Miguel was first settled along the coastline due to it providing a suitable anchorage and the chance to exploit the natural resources of the area. The population grew as people began settling the nearby land. By the end of the 15th Century there were foresters and herders settling in the caldera of Furnas volcano exploiting the wood and grazing land. Interest in the area increased in the late 18th Century with the discovery of mineral waters and their ‘therapeutic’ qualities. Trade links with Europe and America at this time also increased the numbers of visitors to the island, many building homes and gardens around the lake at Furnas. By the 20th Century the island was used for the re-fuelling of trans-Atlantic flights, and hotels and a casino were built. History shows that the two eruptions since settlement of the area have done little to slow development, especially in the long term. Today the population focus on the benefits of living near Furnas volcano, rather than the negative impacts a future volcanic eruption may have.

Research into the historical construction of vulnerability, such as that conducted in these examples, helps develop an understanding of why areas that might seem exceptionally hazardous to an outsider have been settled. It also leads to an appreciation of the vulnerable characteristics of the population and place seen today. Only the study by Dibben and Chester (1999) explicitly outlines the methods used – interviews and document analysis. The studies by Gaillard et al. (2007) and Wisner et al. (2004) utilise the PAR model to help categorise the vulnerabilities they identified. The approach presented here combines the use of the PAR model as a framework for analysis with interviews and document analysis as methods for data collection.

7.3. Method

7.3.1. Framework of analysis

Historical vulnerability could be described by discussing past events, identifying vulnerability variables, etc.. It was felt more useful, however, to have a framework to help guide the reading and summarise the results. Up to now the research has identified a range of vulnerability variables existing today. The aim of this chapter is to understand how they came to be.

A model was chosen, therefore, which creates a framework for an investigation into the temporal aspect of vulnerability and links it to the snapshot in time seen today. The model chosen is the PAR model from Wisner et al. (2004) (Figure 2.2). This is a linear model which describes the construction of disaster risk from two opposing forces – vulnerability and hazard. The 'progression' of vulnerability is divided into three separate stages: 'root causes', 'dynamic pressures' and 'unsafe conditions'. The process begins with root causes that Wisner et al. (2004) describe as the most distant of the three stages. These are *"an interrelated set of widespread and general processes within a society and the world economy"* (Wisner et al., 2004, p.52). The most important root causes are economic, demographic and political and are distant in one of two ways – spatially – i.e. politically or economically away from the study site; or temporally – i.e. in the historical past. Examples of root causes are limited access to political power and resources through marginalisation of certain social groups. Root causes can also be distant culturally in that they are conditions or beliefs that are 'invisible' or 'taken for granted' (Wisner et al., 2004).

The second of the three stages is 'dynamic pressures' which *"are processes and activities that 'translate' the effects of root causes both temporally and spatially into unsafe conditions"* (Wisner et al., 2004, p.53). Wisner et al. (2004) describe them as more immediate and contemporary manifestations of the underlying economic, social and political situation. Examples of dynamic pressures are epidemic disease, rapid urbanisation and foreign debt.

The first two stages in the PAR model are processes. The third and final stage of vulnerability is 'unsafe conditions' which are not a process but specific forms in which the vulnerability of a population at that time is manifested. Unsafe conditions depend upon the well-being of the population and how this varies between regions in a study area. Examples include people living in hazardous areas, living in unsafe buildings, or engaging in dangerous livelihoods (Wisner et al., 2004).

The PAR model was chosen as a framework to look at historical vulnerability for a number of reasons. First, it incorporates the hazard event, and describes the construction of disaster risk as the intersection between the vulnerability and the hazard. The authors also acknowledge that the hazard is not necessarily independent of the vulnerability, and can work to increase or decrease the levels of vulnerability in the model. Vulnerability *"is integrally linked with the hazard events to which people are exposed"* (Wisner et al., 2004, p.35). On an island like St. Vincent natural hazards form an integral part of the history and society and should not be excluded from the analysis.

Second, the PAR model illustrates how vulnerability progresses both in space and time to the 'unsafe conditions' seen today. A number of other models express vulnerability as a checklist of factors, whereas the PAR model allows one to explore the underlying causes of vulnerability and how these are linked to the current situation. Third, the model has a specific place for investigating historical vulnerability and identifying the processes, both dated and more current, which link the past to the present.

7.3.2. Data collection

The previous three chapters have effectively created a list of ‘unsafe conditions’. To understand the root causes and dynamic pressures which led to these unsafe conditions document analysis was conducted. Two main sources of data were used. First, primary data from two sets of interviews conducted with stakeholders on St. Vincent and scientists that work there. These data provide local knowledge of the island’s history, in particular with respect to responses to past eruptions, and tap into the oral histories that are now being utilised in many volcanic hazard studies (e.g. Cronin and Neall, 2000; Cronin et al., 2004a; Cronin et al., 2004c; Donovan, 2009; Németh and Cronin, 2009). Second, secondary data sources were used from local documents and books available on St. Vincent and at the SRC in Trinidad, and a bibliographic search to find theses and historical texts written about St. Vincent’s past. The period of time covered in the analysis became clear through what data were available and what historians had written about. The dates covered are between 1200 AD to present, with more data available about the colonial history of St. Vincent from the 1700s onwards. The following two sections describe the history of St. Vincent and the social and economic conditions existing today.

7.4. Historical development of St. Vincent’s vulnerability

7.4.1. Introduction

The history of St. Vincent is filled with episodes of people on the move, conflict and natural hazards. From the first recorded settlements of Amerindians, to colonisation by the English and French, and eventually independence, people have been migrating to and from, and fighting over this Caribbean island for centuries. Throughout its development, natural hazards, in particular volcanic eruptions and hurricanes have left their mark on the land and its people. This has led to a diverse society that is rich in culture.

7.4.2. First settlers

The first recorded people to settle in the Eastern Caribbean were Amerindians from northern South America around 5000 BC (Adams, 2002). First a group known as Siboneys migrated followed in the 1st Century AD by Arawaks, and later after 1200 AD, the Callinagos. It was the Callinagos, later referred to as Caribs that mainly inhabited St. Vincent.

Nearly three centuries later Christopher Columbus arrived in the region in 1492. Although there is no evidence that he ever came to St. Vincent, he opened the way for more Europeans – Spanish, Portuguese, Dutch, English, Danes, Germans, French and Swedes (Adams, 2002). The first thing that attracted Europeans to the Caribbean islands was gold. Christopher Columbus had found it in Haiti and sent it back to Spain. St. Vincent, however, was originally unattractive to the Europeans for two main reasons. First, the absence of gold, and second, the known presence of the indigenous Caribs. As other islands were colonised by the Europeans, Caribs from across the Eastern Caribbean sought refuge on the two most mountainous islands, Dominica and St. Vincent. Their stubborn resistance helped prevent the Europeans from attempting to settle St. Vincent until the 17th Century.

7.4.3. St. Vincent Caribs

By the 17th Century there were a number of different ‘Caribs’ living on St. Vincent. Two main groups are mentioned in historical documents: Yellow or Red Caribs, and Black Caribs. The Yellow or Red Caribs were descendants of the original Amerindian settlers from 1200AD. The Black Caribs, also known as Garifuna, were of African descent. It is thought that Spanish slave ships were wrecked off the St. Vincent coast in 1635 and a Dutch slave ship in 1675. These slaves integrated themselves on the island of St. Vincent and possibly adopted some of the customs of the indigenous Yellow Caribs, such as the flattening of the head at birth (Howard and Howard, 1983; Adams, 2002). Reports differ as to whether these two groups of people lived cordially. Colonial (and often biased against the Black Caribs) writers say that the Black Caribs killed the Yellow Carib men and stole their women (Miller, 1979; Howard and Howard, 1983). A Vincentian historian, however, suggests they lived peacefully for a while until land disputes arose after which the Governor of Martinique intervened and divided the land up between the two groups: Yellow Caribs in the west and Black Caribs in the east of St. Vincent (Adams, 2002).

7.4.4. European control

Throughout the 17th Century St. Vincent was ‘claimed’ by both the English and the French. Reports suggest that Europeans traded with the Caribs on the island; although, no settlements were established. On March 31st, 1660 a treaty was signed between the English, French and Caribs agreeing to leave Dominica and St. Vincent in undisturbed possession of the Caribs (Adams, 2002).

Despite this treaty, attempts to settle St. Vincent by both the English and the French continued into the 18th Century. The French had the most success and succeeded in owning and operating plantations and estates on the island. They also colluded with the Caribs to keep the English out, and began to export produce during these ‘neutral’ or Carib years, while work began on building the capital, Kingstown, at the site of Ooashegunny Bay.

Later that century, at the end of the Seven Years War (1756-1763) involving all major European powers of that era, Britain emerged as the major colonial power at the expense of the French. British – French hostilities were ended with the Treaty of Paris in 1763 and St. Vincent - despite not being the legal possession of the French - was ceded to the British as a part of the terms.

7.4.5. Carib Wars

The remainder of the 18th Century was filled with conflict over land rights. The English soon realised that the best land on St. Vincent was in Carib territory and set about acquiring it for cultivation. This led to the First Carib War in 1772. It lasted just five months with the Caribs surrendering on January 25th, 1773 and negotiating terms (Adams, 2002). The terms meant the Caribs were dispossessed of 10 miles of relatively flat, fertile land on the eastern side of the island. Although the Caribs had surrendered, and the English had gained more land, *"the victory by the English was still quite inconclusive"* (Adams, 2002, p.43). The Caribs were biding their time until they could banish the English from the island completely, and enlisted the French to help. In 1778 when the English were involved in a war back in Europe, and had deployed troops from St. Vincent leaving it unprotected, the French attacked with the help of the Caribs and captured the island with little resistance on June 16th, 1779. It was restored to the British on January 1st, 1784 as a part of the Treaty of Versailles, although, hostilities with the Caribs continued. The Second Carib War began in 1795, with the Chief of the Caribs, Chatoyer, killed in March of that year during fighting. Hostilities continued for a further year, with the first Caribs surrendering in June 1796. By this time, colonists on St. Vincent decided the only way to deal with the 'Carib problem' was to rid the island of them completely. This had been suggested initially in 1763, and again after the First Carib War in 1772. Over 5,000 Caribs were deported from St. Vincent to the Grenadine island of Balliceaux in 1796, awaiting transportation to Roatan Island, off the coast of Honduras. By

March 1797 the detainees were finally deported, by which time, only around half the original prisoners remained alive.

Not all Caribs were deported, however, and Adams (2002) and Anderson (2001) state that some Yellow Caribs did not take part in the Second Carib War and were given a reserved area in the north of the island known then as 'Carib Country'. In addition, those Black Caribs who escaped deportation were also given a reserve in that area.

7.4.6. British colonial rule

The start of the 19th Century was the beginning of sustained colonisation by the British. By this time the island was inhabited by Yellow and Black Caribs, early French settlers, English settlers and some African slaves. Early colonisation revolved around sugar plantations as land on other British colonies was now in short supply. Having gained the land they wanted, the British now needed a workforce to man the plantations. Early French settlers had first introduced African slaves in 1743, and the British continued this practice. The slave population peaked at around 25,000 in 1808 (McDonald, 2001), with just over 1,000 whites and 1,000 coloureds. Documentation from British colonials at this time report a real hierarchy in society between the white settlers, coloureds, indigenous Caribs, and finally the African slaves. This division of society was to last for many years after slavery was abolished; some historians argue that *"in some respects the black people on these [British Caribbean] islands are still living under apprenticeship today – 166 years after the official abolition of slavery"* (Dunn, 2001, p.xiii).

The abolition of slavery in 1834 on St. Vincent was followed by a period during which an apprenticeship system prevailed that was designed to ease the transition between slavery and freedom. Agricultural workers were to remain apprentices for six years, with domestic workers gaining freedom after just four years. In the end, the period of emancipation ended for everyone in 1838. This led to real changes on the island. It was a period of hope for the newly freed slaves, who believed that they could now form a type of peasant society, working small plots of land and creating new villages (McDonald, 2001). The reality was somewhat different. Land the slaves had previously occupied remained the property of the estates and as a result, many freed slaves migrated to other Caribbean islands where there were better wages and cheaper land. Those that remained tended to be women and children. Childcare was also an issue. During slavery, the care of children was the responsibility of the estates. Now, families had to juggle work with caring for and educating their children (Adams, 2002).

The end of slavery and the apprenticeship system also created heightened levels of social conflict. Racially based hostilities emerged as *"Vincentians from all social strata jockeyed for position in the island's new free society"* (McDonald, 2001, p.28). White Vincentians' negrophobic attitudes continued while the free coloureds lost their status as praedial and non-praedial workers were emancipated.

The estates also suffered in that they had lost their cheap source of labour. Although they had been paid £20 million in compensation for the loss of human property (McDonald, 2001) a devastating hurricane in 1831 aggravated the situation as many estates had little time to recover from this disaster before the abolition of slavery commenced in 1834. In an attempt to flood the labour market to avoid having to pay higher wages to the newly freed slaves, indentured labourers were bought from Madeira, Africa and India (Adams, 2002). The new labour force's willingness to work in poor conditions, and for lower wages, forced more emigration to other Caribbean islands by ex-slaves. Many of the indentured labourers – in particular the Portuguese – decided to stay on St. Vincent when their period of labour expired. This added to the cultural mix on St. Vincent that is still evident today.

7.4.7. Economic hardship and the 1898 hurricane

The second half of the 19th Century saw the decline of the sugar industry, periods of epidemic disease, and conditions of real poverty on St. Vincent. Many of the freed slaves had no choice but to go work on the estates and children were also forced to work to help struggling families. The sugar industry was in decline and labour conditions were poor. Crop diversification was implemented, and some planters replaced sugar with arrowroot, although this could not completely replace the once dominant sugar crop. Colonisation had, however, resulted in the building of facilities for the island, including a hospital, jail, police force, churches, schools and sports ground (Adams, 2002).

Poor conditions were aggravated by two forces of nature at the turn of the century. Between the 11th and 12th of September, 1898, St. Vincent was devastated by a hurricane. Over half of the 40,000 population had no shelter, three quarters had no food, and around 200 people were killed (Richardson, 1989). One reason for the devastation was that in an attempt to improve the economic conditions on St. Vincent, the British government had decided to encourage land redistribution so that farmers could work small plots. Interior lands that were not occupied by plantations were cultivated, in particular by black subsistence farmers. These areas, however, were more hazardous because of the sloping terrain that suffered from soil erosion and landslides, especially during times of heavy rain. For months after the hurricane hit, St. Vincent struggled with sheltering and feeding thousands of homeless and the outbreak of disease in nearly every village. According to Richardson (1989) the hardest hit were black labourers and their families, who lived in makeshift houses.

7.4.8. Response to the 1902 volcanic eruption

Less than four years after the hurricane St. Vincent was once again devastated, this time by a volcanic eruption. On May 7th, 1902, Soufrière volcano erupted killing 1565 people and destroying the agriculture and housing in the north of the island. According to Nanton (1985) nine major sugar estates and mills were destroyed, 2,000 cattle were killed and damages were estimated at £60,000. Deaths could have been much higher but for the fact that many people on the leeward side of the island, including those living in the Carib Reserves in the north, evacuated spontaneously the day before after seeing steam emitted from the crater. Those on the windward side from Fancy to Georgetown were oblivious to the activity as the volcano was covered in cloud and they thought the rumblings were thunderstorms. The majority of deaths occurred on this side of the island.

A relief fund was set up by the Lord Mayor of London to help St. Vincent recover from the devastation of the eruption. Donations reached £67,690 (Nanton, 1985). The relief and recovery effort, however, was not well coordinated by the British, and in the end the discontent of the population led to demonstrations and the refusal to take up voluntary emigration schemes to Jamaica. Much of the displeasure was due to the fact that almost a third of the relief fund was kept in Britain for investment in the long term development of St. Vincent. People were unhappy that the money was not used to help them resettle to other parts of St. Vincent. The British government appeared to favour emigration schemes to other Caribbean islands. In the end there was some resettlement of displaced populations within St. Vincent, but often to areas that were less cultivable than the lands that had been evacuated, so many people returned home once the volcanic activity had subsided. The volcano continued to erupt intermittently for 11 months forcing those people living at the base of the volcano to periodically evacuate. Although the initial eruption destroyed agriculture in the area, the volcanic ash acted as a fertilizer, enriching soils and further encouraging people to return to the hazardous locations.

7.4.9. Social and economic change in the 20th Century

By the 1920s and 1930s, the world had slipped into a depression, and the effects of this were felt on St. Vincent. Indeed Adams (2002, p.154) states that *“not much had changed in the one hundred years since emancipation”*. Child labour continued, as well as poor housing, little education, low wages and few medical facilities and services for the majority of Vincentians. These poor conditions, and an increase in taxes by the government, led to labour disputes in 1935. Four people were killed, 38 injured and over 100 arrested; all were working class, unemployed. Similar disputes and strikes occurred in Cuba, St. Kitts, British Guiana, St. Lucia, Trinidad, Barbados and Jamaica during the 1930s.

Politically, conditions began to change in the second half of the 20th Century. Adult suffrage was introduced in 1951 to all persons over the age of 21. This meant that for the first time the workers had a vote and a new party was put into power in the 1951 elections. In 1969, St. Vincent became a State in association with Britain, effectively preparing it for independence and self-government, which came on October 27th, 1979.

7.4.10. Response to the 1979 volcanic eruption

Prior to independence the Soufrière volcano erupted explosively for a second time that century. The first eruption began during the early morning of Friday April 13th, 1979. By 7.30am that day voluntary evacuation of northern areas of the island had begun. There was no loss of life associated with the 1979 eruption, however economic losses were estimated at US$5.2 million (Robertson, 1995). According to Nanton (1985) banana exports declined 40 percent below the weekly average and one-third of the harvested arrowroot crop was lost, as was a further third of the following year's crop. Stray animals destroyed other crops in abandoned villages, and some evacuated homes were looted.

In a similar way to 1902, the lengthy evacuation and government response to the most recent disaster led to public displeasure and perceived political gain for the party in office at the time. In total around 22,000 people were evacuated for up to nine weeks. Roughly 15,000 in evacuation camps located in the south of the island, with the remainder staying in people's homes. Most of the evacuees were provided with some support by the state. The camps were mainly run by volunteers, and initially evacuees were unable to run camps themselves. According to Nanton (1985) the evacuees were viewed as the recipients of public spirit and kindness, and were expected to be grateful. The evacuees were unhappy at being unable to help themselves and assist in the running of the evacuation camps. The food provided was also unlike their usual rural diet. The Prime Minister, in his daily radio addresses to the nation throughout the crisis, appealed to the evacuees to be patient and improve their behaviour in the camps, in addition to urging people to stop the incidences of larceny and unnecessary trips around the island, in particular to the exclusion zone. The following is an exert from the Prime Minister's daily radio broadcast on Wednesday April 18th, 1979:

> *"...I would like to refer particularly to the local volunteers and the teams of workers who have been assisting to make the evacuees as comfortable as possible. Unfortunately, I must state that the evacuees have not been equally responsive to the help which the voluntary workers have been giving. They have been causing considerable difficulties for the volunteer workers and have not been cooperating. I must appeal to the evacuees in all the various sixty-one camps throughout the State, and naturally this is a generalisation. There are some where the standard of behaviour is excellent, the others where it is hopeless and rotten, and I am appealing to everyone concerned in any way to do everything possible to ensure the highest possible standard of cooperation from the evacuees. The evacuees must remember that the voluntary*

> *workers are not their paid employees. They are doing their best to help them and they must show some response to this. I hope I will not have to touch on this point again. But if the pattern of behaviour among the evacuees, certain evacuees continues to take place, then stronger measures will have to be taken to restrain them and to help us maintain the high standards which have been set by a number of others in different camps.*
>
> *Again we have had incidence of larceny. This time not only among evacuees but from outsiders; from people who are trying to exploit the situation. We have had instances of shop-breaking and general misconduct is stepping up in this moment of crisis. The Police have been asked to take particularly strong measures, and I want to assure all citizens that we will be on the alert to give the maximum protection possible. I would like to repeat that all persons who are interested in joyrides, who are interested in visiting sites are asked to keep away from the prohibited areas, and to keep away from congesting the streets in any part of the State, and not to travel and use petrol and energy unnecessarily. I hope that this warning will be taken seriously and that it will not be necessary to use any other enforcement measures." (GIS, 1979, pp.28-29)*

Nanton (1985) also states that there was a shift in the perception of the Prime Minister's handling of the disaster, from one of working together and national interest to the perception that participation in the response and relief effort was a sign of support for his government and political party. Indeed, the Prime Minister touched on the political wrangling that occurred throughout the crisis in his radio broadcast on Monday April 16th, 1979:

> *"...It is unfortunate that in the face of all this public spiritedness on the part of so many people we still have a few political inspired Vincentians who are zealously spreading malicious propaganda and endeavouring to create panic and discontent among our people. Happily they are failing and would continue to fail with their despicable designs." (GIS, 1979, p.24)*

A local relief fund was established which obtained over $1.1 million Eastern Caribbean Dollars, however accounts for this fund were never published, and local newspapers aired suspicion that the money was being used as bribes for support for the ruling St. Vincent Labour Party (SVLP) in the upcoming election. Later that year, in December 1979 the SVLP regained control. Nanton (1985) argues that the volcanic disaster aided in their re-election. In particular, the support received from countries such as the UK and US was presented as a 'special relationship' which only the SVLP had, and would only continue if they remained in power.

7.5. St. Vincent's current social and economic structure

The following description is taken from data and text included in the 2001 Population and Housing Census Report (Statistics Office, 2001). Note that all figures include the Grenadine islands, whereas this research deals only with the main island of St. Vincent.

7.5.1. Population characteristics

Population increase is often cited as a cause of vulnerability; however this is not necessarily the case on St. Vincent. The first recorded census was taken in 1871 when the total population was 35,688. The population increased gradually until the 1930s (47,961) since when it has more than doubled to its present number of 106,253 in 2001. (Note this is the tabulated population and does not include those persons in prisons, hospitals, those who refused to answer the census questionnaire, and those people who could not be contacted. The total population in the more complete visitation records prior to administering the 2001 census was 109,022 – a difference of 2769 or around two percent). The 2001 total was the first decrease recorded, down 0.2 percent since 1991. The number of households, however, increased by 13 percent over this 10 year period, resulting in a fall in the mean household size from 3.9 persons per household in 1991 to 3.5 in 2001. The Census Report speculates that this is a result of an increase in the number of single parent households, in addition to greater access to credit from financial institutions.

St. Vincent and the Grenadines can be described as a youthful population, although the numbers of under 30s decreased from 66.7 percent in 1991 to 58.4 percent in 2001. Lower birth rates are one explanation, in addition to migration. Migration has long been a part of the history of St. Vincent, and this may be one of the causes of the decrease in the young population. The number of people that migrated between 1991 and 2001 - 18,148 - was 22 percent higher than the period 1980 to 1991. In the 1980s St. Vincent was described as having a large dependant population (Nanton, 1985). Today roughly 50 percent of the population on St. Vincent are of school age (under 19) or retirement age (over 65).

The ethnic and racial composition of St. Vincent and the Grenadines mostly comprises the group African/Negro/Black, accounting for over 70 percent of the total. The next largest group is Mixed at 20 percent. These groups are the result of the colonial history of the islands where slavery was present until the middle of the 19th Century. The indigenous Carib population, who were originally banished from the island by the British in 1793, accounts for 3.6 percent of the population. Over half of the recorded Caribs live in the census district of Sandy Bay in the north which is where the Carib Territory was created in the 1800s. The other groups of White, Indian and Portuguese, again a result of colonial history and indentured labour in the 1800s, account for around three percent of the total population between them. The majority of these groups live in the wealthier census districts of Kingstown and Calliaqua in the south.

7.5.2. Education

St. Vincent and the Grenadines gained independence from Britain in 1979, and as a result of the new country's development goals, education has been a focus. There are effectively three tiers of education; primary (age five to 11), secondary (age 11 to 16) and tertiary (age 16 to 19). Since 1991 primary school attendance has decreased by 22.6 percent (however, there has been a decrease in the primary school age groups of around 18 percent). Secondary school enrolment has increased by five percent and there are more people undertaking Advanced Level exams and professional, vocational and technical college courses. The professional, vocational and technical college enrolment increase is a result of a government initiative to develop a skilled workforce and therefore increase development. One problem that still needs addressing, however, is the disparity between the sexes. There is a high dropout rate of males from secondary school, and in 2001 634 females completed Advanced Level examinations, compared with 241 males. In addition, the provision of special needs education requires attention as only 106 people were attending this type of educational facility in 2001 compared with the 4,096 persons estimated as requiring special education.

7.5.3. Employment

It is recognised that educational attainment reflects on a person's employment prospects. Unemployment in St. Vincent is high at 21.1 percent, an increase of 1.3 percent since 1991. The majority of the unemployed - 66.8 percent - only have a primary level education, and unemployment is higher for males in all age groups. These figures are the manifestation of a shift in St. Vincent's economy. The traditional industries of agriculture, fishing and manufacturing are in decline. Employment levels in these three male dominated industries decreased over the 10 year period by 37 percent, 22 percent and 13 percent respectively. Tourism, finance and real estate, on the other hand, are increasing by 76 percent, 52 percent and 24 percent respectively. Certain census divisions are hit harder by this shift in employment. The northern division of Sandy Bay has a higher than average unemployment rate of 29 percent; a rate that has been increasing since 1980. The southern areas of Kingstown, Calliaqua and Marriaqua, on the other hand, all have unemployment rates below the national average. Agriculture traditionally occurs in the north with fewer facilities to encourage tourism, finance and real estate development, whereas the southern half of St. Vincent is already more developed and is the location of government offices, many industries, the port and airport.

7.5.4. Development standards

Development and housing standards are also lower in the rural north of the island although these issues are being addressed. In the census division of Sandy Bay, for example, two percent of households had electricity in 1991. This has risen to 67.8 percent in 2001. Georgetown has also seen an increase in electricity use rising over this period from 45.8 percent of households to 69.3 percent. In addition to electricity provision, efforts have been made to increase the number of households with access to potable water. In 2001 nearly 70 percent of households had water pumped directly to their home or yard, an increase from 47.6 percent in 1991 and 34.7 percent in 1980. Construction materials have also improved with over 70 percent of houses now being made from concrete, and a decline in the use of wood, adobe and makeshift materials.

7.5.5. Summary

In summary, the total population of the islands has remained fairly constant since the last census was recorded in 1991. There have been large changes, however, in the demographics and development. A large number of people still choose to migrate out of St. Vincent, in particular the young, and with them go the skills needed to improve the economy of the nation. Education and job creation are key focuses for the government; however, unemployment is still high given the decline of traditional industries such as agriculture. Since the late 1970s the government has been encouraging foreign investment in the tourism industry (Nanton, 1985). Improving the education of the population to fill roles in these industries is key. A particular focus needs to be placed in keeping young males in education to learn the new skills that the changing economy demands.

Despite efforts to improve the development of the rural, northern census divisions on the island of St. Vincent, disparities remain. The northern most census division of Sandy Bay where the majority of indigenous Caribs live has the highest levels of unemployment, low school attendance, and lower housing standards. As around 90 percent of those born in Sandy Bay remain, if their standard of living is to improve further, more work is needed in the area itself, rather than rely people to bring skills back to the community. There are some tourism facilities and factories being built in the area which should be beneficial for the local population. Any development, however, in the north in particular, and the island as a whole, is at the mercy of the volcano.

7.6. Historical vulnerability analysis

"Once vulnerability has been identified, it is important to investigate how it came to exist" (Dibben and Chester, 1999, p.136).

Wisner et al. (2004) state that the PAR model can be constructed in reverse and works just as well in either direction of causality, from specific conditions to the general causes. As the previous three chapters have identified a wide range of vulnerability variables that can be grouped together as 'unsafe conditions' this is the form the model will take in this research – from unsafe conditions tracing back through dynamic pressures to root causes. Figure 7.1 below is the PAR model of vulnerability constructed for St. Vincent. The following sections discuss in more detail some of the most important points.

UNSAFE CONDITIONS (as identified in previous chapters)

Economic

- Unemployment
- Vulnerable livelihoods such as agriculture
- Vulnerable agricultural crops such as bananas
- Lack of skilled workforce

Social

- Large dependant population
- Ill health and disabled population
- Poverty
- Vulnerable buildings
- Lack of education
- Lack of access to resources such as transport

Geographic

- Geographical isolation of areas in the north
- People living in hazardous areas – in particular high population centres of Chateaubelair and Georgetown

DYNAMIC PRESSURES

Economic

- Diseconomies of scale on small island leads to fewer job opportunities and a lack of diverse economy
- World economic markets force prices down for agricultural products
- Reliance on agriculture and fertile soil near volcano leads to occupation of hazardous areas

Political

- Politics – previous volcanic activity has been used as a political tool on St. Vincent
- Past trend by governments to focus on response and evacuation rather than preparedness

Social

- Colonial history led to north/south island divide with lower development and resources in the north
- Slavery led to limited access to land for certain social groups
- High rates of HIV lead to ill health – effects working population and puts pressure on social services
- Trend of migration removes educated, skilled population and leaves women, children and high dependant population – remittances from abroad

ROOT CAUSES

- Colonial history
    - Slavery
    - Emancipation
    - Indentured labour
    - Land ownership
- Carib Wars
- Migration

Figure 7.1: PAR model for St. Vincent.

7.6.1. Root Causes

7.6.1.1. Colonial history and land ownership

One effect of St. Vincent's colonial past was the creation of a north-south divide on the island which is still partly evident today. Before plantation owners controlled the majority of cultivable land on the island the indigenous Caribs lived in the productive areas on the windward coast in particular. At the end of the 18th Century the Caribs were banished from St. Vincent and years of slavery and indentured labour followed. The north became a land of large plantations controlled by wealthy colonials, with estate workers living nearby. The few Caribs who were allowed to remain on St. Vincent were restricted to reserves in the north, mostly on the lower flanks of the Soufrière volcano. Kingstown and its surrounding areas in the south grew as the capital and location of all government departments, and in the 20th Century, the base for tourism with hotels and the island's airport. The north-south divide is disappearing slowly. For example, the rural north received a greater supply of electricity and piped water over the last decade or more. In addition, the geographical divide, the Rabacca Dry River, which is impassable when in flood, was bridged in 2007 to increase access and development in the north. In any future volcanic crises, however, it will still be those people in the poorer, rural north who will be forced to evacuate again, and who will likely suffer greater losses of livelihoods and property in an eruption.

7.6.1.2. Migration

The colonial history of emancipation and indentured labour also led to a trend of migration that is still apparent today. In the past the local skilled workforce were forced to migrate to other Caribbean islands for jobs as colonials shipped in cheap labour from abroad. With St. Vincent being a small island, lacking opportunity to create economies of scale and large industries, the current workforce is also required to look abroad for employment. Many of those migrating are healthy, skilled adults, leaving the more vulnerable sections of the population behind on St. Vincent. Nowadays people also move abroad for education. St. Vincent does not have its own University so those seeking higher education have to move to other Caribbean islands such as Trinidad or Jamaica, or further afield to Canada, the US and the UK. There appears to be a cultural acceptance of this kind of migration as it has occurred across the centuries, even for those adults who have children and leave them on St. Vincent in the care of their grandparents. This is the kind of distant root cause that Wisner et al. (2004) discuss as being so ingrained in the cultural assumptions and beliefs of the population that they are ‘invisible’ or ‘taken for granted’.

7.6.2. Dynamic pressures

7.6.2.1. Opportunity for change after volcanic eruptions: disasters and development

At the beginning of the 20th Century the hurricane and volcanic eruption came at a time of economic hardship on St. Vincent. It is unclear, however, whether or not the British government took full advantage of the opportunity to bring about change, and this can also be said of its reaction to the 1979 volcanic eruption. One reason for St. Vincent’s economic troubles prior to the hurricane in 1898 was the uneven distribution of land. Emancipation had freed the workers, but not the land for them to work on. Some black labourers attempted to cultivate small areas of land in the interior of the island, but this was less fertile, and often more hazardous. The majority of labourers were forced to continue working on the estates. When the sugar cane industry went into decline at the end of the 19th Century labourers did not have access to cultivable land for subsistence or cash crops as they did on other islands such as Barbados and St. Kitts (Richardson, 1989). In addition to the land distribution problems, the St. Vincent planters seemed unwilling to invest in modernisation of their estates, and this led to further economic hardships as the sugar cane industry declined further. Prior to the hurricane in 1898 the British government did consider a policy of land redistribution, but no action was taken. After the volcanic eruption in 1902 the Governor of the island attempted to buy up land from planters to redistribute to some of the displaced people. According to Nanton (1985) he experienced opposition from the planters who were unwilling to sell at the proposed prices. In the end, although there was recognition that there was an opportunity to bring about change, the response of the colonial government maintained the status quo in the interests of the planters.

Nanton (1985, p.1) does argue, however, that *"recognition of the need to incorporate response to the disaster within a development strategy was more apparent after the 1902/03 eruptions than after the eruption of 1979"*. He suggests this was to avoid dealing with the difficult relationship that exists between disasters and development. This may be changing now with an increased focus on disasters in the Caribbean. Robertson (pers. comm.) argues that the eruptions did improve the monitoring and focus on the volcano. An earthquake swarm in 1945-46 led to employment of volcano observers and eventually the Seismic Research Unit, now SRC, in Trinidad. The 1979 eruption prompted the improvement of volcanic monitoring on the island, new infrastructure and training of two Vincentians in earth sciences funded by the UNDP (Robertson et al., 2003). Emergency managers on St. Vincent certainly talk about taking the whole spectrum of disaster management cycle into account – from preparedness to mitigation, recovery and response, although the priority remains first and foremost response:

> *"We [NEMO] have to focus on disaster response, because if we didn't there's nobody else that's going to help us. But we recognise that we could do much more, and we are doing a lot more in disaster risk reduction, not just disaster response. But a lot of what we do started with disaster response because that's where we needed to build capacity in the first case. We're now a lot more into mainstream disaster management, so whatever's necessary, whether that's*

> *mitigation, or whatever we need to do to reduce risk." (Director, NEMO)*

For the potential for volcanic disasters to really become a part of the island's development strategy, however, the threat needs to be considered in future planning, in particular in the north of the island. From interviews with the stakeholders on the island there appears to be an awareness of the threat from volcanic hazards, but an understanding that this needs to be balanced with development needs of the north of the island.

> *"I'm seeing now where certain institutions are being built in the red hazard zone. I still don't think…there's too much invested up there and I also think that they have an awareness of the associated hazards. In terms of the possibility of you losing a bit of your investment [unclear] when you create certain institutions there. The major stuff has not gone there, but the basic stuff that you need, for instance your schools, your hospitals, and so forth, they are there, because you have to because you have people living there. And it's a toss up because you have to balance. But I do think that they are aware." (Deputy Director, NEMO)*

Other interviewees had a more relaxed approach to the threat:

> *"So planning for it [volcanic eruption] is something that we would be mindful of, the giant is sleeping, but let's go ahead with our work, when he rumbles, we respect him, and we allow him his time to…spread his ash, spread his lava, and we just get out of the way." (Town planner)*

Regional attitudes towards integrating disaster response into development are now changing with the recognition that countries need to focus more resources into disaster risk reduction, of which response is just one element. At a recent Caribbean Disaster Management Conference in Barbados in December 2008 the Director of the UN ISDR highlighted that many Caribbean countries still primarily focused on disaster response, and that this could actually lead to increased vulnerability. The Director acknowledged that the tendency to rely on response and humanitarian assistance after a disaster is because it is more visible and measurable in the short term, and gains credibility in the eyes of the general public (Downer, 2008). This could certainly be argued as the case after the 1979 volcanic eruption on St. Vincent. Small islands in particular face great challenges in integrating disasters into development as they attempt to achieve higher standards of living, job production and education. A disaster, however, has the ability to set back development for years after the event as monies are directed to relief. Whether the attitude and practice does shift from response and recovery to one of preparedness and mitigation remains to be seen.

7.6.2.2. Politics, volcanic eruptions and disaster management

St. Vincent is a very political island with two main parties at the forefront of politics. The use of the 1979 eruption for political gain was discussed in Section 7.4.10 above. Politics also featured in the 1971 volcanic crisis on the island. Between 1971 and 1972 a viscous lava dome was erupted effusively into the empty crater of Soufrière volcano. There was initial concern that this would lead to an explosive eruption and there was spontaneous evacuation of the north of the island in November 1971, a month after activity began. No official evacuation was ordered at the outset. The political party in opposition was, however, strong in the north, and they suggested to the local residents that the reason the government were not ordering an evacuation was because they did not care about the less developed northern part of St. Vincent (Robertson, pers. comm.). This political pressure led to an official evacuation being ordered on December 7th, 1971, although this subsequently turned out to be unnecessary and residents returned home.

From interviews with stakeholders on St. Vincent it was also implied that politics has filtered its way down into disaster management on the island. One interviewee who was heavily involved in disaster management on the island after the 1979 eruption, and was a member of the St. Vincent Red

Cross, spoke of how he/she felt they were by-passed for the role of Director when NEMO was established. Although the interviewee felt they were far more qualified than the person eventually appointed, they claim they were not selected for the role because of their political affiliation to the opposition party.

7.6.2.3. Economics and agriculture

Nanton (1985, p.2) states that *"the country [St. Vincent] is a marginal producer of agricultural raw materials linked to world capitalist cycles of boom and slump"*. This is evident in the history of the island in the shift from sugar to arrowroot, and now bananas, which can be considered an agricultural construct of vulnerability. Nanton (1985) goes onto explain how even when St. Vincent has had monopoly control over products, such as arrowroot, their control has been undermined when buyers have found alternative products or more cost effective suppliers. St. Vincent is a small island, only 344km^2 - around the same size as the UK's Isle of Wight - and much of the landmass is mountainous and uncultivated. As a result it is unable to achieve the economies of scale that can lead to more competitive prices. Today, agriculture is in decline, and the emphasis is now into diversifying the economy into other sectors such as tourism.

In addition to vulnerability from failing agriculture, another source of income for the island is in decline. There is a large population of Vincentians who live abroad and traditionally they send money back to residents on the island. Indeed this is even a category on the most recent census form, asking how much income a household receives from remittances. In the current global economic downturn, however, remittances from abroad are decreasing and this impacts further on the local economy (Director NEMO, pers. comm.).

7.6.2.4. Challenges of independence

St. Vincent gained its independence from Britain in 1979, and with it came a great number of challenges. Adams (2002) likens the post-independence period with the post-emancipation period of the 1830s. People's expectations were very high, however, it takes time for parties to realise their responsibilities in a newly independent country of around 110,000 people with little land to produce economies of scale. According to Adams (2002) poverty is the root of St. Vincent's problems, and the author states that it is estimated that more than 30 percent of the population live below the poverty line. Compulsory education is not enforced and adult poverty in some families limits the education available to their children. The major challenge for the newly independent St. Vincent is job creation and education. St. Vincent has more of its nationals living outside of its boundaries, and these are commonly the young and educated. The skills these nationals have are needed to help the local economy improve. Another problem is HIV/AIDS. According to recent epidemiological reports, the West Indies is listed second behind sub Sahara Africa with respect to prevalence of the disease (CAREC et al., 2007). The disease commonly affects the 19-55 demographic which form the most productive part of the workforce, and the medical treatment necessary puts pressures on the island's social services. Now that St. Vincent is an independent nation it needs to fund its own initiatives to deal with these most recent challenges and vulnerabilities.

7.7. Critique of method

7.7.1. Advantages

A disaster is a process as well as an event, and one that leads to the vulnerability we see today. Vulnerability is a product of the history and development of an area, and is not something that can be fully understood using a checklist type assessment. One would not necessarily be able to interpret the results of the previous three chapters without some historical research. For example, why are there certain ethnic groups living on St. Vincent today? Why are the population centres located in the areas that they are with different levels of development? Understanding the historical construction of vulnerability is key to gaining a comprehensive view of the situation on St. Vincent today, and the PAR model is a useful framework for guiding the research and summarising the results.

7.7.2. Limitations

Using a framework such as the PAR model, however, does have its limitations. First, and in a similar way to the previous methods of vulnerability analysis utilised in this research, the PAR model requires adequate data sources in order to develop an understanding of an area's history and to capture the wide range of historical vulnerability. An additional limitation of both primary and secondary data sources is bias. This is particularly relevant for somewhere like St. Vincent which has such a rich colonial past. Very few sources were found which were not written by British authors, potentially giving a strongly biased view of the history of St. Vincent, in particular the series of events leading up to the Carib Wars. The only documents found by Caribbean and Vincentian authors are dated from 1985 onwards. St. Vincent was also colonised at times by the French and the researcher is aware of French documents which sometimes contradict the British version of events. These were not available to review by the researcher; however they were addressed in some of the books and papers written by Vincentian authors included here.

Primary data sources such as the interviews conducted throughout this research are an excellent way to add to the secondary data already collected. There are, however, limitations to these as well. First the age and experience of the interviewees will limit the results, in particular when trying to understand the governments' responses to previous volcanic eruptions. Second, as St. Vincent is still very politically divided, this filters into the disaster management, and there is obvious bias when speaking to people with different political affiliations.

The PAR model helps one to look at vulnerability and understand more fully the situation on the ground today, but in terms of identifying points for action i.e. reducing vulnerability, does it help? One of the critiques of the theory behind the PAR model in particular is that it *"calls for social revolution"* (Smith, 1996, p.53). Wisner et al. (2004) acknowledge that it is hard to link root causes to dynamic pressures and then unsafe conditions, and that it is easier, especially in the political short term, to deal with preparedness, response and relief.

7.8. Conclusion: adaptation to the volcanic threat?

This chapter reviewed the history of St. Vincent and tied the different events and traditions to the vulnerabilities measured in the first three chapters. In the opinion of the researcher, historical analysis can add value to quantitative methods for identifying and measuring vulnerability, providing useful insight for planning for future hazard events. Cronin and Neall (2000, p.199), in their work on volcanic hazards in Fiji, state that *"knowledge of the impacts on …past inhabitants forms the basis of volcanic disaster management strategies to minimise future effects"*. In addition to studying past impacts, developing an understanding of *how* the vulnerability of the population was constructed can be used to address, where possible, the causes of the vulnerability to ultimately reduce risk to future disasters.

The historical record in some cases, such as the Philippines, provides evidence of cultural adaptation to disasters, and a 'normalization of the threat' (see Bankoff, 2007). Hazards on St. Vincent are not necessarily frequent enough for this to be the case, however. In particular, volcanic eruptions, that over the past 4000 years had a return period of one eruption every one hundred years. They do not occur frequently enough in one lifetime for the threat to be normalised and for people to learn to adapt, as in other countries with recurrent volcanic activity.

The adaptations to the volcanic threat on St. Vincent have mostly been through relocation of settlements away from the volcano. After the 1902 volcanic eruption many of the sugar plantations were not renovated, and some of the settlements from the north of the island such as Morne Ronde were evacuated and not resettled. The town of Camden Park next to Kingstown in the south was one of the settlements built to accommodate those permanently leaving the north of the island (Hovey, 1909).

Another historical adaptation that has taken place in the Philippines, for example, involves crop diversification. In particular the planting of root crops that are relatively unaffected by many natural hazards. Crop diversification was not something that was ever mentioned by stakeholders on St. Vincent. It was pointed out, however, by the town planner that certain crops such as arrowroot are more resilient to volcanic ash than for example, bananas. The banana crop is especially vulnerable to the hazards from the volcano, and this is a big export for the island. Nevertheless, the threat from the volcano appears not to be frequent enough to cause a change in agricultural practices.

What is clear from looking at vulnerability on St. Vincent through a historical lens is that there are many forces at play. From the colonial history of the island to the current economic and social challenges of independence, and past responses and attitudes to the volcanic hazard, they all contribute to the situation seen today. Looking at vulnerability in a historical context allows for a more perceptive interpretation of the results of the vulnerability analyses in the previous three chapters, and should be an integral part of any vulnerability study.

Chapter 8: Discussion

8.1. Introduction

Three key gaps identified in the literature shaped the design of the research presented here. First, to investigate the socio-economic vulnerability of a population to volcanic hazards and different stakeholder views in order to inform disaster management that traditionally focuses on physical vulnerability; second, to examine a range of different vulnerabilities to volcanic hazards for one area, including the temporal aspect that is often excluded from vulnerability analyses; and finally, to critically evaluate the models and methods available to measure and analyse those vulnerabilities.

The research questions formulated to address these gaps focused on how the shape of vulnerability changes when different aspects are mapped (physical, social, spatial, historical); whether stakeholder views vary in relation to what makes people vulnerable to volcanic hazards on St. Vincent; and whether there is a minimum threshold or saturation point at which vulnerability can be captured and how appropriate and practical the different models and methods are.

This work continues the trend in volcanology to combine social science methods with the traditional physical based studies, and consider societies when looking at reducing disaster risk. The contribution of this work is that, in contrast to the majority of vulnerability studies of volcanic hazards, it has taken a range of models and methods from the literature, and from different epistemological backgrounds, and analysed vulnerability for the same place. Without this approach it is not possible to determine what the most appropriate method is for analysing vulnerability of one place, or determine whether the different models and methods used are actually capturing the same thing. In addition, by including stakeholders throughout the research, and allowing them to contribute towards the shape of the analyses, the results reflect local views, and not Western scientific opinions.

This chapter first compares and contrasts the four methods used in this research, and discusses data, the usefulness of each method, potential users, and maps as an output for vulnerability analysis. The geography of vulnerability revealed by the different methods is then discussed alongside stakeholder views and the question of whether or not there is a saturation point or minimum threshold at which vulnerability can be captured. The chapter concludes with five key issues in vulnerability research in general, identified through the course of this research, and a critique of the methods and analysis used.

8.2. Comparison of the four methods

Four very different methods for capturing and analysing vulnerability were adopted in this research. One specific gap identified in the literature was that very few studies looked at vulnerability of one place using different methods, models, or approaches. Table 8.1 below compares and contrasts the methods used in this research.

	Elements of vulnerability captured	Data requirements	Availability of data	Spatial scale	Time for data collection	Analysis	Validity of data	Cost
Social vulnerability index	Social, economic, geographic	High: secondary data sources for index	Poor	Census division	Low: census data, high: interviews	Time consuming transcription, quick statistical analysis and mapping	Average: census data is nearly ten years old (2001 publication)	$
Building vulnerability analysis	Building	High: primary data used in this research, however secondary data exists if made available	Very good	Enumeration district	High: survey	Time consuming cataloguing video data, quick mapping	Very good: current data, although only a sample	$$
Stakeholder mental maps	Social, building, geographic	Low: primary data	Excellent	Regional (north south divide)	High: interviews	Quick to digitise and combine maps	Good: problem of language and interpretation of 'vulnerability'	$
Historical vulnerability analysis	Historical (social, cultural, political)	High: secondary data sources	Good	National	Medium: historical document analysis	Time consuming reviewing and compiling historical documents and interview data	Average: heavy bias towards British colonial documents	$

Table 8.1: Comparison of the four methods used to analyse vulnerability to volcanic hazards on St. Vincent.

8.2.1. Elements of vulnerability captured

Each of the four methods captures a range of elements of vulnerability. Social vulnerability includes demographic factors, health and education; economic vulnerability includes wealth; building vulnerability addresses residential structures; geographic vulnerability measures aspects of proximity and access; political vulnerability takes into account broader island issues; and cultural vulnerability includes ingrained traditions and practices e.g. migration and government response to hazards.

8.2.2. Data

"The gathering of accurate, reliable and accessible data to estimate and measure vulnerability is a major problem when dealing with vulnerability assessment at various levels" (Birkmann, 2006b, p.66). Other authors also discuss this as a limitation to vulnerability research (e.g. Chen et al., 2003; Villagran De Leon, 2006). This was also a problem encountered throughout this research. Issues of data requirements, availability, validity and scale are highlighted as limitations of the methods described in Chapters Four to Seven. This section discusses these data issues comparing and contrasting the four methods.

The four methods had very different data requirements and included a mix of primary and secondary data sources. In general, to arrive at a holistic and complete a view of vulnerability as possible, it was necessary to have adequate amounts of data to represent the range of variables identified by stakeholders. Data requirements for the SVI were determined by the variables identified in the first set of interviews and the researcher's aim of mapping vulnerability at as high a resolution as possible. To complete a representative building survey of the island, data on a number of characteristics of the residential building stock were also required. For the mental mapping exercise, data requirements were determined by the number of stakeholders engaged in this research. As St. Vincent is a small island with few professionals working on disaster-related issues, the number of stakeholders, and consequently data required for the mental mapping exercise were low. Out of the four methods, the historical vulnerability analysis required the greatest amount of data in order for it to produce meaningful results. Without adequate documentation of the history of the island, and impacts from and response to previous eruptions, the historical vulnerability analysis would have had limited value.

Data requirements and potential availability were considered prior to each method being utilised. The availability of data sets or interviewees, however, was often a factor that could not be fully determined until the researcher was on St. Vincent and could speak to people in person. Consequently, the SVI in particular was limited in that data previously hoped to be included were unavailable, and no data were available at the scale initially hoped (enumeration district). This led in part to the decision to undertake stakeholder mental mapping in order to collect additional data. In addition, the lack of available secondary data sources to analyse building vulnerability led to the decision to conduct a building survey instead.

The lack of available data at an appropriate scale for a vulnerability analysis is a limitation of working in a less developed country. In the US and New Zealand for example, where a number of volcanic vulnerability analyses have been carried out using quantitative methods (e.g. Boruff, 2005; Boruff and Cutter, 2007; Finnis and Johnston, 2007; Wood, 2007b; Wood and Soulard, 2009), researchers have available census data at suitable scales. In addition, disaster management on St. Vincent is not as coordinated as perhaps in other countries. For example, data from the St. Vincent Statistics Office that were acquired for the SVI in this research had not been made available to NEMO. There are a lot of personal conflicts between departments and limits of budgets, personnel, equipment, etc.. As a result of these data problems future studies in areas with similar limitations to St. Vincent would be wise to adopt additional methods to fill gaps left by inadequate datasets.

The time required for collection of data and analysis also varies between the methods. For this research, arranging, conducting and analysing the interviews for the SVI and mental maps was the most time consuming of the four methods, and this is perhaps a reason vulnerability indices in the past have been undertaken as desk-top exercises, without local stakeholder involvement. Once the transcribing was completed, however, statistical analysis for the vulnerability index and mapping of the results for both the index and mental maps were quick processes. Mapping the results of the building survey was also a quick process, however, as with interviews and historical document analysis, collecting and cataloguing the results of the survey was time consuming.

Up until this point, the four methods vary across the different categories of comparison, in particular when considering data availability. The second major difference is the validity of the datasets. This issue is important in terms of deciding upon how much weight to give the results of each method. In the opinion of the researcher the most valid dataset is that collected in the building survey as it is the most up-to-date. It suffers in that in analysing the videos a number of assumptions have to be made; with available time and resources, however, the subjectivity of the exercise can be lessened and a detailed survey completed. In contrast, the census data used for the SVI are nearly 10 years old, having been published in 2001. Some census categories may still show the same trend today as in 2001, however others have certainly changed. For example, in 2001 the proportion of the population with a mobile phone was less than one percent. From experience of conducting fieldwork since 2007 it became clear that the majority of adults have mobile phones, and the main mobile phone company in the Caribbean – Digicel – is very prominent in the towns and villages. When using census data in this way it is necessary to consider how to fill the gap between collection years. Other datasets exist which collect household data and these could be used to make a vulnerability index. Organisations such as the CDB undertake household poverty surveys, for example, however availability is again an issue in obtaining these data, along with the problems of scale and gaps in collection years.

In addition to the limitations of the census data, the documents used for the historical vulnerability analysis suffered from bias as discussed in Chapter Seven. The majority of documents available were British colonial texts, which given the volatile history of St. Vincent, would certainly present a biased view. Finally, the data collected in the mental mapping exercise is considered to be less valid than initially hoped as there were problems associated with terminology and the understanding of the term ‘vulnerability’. With respect to the interview data collected throughout the research political bias of the participant may also be present.

Despite the data and analysis limitations of components of all the methods, the real advantage of these techniques for data collection and analysis is the cost and equipment required. All datasets used in this research were available free of charge, although appropriate contacts had to be found in order to acquire the data, and access to libraries for historical document analysis was needed. A second advantage is that equipment requirements are low. All statistical analysis and mapping was completed in standard statistics and GIS software packages. While the software used in this research requires a license or charge there are a variety of freely available statistical and GIS packages that could be utilised. The equipment requirements for the mental mapping exercise were crayons and paper maps, and for the building survey, a hand-held GPS, video camera and vehicle. There are sophisticated commercial products available to undertake surveys similar to the building survey in this research, such as VIEWS™ from ImageCat Inc.™., however utilising such commercial products comes at a cost to the user. Any of the four methods described above could be replicated at a relatively low cost and, in the opinion of the researcher this is a real benefit of the approach taken in this research.

8.2.3. Usefulness of method

At the beginning of each of the chapters describing one of the four methods the specific aim of that method was stated and included at the end of the relevant chapters there was a discussion as to whether or not that aim was achieved. Table 8.2 below compares the aims and achievements of each of the four methods and considers the usefulness of each method, and potential end-user.

✓

Method	Aim	Achieved	Usefulness in this research	Potential end-user
Social vulnerability index	Capture social factors of vulnerability normally excluded from volcanic vulnerability analysis. Include stakeholder views of vulnerability	✓✓	Good: need access to more current and complete data sets	St. Vincent NEMO and Red Cross
Building vulnerability analysis	Survey residential building stock and analyse with respect to potential damage and loss of life from pyroclastic flows/surges and tephra	✓	Very good: gives up-to-date overview of residential building stock on St. Vincent	St. Vincent NEMO, Red Cross, Town Planners, Scientists
Stakeholder mental maps	Obtain more detail than available with social vulnerability map. Rid map of arbitrary boundaries, identify what boundaries stakeholders draw	✓✓✓	Good: useful to have map as a prop in interview, however terminology and detail limitations	Red Cross, Community Disaster Groups
Historical vulnerability analysis	Understand construction of vulnerability identified in first three methods		Excellent: allows for a more complete understanding of results from first three methods	Scientists, Academics

Table 8.2: Aims, achievements, usefulness and end-users of methods. Ticks denote the degree to which the aims of each method were achieved.

The historical vulnerability analysis was the most successful of the four methods as it achieved its aims and added a great deal of understanding to the research as a whole. The building vulnerability analysis was also very successful in that it provided data for potential loss calculations and added an extra dimension to the social vulnerability maps. The method for creating the SVI and maps is straightforward and quick to complete, however the usefulness of the results relies on adequate data being available. Consequently this method did not fully achieve the aims set out at the beginning of the research. Finally, the mental mapping method is a useful tool, particularly when incorporated into an interview as having a map as a prop throughout allows the participant to point out places he or she mentions. In this research, however, the method did not fully achieve its aims as the desired level of detail was not obtained from the interviewees, and the problem of terminology brings into question what was actually being drawn – vulnerability or hazard awareness.

8.2.4. Potential end-users

The usefulness of each method and results are evaluated from the point of view of the researcher and usefulness for this research. It is worth considering, however, which methods might be useful to stakeholders on St. Vincent as practical tools to help them analyse vulnerability to volcanic or other natural hazards. The stakeholder groups involved were scientists, emergency managers (NEMO), Red Cross personnel, town planners, and community disaster group members.

It is felt that the social and building vulnerability indices and maps will be the most practical tools for stakeholder groups on St. Vincent, particularly NEMO, the Red Cross and town planners. These two methods provide national level analyses of vulnerability, at the detail of available data, and can help inform where to target specific disaster management measures; for example, in the response stage of disaster management, the social vulnerability maps can be used to show areas where people are less able to evacuate owing to mobility limitations and lack of access to a private vehicle. The building vulnerability maps show areas that might suffer greater levels of damage and require a particular focus in the relief stage of a disaster. This information can also be used to target mitigation measures to reinforce houses prior to an eruption. An added benefit of these two methods lies in the fact that they can be completed with minimal data collection and as a desktop exercise if necessary.

In contrast to NEMO, the Red Cross and town planners, scientists' involvement in issues of disaster management and planning is a grey area. Many scientists believe their role is purely to assess the hazard and present this information to emergency managers to inform their work. One could argue that scientists should not get involved in vulnerability analysis at all, particularly in relation to human vulnerability. In a number of cases, however, scientists have been asked to provide opinions as to how to act on the hazard information provided. On St. Vincent the role of the scientists at the SRC and the SMU is to provide the hazard information, in addition to help educate the public about the hazards and potential risks. Vulnerability information, particularly of the residential building stock, is therefore useful for scientists undertaking this role.

The historical vulnerability analysis is felt to be of most use to academics or off-island researchers who are not necessarily involved in decision-making, but interested in studying particular aspects of vulnerability in the area. Whether it provides a practical tool that would be utilised by NEMO, the Red Cross or town planners is debatable as it is long term in its scope, identifying 'root causes' of vulnerability. Political parties and government organisations are not inclined to attempt to tackle these root causes, but rather look to short term measures that can be implemented during their term in office. Work by Cronin and Neall (2000), however, does suggest that these types of historical vulnerability analyses can be forward-looking and provide information for disaster management, although this is yet to be demonstrated. In addition, scientists may be interested in the historical impacts and response to past eruptions. The process of hazard mapping and determination of the most likely scenario for a future eruption requires historical information on the volcano.

Finally, the mental mapping exercise did not as hoped provide useful results at a local scale, owing to lack of detail. Consequently it is unlikely to be of practical application to national level decision makers. The Red Cross, however, may find this tool useful in conjunction with community disaster groups at a local level. If the method was completed in villages and towns either as a participatory exercise, or completed by individuals, it could provide a great deal of insight as to the vulnerabilities local people identify. In some of the more active community disaster groups this type of exercise is already being completed identifying local hazards.

8.2.5. The geography of vulnerability in relation to volcanic hazards

In Chapters Four to Seven the results of the analysis are discussed and reasons suggested for the patterns of vulnerability revealed by each method. Here, the maps produced by the first three methods are compared and a discussion presented around whether the geography of vulnerability is similar.

Figure 8.1 displays three of the vulnerability maps: relative social vulnerability (without location and isolation factors), relative building vulnerability, and composite stakeholder mental map (including non-residents).

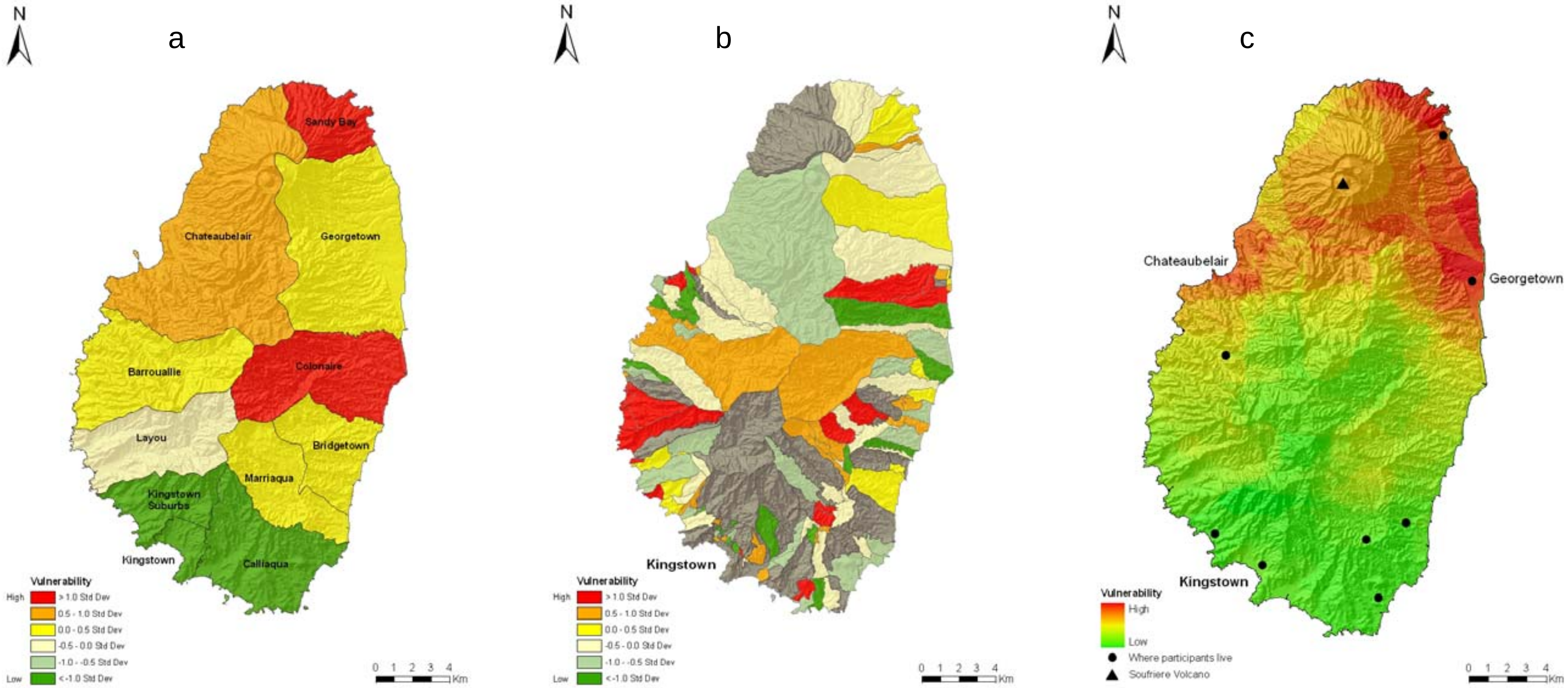


Figure 8.1: Relative social vulnerability (a), relative building vulnerability (b), and composite stakeholder mental map (c).

When considering relative vulnerability, the social map and composite mental map show a similar trend of vulnerability increasing to the north. In the social map, however, high vulnerability extends farther south to the census division of Colonaire than in the composite mental map. If the social map is disaggregated to its original parts (Figure 4.5), it is the proximity and isolation variables that show the same distribution as the composite mental map. This suggests that people are most concerned about proximity to the volcano and geographic barriers as factors contributing to high vulnerability. This in fact measures an aspect of hazard, rather than vulnerability. This perception was also evident in the interviews wherein proximity was the variable mentioned most commonly by participants.

The relative building vulnerability map and composite mental map both highlight areas around three prominent towns as being particularly vulnerable: Chateaubelair in the west, Georgetown in the east, and Sandy Bay in the northeast. Inadequate housing in the north was mentioned by one interviewee, suggesting that building condition was a factor considered in at least one person’s mental map.

The extra detail in the building vulnerability map makes it hard, however, to see any patterns as in the social and mental maps. It is possible to see that the distribution of high and low vulnerability is not the same as in the social map. The socially vulnerable north has average building vulnerability. There are pockets of high building vulnerability in the south of the island in particular, and this trend is not seen in either of the other maps.

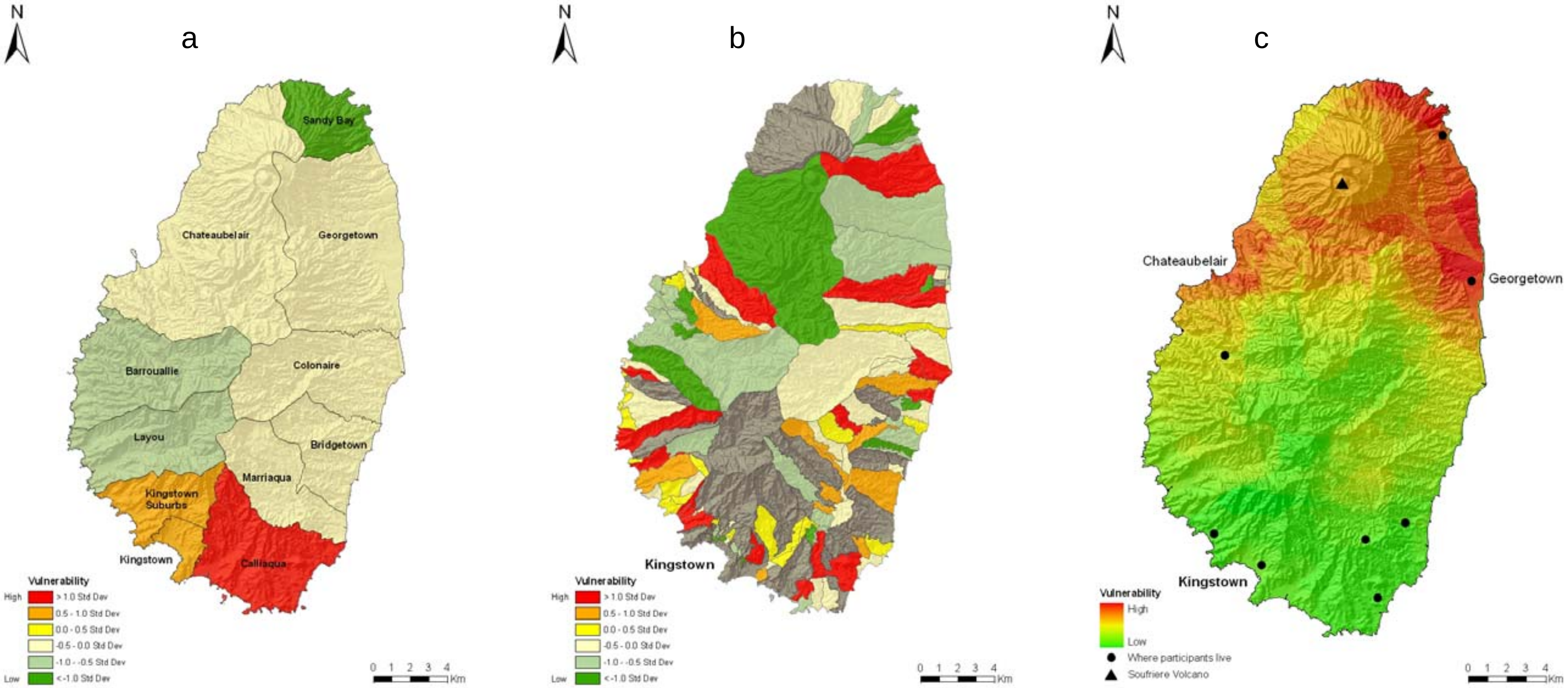


Figure 8.2: Absolute social vulnerability (a), absolute building vulnerability (b), and composite stakeholder mental map (c).

Figure 8.2 displays the composite mental map again with the *absolute* social and building vulnerability maps, i.e. those that take into consideration the total number of vulnerable people and buildings in each district. When absolute vulnerability is considered the social map and composite mental map are almost mirror opposites. High social vulnerability is in the south as these are the areas of high population. This suggests that when drawing mental maps of vulnerability stakeholders are considering relative vulnerability and including hazard-dependant factors such as proximity and geographic isolation.

The social and building vulnerability maps have one factor in common; more weight is given to areas of high population or high household numbers. There are more red high building vulnerability areas in the south when absolute vulnerability is mapped, and social vulnerability is now high in the south. If the social map contained more detail it might reveal a similar pattern to that of building vulnerability.

The absolute building vulnerability map again highlights areas around the towns of Chateaubelair, Georgetown and Sandy Bay as being most vulnerable. In this way it is similar to the composite mental map where people specifically coloured these three towns as areas of high vulnerability.

Overall, the geography of vulnerability does change when different elements are mapped, although there are some similarities. Relative social vulnerability is high in the north, mirroring local views. Building vulnerability varies across the island, with no real pattern emerging, although some main settlements are identified as being most vulnerable. More detail in the social vulnerability maps would allow for a better comparison between the two. On the whole it appears that high levels of social and building vulnerability do not occur in the same areas and stakeholder views on vulnerability focus on geographic hazard-related factors such as proximity and isolation and areas with large populations.

8.2.6. Differences between stakeholder views

One of the research questions proposed in Chapter Three addressed the issue of whether or not different stakeholder groups had differing views of vulnerability to volcanic hazards. This question was formulated in response to the wide variety of vulnerability definitions in the literature and the range of methods to measure vulnerability from different disciplines. Two of the four methods revealed stakeholder views of vulnerability: interviews for the SVI and the mental maps. The difference between stakeholder mental maps is discussed in Chapter Six. Overall, there was not a great deal of variation of where vulnerable people and places were located by the stakeholders. The difference was in the amount of detail and area that each mental map covered.

The interviews conducted in order to create the SVI did reveal a difference in stakeholder views. Table 8.3 below lists vulnerability variables identified by each stakeholder group and the number of interviewees that mentioned that variable. The table includes participants from both St. Vincent and Dominica. Out of the 18 people interviewed on the two islands, 15 discussed variables which they thought made people vulnerable to volcanic hazards on their island.

	Scientist (1)	Red Cross (2)	Emergency managers (3)	Town planner (1)	Community group members and local government employees (8)
Proximity	x	xx	xxx	x	xxxxxx
Poverty	x	x	xx		xx
Dependants	x		xx		xxxx
Disabled	x		x		xxxx
Livelihoods	x		xx	x	x
Transport			xx		xx
Access		x	xx	x	
Health			xx		x
Education		x			x

Table 8.3: Vulnerability variables identified by stakeholders on St. Vincent and Dominica during semi-structured interviews. The number in brackets is the number of that stakeholder group interviewed during the first fieldwork.

Table 8.3 shows that emergency managers and community leaders involved in disaster work have a broader interpretation of what makes people vulnerable to volcanic hazards compared with Red Cross personnel, the town planner and scientist. Community group members and local government workers did not highlight geographic access as a problem when considering vulnerability. Perhaps this is because they are concerned with a smaller geographic area, rather than considering the national picture. It is worth noting that the mental maps produced by community disaster group members from St. Vincent had a narrower focus than the range of factors identified in the interviews. Of the eight people represented in this group, only one was re-interviewed using the mental mapping technique. That participant's mental map was the most complete of the three produced (Figure 6.11). There is a broad spectrum of people from different backgrounds involved in community disaster groups, and therefore there will be variation in results depending on which people are interviewed.

In addition to the community disaster group and local government members, the emergency managers also identified eight vulnerability variables. This reflects their participation in all aspects of the disaster management cycle from response to relief, mitigation and preparedness. Interestingly, though, of the nine social vulnerability variables identified in this research, the one not mentioned by emergency managers was education. This is despite emergency managers being responsible for hazard and risk education to the public.

The two members of the Red Cross that were interviewed presented a narrow view of vulnerability. The Red Cross member from St. Vincent only discussed vulnerability as a result of proximity. The member from Dominica discussed education, poverty and geographic access as well as proximity. The Red Cross on Dominica are involved in conducting community vulnerability and capacity assessments. On St. Vincent they are involved in community education and planning for a hazard event in addition to practicing evacuation. This narrow view of vulnerability presented by these two participants is not representative of the Red Cross as a whole, but perhaps reflects individual opinions, and the fact that the strategy of the Red Cross and the community work conducted on both islands is to allow the communities themselves to identify their own vulnerabilities.

The local scientist from St. Vincent identified four of what are considered standard vulnerability variables to do with poverty, livelihoods, dependants and disability. In addition, proximity to the volcano was mentioned. This view is in contrast to the physical science background of the participant and shows that they have a broader understanding of vulnerability than purely exposure to the hazard and the vulnerability of the buildings.

Finally, the town planner presented a narrow view of vulnerability, specifying just three of the nine social vulnerability variables used in this research. Two of those three factors were proximity and geographic access which reflects the planning background. Economic vulnerability of livelihoods such as agriculture was also identified as being important, and this was drawn as a second mental map during the second round of interviews.

To return to the research question on stakeholder views, the answer is yes, views do vary considerably in what is thought to make people vulnerable to volcanic hazards. The semi-structured interviews revealed this pattern more than the mental mapping exercise. However, a few core variables are generally agreed upon. These are vulnerability as proximity to the volcano, poverty, dependants, disability and livelihoods. The difference is in the detail reflecting different roles and opinions. A positive sign is that stakeholders agreed that people were vulnerable to the volcano, and on the whole, not just because they were exposed to the hazard or lived in vulnerable buildings. This hopefully means that if all stakeholders are on the same page to begin with, working together to reduce vulnerability and risk to disasters should be effective in the future, as they at least agree on the basic concept of what makes people vulnerable (Buckle, 2000).

8.2.7. A minimum threshold for vulnerability analysis

One contribution of this research to the literature on vulnerability analyses is that by completing four different methods for analysing vulnerability of the same place it is possible to compare and contrast the results. As discussed above there are some similarities between the maps however on the whole they are not revealing the same distribution of vulnerability. This is in part because they are measuring combinations of different things. The social vulnerability map captures issues of social, economic and geographic vulnerability. The building vulnerability map addresses the residential building stock. The mental maps capture aspects of social, building and geographic vulnerability.

What does the fact that the maps reveal different patterns of vulnerability tell us? First, being vulnerable in one category does not necessarily make you vulnerable in another. For example, just because you live in a building that has been identified as being particularly vulnerable to tephra fall does not mean you are also vulnerable because of your social status. There will always be examples of where households or communities are vulnerable in a number of ways. However, without analysing and mapping different aspects of vulnerability one would not know what makes that household or area vulnerable, and consequently not know how to target that specific vulnerability to reduce risk.

This leads onto a second point; the need for simplicity. If one would try and incorporate all aspects of vulnerability covered in this research into one map the results would be convoluted and uninformative. The researcher would also argue that this reinforces the need for a number of models and methods for analysing vulnerability. It is inappropriate to try and capture all aspects of vulnerability in one analysis or map, and one model and method are unable to do so. In order for vulnerability and risk reducing measures to be targeted efficiently, it is necessary to identify the different aspects of vulnerability of interest, and measure them separately. Consequently, in the example of St. Vincent, there is no minimum threshold at which a vulnerability analysis could be completed using only one model and method.

The fact that no single map of vulnerability was the same means that it is necessary to complete all the methods in order to gain as holistic a view of the situation as possible. If, for example, the mental mapping exercise had revealed the same pattern of vulnerability as one or all of the other maps, this could have been the only method necessary to adopt and would save on data limitation issues discussed above. It might have been possible, for example, to adopt an expert elicitation type approach in which a group of experts are questioned on their views about vulnerability on the island. Indeed Schmidtlein et al. (2008) suggest getting experts to draw maps of vulnerability in order to validate the results of a vulnerability index construction and map. What the results of these stakeholder mental maps have suggested is that proximity and access are variables of vulnerability that stakeholders consider important and that the relative vulnerability method of index construction is the most appropriate. For a detailed comparison between expert maps and those constructed from a vulnerability index to be possible one would have to ask experts to colour in the same areal units as those mapped with an index.

Historical vulnerability has not been mentioned so far as there was no spatial map to compare with the output of the other three methods. What the historical vulnerability analysis *has* revealed is the influence all the different aspects of vulnerability identified in this research have had in the past. Consequently it is recommended that a complete historical vulnerability analysis is always undertaken where possible as it provides extra information with which to analyse and understand the results of the more contemporary-focused quantitative methods.

8.3. Key issues

Through reviewing the literature on vulnerability definitions, models and methods of analysis and with evidence generated from this research, a number of key issues arise as to the most appropriate way to analyse vulnerability, and some general challenges become apparent. These are quantitative or qualitative methods; relative or absolute vulnerability; hazard specific or multi-hazard vulnerability; maps as a useful tool; and the problem of terminology. Each of these is discussed in the following sections.

8.3.1. Quantitative or qualitative methods

The majority of studies that measure vulnerability do so using either quantitative or qualitative methods; rarely are these two approaches combined. The choice may be dictated by the discipline of the researcher (engineering or social science for example), methods of data collection and analysis familiar to the researcher, data available, and objectives of the study. The research presented here initially began quantifying vulnerability through the creation of a SVI based on secondary data. Qualitative techniques were used to provide the inputs to the index; however quantitative methods could also have been adopted for this purpose. The inability of this quantitative index method to capture all aspects of vulnerability identified as important to the stakeholders meant that qualitative techniques were necessary to fill the gaps.

What this research has shown is that through a combination of both quantitative and qualitative methods, a holistic view of vulnerability can be achieved. Different methods of data analysis may be more appropriate for different user needs. For example, at the national level, a detailed quantitatively derived index and map may be suitable to provide an overview of vulnerability across the island. The advantage to a quantitative method such as this is that with appropriate data available, results can be quickly updated over time. Qualitative methods of data collection and analysis often require more time on the part of the researcher, and rely on participation of stakeholders. Results may provide more insight into local dynamics relating to vulnerability and volcanic hazards, and may give ownership of the results to the stakeholders; however difficulties arise in dealing with relationships between stakeholders, terminology and the logistics of collecting data.

8.3.2. Relative or absolute vulnerability

A second key issue emerges as to whether one calculates relative or absolute vulnerability if a quantitative method for data collection and analysis is carried out. The differences between the results of adopting these two approaches are discussed in Chapter Four on social vulnerability and Chapter Five on building vulnerability. Calculating relative vulnerability highlights areas that experience high vulnerability when compared to an island average. If absolute vulnerability is calculated the emphasis is on areas with the greatest number of vulnerable people, not necessarily the most vulnerable. Surprisingly, in the literature on quantifying vulnerability with indices there is little discussion on which approach is most appropriate.

All the indices reviewed in Section 4.1 measuring social aspects of vulnerability – DRI, World Bank Hotspots, IADB indicators of disaster risk and risk management, and SoVI –measure relative vulnerability, which is useful when comparing vulnerability at a regional or global scale. Absolute vulnerability calculations, in contrast, focus on areas of high population, large number of households, or large economic wealth. Wood (2007), Wood et al. (2007) and Wood and Soulard (2009) calculate metrics similar to these here in that they compare a community's total number of people or assets exposed to a hazard with the proportion of that community's people or assets exposed. Calculating these different metrics produces very different results. In terms of looking at the costs or potential costs of disasters, absolute measurements would underemphasise the impact on developing countries with a small economy, for example. If, however, on a small island such as St. Vincent, resources are limited and need to be targeted efficiently, the goal may be to reduce the vulnerability of the greatest number of people, in which case absolute measurements may be more appropriate.

8.3.3. Hazard specific or multi-hazard vulnerability

The research into vulnerability described in this thesis is specifically focused on analysing vulnerability to *volcanic* hazards. Methods described in the literature, however, often take a multi-hazard approach (see Birkmann, 2006c for examples). Birkmann (2006a) discusses the hazard specific versus hazard-independent focus and suggests that there is a need for more work investigating how to combine hazard dependent and hazard independent indicators. Weichselgartner (2001) in his paper on revisiting the concept of vulnerability, and taking a ‘hazard of place’ type approach similar to Cutter (1996), suggests mapping multi-hazard vulnerabilities separately and then overlaying them to interpret the results.

Conversely, some researchers emphasise how vulnerability is hazard specific. For instance, Wisner et al. (2004, p.35) state that vulnerability *“is integrally linked with the hazard events to which people are exposed”*. A homeless person in Tokyo might be vulnerable to extreme winter weather and typhoons because of their exposure; however they are less vulnerable to earthquakes as they are less likely to be exposed to building collapse (Wisner, 2004). Consequently, are multi-hazard vulnerability analyses appropriate? Representatives of the Asian Disaster Reduction Centre at the United Nations University expert working group meeting on ‘Measuring Vulnerability’ in 2005 recommended that disaster indicators that included data on vulnerability should be constructed according to a specific disaster type (Birkmann, 2005).

Birkmann (2006a) also discusses the need to consider ‘hazard nesting’ which refers to a situation whereby one hazard event results in multiple secondary hazard effects. He argues that often the primary hazard is the only one analysed with respect to vulnerability. The concept of hazard nesting is particularly relevant to volcanic eruptions which could be considered multi-hazard themselves, in that they produce a range of effects from primary pyroclastic flows and surges, ballistics and tephra, to secondary hazards of lahars. The way a building responds to tephra versus pyroclastic flows and surges versus lahars are different. The approach taken in this research was to analyse the vulnerability of buildings to each hazard separately and then combine for interpretation, as recommended by Weichselgartner (2001).

If one started overlaying the vulnerability for a large number of hazards, however, it is this researcher's opinion that the results would become overly complicated and not reveal any useful patterns that could guide risk reducing strategies. Therefore, it may be worth limiting vulnerability evaluation to one hazard mechanism such as a volcanic eruption, and analyse the range of primary and secondary hazard effects and associated vulnerabilities from that mechanism. Structures will respond differently to different hazards, as would livelihoods (for example agriculture might not be affected in an earthquake) and the proximity factor which was of most concern to the stakeholders on St. Vincent would alter depending on the hazard.

8.3.4. Usefulness of maps and GIS as a tool for vulnerability analysis

The outputs produced by three of the four methods for vulnerability analysis are maps. This is standard practice for visualising vulnerability, and seen in a number of the vulnerability analyses reviewed in this research (e.g. Spence et al., 2005b; Boruff and Cutter, 2007). Whether maps or GIS-based scenarios are the most appropriate decision making tools, however, is rarely elaborated on. For example, Thouret (1999) discusses how GIS-based scenarios can be useful tools for civil authorities for mitigation and preparedness, and Chardon (1999) states that one of the 'major objectives' of her study of vulnerability mapping in Manizales, Colombia is to *"elaborate a tool to help in decision-making"* (p.211). Neither of these studies discusses explicitly whether or not these decision-making tools are understood and used effectively.

This research aimed to engage stakeholders throughout. It is recognised that the use of maps relates to the culture and working practice of the study area. Consequently a section of the interview guide used during the first fieldwork was aimed at revealing whether maps were used in the everyday work of the interviewee, and for what purpose. What the research showed was that maps were available to stakeholders, but were not utilised fully, with many people relying on local knowledge. In addition, GIS was not utilised due to lack of staff resources and inter-departmental integration. Issues of updating maps were also raised. Stakeholders commented that some of the hazard maps they used were created over 20 years ago and had never been updated. In addition, it was recognised that local community hazard maps needed updating overtime, however stakeholders did not have the time to work with the communities to aid in this process.

Maps were used for two main purposes – town planning and community work. On both Dominica and St. Vincent the town planners said they used hazard maps, especially as over time evidence of the hazard event (such as a landslide) may not be immediately obvious:

> *"A map, or maps, are the basic tools with which planners work….We welcome them, you know, because what they do is really inform our processes." (St. Vincent town planner)*

The local scientist on St. Vincent also said she used hazard maps to help planning:

> *"For instance we have the DeGraph landslide hazard map, that I use, generally, for planning, for planning purposes." (St. Vincent local scientist)*

The second use of maps identified was for local community mapping of hazards and vulnerabilities. This work is carried out in the communities with the help of the Red Cross and the emergency management office:

> *"We do programs with communities, we do VCAs, vulnerability capacity assessments, mapping of these communities. What we have done in the past is to use maps from Lands and Survey, blow them up a bit, and manually input the various hazards for that community on the maps…. We don't do any computerized mapping at present, so really it's manually inputting the information on the maps we get from Land and Surveys." (Director, Dominica Red Cross)*

> *"In terms of making maps, the communities are small and people know their areas. They know where the special needs groups are located. They would use maps perhaps for schools and for informing new members." (notes on interview with Dominica District Disaster Officer)*

Similar community mapping occurs on St. Vincent as well as Dominica. The President of the Red Cross on St. Vincent emphasised, however, how they use local knowledge instead of maps:

> *"No we don't need, we don't need a map. Because we do things from a more practical standpoint. A map is for people like you [outsider] who want to go elsewhere so you can relate it to what happens here." (President, St. Vincent Red Cross)*

GIS systems or maps were rarely used on St. Vincent or Dominica as a part of emergency management. On St. Vincent, recognising the importance of GIS and integrating its use between government departments, an international consultant team was employed to create a national land mapping database (called NALIMP). The aim was to collect all digital data from various departments, project everything into a common spatial projection, and train staff from different departments on the use of GIS. The project was completed and the researcher attended the awards ceremony and presentation in 2007 demonstrating how GIS could be used on St. Vincent. Although the project was presented as being a success, there were still problems with the implementation of the national GIS, in particular for NEMO. NEMO's offices were not networked onto the government system to access the data, and they were not included on the presentation leaflet as a stakeholder:

> *"But if you look at the printout [NALIMP presentation] they still didn't have NEMO on the invitation thing, so they still didn't have NEMO as one of the stakeholders. A lot of people still don't recognize the importance of having NEMO. It's not about disaster…its not about hurricanes only, they are not seeing the bigger picture." (Deputy Director, NEMO)*

GIS-based resources were not available to other stakeholders on St. Vincent. For example the local scientist who has GIS training from the University of the West Indies in Jamaica was asked whether she used GIS or digital maps in her work:

> *"[I use] mainly the paper versions [maps]. I have a lack of resources, so I use mainly the paper versions." (St. Vincent local scientist)*

GIS maps were not often used by NEMO either:

> *"not much interaction in terms of the GIS maps but regular maps in terms of determining areas, and plotting which areas that we have problems…that's about it. Normal topography maps." (Deputy Director, NEMO)*

In 2008, 16 months after the national GIS had been implemented, it was found to be poorly utilised. A town planner on St. Vincent said that government departments continued to work independently of each other, with no integration of data or software. For example a number of individual software licenses had been purchased for different departments which was not efficient as it meant the software could only be used on one computer and not networked throughout the government. Staff resources were also insufficient, which was a key reason why the researcher was not able to get access to the GIS database as no one was available to assist.

A final issue raised by interviewees was that of updating maps. It was recognised that at both the national and community level, maps needed to be updated on a regular basis in order for them to be useful:

> *"It's a question really of the communities if something new comes up for them to update it themselves. But, we don't always have the resources to come back and to, you know, review the maps for them." (Director, Dominica Red Cross)*

> *"Well, the landslide map has never been updated…since 1988… But, we're trying to see how we can get it updated because we realise that it needs to be updated." (St. Vincent local scientist)*

In summary, any vulnerability maps produced by this research may be utilised by stakeholders on the island. The impression, however, is that they rely primarily on local knowledge. As this research is focused on *methods* for conducting vulnerability analysis, and not just the output, what it suggests is that the participatory mental mapping approach may be most useful for local communities in identifying vulnerability. If available, GIS software could be used to combine these data for national level overview. Any method for vulnerability analysis (social or building) utilising GIS would only be successful if resources improved, and the researcher does not envisage this happening in the near future. St. Vincent recognises the value of GIS software and techniques, however without the necessary staff and inter-departmental collaboration (for example between the Statistics Office with the census data and NEMO who wish to conduct vulnerability analyses) the value will not be realised.

Consequently, future studies of vulnerability analysis producing maps and GIS-based tools as outputs need to take into account the characteristics of the study area. Technology focused methods may not be appropriate in developing countries without a dedicated person to drive it. Paper-based maps, local knowledge and participatory techniques may be more suitable for some countries. The value of the maps produced in this research, however, is that they can be compared and contrasted and used to appraise the usefulness and appropriateness of each method at the end of the research. Vulnerability maps may also be of use for local and regional scientists involved in volcanic hazard monitoring and risk assessment.

8.3.5. Terminology

Throughout the previous chapters the problem of terminology, in particular how to define vulnerability has been stated. Terminology is not a problem restricted to this research; it has been highlighted as a particular obstacle for interdisciplinary research in general (Bracken and Oughton, 2006). In their assessment of the importance of language in interdisciplinary research, Bracken and Oughton (2006) identify three overlapping aspects which play an important role – metaphors, articulation and dialects.

Metaphors were not a problem encountered in this research. Articulation and dialect were. Acknowledging that there are a variety of different definitions of the word ‘vulnerability’, the researcher sought stakeholder views of the term, rather than pick a definition from a specific discipline. Stakeholders had difficulty articulating what they meant by the word ‘vulnerability’. For example:

> *“Vulnerability to me is the....the erm.....[pause]...it’s like the....how prone the person or the location is to being affected by a hazard.” (St. Vincent local scientist)*

> *“Oh vulnerability…ohhhh…[pause]…my mind just went blank! [laughs]. It’s basically…like vulnerability to me is those persons and facilities or whatever that can actually have impact by any hazard. Impact on environment, on people living in particular areas, by hazard events.” (Deputy Director, NEMO)*

Articulation of other words was a problem as well:

> *"Risk? That one kinda always ties me up!" (St. Vincent local scientist)*

The main terminology problem encountered was a dialect one, where different disciplines use the same word to mean different things, in addition to differences between expert and everyday use of the word. This is evident by the range of vulnerability definitions in the literature. As previously stated, recognising that this was a problem, the research sought stakeholder views of the word.

Furthermore, there was stakeholder confusion over the meaning of the words hazard, vulnerability and risk. The interview questions specifically asked how interviewees thought about each term, and the differences between them. It was clear from the responses that people first had problems articulating their definitions of the words, and second used them interchangeably:

> *"I have always had some contention, which is the risk and which is the hazard." (St. Vincent town planner)*

> *"Basically you look at hazards in a sense these are things that present risk. [laughs] You see the words I use interchangeably." (Dominica Local Government Commissioner)*

A final terminology problem involved the communication of these terms to the public. The majority of the stakeholders participating in this research are involved in community education about hazards and risks. A number of them stated that they thought the word 'vulnerability' in particular was too confusing for communities, and that they stick with hazard and risk, or which areas are dangerous:

> *"When you're doing, when you're working along with communities…it is not the best thing to be telling them…giving them all of these…terms. Okay. We try to avoid it. You speak to them, you tell them what it is, you get*

> *them to understand what it is, but what is more important to them…practical. Something happens…get out. If you get a warning signal…get out….Because if you're telling them, if you find it difficult even in training too, get them to understand vulnerability, risk and all of that. Okay. And if you start giving them equations and how you…vulnerability and risk and all of that it gets complicated." (President, St. Vincent Red Cross)*

> *"Basically as you were saying, vulnerability, I would probably have a different idea of what that is, compared to what people will give you. I think that's one of the problems with talking about this, because we've got these very specific terms, but most people what they want to do is, want to know, can be pretty much summarised between hazard and risk. Basically, something can happen or can I be affected by something. So that's a term [vulnerability] I don't use for that particular reason…I want the people to remember two things. One is actually what may happen, the other one is literally whether we have people around that might be affected. That's for communication with people. Because it confuses everybody including myself." (SRC scientist)*

With these different terminology problems in interdisciplinary research in general, and specifically using the words vulnerability, hazard and risk, it is necessary to articulate at the beginning what is referred to with each word, and how they are going to be used. If, as in this research, stakeholder participation is sought, it pays to get stakeholders to define the terms for the research in order for the results to be appropriate and comprehensible to all the users.

8.3.6. Summary

These five key issues were raised as a result of this work and not identified as specific research aims at the beginning of the thesis and are not discussed in any great detail in the current literature. The questions are related to *practical* issues of how to best go about conducting a vulnerability analysis, and in the opinion of the researcher they are important topics that require further work if the field of vulnerability analysis is to advance.

8.4. Critique of work

Chapters Four to Seven critiqued the particular method presented and identified the limitations in the work. There are four broader points of criticism of the work as a whole that will be discussed in this section: scale, both spatial and temporal, capacities and resilience, and uncertainty.

8.4.1. Spatial scale

The work completed here was at a national, island-wide scale, identifying the distribution of vulnerability across St. Vincent as a whole, and the differences between regions on the island. Limitations of data availability determined that the scale of aggregation for the SVI in particular was very coarse. The building vulnerability analysis was mapped with a finer resolution. Community-based participatory approaches for vulnerability analysis, however, may give richer data identifying specific local needs. Despite reservations of some of the stakeholders around using the word vulnerability with communities, many non-governmental organisations conduct successful community-based vulnerability and capacity assessments. This research has presented a national picture of vulnerability. Further work at a local community scale could complement the results presented here.

8.4.2. Timescale

This research looked specifically at vulnerability to volcanic hazards, centred upon a hazard scenario presented by the SRC in the Volcanic Hazard Atlas of the Lesser Antilles (Robertson, 2005). The historical vulnerability analysis investigated how vulnerability had evolved over time. The remaining three methods presented a snapshot in time given this future volcanic hazard scenario and consequently present a short term perspective. The building vulnerability analysis addressed the impacts from pyroclastic flows, surges and tephra fall. These are primary hazards occurring during an eruption. It is also necessary to consider vulnerability to secondary hazards such as lahars. Months and even years after an eruption, heavy rainfall can remobilise ash and produce lahars down the slopes of the volcano. Evidence from Mount Pinatubo in the Philippines and Merapi volcano in Indonesia in particular demonstrates how destructive these lahars can be. After the 1991 eruption of Mount Pinatubo for example, rain-generated lahars occurred every year for the remainder of that decade. The eruption and subsequent lahars forced the evacuation of over 40,000 families (Leone and Gaillard, 1999). On the slopes of Merapi volcano in Indonesia a total of 34 people were killed by rain-generated lahars in 1974 and 1976. A study after the 1994 eruption showed that around 13,000 people are at risk from lahars in the main city of Yogyakarta (Lavigne, 1999a). On St. Vincent, more detailed hazard mapping of potential lahar routes is required in order to fully assess the long term vulnerability of the population living in those areas.

The social vulnerability variables dealt with a range of issues. A number were to do with a person's ability to evacuate from their homes given an eruption. Again, this is a very short term focus. The remaining vulnerability variables were demographic characteristics such as age and disability which might increase a person's likelihood to suffer loss during and after an eruption. In addition, economic characteristics regarding a household's wealth were analysed, which might decrease that household's ability to recover after an eruption. The demographic and economic characteristics could be used to investigate vulnerability on a longer time scale, in particular to track how the specific vulnerability of a community or household has increased or decreased (for example, see Cutter and Finch (2008) who present an analysis of temporal and spatial changes in social vulnerability to natural hazards in the US from 1960 to present, using the VoP model of vulnerability and the SoVI). Overall, however, the analysis presented here provides insight into the development of vulnerability over the past centuries, and a short term analysis of the potential immediate impacts following a volcanic eruption producing pyroclastic flows, surges and tephra.

8.4.3. Capacities and resilience

A further criticism of the work presented here lies in the fact that investigating vulnerability only tells half the story; capacity to cope and resilience also need to be analysed in order to fully understand how a person, household or community will be impacted and recover from a hazard event. Traditionally, anthropologists have looked at aspects of capacity and resilience:

> *"Although nonanthropological disaster research has generally portrayed traditional societies as vulnerable and unable to cope, more or less fatalistically living under a continual reign of terror from the environment, anthropology has demonstrated the resilient and adaptive capacities with which traditional peoples respond." (Oliver-Smith, 1996, p.312)*

Other disciplines are now addressing resilience and capacity to natural hazards, building on the foundations of the vulnerability paradigm of disaster research. As Mercer et al. (2007, p.246) state *"there is currently evidence of a steady movement away from an era of 'vulnerability'…terms such as 'resilience' and 'coping capacity' are now being used."*

As with vulnerability, the terms resilience and coping capacity are difficult to define. Gaillard (2007) discusses the term resilience and reviews a number of definitions. These include resilience as a component of vulnerability (see also McEntire, 2001); resilience as the flip-side to vulnerability; resilience as the capacity to absorb losses and recover; and the ISDR definition of resilience as the capacity of a system, community or society to resist change. In Thywissen's (2006) glossary on components of risk, there are nine definitions of capacity and 14 of resilience. In the same way that the definition of vulnerability varies between disciplines, so do those of capacity and resilience. Consequently, if these were to have been included in this research it would have required further exploration into how stakeholders think about and use the terms, and what models or frameworks are used to conceptualise them.

Capacity to cope was mentioned by five of the participants in the first round of interviews. Often the phrase was used to describe the opposite of vulnerability, i.e. poor versus wealthy:

> *"Because you can't speak about vulnerability unless you speak about your capacity to be able to respond or to cope. Because if you do have a lot of money, or you do have a lot of resources then the person who has that who lives in the same place as a poor person is not necessarily as vulnerable." (Director, NEMO)*

Given the difficulty defining and understanding vulnerability and the terminology problem with stakeholders, including two more terms would increase the complexity of this research. As a result, capacities were excluded from the SVI. In part due to the confusion in how to define and use the term, but also as when used by stakeholders it was often referring to the flip-side of a vulnerability factor already being measured. Indeed Cutter et al. (2008) list a range of potential indicators of resilience to natural hazards and many are the same as common indicators of vulnerability, including those used in the research presented here (e.g. demographics, health, employment, wealth, and building stock).

Despite the exclusion of the terms in this research, the trend identified by Mercer et al. (2007) of a movement away from vulnerability to recognising the capacities and resilience of the population at risk is evident in the volcanology literature. Work, particularly in New Zealand, has focused on identifying predictors of vulnerability and resilience to volcanic hazards (Miller et al., 1999; Paton et al., 2000; Paton and Johnston, 2001; Paton et al., 2001; Finnis and Johnston, 2007). Also included are psychological aspects of vulnerability and resilience such as self-efficacy, coping-style and sense of community.

Although these terms were not included in this research, the methods adopted to capture vulnerability are equally as applicable to analysing factors of resilience and capacity. It would be interesting to see what factors stakeholders identified as making people resilient to volcanic hazards, and what their mental maps of resilience and capacities would look like.

8.4.4. Uncertainty

A final broader critique of the work presented in this thesis regards the problem of uncertainty. Uncertainty is a term with various meanings depending on the discipline of the researcher. In the context of this research the problem of uncertainty lies in the fact that the vulnerability maps and analyses presented here are *representations* of the Earth's surface, where decisions have been made about what is represented (vulnerability) and how. Linked to this is the question of who chooses the type and method of representation. People perceive space in different ways and assign labels differently. These representations are incomplete and hence uncertain (Longley et al., 2005).

A useful conceptual view of uncertainty is provided by Longley et al. (2005) (Figure 8.3):

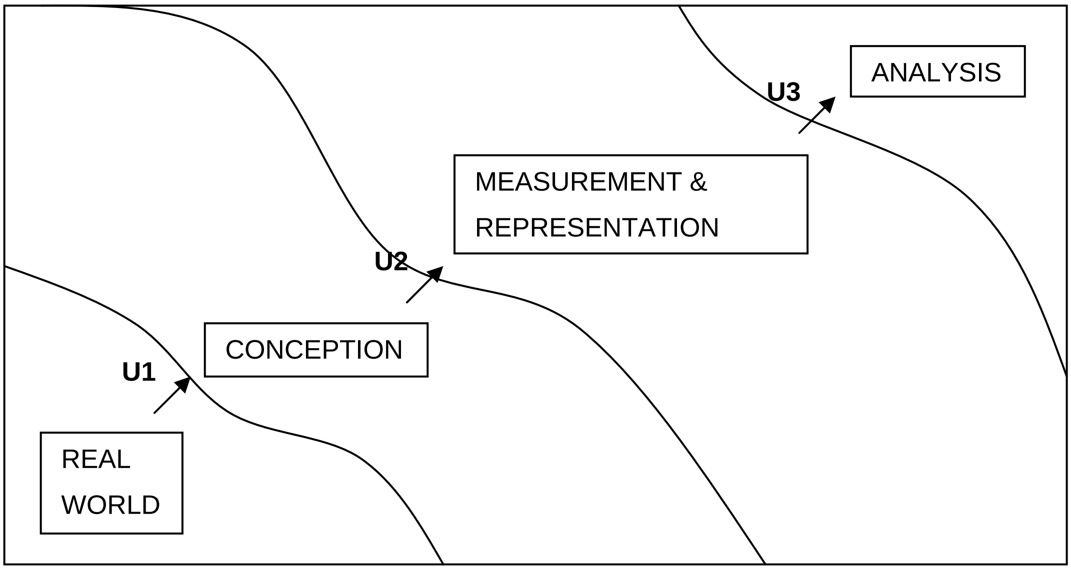


Figure 8.3: A conceptual view of uncertainty. The three filters, U1, U2, and U3 can distort the way in which the complexity of the real world is conceived, measured and represented, and analysed in a cumulative way. (Reproduced from Longley et al. 2005, p.129).

The first level of uncertainty arises out of the way people conceive the real world. *"The way in which we conceive of a geographic phenomenon very much prescribes the way in which we are likely to set about measuring and representing it"* (Longley et al., 2005, p.129). Longley et al. (2005) discuss two types of uncertainty at this stage: ambiguity and vagueness. Ambiguity refers to the way in which an object, term, etc., can be interpreted in more than one way. This was discussed as a problem related to terminology in Section 8.3.5, and is also an issue when choosing indirect indicators of vulnerability for the SVI. The variables chosen as proxies for vulnerability are not direct measures, rather the best available measure with a perceived link to the phenomenon of interest. The conception of that linkage is subjective and hence ambiguous. Different researchers may choose different indicators and if the correspondence is imperfect it can lead to systemic measurement errors.

Vagueness refers to when the extent or characteristic of an object, term, etc., is unclear. It is less of a problem in this research as the boundary extents with which social and building vulnerability was mapped were predefined by the census data. However, the locations of objects on the output maps may be considered vague. For example, Soufrière volcano is represented as a point on each map, but what is the extent of the volcano – summit, crater, flanks – and how should it be represented? The extent of the volcanic hazard zones in Figure 3.5 are also vague in that a subjective decision was made to define the boundaries between hazards, whereas in reality it is not known where 10cm of ash, for example, will be deposited.

The second ‘filter’ that can create uncertainty refers to measurement and representation. Potential errors and therefore uncertainty in the measurement of vulnerability are discussed in the relevant chapters (e.g. out of date census, limitations in recording building stock on St. Vincent). The sensitivity of the results to the method of calculating various vulnerability parameters is also explored in the sensitivity testing described in Section 4.4.3 and the alternative loss calculations in Section 5.4.4. In addition the representation of lahars, for example, is generalised and therefore uncertain as to where that hazard will go.

The final filter refers to uncertainty in the analysis of geographic phenomena. Of particular relevance to this research are the limitations of census data known as the modifiable areal unit problem and the ecological fallacy. These are problems associated with the spatial analysis and mapping used in this research. These limitations are also discussed by Schmidtlein et al. (2008) in a sensitivity analysis of the SoVI. The *modifiable areal unit problem* refers to how different aggregations of spatial data, such as census boundaries, may lead to changes in the mapped results (O’Sullivan and Unwin, 2003). This research used census divisions for the social vulnerability maps and enumeration districts for the building vulnerability maps. These are aggregations of data collected at the household level. Were the households to be grouped into different areas the results from the vulnerability analyses may have been different.

In addition, the vulnerability boundaries are arbitrary; vulnerability does not change abruptly as illustrated on the maps.

A more general statistical problem that is related to the modifiable areal unit problem is the *ecological fallacy* (O'Sullivan and Unwin, 2003). This states that a statistical relationship observed at one level of aggregation may not hold for a different level of aggregation. Therefore the results from this research are only valid at the level at which they are presented, and assumptions about a particular town, for example, cannot be made based on the broad scale vulnerability maps. As a consequence, when considering the vulnerability maps as an output they can give a false sense of the picture. For example, much of St. Vincent is uninhabited; populations are concentrated along the coasts, in particular in the south of the island. The very large census division of Chateaubelair is calculated as having very high (red) social vulnerability and on the map, owing to its size, appears to be a particularly vulnerable area (Figure 4.6). In reality, however, few people live in Chateaubelair. Those that do, live in the south of the census division along the boundary with Barrouallie. This problem could be improved by calculating vulnerability at a finer spatial resolution if the data are available.

In their discussion of uncertainty, Longley et al. (2005, p.152) conclude that *"uncertainty is inevitable"*. Uncertainty will occur: where possible in the research presented here measures have been taken to reduce various types of uncertainty (for example the exclusion of old datasets such as 1983 locations of hospitals and internal validation of the building survey DVDs). Future work on representing vulnerability with improved, up-to-date datasets and validation of results could help reduce this uncertainty further.

8.5. Summary

Vulnerability analysis in relation to volcanic hazards is of paramount importance if one is to analyse the potential impacts of a future eruption. Evidence from past eruptions demonstrates that people are impacted differentially depending on their social, economic and cultural characteristics, in addition to where they live and the type of building they occupy. All these factors need to be considered, in addition to the physical hazard, in order to help forecast the potential impacts of a future eruption. This information can then be used to inform preparedness and response in an attempt to reduce disaster risk.

Identifying the importance of vulnerability is only the first step. Suitable models and methods need to be used in order to capture appropriate measures of vulnerable people and buildings. The literature is awash with different conceptual and theoretical models and definitions of the same word which makes the task of conducting a vulnerability analysis problematic. Few studies critically evaluate a range of methods for one area allowing a comparison of the outputs of the method and the appropriateness for the given task.

The approach taken in this research was to apply a range of methods for vulnerability analysis in order to evaluate the appropriateness and practicality of each and ask whether or not they captured the same geography of vulnerability. This research has shown that a single model and method cannot capture all aspects of vulnerability. Each model is conceptualised from a specific perspective and will not necessarily include all the different elements of vulnerability identified and measured in this research. In addition, the difference between user needs and user understanding of the terms does not make it appropriate to try and have one model and method of assessment and analysis capturing everything. Vulnerability is often described as complex (Birkmann, 2006d; Villagran De Leon, 2006); the complexity and the inability of one model to capture all aspects of vulnerability provide further support for stakeholder input. An outside researcher will bring a particular perspective with them as a result of their background or familiarity with the literature. As outsider views about vulnerability may not coincide with local views, stakeholder engagement is key, even at national level scales, as they are the users of the information.

Research relying on stakeholder engagement, however, brings with it difficulties, as highlighted in Section 3.3.5 on fieldwork design. For the research to produce reliable, valid results as many stakeholders as reasonably possible should be interviewed/surveyed. However, working on an island remote from the researcher's base presents problems of adequate contact with and response rate from key personnel, in addition to problems of time and resources. It is recommended to have a local contact to make introductions and to provide endorsement for the research, and also to understand local politics and working practices. Focusing the research on one or two stakeholder groups will also help make the fieldwork manageable.

An evaluation of the four methods suggests that quantifying vulnerability using social and building indices is very useful as it can be completed as a desktop exercise in many cases and visualised using maps. Consequently it forms an excellent start to any vulnerability research. To really understand the results, however, it is necessary to use qualitative techniques to gather background information, and consider factors such as politics and personal experience that are hard to quantify. Ideally, a historical vulnerability analysis would be coupled with two quantitative assessments of social and building vulnerability using adequate data. Where possible stakeholder engagement should be used to determine the social vulnerability variables in particular to ensure that the results are appropriate to user needs. Coupled with this the mental mapping exercise should be completed at a local level to engage communities and provide detailed local vulnerability analyses.

Overall, the methods complemented each other well, but all had advantages and disadvantages. The historical vulnerability analysis provided the background and understanding; the mental maps tapped into local knowledge and different stakeholder views; the social and building vulnerability indices presented targeted analyses. If one started with a blank canvas in a new volcanic region, applying these four methods would provide a very useful insight into vulnerability, and could be used to inform risk reducing measures. The research also provides insight into the limitations of these methods, in particular when working in a developing country where data availability and quality may not be as good as in countries such as the US and New Zealand, where a number of quantitative vulnerability analyses have been completed.

The work presented here has also highlighted five key issues related to the practical aspect of completing a vulnerability analysis that require further work. The quantitative versus qualitative and multi-hazard versus single hazard debates are discussed in some of the current literature (see Birkmann, 2006a; Villagran De Leon, 2006; Schmidtlein et al., 2008). Terminology has also been identified as a difficulty in hazards research in general with the plethora of definitions and interchangeable use of words such as hazard, vulnerability and risk (see Thywissen, 2006). There is little consideration given, however, to whether or not vulnerability should be presented as a relative or absolute measure, although it is covered briefly in Villagran De Leon (2006), Wood (2007), Wood et al. (2007) and Wood and Soulard (2009). This issue requires further work. How the results of the vulnerability analysis will be used must surely drive the measurement task.

Furthermore, how best to present the results of a vulnerability analysis is a key question. If the goal of a project analysing vulnerability is to provide a tool for decision-making or communication, as a number of papers on this subject state in their conclusions (e.g. Thouret, 1999; Chardon, 1999), then user feedback on the visualisations of GIS-based tools produced needs to be factored into future research projects. It is acknowledged that this is a limitation of the work presented here as no user feedback has been obtained; however designing a tool or map for use by stakeholders was never an aim in this research. Rather, it centred round *practically* how do you go about conducting a vulnerability analysis. Whether or not maps are a useful method for visualising the results of a vulnerability analysis would be something that further work should address as it is the next step having identified which methods to adopt when carrying out a vulnerability analysis. From the results of the interviews conducted throughout this research it became clear that in the case of St. Vincent, maps, GIS technology and trained staff are not readily available, and therefore producing a map of vulnerability may not be the most appropriate method of communicating the information to users.

Finally, it can be argued that although this research has focused on volcanic hazards, and not explicitly investigated capacities and resilience, the methods presented here are easily transferable. While the variables used to capture vulnerability may change depending on the hazard, the methods for data collection and analysis would remain the same and the key issues raised as a result of this research would be applicable to other hazard events and the analysis of resilience and capacity in addition to vulnerability.

Chapter 9: Conclusion

Here the thesis is concluded by first reviewing the research objectives and highlighting the methodological and empirical contributions of the study and what the research has shown about the situation on St. Vincent; second by discussing the concept of vulnerability and whether or not this is a useful term to adopt. The chapter concludes with suggestions for future work and concluding thoughts on the thesis and vulnerability research.

9.1. Meeting the research goals

The research goals were to investigate the spatial and temporal aspects of vulnerability to volcanic hazards and evaluate how one can practically go about measuring and analysing vulnerability. Chapter One demonstrated how vulnerability is now a key goal in understanding disaster losses and action aimed at reducing disaster risk. Evidence from past volcanic eruptions shows how the vulnerability of the population plays a role in who suffers impacts from the effects of volcanic hazards. Vulnerability variables, however, vary greatly, from age and gender to education and beliefs. The review of the literature in Chapter Two presented a range of theories of disaster causation, and how the concept of vulnerability differs between the theories. The different disciplinary backgrounds from which research into vulnerability has emerged has shaped the models and methods with which the concept is measured and analysed. There are similarities between the various approaches, however the elements of vulnerability that are included can differ and consequently the results of the analyses vary. One objective of this research was to explore how these methods compare and contrast. Therefore a multi-disciplinary, multi-method approach was adopted which allowed the researcher to appraise the different models and methods. Common vulnerable elements considered in volcanology are exposure to the hazards and vulnerable buildings; however they do not give the whole picture, and therefore aspects of societal vulnerability need to be included. Determining, however, what to include in a social vulnerability analysis can be problematic because of differences in definitions and peoples' understanding of the term. The solution proposed here was to engage the stakeholders on the case study island of St. Vincent in deciding what variables to include in the social vulnerability analysis in addition to utilising the literature to guide the building vulnerability survey, and historical vulnerability analysis.

For the case of St. Vincent it was found that:

- A person's proximity to volcanic hazards was the most common variable included in people's lists of vulnerable characteristics, although this is not considered a vulnerability variable in the literature, rather it measures an aspect of the hazard;
- Other factors identified by stakeholders included those commonly seen in the literature, such as age, income, and education;
- Stakeholder views (scientists, emergency managers, Red Cross personnel, town planner, community group members and local government) on vulnerability differ, however a few core variables are common. These are vulnerability as proximity to the volcano, poverty, dependants, disability and livelihoods;
- Areas of high volcanic hazard, high social vulnerability and high building vulnerability do not coincide;
- Historical document analysis identified that the root causes of St. Vincent's vulnerability lay in the colonial development of the island, years of slavery and indentured labour, and culture of migration to find work and education abroad; and
- The four methods of vulnerability analysis used in this research complement one another as it appears no single model or method is able to capture all aspects of vulnerability.

9.2. Methodological contributions

The work presented here continues the trend in 'social volcanology' discussed by Donovan (2009, p.1) whereby volcanologists *"have begun to undertake and publish work incorporating social science theories and methodologies"* in response to the shift in the international arena towards reducing disaster risk through examining societies in addition to the hazards. The four methods described in the previous chapters add value to the field of social volcanology and natural hazards research in general in that they demonstrate how vulnerability of both people and buildings can be captured and analysed using a variety of tools. The work also compares and contrasts the four methods and discusses the advantages and disadvantages of each and the possible utilisation by different stakeholders. Without this approach one cannot appraise different models and methods and cannot compare the spatial distribution of different elements of vulnerability. The fact that there is no consensus on definitions of vulnerability, nor how to model and measure the concept, is a barrier to the advancement of the work in this field. The work presented here helps in that it has provided a critical appraisal of different models and methods and demonstrated how they can be practically applied in the field.

Furthermore, the majority of vulnerability analyses take either a quantitative or qualitative approach. Recognising the limitations of data availability, qualitative data gathering methods are excellent tools for capturing information on vulnerability, as demonstrated with the interviews and mental mapping exercises carried out here. Quantitative methods such as statistical analysis or GIS can be used to combine the qualitative data and produce indices or maps as outputs.

In addition, this work has presented a method for incorporating the views of stakeholders into traditional vulnerability index methods. Through the combination of qualitative methods of data gathering via interviews and thematic content analysis with quantitative methods for calculating a vulnerability index, stakeholder views of what makes them vulnerable to volcanic hazards on their island can be mapped. Mental mapping exercises are also a useful tool to adopt in engaging stakeholders and gathering information on their views of vulnerability and hazards.

9.3. Vulnerability to volcanic hazards on St. Vincent

The empirical contribution of this work is what it reveals about vulnerability to volcanic hazards and the situation on St. Vincent. Previous work on vulnerability to hazards on St. Vincent has been conducted, however it is poorly reported or utilised. For example, the CDERA report on the status of hazard maps and vulnerability assessments on St. Vincent concludes by *saying "it appears that not a lot of work has been done on hazard mapping and vulnerability assessments for St. Vincent and the Grenadines"* (Opadeyi et al., 2003, p.9). Those that had been completed were island wide storm, seismic hazard and beach erosion assessments and conducted by USAID and OAS. A multi-hazard vulnerability assessment including volcanic eruptions is listed, but focuses on the vulnerability of the electrical infrastructure on the island. Robertson (1995) completed a volcanic risk assessment of St. Vincent (described in Section 2.8.1), although this was not included in the 2003 CDERA report. More recently, doctoral research by Boruff (2005) on the island, which conducted a multi-hazard vulnerability assessment, was never mentioned by any of the stakeholders on the island and was clearly not being utilised.

9.3.1. The situation on St. Vincent

What do these vulnerability analyses tell us about St. Vincent specifically? Those areas that experience high levels of socio-economic vulnerability are also those that are located closest to the volcano, and therefore are vulnerable spatially as well. High building vulnerability, however, is not concentrated in the north near the volcano. Consequently, no one specific group is highly vulnerable. Rather a number of groups located across the island are vulnerable for different reasons. The implications are that in total, when both social and building vulnerability are included, there are a greater number of vulnerable people, vulnerable in different ways. Socially (i.e. uneducated, poor, disabled); spatially (i.e. geographic isolation); and through living in vulnerable buildings (i.e. wooden houses or concrete houses in poor condition). Each vulnerable group will be affected in different ways and will require targeted assistance or planning. For example, the areas which experience high levels of socio-economic vulnerability could be targeted with education campaigns to improve awareness of the hazard and possible impacts, or measures to increase development of poor areas. Indeed improvement to the infrastructure in the north of St. Vincent has begun with the surfacing of the road. Those areas that are vulnerable due to proximity to the volcano could practice evacuation drills and organise increased access to transport for all residents. Areas that have been identified as having a large proportion or number of vulnerable buildings could have investment to improve the condition of houses. The fact that a number of different areas have been identified as being vulnerable for different reasons puts extra pressure on the emergency management organisation on the island. Already limited resources need to be stretched to reduce the vulnerability of the population. The measures also span many aspects of the disaster management cycle from mitigation and preparedness to response. In the past St. Vincent has focused on response and recovery in managing disasters, and it was acknowledged during interviews with NEMO staff that this is still their priority, however they are now trying to look towards mitigation and preparedness. Rather than be able to reduce the vulnerability of a large number of people with, for example, one measure such as an education campaign across the island, vulnerability reducing measures need to be varied and targeted at different areas. This translates into more work for NEMO and other stakeholders in disaster management.

A NEMO staff member reflected on the difficulty of measuring vulnerability of specific areas during one interview. When asked to draw areas of high vulnerability on the mental map the interviewee said the whole island would be red because everyone is vulnerable for one reason or another. Some people will be affected because they have to evacuate (spatial vulnerability), some will lose their livelihoods (economic vulnerability), others may suffer health problems (social vulnerability). Those people in the south who are not evacuated are affected because the evacuation camps are located in their towns and villages, there is a large influx of people, and schools and churches are closed as they are being used as evacuation camps. For example, during the evacuation of the north of St. Vincent in 1979 over 30,000 school pupils were displaced for two months and examinations were postponed (Robertson, 1995). It is hard to capture all of these nuances of vulnerability in one assessment and analysis, and, in the opinion of the NEMO staff member, impossible to highlight one area as being more vulnerable than another, as different elements of vulnerability affect different areas. This point of view provides further evidence of the need for a range of methods to identify and capture indicators of these different vulnerable elements.

Whilst capturing the current shape of vulnerability on St. Vincent it is interesting to investigate how this compares to the impacts on the island from past volcanic eruptions. Are the vulnerabilities identified here the same as those in 1902 and 1979? According to Anderson et al. (1903) in 1902 it was the black labourers who were initially impacted the most as they were the agricultural labourers who were working in the fields at the time of the eruption. Some were caught in the fields by the pyroclastic flow and surge, whilst those who sheltered in their wooden houses also perished. The white plantation owners were able to shelter in stronger buildings and many survived as a result. Currently, agriculture as a livelihood was a factor mentioned in the interviews that would increase a person's vulnerability, although today there appears to be fewer social and racial divides. Those people who are able to shelter in stronger built houses may still be less vulnerable, however. Furthermore, it will still be those people in the north and in close proximity to the volcano who will be forced to evacuate. In these two cases – agricultural livelihood and proximity to the volcano – the vulnerabilities identified now are similar to those in 1902.

There are fewer detailed accounts of the effects of the 1979 eruption on the population of St. Vincent as there were in 1902. Nanton (1985) reported that some evacuees suffered whilst in the evacuation camps as they were treated as helpless and receivers of charity. Similar problems may occur today if evacuation is not handled differently, and in this respect lessons can be learned from the ongoing eruption of Montserrat.

9.3.2. Lessons from Montserrat

The Soufrière Hills volcano on Montserrat has been erupting since 1995 forcing the evacuation of over half the population. The well documented impacts of the eruption can be compared to the current situation on St. Vincent. Given the similarities between the two islands (small island developing states; reliance on agriculture; small tourism sector; one active volcano), what lessons can be learned?

The problems experienced in the evacuation camps on Montserrat mirror those on St. Vincent in 1979. On Montserrat the south of the island was evacuated on a number of occasions from 1995 onwards and there were many reported problems with the shelters set up in the north, such as overcrowding, lack of privacy, non-availability of cooking facilities and inadequate hygiene (Pattullo, 2000). Consequently, many people returned to the exclusion zone where 19 people were killed in an eruption on June 25th, 1997 (Skelton, 2000). Furthermore, in the UK's Evaluation Report on the government's response to the crisis on Montserrat, it was reported that *"a high proportion of vulnerable groups, the elderly and those without* *family support, are in public accommodation"* (Clay et al., 1999, p.5). Vulnerable groups on St. Vincent may also be forced to remain in evacuation shelters if no family support is available. In addition, given the discontent with shelters on St. Vincent in 1979 and on Montserrat, plans need to be in place to improve shelter life and ensure people are not tempted to return to exclusion areas as on Montserrat in 1997.

A further consideration in relation to prolonged evacuation is the migration of the skilled workforce abroad, as occurred on Montserrat (Pattullo, 2000). If a future evacuation on St. Vincent is long term then the government needs to guard against the skilled workforce leaving the island, particularly as there is already a shortage of skilled labour on St. Vincent and unemployment is high. Eruption-forced migration of teachers, nurses, and other professionals will further increase vulnerabilities already present.

Furthermore, both Montserrat and St. Vincent rely on agriculture. During the evacuations on Montserrat farmers regularly returned to their land. Some farmers had loans to repay and no insurance to cover their losses. Others were actually contracted by the emergency operations centre on the island to provide food for evacuees (Pattullo, 2000). According to one interviewee on St. Vincent, during the 1979 evacuation farmers were keen to return to their land as animals were destroying crops. On Montserrat the areas evacuated included much of the fertile land. The north, where people were encouraged to resettle, is dry and less fertile. The situation on St. Vincent is better in that not all prime agricultural land would have to be evacuated if a future eruption is similar to the current hazard scenario. Contingencies need to be in place, however, to provide suitable land for farmers in the safe zone should an evacuation become long term, and insurance against agricultural losses to encourage farmers not to return to tend crops in the exclusion zones.

The unpredictable and long term volcanic activity on Montserrat has been an eye opener for the people of the Eastern Caribbean and those whose job it is to plan for future disasters. Although each island will be impacted and managed in different ways, many lessons can be learned from the experience of Montserrat.

9.3.3. Disaster management increasing vulnerability?

In Chapter One, disaster management was identified as a variable that could either increase or decrease the vulnerability of a country or region. On St. Vincent circumstances suggest that the disaster management may increase the island's vulnerability. Although the individual's involved recognise the need to be prepared, and not just be reactive to hazard events, limited resources present challenges. First, on a small island such as St. Vincent there are few official positions dedicated to disaster management full time, and often good management relies on key personalities with extensive knowledge. If one person leaves then it can have a big impact on the overall structure. For example, between the first and second fieldwork trips in this research, the Deputy Director of NEMO left to study abroad. A very suitable replacement was found as a local school teacher had disaster management training; however this may not always be the case.

Second, St. Vincent has a lot of hazards to deal with annually. Hurricanes and associated flooding and landslides are the key issues as they are more likely to impact the island year on year. Volcanic disaster management can take a back seat as a result. A third issue is that disaster management nationally is not as coordinated as it could be. For example, NEMO did not have an up-to-date list of the local community disaster groups, nor the contact person for each group. Government departments involved in disaster management do not necessarily work together as well as they could. Data received by the researcher from the Statistics Office was not made available to NEMO, for example. A final example is the lack of coordination in the use of GIS by the government departments, where they all buy individual software licenses, and do not network and share their resources. These broader scale, national issues need just as much attention as the vulnerability analyses presented in this research if St. Vincent is to reduce its vulnerability to volcanic hazards in the future.

9.4. Future work

In 2006 the Director of the United Nations University Institute for Environment and Human Security stated *"we are definitely still at the beginning of what may be called 'vulnerability research'"* (Bogardi in Villagran De Leon, 2006, p.5) and referred to this discipline as being in its 'evolutionary stage'. The amount of work conducted on vulnerability and natural hazards is rapidly increasing. For example, a search of the words 'vulnerability' together with 'natural hazard' in a physical and social science database reveals the sharp increase in the number of published journal articles, books and conference proceedings on the subject over the past 50 years (Figure 9.1).

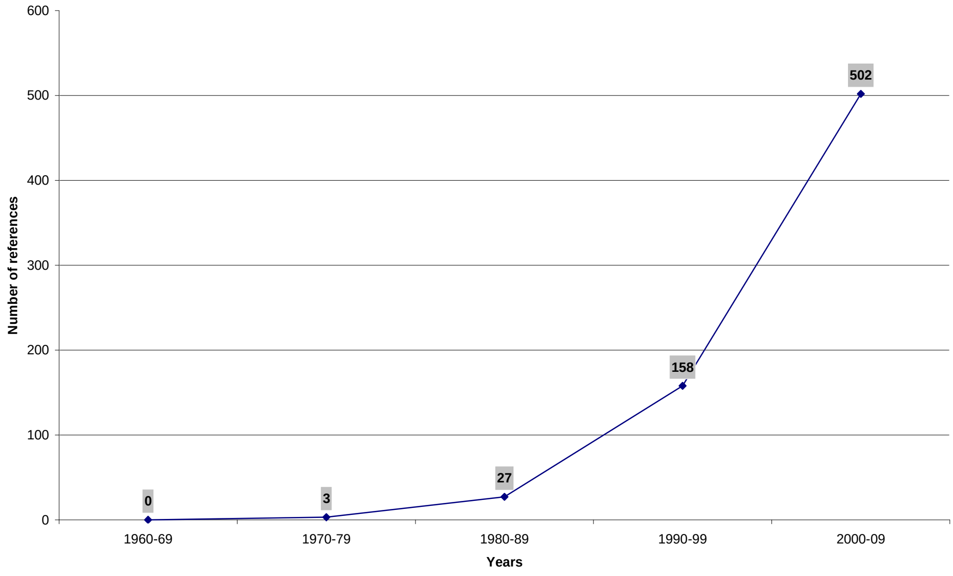


Figure 9.1: Graph to show the sharp rise in the number of peer-reviewed journal articles, books and conference proceedings covering the topics of 'vulnerability' together with 'natural hazard'. Data from Scopus database www.scopus.com.

The range of disciplines working on this topic is also expanding; however key issues still remain that need addressing if vulnerability research is to move forward collectively. Future work should address those issues identified in Chapter Eight.

Furthermore, to test the methods presented here, similar research could be conducted in new volcanic areas, or areas exposed to different hazards. The vulnerability variables presented here are specific to volcanic hazards on St. Vincent. Which are generic? How do other islands and communities perceive their own vulnerability? While the Volcanic Hazard Atlas of the Lesser Antilles (Lindsay et al., 2005) provides volcanic hazard maps for 12 of the Eastern Caribbean volcanic islands, the methods presented here could be used to map, in a consistent way, the vulnerability of each island to those volcanic hazards. In addition, to investigate those variables that are generic across hazards, vulnerability could be analysed with respect to different natural hazards such as tsunami. The variables to include in an index or rank may change, however, it is expected that similar problems to those found here in finding suitable methods and data sets will no doubt remain.

An interesting line of further work would be to conduct the mental mapping exercise with stakeholders in a volcanic area that does not have a published hazard map. A limitation of the exercise conducted on St. Vincent was that some participants redrew the integrated hazard map and it may be that what was assessed was hazard awareness and not vulnerability awareness. However, this may be a result of extensive publication of the integrated hazard map and its use in education campaigns, exhibitions, etc.. It may also be a product of how people conceive hazard, risk and vulnerability. The general public might not make such a clear distinction between the terms, but rather think in terms of ‘dangerous’ areas, for example. If no hazard map exists and if awareness of the location and extent of future hazards is low, the mental mapping exercise could be a very useful way of gathering local knowledge on areas of vulnerability. Work on the volcanic island of Fogo, in the Cape Verde islands, will include this mental mapping exercise as a part of a questionnaire designed for school children and their families. No published volcanic hazard map currently exists, and therefore this questionnaire survey will be able to gather information on people’s perceptions of their vulnerability and risk to volcanic hazards without the possibility of the results being influenced by existing maps (see Narciso et al., 2009, for details of the project).

A final area to continue this research is to investigate how the vulnerability maps produced here would be utilised by stakeholders. It has already been suggested that maps or GIS tools may not be the most appropriate method for presenting these data. In Chapter Eight possible applications of the different methods and outputs by stakeholders was listed, however this was never assessed with people on St. Vincent. In addition, where possible, it would also be desirable to verify the results of these vulnerability analyses if a volcanic eruption occurs on St. Vincent. In this way it would be possible to test the methods applied in this research and refine indicators and measures of vulnerability.

9.5. Concluding thoughts

The work presented here focused on *vulnerability* to volcanic hazards, and methods for capturing and analysing the concept. Bankoff (2001; 2003) argues, however, that vulnerability is a 'Western concept' and too narrow to explain disaster risk. By 'Western concept' he means that it is Western society that categorises parts of the world as vulnerable or 'unsafe'. Despite the emergence of a radical critique of the dominant view of natural hazards and the need for Western, technocratic fixes, Bankoff (2001, p.29) suggests that *"the discourse of vulnerability…belongs to a knowledge system formed from within a dominant Western liberal consciousness and so inevitably reflects the values and principles of that culture"*. The discourse on vulnerability and Western relief is compared to the period of colonialism in the 17th to 20th Centuries, and that of development and aid after 1945. Three main criticisms of vulnerability as a concept are outlined. First, that it divides the world into 'dangerous' and 'safe' areas. Second, that vulnerability is increasingly expressed in economic terms. And third, that the cure is often technocratic Western 'interference'. Bankoff does not deny that vulnerability has proven a useful concept for assessing disasters within their socio-economic, political and environmental contexts, and as a guide for preparedness and relief. What he suggests is that the discursive framework is broadened to include a culture's adaptability, and not solely its vulnerability to a hazard event.

Recent work is taking the approach advocated by Bankoff to focus on the *adaptability* of a community to hazard events and a community's *resilience* (see Section 8.4.3). As Twigg (2007, p.6) states in the publication 'Characteristics of a disaster resilient community', *"a focus on resilience* *means putting greater emphasis on what communities can do for themselves and how to strengthen their capacities, rather than concentrating on their vulnerability to disaster or their needs in an emergency"*. The term resilience is also more politically appealing, rather than negatively labelling people and communities as vulnerable (Handmer, 2003), and portrays a *"positive expression of community engagement with natural hazard reduction"* (Cutter et al., 2008, p.598).

However, even if you decide to focus on resilience and adaptability, the methodological contributions of this study remain. Section 8.4.3 discussed that there are similar problems in defining resilience as there are with vulnerability. Furthermore, it is likely that attempts to capture and analyse resilience will incur similar problems to those encountered here while investigating vulnerability.

A further consideration is how important are volcanic hazards to locals? The radical paradigm suggests putting vulnerability to a hazard event into the context of everyday life. With an infrequent hazard such as volcanic eruptions, other everyday pressures and other hazards can take priority. During the first round of interviews participants were asked to list all the natural hazards their island was exposed to. Having listed them, they were asked to rank the hazards in order of concern. Unsurprisingly for the Caribbean, hurricanes were mentioned by everyone, and ranked first by eight of the 14 people who completed the exercise. The most common reason was the frequency of the hazard. Although a hurricane does not hit St. Vincent every year[15], stakeholders are aware that the hurricane 'season' runs from June to November, and consequently, more people are concerned with this threat, than that of a volcanic eruption. Volcanic eruptions were listed as being of most concern by only three of the 14 participants; in one case it was last as the person had so much faith in

[15] According to data on www.stormCARIB.com 10 hurricanes have passed within 69 miles of St. Vincent and the Grenadines in the last 150 years, with four making landfall.

scientific monitoring and early warning systems. In the context of everyday life, and the range of hazards that the Caribbean is exposed to, volcanic eruptions are just one of many potential causes of disaster. They are infrequent when compared to other hazards such as hurricanes and landslides, and many people have not experienced an eruption. In addition, on St. Vincent, the Soufrière volcano brings benefits to the population. The volcanic soil is fertile for agriculture, and the volcano is a tourist attraction on the island. This poses challenges in disaster management to keep people aware of the potential threat from the volcano and inform them of how to prepare for and mitigate against future losses. History, however, has shown how destructive volcanic eruptions can be and the magnitude of their impacts on the population and infrastructure. Consequently, despite their infrequency, volcanic eruptions need to remain a focus, and practical approaches are required to assess the impacts of a future eruption in order to reduce disaster risk.

With respect to the continuing research on vulnerability, are we any closer to a consensus? The main limitation in vulnerability research lies in the inability of the academic and practitioner to find common ground and definitions. There are clearly similarities between approaches, and vulnerability analysis does need to be tailored to the goal of the research and the needs of the user so it is probably not realistic to have a single method or definition. White, Kates and Burton - three of the pioneers of natural hazards research - suggested that *"in the years ahead, it can be expected that differences in interpretation of vulnerability may be sorted out, and relatively standard measures of vulnerability will emerge"* (White et al., 2001, p.86). Nearly 10 years after this was written a consensus does not appear close, in part owing to the inability to agree on the use of terms such as vulnerability. In his review of concepts and methods for capturing vulnerability Villagran De Leon (2006, p.8) states:

> *"the use of the same words with different meanings by research and academic communities is leading to a lack of*

> *consensus which is necessary to advance on the issue of disaster reduction. A case in point is the use of the term vulnerability."*

Given that it is unlikely that a common definition of vulnerability will be agreed upon in the near future, it is proposed here that the most suitable way to develop the field of vulnerability research is to engage stakeholders throughout the analysis, and keep an open mind when defining terms and deciding upon appropriate models and methods. In this way a range of elements and views of vulnerability to hazards can be incorporated, and the results can reflect the opinions of the end-users.

A final thought is the need for *local*, *context-specific*, vulnerability indices and analyses, and not standardised global measures. The newly created VOGRIPA project[16] (Volcano Global Risk Identification and Analysis) aims to develop 'simple' metrics of vulnerability around volcanoes, and to create a global database of vulnerability indices. The work presented here, however, has shown that the task of developing vulnerability indices for one island is problematic enough, with no single method of analysis able to capture all elements of vulnerability identified as important by stakeholders. How then, would a global vulnerability index capture appropriate indicators of vulnerability in relation to volcanic hazards for areas as culturally different as the Caribbean, the US, Indonesia and South America? It is proposed here that, for stakeholders globally, the drawing-up of guidelines on how to conduct a vulnerability analysis would be more useful, identifying the various methods available and their advantages and disadvantages, in the light of the local context, data and resources available. The evaluation of different vulnerability models and methods, presented in this thesis, can be used to develop such guidelines.

[16] www.bris.ac.uk/brisk/research

Appendix A: Volcanic hazard definitions

The definitions of the volcanic hazards included in Figure 3.5 are taken from Lindsay et al. (2005, pp.xvii-xviii). The description of the likely extent and impact of each hazard on St. Vincent during a future eruption are taken from Robertson (2005, pp.253-255).

Ashfall

Definition

Explosive volcanic eruptions produce fine material called volcanic ash, which is carried upwards in a buoyant eruption column before it settles out downwind. Both gravitational and explosive dome-collapse events also generate large amounts of volcanic ash, usually associated with pyroclastic flows. Ash falls can blanket the entire landscape for kilometres around a volcano, and may even reach nearby islands. Close to the eruption vent, ash may be thick enough to collapse buildings and destroy vegetation. Ash can cause aircraft, ship and car engines to malfunction. Ash may cause serious respiratory problems if it is inhaled. Ash fall can be particularly damaging to livestock as small amounts of ash can lead to fluorosis if ingested. This hazard from ash fall may persist long after the eruption itself has ended. On hazard maps, ash fall is typically depicted as lines joining points of equal estimated thickness (isopachs).

Description of extent and impact of ashfall on St. Vincent

The impact of ash fall, volcanic gases and lightning strikes will depend largely on atmospheric conditions in the area at the time of the eruption. The explosivity of the eruption and the force with which material is ejected will also contribute to the scale of these phenomena. The Easterly Trades are the dominant surface winds and will affect plumes located below 5 km. Above 5 to 8 km height, the Easterly Trade winds are replaced by the westerlies which are in turn replaced by the easterlies at the tropopause which can vary between 16 and 18 km (citing Sigurdsson and Carey, 1981). At low altitudes the Easterly Trades will cause dispersal of pyroclasts towards the west of the island. The effect of the higher-level westerlies (>10 km) will be more marked since most eruption columns are likely to attain this altitude. Fine ash may be transported eastwards across the Atlantic to Africa in 3 to 5 days (citing Barr and Heffter, 1982; McCormick et al., 1982), and ash plumes from the 1902 eruption were carried over 1200 km east into the Atlantic (citing Sigurdsson and Carey, 1981). If the ash plume gets above the tropopause and into the stratosphere the wind direction is again east to west and ash will be deposited to the west of the volcano. Regionally the effect will be most marked in an area extending from 350 km east-west, and 150 km north-south of the volcano.

Locally a continuous ash blanket may extend up to 9 km in all directions. Within 2.5 km of the vent, in eruptions of the scale of 1979, up to 45 cm may accumulate (citing Brazier et al., 1982). This may decrease to 45 mm up to 4 km from the crater rim. Eruptions with greater magnitude will cause the ash deposited from an entire eruption to reach up to 6 mm in Kingstown (Anderson et al., 1903), 21 km from the volcanic centre. The effects of ash falls during an eruption will vary with distance from the crater and with local variation in the wind speed and direction. Changes in wind direction may cause areas previously unaffected to experience heavy ash falls for brief periods. The pattern of ash fall produced during the 1979 eruption has been scaled upwards to a 1902-magnitude eruption to obtain isopachs for this eruption scenario.

Ballistic projectile

Definition

A ballistic projectile is a hot rock, generally >64 mm in size, that follows a ballistic trajectory (i.e. travels like a cannonball from a cannon) when ejected from an erupting volcano. These hot rocks are called blocks if they were solid at the time they were fragmented and bombs if they were liquid.

They usually land within 2 km of the vent but can travel as far as 5 km, or even further if the eruption is very explosive. Fist and headsized ballistic blocks can plunge through the walls and roofs of buildings while still red-hot, and start fires within the buildings after impact. On hazard maps, the hazard from ballistic projectiles is typically presented as concentric zones around the vent.

Description of extent and impact of ballistic projectiles on St. Vincent

The range and effect of projectiles will be limited by the velocity of their emission from the crater. Although 21 kg bombs reached up to 6 km from the summit during the 1902 eruption (Blong, 1984), the area of maximum impact is not expected to extend beyond 5 km from the volcano. Damage will be minimal in areas far away from the summit since most of the energy of the bombs will be expended in movement through the atmosphere.

Lahar

Definition

A lahar is a mudflow formed when volcanic particles mix with water. Lahars can be generated by the collapse of the walls of a crater containing a lake, or heavy rain washing loose volcanic material from slopes. The loose ash and volcanic fragments are transformed into a dense fluid mixture that rushes down the slopes of a volcano and into surrounding valleys. Lahars are destructive to everything in their path, and the threat from lahars may last for years after the eruption has ended.

Description of extent and impact of lahars on St. Vincent

Mudflows (lahars) can be generated at any point on the volcano’s flanks since the radial drainage pattern provides ample depressions to guide mobilised tephra. The likelihood of flows developing early in an eruption sequence is greatly increased if there is a crater lake to be discharged. Abundant tropical rainfall provides adequate moisture for the development of mudflows later in the eruption.

Discharge of mudflows along the Rabacca and Wallibou river valleys is of particular importance in the evaluation of hazards. The accumulation of debris in these valleys and destruction of the coastal road will effectively cut off villages to the north and sever links with the rest of the island.

Mudflows may continue to present a hazard for some time after an eruption has ceased. Secondary mudflows are expected to occur as rainfall washes tephra from the upper slopes of the volcano. Mudflows may reach further downslope than pyroclastic flows, adversely affecting a larger area. During the 1902 eruption, secondary mudflows overturned several small houses at Georgetown, approximately 7 km from the volcano summit (Anderson et al., 1903).

Pyroclastic flow

Definition

A pyroclastic flow is a hot (100-900 °C), fast-moving (>100 km/hr) mixture of ash, rock fragments and gas. Such flows form when an eruption column or a lava dome collapses. They usually travel down valleys and cause total devastation of the area over which they flow. Small flows travel 5-10 km down topographic lows; large flows can climb topographic obstructions and travel for 50-100 km. People in the path of a hot pyroclastic flow are usually killed instantly by asphyxiation, heat and noxious gases. Pyroclastic flows have been the main cause of destruction and loss of life in Montserrat since 1995.

Pyroclastic surge

Definition

A pyroclastic surge is a dilute, turbulent cloud of gases and rock debris that moves above the ground surface at great speeds. Pyroclastic surges form in a similar way to pyroclastic flows, but their effects are more widespread as they are less confined by topography and may therefore sweep across ridges and hills as well as down valleys. Pyroclastic surges can be either hot (several hundred °C) or cold (< 100 °C). Cold pyroclastic surges are generally known as base surges, and are commonly generated by phreatic and phreatomagmatic explosions. Both types of surges result in the destruction of vegetation and structures, and burial by ash and rock debris. People in the path of a hot pyroclastic surge can also be killed by asphyxiation, heat and noxious gases. Pyroclastic flows and surges from Montagne Pelée completely destroyed the town of St. Pierre in Martinique in 1902, killing about 30,000 people.

Description of extent and impact of pyroclastic flows and surges on St. Vincent

Pyroclastic flows in future eruptions will be generated either by partial or complete collapse of eruption columns or by the boiling over of dense gas-charged ejecta from the crater rim. Although dome growth has been associated with explosive eruptions in the past, it has always occurred at the end of an explosive phase. Experience from past eruptions of the volcano suggests it is unlikely that pyroclastic flows will develop whilst a dome is actively growing in the crater. However, based on the evidence of past eruptions at similar volcanoes (e.g. Mt Pelée, 1902), the possibility still exists that flows could develop from the collapse of domes that rise above the crater rim.

Fluidised overspill of hot, fragmented ejecta from the crater rim may be the dominant method of pyroclastic flow formation during the early stages of an explosive sequence when large eruption plumes have not yet developed. Such flows occurred during the 1979 eruption (Shepherd et al., 1979) and will most likely follow paths of least resistance down river valleys that extend from minor depressions in the otherwise continuous crater rim. Flows will initially go down the Rabacca river valley to the east, and the Wallibou and Larikai river valleys to the west of the volcano. Eruptions of the magnitude of 1902 are likely to generate additional flows down river valleys leading to Baleine Bay and Morne Ronde on the western side of the volcano. These flows, due largely to partial collapse of an eruption column, may also advance down the Tourama and Waribishy river valleys on the east. With increasing magnitude, collapse of large dense columns (>>20 km) may lead to flows that surmount the Somma Ridge and follow the Fancy, Owia, Agrabay, Karo and Cayo rivers to the north and northeast coast.

Appendix B: Integrated volcanic hazard zones

The descriptions of the integrated volcanic hazard zones (Figure 3.9) are taken from Robertson (2005, p.257).

The zones are based on the projected effect of explosive activity from scenario 1b (Figure 3.5), although some consideration is also given to activity in the long term outlined in scenario 2 (greater than 20km eruptive column).

Hazard Zone 1 (Red Zone):

This includes all areas expected to experience maximum damage in the short term, and is the zone where all hazardous events have their greatest influence. It is defined by the zone of expected total destruction from pyroclastic flows, surges and mudflows and by the zone of maximum expected damage from all projectiles. Whatever the scale of the eruption, all areas in this zone are likely to be covered by >30 cm of ash. During the course of an eruption this zone would be unsuitable for human habitation. Eruptions of the type expected in the long term as outlined in scenario 2 will cause total devastation in the area.

Hazard Zone 2 (Orange Zone):

These areas will be affected in a similar manner as Zone 1 during larger scale versions of scenario 1-type eruptions. The division between Zone 1 and Zone 2 is based on the thickness of ash expected in Zone 2 (10-30 cm) and the experience of past eruptions which indicate that the latter areas are somewhat sheltered by topographic highs from the direct impact of pyroclastic flows, mudflows and ballistic projectiles. A distinction is therefore made between areas that are certain to be destroyed by mudflows, pyroclastic flows, surges and ballistic projectiles (Zone 1), and those that will only be destroyed during large scale eruptions (Zone 2). The potential for damage may be similar, but the greater distance of villages from the volcanic centre would reduce the likely impact. Eruptions of the type expected in the long term as outlined in Scenario 2 will cause total devastation in the area of Zone 2.

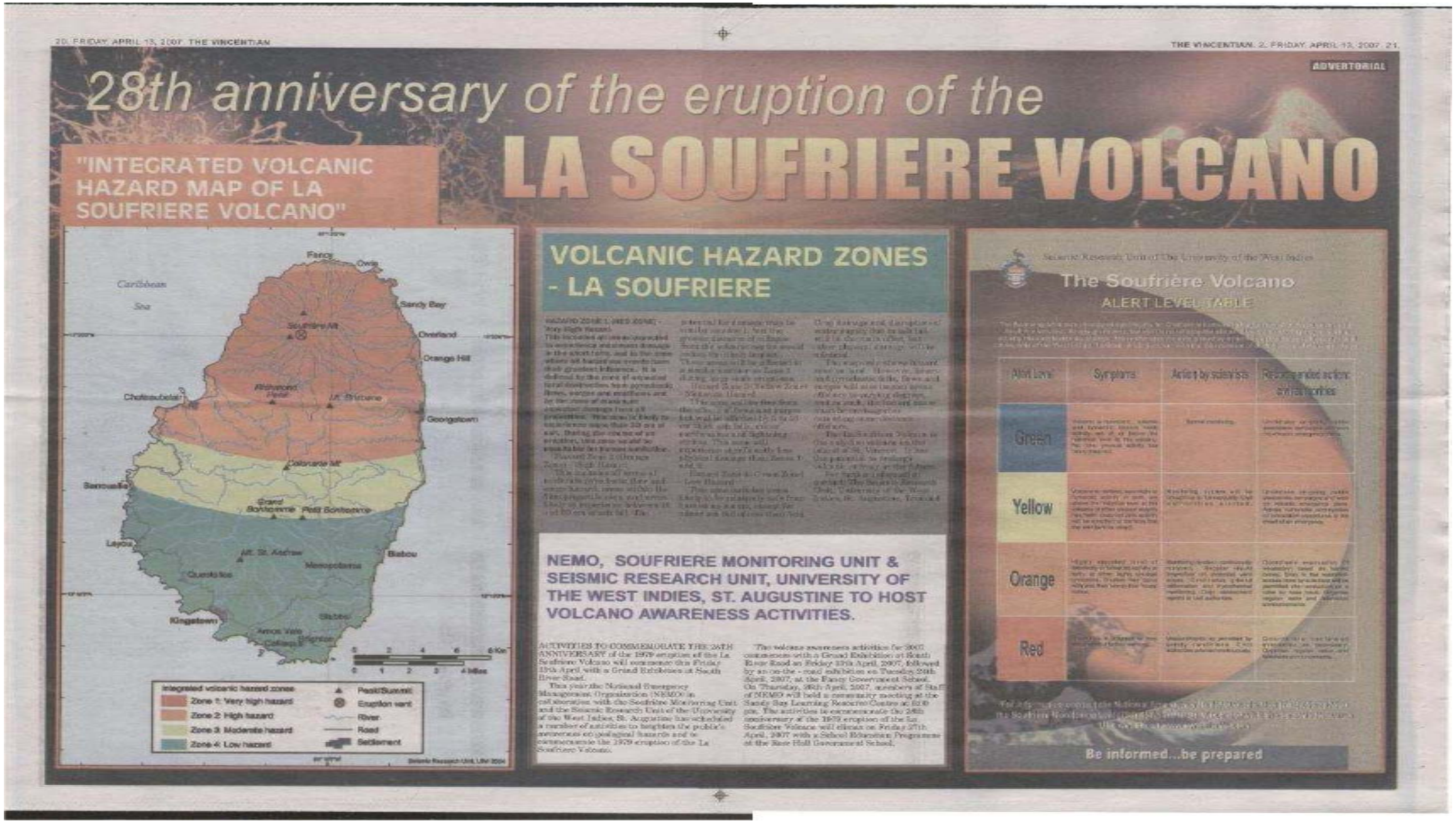
Hazard Zone 3 (Yellow Zone):

This zone will be free from the effects of flows and surges but will be affected by thick ash falls, minor earthquakes and lightning strikes. The 10 cm ash isopach for the 1902 eruption is taken as the cut-off point between this zone and integrated hazard Zone 2. The area of Zone 3 will experience less physical damage than Zones 1 and 2. Damage to flora will probably be restricted to the foliage with root systems left intact. Despite relatively minor impact on the physical infrastructure, hazardous events, nevertheless, may still cause major problems for the human population. The area will be included within the zone of total devastation during eruptions expected in the long term (scenario 2).

Hazard Zone 4 (Green Zone):

This embraces an area expected to experience relatively minor impact from eruptions. The 5 cm ash isopach is taken as the inner boundary for this zone. Crop damage and disruption of water supply due to ash fall will be the main effect but other physical damage will be minimal. However, in areas close to the boundary with zone 3 the physical signs of volcanic activity may cause some anxiety to the local population. Zone 4 will be relatively safe from hazardous events. In areas located in the south of this zone infrequent heavy ash fall may occur due to exceptionally strong local winds. In these areas the impact of the eruption will be felt only in terms of the additional burden placed on resources by people evacuated from higher risk zones further north. In the long term (scenario 2), these areas will be more strongly affected by ash fall. They may remain largely unaffected during the first few months of activity but will become increasingly impacted with time, due to the accumulation of ash fall.

Appendix C: The Vincentian newspaper, Friday April 13th, 2007



From the right-hand side of the newspaper article:

"This table was developed specifically for Onshore Volcanoes in the Eastern Caribbean such as the Soufriere volcano. At any given time, the alert level reflects the status of the volcano. Depending on the activity the alert level may change. These changes are determined by scientists at the Seismic Research Unit (University of the West Indies, Trinidad) in conjunction with the Government of St. Vincent and the Grenadines."

Alert Level	Symptoms	Action by scientists	Recommended action: civil authorities
Green	Volcano is quiescent; seismic and fumarolic activity are at or below the historical level at this volcano. No other unusual activity has been observed.	Normal monitoring.	Undertake on-going public awareness campaigns and work on volcanic emergency plans.
Yellow	Volcano is restless; seismicity of fumarolic activity or both are above the historical level at this volcano or other unusual activity has been observed (this activity will be specified at the time that the alert level is raised).	Monitoring system will be brought up to full capacity. Civil authorities alerted.	Undertake on-going public awareness campaigns and work on volcanic emergency plans. Advise vulnerable communities of evacuation procedures in the event of an emergency.
Orange	Highly elevated level of seismicity or fumarolic activity or both, or other highly unusual symptoms. Eruption may occur with less that twenty-four hours notice.	Monitoring system continuously manned. Regular visual inspection of potential vent areas. Continuous ground deformation and hydrothermal monitoring. Daily assessment reports to civil authorities.	Coordinate evacuation (if necessary) based on hazard zones. Entry to the restricted access zone by scientists will be permitted after evaluation on a case by case basis. Organise regular radio and television announcements.
Red	Eruption is in progress or may occur without further warning.	Measurements as permitted by safety conditions. Civil authorities advised continuously.	Coordinate continued evacuation as necessary. Organise regular radio and television announcements.

Appendix D: Copy of interview guide

Below is a copy of the interview guide used for the semi-structured interviews on St. Vincent and Dominica during the first field work.

INTRODUCTION

I would like to talk to you about your official role in preparing for and responding to volcanic disasters – in particular I'd like to discuss volcanic vulnerability, risk and the use of maps. I am doing this research so that in future it will be possible to provide you with tools and information that you can use in preparing for a volcanic disaster. We want to ensure that the system we are developing is suitable to your needs.

GENERAL OPENING QUESTIONS

Can you tell me about your role as…

How long have you been in this job?

How much of your working week do you dedicate to this role?

Can you tell me about how the system here works in terms of who you report to, who you work with, etc?

People's different roles…?

Vertical and horizontal organisation…?

What other agencies/ministries do you liaise with/work with respect to preparing for a volcanic emergency?

Who in particular?

How closely?

For what purpose?

Formal arrangements and meetings?

Informal exchanges of information?

EMERGENCY PLANNING

What is your role in terms of being prepared for a volcanic emergency?

What are your roles/responsibilities during a volcanic emergency?

At this stage will have the relevant emergency/contingency plan open in front of us or on laptop.

How are the risk, vulnerability and evacuation areas mentioned in the emergency/contingency plan currently decided upon?

Who makes these decisions?

What else is considered other than hazard data?

Where do these data come from (census, local knowledge…)?

At what scale do you plan/prepare for a volcanic eruption? Do you group areas/people into streets, towns, parishes, census districts for planning and preparing evacuations and deciding on risk and vulnerable areas?

MAPS AND GIS

Do you use maps as a part of your role in preparing for a volcanic emergency?

What are the maps of (risk, hazard, population…)?

Who makes them?

How often are they updated?

Using what data?

At what scale (town, parish…)?

Have you seen the Volcanic Hazard Atlas produced by the Seismic Research Unit?

What do you think about it?

Do you use it?

If yes – for what purpose?

Have you ever used computerised/digital maps in your role here?

What of?

For what purpose?

Who made them/provided you with them?

Are you familiar with Geographical Information Systems (GIS)?

May need an explanation here of GIS – if so say it is a set of GIS is a system of hardware and software used for storage, mapping, and analysis of geographic data.

Does your role require the use of GIS?

Does anyone in your office use GIS?

For what purpose?

What software?

Did you/they receive any training – from where?

<u>DEFINITIONS/UNDERSTANDING OF RISK AND VULNERABILITY</u>

The words exposure, hazard, vulnerability and risk mean different things to different people depending on their background and their job/role.

Which of these words are you familiar with/use?

Are there any other words you use?

Can you tell me how ***you*** understand/perceive/think of the difference between:

HAZARD and RISK?

HAZARD and EXPOSURE

VULNERABILITY and HAZARD

VULNERABILITY and RISK

(don't necessarily need to ask all of these…depends on discussion)

Can you tell me what areas of SVG/Dominica you think are particularly at risk from volcanic eruptions?

Why?

Can you tell me what groups of people you think are particularly vulnerable?

Why?

<u>FUTURE/PLANNING</u>

How important is planning and preparing for a volcanic eruption compared with other natural hazards SVG/Dominica is faced with?

List hazards discussed

How would you rank these hazards in terms of time and resources that go into planning and preparing for them?

Do you look at information about past and current eruptions in the Caribbean? E.g. past eruptions on this island and past/current eruptions on other islands?

If yes – explain

Have you seen/been given any information on the frequency of volcanic eruptions in the Caribbean?

If yes – what was it *(can I get a number)*

Are you familiar with the situation on Montserrat in terms of the number of years the volcano has been active and the evacuation/destruction of the island?

Has this changed your views about the risk from volcanic hazards here on SVG/Dominica?

If so, how?

Are you familiar with SVG/Dominica's land use development plans?

Can you tell me about how the potential threat from volcanic hazards is taken into consideration?

Restricted building in high risk zones

Engineering works to control hazards

Building codes for roofs, etc.

Other…

In terms of being prepared for a volcanic emergency, is there any other information/data you would like to have?

Maps

Population data

Tourism numbers

Other…

CONCLUSION

Is there anything else you can think of that might be important to discuss in terms of this research?

Are they any other people you think I should contact with respect to this research?

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