A Participatory GIS approach to Flood Risk Assessment of Informal Settlements: The Case of Cape Town

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Declaration

I know the meaning of plagiarism and declare that all the work in this document, save for that which is properly acknowledged, is my own.

Signed: ..... Date: .....

Abstract

Rural-urban migrations have contributed to the steady increase in the population of Cape Town. Many of the migrants have settled in informal settlements because they cannot afford to rent or buy decent housing. Many of these settlements are however located on marginal and often poorly drained land. Consequently, most of these settlements are prone to flooding after prolonged rainfall. Current flood risk management techniques implemented by the authorities of the Cape Town City Council (CTCC) are ideal for formally planned settlements but are not designed to support informal settlements. In fact, owing to a lack of information about the levels of flood risk within the individual settlements, either the CTCC has often been uninvolved or it has implemented inappropriate remedies within such settlements. Various authors purport that the inadequate flow of information between all the stakeholders has hampered development of sustainable flood risk management strategies. This study sought to investigate a methodology that the CTCC could use to improve flood risk assessment.

Using two case studies of flood-prone informal settlements in Cape Town, this study proposed a methodology for the collection and integration of community-based information into a Geographic Information System (GIS) that can be used by the CTCC for risk assessment. In addition, this research also demonstrated the use of a participatory multi-criteria evaluation (MCE) for risk assessment. Two questionnaires were used to collect community-based information. The shack outlines of the two informal settlements were digitized using aerial imagery from the CTCC. Responses to the questionnaires were captured using spreadsheets and linked to the corresponding shacks in the GIS. Risk weights were subsequently calculated using pairwise comparisons for each household, based on their responses to the questionnaires. The risk weights were then mapped in the GIS to show the spatial disparities in risk.

It was found that flood risk assessment should transcend the traditional analysis of the physical impact of floods. Also, any other hazards in the area of interest should be taken into account when doing flood risk assessment. The risk maps showed that flood risk could vary based on factors such as income, sanitation, exposure to hazards and inefficient mitigation measures.

This work contributes to the body of Participatory GIS (PGIS) and MCE. The overall contribution of this work lies in demonstrating a practical participatory approach to data collection and the use of MCE for risk assessment in informal settlements in Cape Town.

Key words: Informal settlements. Flooding. Flood risk management. Participatory GIS. Multi-criteria evaluation. Community participation.

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Terms and concepts

CCAA	Climate Change Adaptation for Africa
CORC	Community Organization Resource Centre
CTCC	Cape Town City Council
DFID	Department for International Development
EBE	Engineering and the Built Environment
FEMA	Federal Emergency Management Agency
FliCCR	Flooding in Cape Town under Climate Risk
GIS	Geographical Information Systems
GISP	Geographical Information Systems with Participation
GKS	Geographical Knowledge Systems
IDRC	International Development Research Centre
IK	Indigenous Knowledge
MADM	Multi Attribute Decision Making
MCDA	Multi Criteria Decision Analysis
MCE	Multi Criteria Evaluation
MODM	Multi Objective Decision Making
NGO	Non-Governmental Organisation
PAR	Pressure And Release
PCM	Pairwise Comparison Method
PGIS	Participatory Geographical Information Systems
PPGIS	Public Participation Geographical Information Systems
PRA	Participatory Rural Appraisal
SDI	Slum Dwellers International
TAM	Trade-off Analysis Method
UCT	University of Cape Town
UN DHA	United Nations Department of Humanitarian Affairs
VBA	Visual Basic Application

Chapter 1 Introduction

This chapter presents a description of the problem that necessitated this research.

1.1 Background and Motivation

The town planning policies that govern development in Cape Town are typically structured to mitigate hazards, such as flooding. However, rapid urbanisation in Cape Town has led to the birth and spread of informal settlements and high density townships, which do not subscribe to typical town planning norms. As of 2007, the Cape Town City Council (CTCC) reported that there were approximately 109,000 families living in informal settlements (City of Cape Town, 2008a). The report also noted that many of these informal settlements have developed along the Cape coastline and on inland areas prone to flooding, such as natural drains and flood plains. The extent of flooding in informal settlements has formed the basis of various studies and reports (Bouchard *et al.*, 2007; SDI, 2009). These studies have shown that, in some settlements, up to 92% of the residents experience flooding every winter.

The CTCC is responsible for flood risk management in Cape Town. There are several municipal organisations involved in flood risk management, including the Departments of Housing; Sports and Recreation; Water and Sanitation; Roads, Transport and Storm Water; Solid Waste; City Health and the Call Centre 107 (City of Cape Town, 2009). In the formal settlements of Cape Town, there is sufficient infrastructure in the form of storm water drains, channels, canalized rivers, culverts etc. to offset any potential floods. Such infrastructure is typically non-existent in informal settlements. Consequently, current responses from the CTCC to flooding in informal settlements are focused on post-flood interventions. Interviews with the CTCC winter preparedness 2010 committee on 23rd June 2010 confirmed that the CTCC was responsive rather than preventative in the management of flood risks in informal settlements. Responses included the provision of blankets, sand, plastic, meals and temporary accommodation to victims of flooding in informal settlements. These responses have generally been replicated in all flood-prone informal settlements. According to the 2009 winter preparedness strategy (City of Cape Town, 2009), a 7.5% increase from 8000 to 8600 households in July 2007 and July 2008 respectively was recorded in the number of households for which such provision was being made. It is worth noting that with the ever increasing populations in informal areas, the current response to flooding by the CTCC will become increasingly unsustainable.

Also, studies have revealed that the local communities and CTCC officials often have different perceptions of what the solutions to the problems are and that this creates various limitations, especially with regard to the implementation of proposed solutions (Tyler, 2011). Studies have shown that sustainable solutions can only be created when there is dialogue between all the stakeholders involved.

The CTCC subsequently approached the Climate Change Adaptation for Africa (CCAA) research group at the University of Cape Town (UCT) in order to investigate alternative ways of

risk assessment in informal settlements. This prompted the creation of a section within the CCAA FliCCR (Flooding in Cape Town under Climate Risk) project whose focus was on flood risk assessment in informal settlements. The other sections of the CCAA FliCCR research group focussed on assessing governance structures in informal settlements and the effects of sea-level rise along the coast of the Cape. This particular study was focussed on flood risk assessment. The project was funded by the International Development Research Centre (IDRC) in Canada and the Department for International Development (DFID) in the United Kingdom.

1.2 Research Problem

This study was focused on identifying ways of developing dialogue between informal settlements and the CTCC. It investigated ways in which information could be gathered from local communities in a format that the aforementioned departments of the CTCC could utilize in developing policies around flood risk mitigation. It also investigated novel ways of risk assessment in informal settlements.

1.3 Research Questions

Given the research problem, the following research questions were investigated:

- How can valid information be sourced from various stakeholders including local communities in informal settlements for flood risk assessment?
- How can partnerships be developed to enhance holistic flood risk assessment in flood-prone informal settlements?
- How does the distribution of flood risk vary spatially within flood-prone informal settlements and what are the implications for mitigation?

1.4 Aims, Objectives and Outcomes

The goal of this research work was to assess flood risk in informal settlements of Cape Town. In order to achieve this, the following aims and objectives were identified:

- To ascertain all the hazards and their outcomes in the informal settlements. The reason for this is that a community can only be at risk if they interact with a hazard. Although flooding forms the focus of this study, the occurrence of any other hazards will exacerbate flood risk. This will be achieved by conducting interviews with stakeholders such as NGOs and the CTCC.
- To establish the validity of the information sourced from communities. This will be done by comparing datasets from different stakeholders.

- To identify institutions and their roles in affecting the vulnerability of the informal settlements. This will be realised by using the local community and the other stakeholders in the data collection.
- To develop methodologies for assessing different levels of vulnerability in informal settlements. This will be accomplished by involving the local community in the vulnerability assessment.
- To establish differential risk within informal settlements and any dynamics causing unexpected outcomes. This will be achieved by calculating weights for the identified indicators of vulnerability.
- To link the risk analysis to potential solutions. This will be realised through discussion of the findings with stakeholders.

At the end of this research, the following outcomes were achieved:

- It was found that the informal settlements were exposed to both flooding and fires.
- Data validation was done by cross-referencing the responses in the questionnaires, engaging with the communities, and checking for inconsistencies by mapping the responses.
- It was found that Non-Government Organizations (NGOs) and the CTCC were involved in flood risk management in informal settlements.
- Multi-criteria evaluation (MCE) was used in combination with Geographic Information Systems (GIS) to develop risk weights in partnership with the local communities and to map the magnitudes of risk spatially.
- An assessment of the spatial distribution of risk pinpointed some potential solutions for risk mitigation.

1.5 Significance

This study contributes to the body of research on participatory GIS and MCE. A unique contribution of this study is the development of a participatory approach to the combination of multi-criteria evaluation and GIS in flood risk assessment.

1.6 Limitations

In accordance with the design of the study within the CCAA FliCCR project, this study is limited to the assessment of risk at a local level, prior to a flood event.

1.7 Methodology

The study started with the identification of informal settlement areas that are flood-prone. Partnerships were then developed with the CTCC, an NGO called Slum Dwellers International (SDI) and the community leaders in the informal settlements. The next stage involved questionnaire design as well as enumeration and mapping. This was followed by data validation. Risk weights were calculated using MCE and mapped in a GIS environment.

1.8 Organisation of Dissertation

Chapter 2 describes the research framework and existing theory in the area of risk assessment. Risk is split into bio-physical and social elements. This chapter also identifies existing research on flooding as well as research on MCE and Participatory GIS. Chapter 3 presents a background to the two informal settlements that were used as case studies in this research. The geographic locations of these settlements in Cape Town are also discussed. Chapter 4 describes the methodology developed in the course of this research. It also includes a comment on the integrity of the data collected. Chapter 5 presents the results of the analysis, which is followed by a discussion of the results in Chapter 6. Chapter 7 puts forward the conclusions and recommendations based on the findings of this study. Lastly, the References and the Appendices are included after Chapter 7.

Chapter 2 Research Framework and Theory

This research is founded on literature on risk analysis and risk management. Consequently, it is subject to the linkages between hazards, exposure of communities to hazards, as well as their ability to cope with the hazards. This chapter will report on the link between hazards, risk and vulnerability.

2.1 Flooding

In the period between 1996 and 2005, floods had devastating effects on the continents of Africa, Asia, and the Americas (Satterthwaite *et al.*, 2007). It is reported that, during that period, there were 290 flood-disasters in Africa alone, which left 8,183 people dead and 23 million people affected, and which caused economic losses of $1.9 billion (ibid). Similarly, 472 flood-disasters in Asia over the same period killed 42,570 people and affected 1.3 billion people, and were responsible for economic losses estimated at $129 billion (ibid). It is also worth mentioning that floods were the most frequent natural disaster in Africa and the most common in Asia during that time period (ibid). Magrin *et al.* (2007) recounted that the incidence of disasters related to weather have increased 2.4 times between 1970 and 2005, and more increases are expected in the future. Studies on the changing weather patterns in South Africa predict increased intensity of high rainfall events (Mason *et al.*, 1999). Incidentally, Satterthwaite *et al.* (2007) reported that climate change has the potential to increase flooding risks in cities because of rising sea levels and storm surges, as well as heavier and prolonged rainfall and increased river flows.

Douglas *et al.* (2008) distinguished four different forms of flooding in urban areas, namely:

a) localized flooding due to inadequate drainage;
b) flooding from small streams with catchment areas in built-up areas;
c) flooding from major rivers on whose banks exist urban areas; and
d) coastal flooding from the sea or high tides as well as high river flows from inland areas.

Satterthwaite *et al.* (2007) investigated the propensity for flooding in cities and found that urban areas are prone to flooding when it rains, since buildings, roads, paved areas and other infrastructure often prevent water from seeping into the ground. Consequently, prolonged rainfall can increase runoff and cause floods, especially where buildings or structures encroach on natural drains. Also, inadequate solid-waste management and drain maintenance can lead to clogged drains, which in turn leads to localized flooding even with light rainfall (ibid). However, for most urban environments, properly maintained infrastructure such as road drains and channels are adequate to prevent flooding. Unfortunately, owing to high numbers of rural-urban migrations, there has been a growth of illegal settlements in cities across the world. The migrants are often too poor to afford proper housing in the serviced parts of the city and therefore settle on risk prone land (SDI, 2009; Barry & Rüther, 2005).

In a local context, according to the 2007 CTCC census report, there were approximately 109,000 families living in informal settlements in Cape Town (City of Cape Town, 2008a). The report also pointed out that many of these settlements are located in inland areas that are prone to flooding, such as natural drains and flood plains (see Table 2.1).

Flood hazard locality	Affected informal settlements	Estimated no. of dwellings affected
Storm water ponds	7	457
Environmentally sensitive wetlands	2	927
Trapped low-lying areas	33	3885
Flood plain or within 25m of water course	18	1848

Table 2.1 Occurrence of informal settlements in flood prone areas (City of Cape Town, 2009)

A number of reports point out the extensive effect of flooding in these informal settlements. The CTCC conducted a study in three informal settlements, namely Joe Slovo, Sweet Home and Nonqubela K-Section in Khayelitsha. The study reported that 83% of the residents had been affected by flooding (City of Cape Town, 2005). Bouchard *et al.* (2007) reported that, during the winter month of July 2007, 120mm of rainfall had been recorded over a period of five days in Cape Town. This led to flooding that affected 8,000 households, comprising 38,000 residents, primarily in the informal settlements of Khayelitsha and Philippi. Slum Dwellers International (SDI) published the findings of their 2009 enumeration survey in Joe Slovo, another informal settlement in Cape Town, and reported that the predominant disaster experienced was flooding (SDI, 2009). Of the 2,748 families surveyed by SDI, 1,708 had experienced flooding more than once during their stay in that settlement. A survey carried out in Masiphumulele, another informal settlement, in 2010 indicated that, of the 70 households interviewed, 92% had experienced flooding in that settlement (Tyler, 2011). All the aforementioned studies demonstrate the significant impact of flooding on informal settlements across Cape Town and the consequent need for an efficient flood management policy in such areas. In this regard, Meyer *et al.* (2009) identified the two main components of flood risk management as flood risk assessment and flood risk mitigation. Although potential mitigation measures will be identified, this study will focus on the risk assessment component of risk management. It is therefore important to appreciate the concept of risk.

2.2 A Discourse on Risk

The definition of risk has been explored in various studies. Although the definitions of risk vary according to context, they are inexorably linked to hazards. Hence, a number of descriptions of hazards have been advanced by different scholars. Donohue *et al*. (2000: 457) conducted a study on disaster management and put forward the following concise description for hazards:

"A hazard may be defined as a threat to life, wellbeing, property and/or the environment".

A more thorough description provided by Cardona *et al*. (2003) and Cardona (2004:2) will be adopted for the purposes of this research:

"A hazard is defined as a latent danger or external risk factor of a system or exposed subject. It is the probability of the occurrence of an event of certain intensity in a specific site and during a determined period of exposure".

The definitions of risk may be broadly divided into two main themes: a hazard-based approach and a vulnerability-based approach. A number of authors including Helm (1996), Sayers *et al*. (2002a) and Sayers *et al*. (2002b) considered risk to be a function of the probability and magnitude of a hazard, and the extent of the consequence of exposure by a community or environment to that hazard.

Sayers *et al*. (2002a) as cited by Kelman (2003: 7) defined risk as follows:

"Risk is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components – the chance (or probability) of an event occurring and the impact (or consequence) associated with that event. The consequence of an event may be either desirable or undesirable".

A similar definition of risk was afforded by Smith (1996) as cited in Kelman (2003: 7) when he stated that:

"Risk is the actual exposure of something of human value to a hazard and is often regarded as the combination of probability and loss".

The singular difference in the two definitions is that Smith (1996) explicitly linked risk to a negative impact (loss) whilst Sayers *et al*. (2002a) allow for a positive outcome after the occurrence of an event or hazard in their definition of risk. Nonetheless, these authors agree that risk may be defined by the following equation:

$$\text{Risk} = \text{Probability} \times \text{Consequence} \qquad (2.1)$$

This description denotes a purely hazard-based approach to risk. Sayers *et al*. (2002a) also pointed out that anyone applying Equation 2.1 should take into consideration the individual elements. In other words, although the numerical value may be equal for risk arising from a low probability and high consequence on the one hand, and risk arising from a high probability and low consequence on the other, they require different responses. Response involves themes such as vulnerability, resilience and adaptation, which go beyond the bounds of a pure hazard-based approach. It is worth noting that, although Stenchion (1997) adopted a similar definition to that of Sayers *et al*. (2002a), he added that a better description of risk could be achieved by taking into account vulnerability. Lewis (1999) further stated that, instead of focussing on the

magnitude of risk in a particular context, emphasis should be placed on studying vulnerability within that context (Kelman, 2003).

Thus the second theme in risk literature was raised by scholars who take into account vulnerability when defining risk. De la Cruz-Reyna (1996), as cited by Kelman (2003), described risk as a function of the hazard, the level of vulnerability, the value of the threatened area and the degree of preparedness. In so doing, De la Cruz-Reyna (1996) emphasised the value of loss, but extended the previous description by Smith (1996) to include vulnerability and preparedness. Consequently, the notation proposed by De la Cruz-Reyna (1996) and cited by Kelman (2003) is as follows:

$$\text{Risk} = \frac{\text{Hazard} \times \text{Vulnerability} \times \text{Value}}{\text{Preparedness}} \qquad (2.2)$$

However, preparedness is influenced by the extent of knowledge of vulnerability, among other things. This is highlighted in the description of preparedness by Canada (2002), who stated that preparedness involves a number of activities such as development of flexible response plans, training and equipping of responders, and assessment of a community's vulnerabilities. Furthermore, the Federal Emergency Management Agency (FEMA) states that preparedness can be described as follows:

"Preparedness is a continuous process that involves efforts at all levels of government and between government and private sector and non-governmental organizations to identify threats, determine vulnerabilities, identify required resources, and formulate and apply solutions" (FEMA, 1997).

In other words, both descriptions state that, only after assessing vulnerability, can one arrive at an estimate of preparedness. Also, the value of loss caused by a hazard is inextricably linked to the magnitude of the hazard. Hence, some scholars have not explicitly included preparedness and value in the description of risk. For instance, an alternate description was offered by the United Nations Department of Humanitarian Affairs (UNDHA) and adopted by Turner *et al.* (2003) in the PAR (Pressure and Release) conceptual model as follows:

"Risk is expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability". (UNDHA, 1992)

The notation offered by this description is:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \qquad (2.3)$$

It is noteworthy that this description includes a reference to loss but it is not carried into the subsequent equation (2.4). Still, there is a link between the value of loss caused by a hazard and extent of exposure of assets, people or the environment to the hazard. Hence, many authors have

explicitly included exposure as an indicator of risk. This is evidenced by the widely accepted description of risk offered by Crichton (1999) as cited by Kelman (2003: 7):

"Risk is the probability of a loss, and this depends on three elements, hazard, vulnerability and exposure".

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \quad (2.4)$$

Based on this Equation (2.4) Crichton (1999) postulated that if any of these three elements in risk increases or decreases, then risk increases or decreases respectively; an opinion shared by Cardona (2004). Cardona (2004) also suggested that hazard and vulnerability cannot exist independently of each other. Hence any changes in hazard and/or vulnerability will influence the risk. Furthermore, Cardona (2004) pointed out that since hazards cannot be modified; efforts aimed at reducing risk to a hazard can only be focussed on reducing vulnerability of the exposed communities or environments to that hazard.

From Equation 2.4, it may appear that reducing exposure would also reduce risk. Nevertheless, a different argument was offered by Wilde (1994), Etkin (1999) and Kelman (2001), as cited in Kelman (2003). They subscribed to the theory of risk homeostasis, which basically states that individuals, communities and societies maintain a constant level of risk, irrespective of external influences (Kelman, 2003). For instance, reducing exposure to a hazard will cause behaviour that inadvertently reduces preparedness in relation to the hazard and consequently increases vulnerability. They subsequently contended that external measures do little to influence overall risk in the long term. Instead, Kelman (2003) agreed with Lewis (1999) that, since vulnerability assesses the processes at work between hazard and risk, and since it is applicable to any hazard, targeting vulnerability will reduce overall risk to an acceptable level.

Drawing from the arguments of Wilde (1994), Etkin (1999), Kelman (2001), Cardona (2004), Crichton (1999) and UN DHA (1992), vulnerability has a strong bearing on the magnitude of risk. Consequently, studies into the level of vulnerability of an environment or community to a particular hazard will invariably provide insight into the magnitude of risk of the environment or the community to that hazard. This research will therefore adopt vulnerability as an indicator of risk, and the next section will describe the status of vulnerability studies.

2.3 A Discourse on Vulnerability

From the preceding section, it is evident that the notion of vulnerability has played a huge role in deconstructing the concepts of hazard and risk. Kumpulainen (2006) stated that vulnerability could be viewed as a state of conditions and processes resulting from physical, social, economic and environmental factors that increase the liability of a community with regard to the impact of hazards. Consequently, Kumpulainen (2006) adopted the following notation for vulnerability:

$$\text{Regional Vulnerability} = \text{Damage potential} + \text{Coping capacity} \qquad (2.5)$$

The definitions on vulnerability also vary based on context. Cutter (1996) identified three main themes in vulnerability research as cited in Kumpulainen (2006):

- Vulnerability as exposure to a hazard: This type of research focuses on the geographical distribution of a particular hazard, the human occupancy of such a geographic area and the extent of loss associated with a hazardous event. Here vulnerability exists prior to the event.

- Vulnerability as a social response: Here research is directed at the response and coping capacity of a community. It includes resistance and resilience to hazards, and the recovery after an event. This has also been described as the social dimension of vulnerability.

- Vulnerability of places: This type of research is intended for contextualizing the combination of hazard exposure and social response within a particular geographic location.

It can be seen that the vulnerability of exposure to hazards can be linked to 'damage potential', whilst vulnerability as a social response can be linked to coping capacity, in terms of Equation 2.5. In a critique of the literature on vulnerability, Cardona (2004) proposed that any holistic approach to studies on vulnerability should take into account all the origins of vulnerability. Consequently, Cardona (2001, 2004) suggested that vulnerability could be instigated or exacerbated by:

- Physical fragility or exposure: This comprises the predisposition of a human settlement, and by extension individuals, to be affected by an event or hazard because of their location in the area of manifestation of the event or hazard and because of a lack of physical resistance.

- Socio-economic fragility: This comprises the susceptibility to harm of a community based on pre-existing levels of marginality and social segregation of human settlements, and by extension individuals, and the detrimental conditions and relative weaknesses related to social and economic factors.

- Lack of resilience: This comprises an expression of the limitations of access and mobilization of the resources of human settlement, and its incapacity to respond when it comes to absorbing the impact.

It is noteworthy that Kumpulainen (2006) and Cardona (2001, 2004) both added that any discourse on vulnerability must additionally encompass the extent of a community's potential to respond to, and cope with a disaster.

Brooks (2003) and Cutter *et al.* (2003) concurred with the research themes on vulnerability noted by Cutter (1996) but referred to vulnerability on hazard exposure as "biophysical vulnerability"

and vulnerability as a social response as "social vulnerability". The following discussion will expound on these two widely accepted broad themes.

2.3.1 Biophysical and Social Vulnerability

Scholars on biophysical vulnerability focus on analysing the human exposure to a hazard. This approach is also referred to as the 'hazards and impact' approach. In this case, the vulnerability of a particular system is a function of the type of physical event/hazard, the degree of human exposure to the hazard, and that system's sensitivity to the hazard (Brooks, 2003). Biophysical vulnerability incorporates both the immediate physical impact of the hazard and the traits of the affected system, both biological and social, that act to amplify the effect of the initial impact (Brooks, 2003). An example of such a description of vulnerability is that by Smit *et al*. (1999) and the IPCC (2001) (both cited in Brooks, 2003: 5) wherein vulnerability is defined as:

"The degree to which a system is susceptible to injury, damage, or harm."

Also, Cutter *et al.* (2003: 242) simply described vulnerability as: "The potential for loss." An additional example is found in Turner *et al.* (2003: 8074) where it is stated that:

"Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard"

In the biophysical context, vulnerability is measured from the consequence of a hazard and typical indicators would be monetary cost of damage, mortality and environmental damage (Yalcin & Akyurek, 2004; Yahaya & Abdalla, 2010). It stands to reason that, because damage is dependent on the manifestation of the hazard, this principle of vulnerability is a function of external factors, and that it is only quantifiable after the event. Additionally, this tenet of vulnerability subscribes to the first part (damage potential) of Equation 2.5. There have been a number of critiques of this ideology. For instance, a natural hazards approach to vulnerability studies is deficient because:

i. It does not take into account the variations in systems that cause substantial distinctions in the magnitude of damage when exposed to the same hazard (Downing, 1991; Cutter, 1996; Bohle, 2001) and;

ii. It does not take into account the ways in which the social fabric of the communities in contact with the hazard exacerbates the impact of the hazard in question (Kasperson *et al*. 1988; Martine *et al*., 2002)

Incidentally, the term 'system' in the studies above is used to refer to the elements being exposed to the hazard, e.g. people and/or the environment. These inadequacies established a school of thought in which vulnerability is seen as a function of the state of a system prior to, rather than after the event. Social vulnerability is viewed as being the result of the internal traits of the

system itself and as being independent of external hazards or events. For instance, the second definition of vulnerability by the IPCC (2001: p 995), cited in Brooks (2003), is as follows:

> "The degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity."

This description is extended to include social vulnerability because it places emphasis on the state of the system prior to the event rather than damage caused. For instance, indicators for social vulnerability include factors, such as the marginalisation of or within communities, poverty and inequality, proximity to transport nodes, access to insurance, infrastructure, access to food, and the quality of housing (Abbot *et al*., 1998; Blaikie et al., 1994; Erdlenbruch *et al.*, 2009; Adger & Kelly, 1999; Shrubsole, 2001; Cross, 2001) cited in Brooks (2003). Studies, such as those of SDI (2009), Abbot (2000), Bouchard *et al*. (2007) and Raaijmakers *et al*. (2008), that focus on determining the most vulnerable members in communities in the face of a common hazard are vested in the precept of social vulnerability.

Brooks (2003) and Cutter (2003) both drew a link between social vulnerability and biophysical vulnerability. Brooks (2003) postulated that the interface between social vulnerability and the hazard produces a consequence that is measurable by using the indicators of biophysical vulnerability. For that reason, social vulnerability plays a role in determining biophysical vulnerability. Conversely, Cutter (2003) believes that they act simultaneously, and she explains the link between biophysical and social vulnerability in more detail using Figure 2.1.

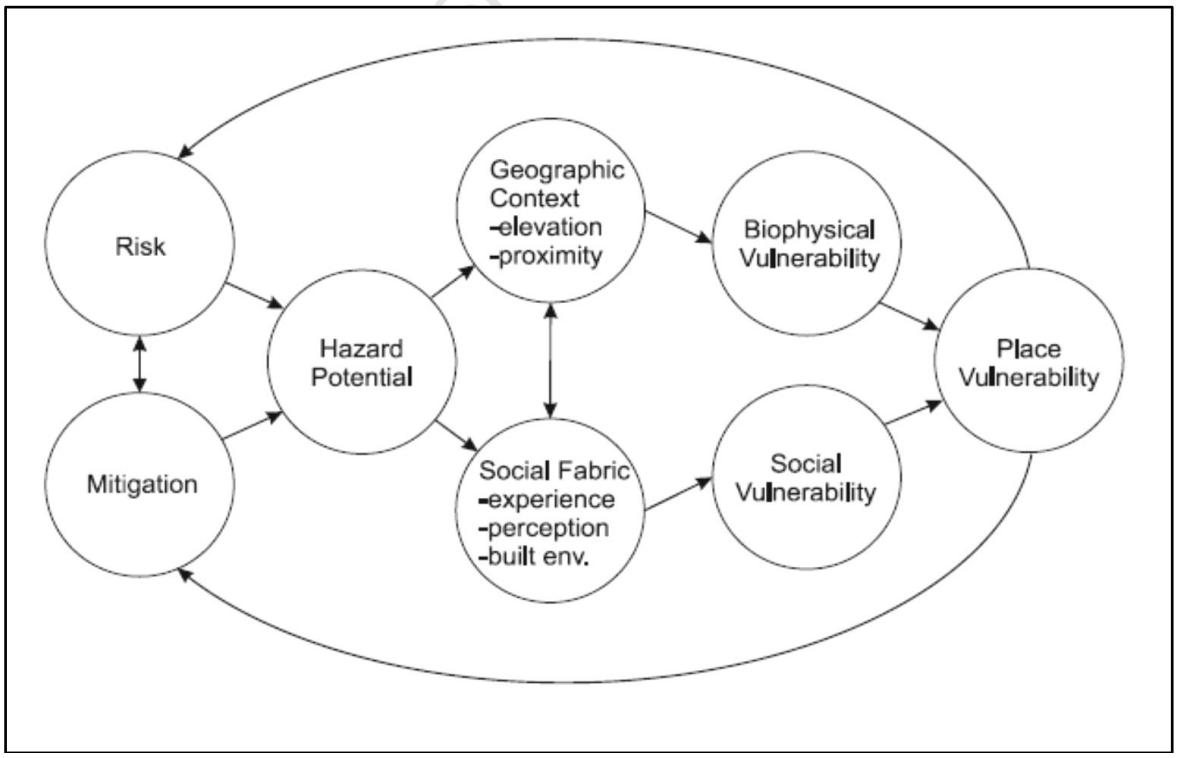

Figure 2.1 Hazards of place vulnerability model (Cutter, 2003).

In Figure 2.1, the initial impact (hazard potential) of a hazard will be based on the interaction of the hazard and the mitigations already in place. The impact of the hazard can either be exacerbated or diminished by the location of the area with regard to the hazard and the previous experiences of those affected by the hazard. The inherent qualities of the community constitute social vulnerability whilst the influence of the geographic environment on the magnitude of loss constitutes biophysical vulnerability. The interaction of the biophysical and social vulnerability translates into the overall vulnerability of that place. The overall vulnerability will then determine new mitigation techniques and influence the subsequent effects of risk, and the cycle starts all over the next time the hazard manifests.

Considering both arguments of Cutter (2003) and Brooks (2003), the common ground is that determining social vulnerability is important for the overall determination of vulnerability and risk. Reducing social vulnerability will in turn reduce overall vulnerability and implicitly reduce risk. It is imperative that any holistic research on the topic of vulnerability is cognisant of biophysical and social vulnerability. The next section reports on a commonly used framework for vulnerability assessment.

2.3.2 A Framework for Vulnerability Assessment

It has been noted in the preceding section that there are various facets to vulnerability studies. Turner *et al.* (2003) developed a widely used framework that incorporated studies on both biophysical and social vulnerability. The model developed in that literature stated that social vulnerability studies have to ascertain the following:

- The entitlements of the communities being studied: The rights of communities influence how much help they can receive from external sources and this therefore plays a role in determining differential risk. The more marginal a community is, the more vulnerable it is.

- The coping capacities of the communities at risk: Every community, regardless of economic standing, will develop mitigation techniques. The diversification of these techniques may contribute to differential levels of success in deterring potential harm. It is therefore important to study the mitigation techniques in these communities.

- The resilience of the affected communities: Turner *et al.* (2003: 8075) defined resilience as "the capacity of a system to return to a reference state after a disturbance or maintain certain structures and functions despite disturbance". It is also noteworthy that resilience is not necessarily homogenous within a community.

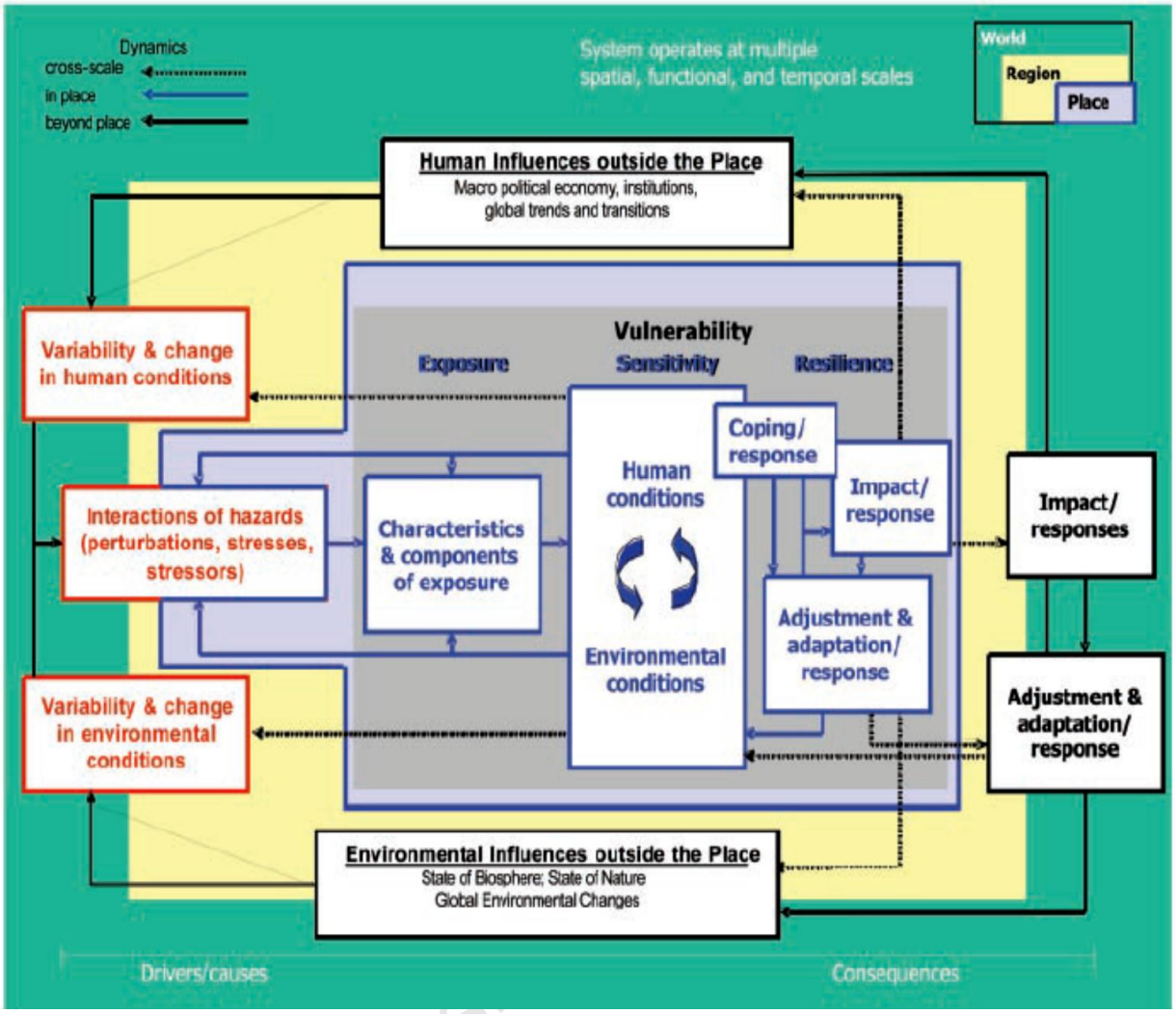

Figure 2.2 Vulnerability framework by Turner *et al.* (2003: 8076)

The preceding discussion has dealt with *social vulnerability* but decision making in sustainable risk management should ideally be based on studies that also acknowledge *biophysical vulnerability*. In that regard, Turner *et al.* (2003) stated that holistic studies on vulnerability, which are meant to have an input in decision making, should include, among others:

- A study of all the hazards affecting the system (community and environment);
- A study of how the system is exposed to the hazard;
- The coping capacity of the system;
- The sensitivity of the system;
- Adaptations of the system after a disturbance; and
- The scale of the hazards as well as the scale of the responses.

This framework is represented in Figure 2.2. The framework accommodates the three possible scales of vulnerability studies, namely the place (blue), the region (yellow) and the world (green). The components of studies of vulnerabilities of places are further expounded in Figure 2.3.

In Figure 2.2, the areas in which human and environmental conditions (the system) interact with hazards constitute the place of analysis. Since the hazards affecting the place of analysis are a product of influences from both outside and inside the system, the manifestation of the hazard will be unique in a given environment. For this reason, hazards are located on a larger scale than the place of analysis. The human and environmental conditions (biophysical and social) determine the sensitivity of the system to exposures. The conditions influence the coping mechanisms in response to exposure to a hazard, such as existing policies and programs, as well as those coping mechanisms that have been created or adapted in response to exposure to the hazard in the past, such as new policies and programs (Figure 2.3). These coping mechanisms could be individual, communal or policy directed, and could lead to modifications in policies, in similar environments outside the place of analysis or by human institutions outside the place of analysis. All these interactions affect the resilience of the system and may even translate to systems at a greater scale.

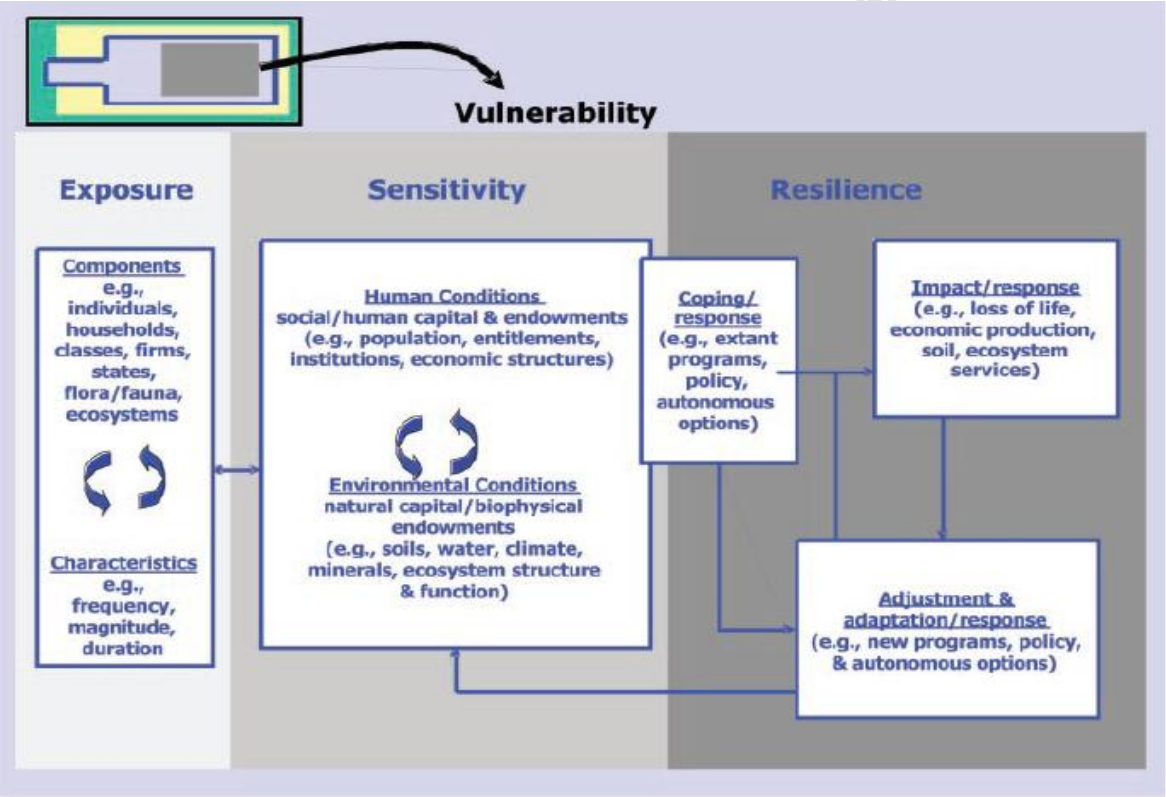

Figure 2.3 Vulnerability of places framework by Turner *et al.* (2003: 8077)

Turner *et al.* (2003) noted that, although the holistic approach described in the preceding discussion would take all contributors of vulnerability into account, it is often impossible to analyse vulnerability at all scales. However, studies on vulnerability can be considered essential for decision making when the following conditions apply:

- They go beyond the analysis of the traditional consequences of the hazard and adequately cover all the outcomes of the hazard that need to be avoided;

- They establish differential vulnerability, taking into account that, within a system, the units are rarely equally vulnerable;
- They address the roles of institutions that affect the sensitivity and resilience of the system;
- They develop appropriate methodologies for assessing, modelling and testing vulnerability;
- They identify irregular fundamental structures that affect vulnerability and establish a link between the cause and effect;
- They identify the dynamics within the system that cause unexpected outcomes; and
- They develop structures to link the analysis of the system to decision making, clearly stating the reliability and validity of the information provided.

An examination of these essential requirements postulated by Turner *et al*. (2003) reveals the need for the participation of the different stakeholders in determining vulnerability and consequently sustainable solutions towards the mitigation of hazards. For instance, it is impossible to determine all the outcomes of a hazard in a community without engaging with that community. Likewise, addressing the roles of institutions both within and outside a place of study requires engagement with both the internal and external institutions. The success of vulnerability assessment and decision making to mitigate vulnerability is therefore vested in partnerships. However, partnerships require common platforms for sharing of information. The next section identifies technologies and methodologies for developing common platforms for the sharing of information at different scales for vulnerability and risk assessment.

2.4 Stakeholder Participation and GIS

Geographic Information Systems (GIS) have commonly been used to facilitate decision making. A GIS may be defined as a computer-based tool for storing, mapping and analysing spatially referenced data (Quan *et al*. 2001). Since GIS technology is a common choice for the capture and display of location based data, it has been used in various institutions to facilitate the comprehension of spatial aspects of social and economic development. For instance, Quan *et al*. (2001) reported that GIS could be used as a tool:

i. To compare and contrast socio-economic variables to natural resources and the physical world;

ii. To facilitate the targeting of interventions and monitoring of impacts at various scales and over wide areas; and

iii. To place planning and research technology into the public domain in order to enhance access to information and improve understanding of conflicting viewpoints.

These characteristics of GIS make it a potentially useful platform for location-based vulnerability assessment, based on the recommendations of Turner *et al.* (2003). However, this potential of GIS to facilitate dialogue between stakeholders at various scales has often been unrealised, mainly because GIS development has traditionally been carried out exclusively at a technical level by various professionals without input from communities located in the actual geographical space of the GIS (Edney, 1991; Pickles, 1991; Carver, 2001; Quan *et al.*, 2001).

Also, Laituri (2003) noted that access to GIS technology and data is dependent on, among other things, the relationship between the stakeholders (context); the technological infrastructure, policy and funding available (connectivity); the basic, computer and spatial literacy of the participants (capabilities); the availability and types of data, such as public data or sensitive data from government entities (content). Hence, the use of GIS required a certain level of expertise, and communities could not gain access to the data in the GIS (Edney, 1991; Pickles, 1991; Carver, 2001; Quan *et al.*, 2001). Consequently, traditional development of GIS has often frustrated participation rather than encouraging it.

Conversely, the absence of an input of information from communities meant that the traditional GIS did not have the full scope of information required by decision makers to come to the best conclusions. Furthermore, if decisions were being made based on information in the GIS, it meant that the marginalised communities could not participate in the decision-making process. Taylor (1990) postulated that incorporating the full scope of information on a locality would transform the corresponding GIS into a Geographical Knowledge System (GKS) and thereby facilitate better decision making.

These deficiencies in traditional GIS facilitated the body of research in what became known as Participatory GIS (PGIS) and Public Participation GIS (PPGIS). The acronyms PGIS for 'Participatory GIS' and GISP for 'GIS with Participation' have been used interchangeably by scholars on the subject. Various definitions have been postulated in the body of research on participatory GIS. For instance, Quan *et al.* (2001: 2) provide the following definition:

> "Participatory GIS is the integration of local knowledge as well as stakeholders' perspectives in a GIS".

Laituri (2003: 25) conversely, describes Participatory GIS as:

> "A confluence of social activity such as grassroots organizations and government decision making with technology in specific places or grounded geographies".

Although definitions vary, they all address the development of a link between a locality and the sharing of information between stakeholders in that locality. Naturally, the body of research on Participatory GIS can be split into two broad themes, addressing the two deficiencies highlighted in the preceding discussion. Some scholars address the issues involved in enabling access of the various stakeholders to information in the GIS (Carver, 2001; Laituri, 2003; McCall, 2003),

whilst others advocate the inclusion of information from various stakeholders including communities in a GIS (Abbott *et al.*, 1998; Abbott, 2000; Karanja, 2010). PPGIS is employed mostly in the planning profession and is essentially a component of PGIS that focuses on empowerment of communities (Carver, 2001). The primary aim of PPGIS is to use GIS to provide information that can strengthen the involvement of communities or marginalized groups in actual decision making (Ghose & Elwood, 2003; Sieber, 2006).

PGIS meets all the requirements to facilitate biophysical and social vulnerability assessment. There are a number of case studies on the use of PGIS in facilitating data collection and data access from various stakeholders. They do not necessarily deal with the issue of vulnerability, but the methodologies employed can nonetheless be adopted in vulnerability assessment studies. The next section reports on some of these methodologies and case studies.

2.4.1 Methodologies in developing a Participatory GIS

A number of methodologies have been employed in integrating community information and GIS with an emphasis on either enriching the traditional information in the GIS or allowing access to the GIS. With regard to access to data, one common method is the use of the internet. Carver (2001) reported on a case study in Leeds, England, where spatial datasets were uploaded onto the internet and communities were able to access the data and voice their opinions online on various issues affecting their lives. Online interaction between stakeholders has also been referred to as e-participation (Carver, 2001).

Similarly, methodologies in data integration are dependent on the ready availability of data from the various stakeholders. In other words, depending on the availability of data, researchers either engage directly with the community or use already existing information on the community. For instance, Meyer *et al.* (2009) assessed flood risk in the Mulde River in Germany using official statistics on the risk-prone community as well as land use and flood data held by the local authorities. The official statistics furthermore included data, such as insurance data, taxation data and environmental studies collected within the area of study. Using a different approach, Tran *et al.* (2009) used GIS and local knowledge to contribute to proper planning and resource allocation for disaster preparedness in Thua Thien Hue, Central Vietnam. Community information included existing infrastructure, demographic and socio-economic conditions as well as information on the damage and loss caused by previous flood disasters. Participatory Rural Appraisal (PRA) techniques, such as focus groups, were used to highlight the most flood prone residential units as well as factors that contribute to flood vulnerability.

Other studies point to different methods of community involvement, such as the use of interviews by Iuliana & Eugen (2009) in Romania; a review of the use of questionnaires by Bird (2009) and the actual use of questionnaires by Abbot *et al.* (1998), Abbot (2000) and Bouchard *et al.* (2007) in South Africa and Raaijmakers *et al.* (2008) in Spain; the use of voice and video recordings (Roux & Barry, 2001; Barry & Rüther, 2005); and the general use of ephemeral mapping, sketch mapping and scale mapping by Rambaldi *et al.* (2006). Similar methods are

highlighted by Tripathi & Bhattarya (2004) who carried out an elaborate study, looking at various authors with regard to the relevance of indigenous knowledge (IK) and the trends in integration of IK into GIS. In general, studies on the sourcing of community data in formal urban areas allow for less interaction with the actual households compared to rural and informal settlements. This is because, in the case of formal areas, data is readily available from various sources, such as health facilities and flood reports as well as from land use and insurance registers. Regardless of the method used, all these methods have been developed on the premise that locals know best about their habitat. Additionally, only by incorporating local knowledge into a GIS can it be transformed into a GKS with the potential to facilitate better decision making. The following section reports on some pertinent case studies.

2.4.2 Case Studies in Participatory GIS

Abbott (2000) explored the possibility of including community gathered information in a GIS for in-situ informal settlement upgrading using New Rest, an informal settlement in Cape Town, as a case study. The study used questionnaires to gather demographic information from community members, which was subsequently integrated into a GIS containing spatial data, such as storm water drainage routes, roads, foot paths, shack outlines and geological data from the CTCC. Subsequently, they generated thematic maps and statistical reports from the demographic data and came up with indicators of vulnerability. Abbott (2000) showed that, by overlapping these thematic maps with the spatial data showing areas prone to disasters, such as flooding and fires, one could deduce the people most likely to suffer the brunt of a disaster. Additionally, by looking at current socio-economic activities in the settlement, the planned infrastructure could be laid out to facilitate even access to transportation hubs and to identify locations that were suitable for business opportunities.

Karanja (2010) conducted a study in partnership with the local community, an NGO and a savings group in an informal settlement in Kisumu, Kenya with the aim of soliciting information for upgrading and provision of secure tenure for that settlement. Demographic data was collected from the various households and linked with maps of the existing house structures that had been drawn on satellite imagery. The updated maps including the slum dwelling numbers were digitized into a GIS database and presented back to the informal settlements. Although Abbott (2000) indicated that, with training, communities could be given access to data in the GIS, Karanja (2010) actually allowed the community to engage with the GIS from the enumeration in order to verify the data and to stir debate within the community on its own needs, thus giving them an opportunity to set priorities collectively.

Quan *et al.* (2001) reported on a project that combined scientific and indigenous knowledge of soils in Uganda and Tanzania using GIS. The research employed group discussions, individual household interviews and participatory mapping to understand local soil classifications. They overlaid the geo-referenced knowledge of the local community with scientific maps in order to compare scientific and local knowledge of soil and land resources. The research was used to draw conclusions on the various applications of the different soil types in local communities.

Quan *et al.* (2001) only investigated the integration of different datasets, however, and did not look at how the communities could be given access to the subsequent GIS.

Bouchard *et al.* (2007) conducted a study aimed at improving flood risk management in informal settlements in Cape Town. The research involved using the GIS data from the CTCC to investigate the trends in rainfall and flooding in informal settlements in order to analyse biophysical vulnerability. In addition, they used interviews and case studies to investigate current mitigation and coping techniques within the community. In this study, the information from the settlement was not wholly captured in the GIS; however, it was used in the weighting of risk indices. For instance, the topography of areas where the community members reported the most severe incidents of flooding was analysed in order to tease out the elements that might amplify the severity of the hazard. A major critique of this study is that, although the data collection initially involved some community participation, the analysis was done by experts without any input from the community. For instance, flood risk weights were generated subjectively without any theoretical background or partnership with the communities, and the subsequent risk maps therefore did not necessarily represent the views of the community. In this instance, the data collection was participatory, but access to and application of the GIS was not.

In conclusion, based on the various case studies in the above discussion, traditional GIS can be merged with information from various stakeholders into a singular database. It is also possible to allow various stakeholders to access the datasets in the resultant GIS. It is imperative though to look critically at the existing relationships between the various stakeholders; taking into account the scales of interaction that can affect the extent of participation of the stakeholders in the GIS.

Nonetheless, it is important to recall that GIS is simply a means to an end. It is simply a technology that facilitates the pooling of various datasets. In order to assess differential vulnerability within a system, one needs to pool the data on all the units of the system and then assess the various qualities of the units in the system. This second step would require grading the various human and environmental conditions in the system relative to each other, based on certain criteria. The simultaneous analysis of various qualities of a feature is thoroughly covered in the body of literature on Multi Criteria Evaluation (MCE) and Multi Criteria Decision Analysis (MCDA). It is for this reason that authors such as Messner & Yamagishi (2006: 162) prescribe MCE for flood risk analysis. MCE can be used to rank conditions of a social unit from the most desirable to the least desirable, which would correspond in this context to the least vulnerable and the most vulnerable situations respectively. Integrating GIS and MCE would thus provide the ideal environment for vulnerability assessment in a geographical space. The next section looks at some of the methods employed in MCE to rank alternatives.

2.5 Multi Criteria Evaluation

Multi Criteria Evaluation (MCE) is used to analyse a series of alternatives or objectives with a view to ranking them from the most preferable to the least preferable, using a structured approach. Consequently, Malczewski (1999: 85) distinguished two main bodies of research

namely; the multi-attribute (MADM) and multi-objective decision making (MODM). Attributes are the measurable quantities or traits of units in a geographical system, whilst objectives refer to the preferred state of the geographical system being observed (Malczewski, 1999: 85). It is noteworthy that vulnerability assessment could straddle both types of studies. For instance, the economic standing of households as well as the variety and choice of methods of risk mitigation will very likely affect the ability of such households to cope with hazards. However, economic standing is an attribute of a household, and mitigation measures are taken with the objective of alleviating risk. Therefore, the analysis of the contribution of economic standing and mitigation methods with regard to reducing vulnerability in this case would straddle both MADM and MODM.

The end result of MCE is often a set of weights linked to the various alternatives. The weights indicate the preference of the alternatives relative to each other. They may also be seen as the perceived advantage or disadvantage when changing from one alternative to another. The choice of methodologies for the calculation of these weights varies from text to text. Several authors (Ayalew & Yamagishi, 2005; Jankowski *et al.* 2001; Yahaya & Abdalla, 2010; Kourgialas & Karatzas, 2011) have used the methods highlighted by Malczewski (1999) when calculating weights in MCE. The following section will report on the four methods discussed by Malczewski (1999) when developing weights for a given set of alternatives or criteria.

2.5.1 Ranking Methods

Ranking methods are the most simplistic option for deriving weights. In this method, all the alternatives are listed in order of preference from most preferable to least preferable or vice versa. Once an ordered list is generated, the weight of a particular alternative can be calculated based on the position of that alternative relative to the rest. Malczewski (1999: 178) highlighted three popular approaches to calculating the weights namely: the rank sum method; the rank exponent method, and the rank reciprocal method.

In the *rank sum method*, the normalised weights are given by the formula:

$$w_j = \frac{n - rj + 1}{\sum(n - r_k + 1)} \qquad (2.6)$$

Where w_j is the normalised weight of the jth alternative, n is the total number of alternatives in question (k =1,2,3,… n), and rj is the rank position of the alternative relative to the other alternatives. Each alternative is given a weight $(n - rj + 1)$ and then the weight is normalized by the sum of all weights $\sum(n - r_k + 1)$.

The rank sum method is a special case of the rank exponent method. In the *rank exponent method*, the following formula is used:

$$w_j = \frac{(n - rj + 1)^p}{\sum(n - r_k + 1)^p} \quad (2.7)$$

Where p denotes a power meant to control the relationship between the various alternatives. In this method, a weight is allocated to the most important or preferred alternative and then p is solved through an iterative procedure. When $p = 0$, all the alternatives have equal importance, and when $p = 1$, the method culminates into the rank sum weights method.

The *rank reciprocal method* calculates the weights as a function of the normalized reciprocals of the alternative's rank. It is given by the following formula:

$$w_j = \frac{1/r_j}{\sum(1/r_k)} \quad (2.8)$$

The differences between these methods are best illustrated with an example. Say there was a situation with five alternatives A,B, C, D and E and the order of preference was E, B, C, A and D. Table 2.2 illustrates the calculation of the weights using the three popular ranking methods.

		Rank Reciprocal		**Rank Exponent (p =2)**		**Rank Sum (p =1)**	
Alternatives	**Straight Rank**	**Reciprocal Weight**	**Normalised Weights**	**Rank²**	**Normalised Weights**	**Rank**	**Normalised Weights**
E	5	0.200	0.088	25	0.455	5.000	0.333
B	4	0.250	0.109	16	0.291	4.000	0.267
C	3	0.333	0.146	9	0.164	3.000	0.200
A	2	0.500	0.219	4	0.073	2.000	0.133
D	1	1.000	0.438	1	0.018	1.000	0.067
Sum:		**2.283**	**1.000**	**55**	**1.000**	**15.000**	**1.000**

Table 2.2 Table showing the calculation of weights in ranking methods

Firstly, the criteria are ranked in their order of preference. In the **rank reciprocal method**, the reciprocal weights for each alternative were calculated by inverting the straight rank value. The resulting reciprocal weights were summed up. In this example, the sum was 2.283. Each reciprocal weight was then divided by the sum to calculate the normalised weights. The normalised weights should all add up to 1.

In the **rank exponent method**, a power of 2 was adopted for this example. The rank of each alternative was squared and then the squares of all the ranks were summed up. The sum in this example is 55. Each square rank was then divided by the sum of square ranks to calculate the normalized weights.

In the **rank sum method**, the straight ranks are simply added up. In this case, the sum of the ranks is 15. Each rank is then divided by the total to deduce the normalised weights. The normalised weights should all add up to 1.

These ranking methods are popular because of their simplicity. However, two major critiques of the method are that it lacks a theoretical foundation and that it becomes less appropriate as the number of alternatives increases (Malczewski, 1999: 179). It is therefore necessary to do more than a ranking weight approximation in most cases of MCE.

2.5.2 Rating Methods

In this method, weights are estimated based on a predetermined scale. For instance, one ranking method is a *point allocation method*. In this method, a discrete number of points are allocated between a set of alternatives. The more points are given to an alternative, the more preferable it is (Malczewski, 1999: 181). For instance, say 100 points had to be allocated between five alternatives A, B, C, D and E, and they were allocated 10, 30, 15, 26 and 19 points respectively. Then the weights would be calculated by dividing the respective points by the total number of points. Consequently, the weights in this case would be 0.1, 0.3, 0.15, 0.26 and 0.19 respectively.

These rating methods are popular because of their simplicity, but this method is criticized for a lack of theoretical foundation with regard to the way in which the points are allocated. Specifically, it is often difficult to justify how the weights have been allocated (Malczewski, 1999: 182).

2.5.3 Pairwise Comparison Method

The Pairwise Comparison Method (PCM) is derived from the analytic hierarchy process (AHP) by Saaty (1980). This method involves the consecutive comparison of one alternative to another using a scale from 1-9 (see Table 2.3).

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely strong importance

Table 2.3 Table showing scale for Pairwise Comparison.
Source: Saaty (1980) in Malczewski (1999: 183).

For instance, say three alternatives A, B, C were being compared to each other. If A was of moderate importance to B, then B would be given a comparison result of 3 (see Table 2.3). The PCM steps would involve comparing A to B, then A to C and then B to C. It is assumed that the preference is reciprocal. For instance if A is three times preferred to C, then C is a third preferred to A. This method involves creating a ratio matrix from the paired comparisons and then calculating the weights from that matrix. This method can best be illustrated with a hypothetical example.

Consider the example below (Table 2.4), where three alternatives A, B and C are being compared to each other. Say A was of moderate to strong importance to B and of very to extremely strong importance to C. Also, say B was of strong importance to C. The comparison values in the first instance would be 4 and 8 for a comparison of A to B and A to C respectively (see Table 2.3). Similarly, the comparison value between B and C would be 5. The comparisons between B and A as well as C and A would simply be the inverse of 4 and 8. Comparisons along the diagonal are simply 1. Also, comparing C to B would yield a comparison value of the inverse of 5.

PAIRWISE COMPARISON MATRIX				**NORMALISED PAIRWISE COMPARISON MATRIX**				**RELATIVE WEIGHTS**
Criteria	**A**	**B**	**C**	**Criteria**	**A**	**B**	**C**	**Average:**
A	**1.000**	4.000	8.000	**A**	0.727	0.769	0.571	0.689
B	0.250	**1.000**	5.000	**B**	0.182	0.192	0.357	0.244
C	0.125	0.200	**1.000**	**C**	0.091	0.038	0.071	0.067
SUM:	1.375	5.200	14.000		1.000	1.000	1.000	1.000

Table 2.4 Table showing calculation of weights in PCM

These values would then comprise the pairwise comparison matrix. The next step would be to sum up the columns of the comparison matrix and then to normalise the matrix by dividing each comparison value with the total of the comparison values in its column e.g. 1/1.375=0.727. The weights are then calculated by averaging the normalised comparison values in each row, e.g. the average of 0.727, 0.769 and 0.571 is 0.689.

Ideally, the values in the rows in the normalised pairwise comparison matrix would be very precise if the comparisons have been consistent. If option A is better than option B and option B is better than option C, it would be consistent to say that option A is better than option C. This method allows the user to calculate the consistency of the comparisons. The calculation involves firstly multiplying each row in the original pairwise comparison matrix with the matrix of calculated weights to give a row with the matrix product. Each value in the matrix product is then divided by the weight in the corresponding row to give a consistency vector matrix e.g. 2.200/ 0.689 = 3.191. The values in the consistency vector are then averaged to give a value lambda (λ).

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
2.200	3.191	0.048
0.751	3.080	
0.202	3.016	**Consistency Ratio**
Lambda:	3.096	0.082

Table 2.5 Table showing calculation of precision in PCM

n	**RI**	n	**RI**	n	**RI**
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Table 2.6 Table showing Random Inconsistency Indices (RI)

Source: Saaty (1980) in Malczewski (1999: 186).

The consistency index (CI) is then calculated from the following equation (Malczewski 1999: p184):

$$\mathrm{CI} = \frac{\lambda - n}{n - 1} \qquad (2.9)$$

In this equation n is the number of alternatives. Lastly, the consistency ratio, which is the measure of precision in the comparisons, is given by the following equation (Malczewski 1999: 184):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (2.10)$$

In this equation, RI is the random index corresponding to the number of alternatives (n). In this example in Table 2.4, the value of RI corresponding to three alternatives is 0.58. The design of the consistency ratio (CR) is such that if the value is less than 0.10, then the comparisons can be deemed reasonably consistent. The lower the value of CR, the more consistent the comparison is (Malczewski1, 999: 186).

The major advantage in PCM is that only two alternatives need to be compared at a time. Also, it can be tested empirically, since it is built on a statistical foundation. However, the disadvantage of this method is that, the more alternatives there are, the more there are pairs of comparisons between the alternatives. Given n alternatives, there will be $n(n-1)/2$ pairs of alternatives to compare; hence this method can be cumbersome. It is worth mentioning, though, that this method has already been incorporated into GIS based decision-making technologies, such as IDRISI (Malczewski, 1999: 187).

2.5.4 Trade-off Analysis Method

In the trade-off analysis method (TAM), the user has to decide between pairs of alternatives based on certain criteria. For instance, given two alternatives A and B, the user must decide whether they prefer A to B, or B to A or whether the user is indifferent between A and B. One method of calculating weights in TAM is the 'swing weights' method (Malczewski, 1999: 188). This method is best illustrated with the example given by Malczewski (1999: 188), where a user must choose an ideal site for a factory, assuming that the three alternatives were cost of the site, the terrain of the site and the aesthetics of the site, in that particular order of importance. The user then allocates a weight of say 100 to the most preferred alternative, in this case cost. The user then has to decide where he would compromise between terrain and cost. In other words, if the cost was slowly moved to its worst position (high cost site) and that of the terrain was slowly moved to its best position (ideal terrain), at what point would the user consider terrain over cost in choosing a site. Supposing the user decides that, if the cost exceeds 65% of the ideal cost, but the terrain was ideal, the user would still take the site. A weight of 65 would thus be allocated to the terrain. Similarly, the process can be repeated between a change from ideal cost to highest cost and a change from worst aesthetics to best aesthetics. Supposing the user decides that, if the cost exceeds 25% of the ideal cost, but the aesthetics were ideal, the user would still take the site. A weight of 25 would be allocated to aesthetics. The weights can then be normalised by summing them up and dividing each individual weight by the sum of weights. The total of the normalised weights should be 1.

This method has been criticised for being inappropriate when the alternatives cannot be empirically quantified. When the ratings of the various alternatives have to be allocated subjectively, the calculation of weights loses credibility (Pitz and McKillip, 1984, cited in Malczewski, 1999: 189).

2.5.5 A Comparison of the Various Methods

Table 2.7 summarises the attributes of the MCE methods presented by Malczewski (1999).

Methods in MCE				
Feature	***Ranking***	***Rating***	***Pairwise Comparison***	***Trade-off analysis***
Number of judgements	n	n	$n(n-1)/2$	$n <$
Response scale	Ordinal	Interval	Ratio	Interval
Hierarchichal	Possible	Possible	Yes	Yes
Underlying theory	None	None	Statistical / Heuristic	Axiomatic/ deductive
Ease of use	Very easy	Very easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not precise	Quite precise	Quite precise
Software availability	Spreadsheets	Spreadsheets	Expert Choice	Logical Decisions
Application in GIS	Weights can be imported	Weights can be imported	Part of IDRISI	Weights can be imported

Table 2.7 Table showing comparisons of method. Source: Malczewski (1999:190).

PCM involves the most number of judgements because the user has to assess each alternative individually against every other alternative. This methodology does however mean that the PCM is quite precise, and since each alternative is graded against the other, the resultant weights actually represent an accurate hierarchy of preference with regard to the alternatives.

Trade-off analysis has the least number of judgements, however, because the various alternatives are simply altered at the expense of the most preferred alternative. In the example in the foregoing discussion, it was noted that two assessments were done for three alternatives. Also, since a preferred alternative is compared to the other alternatives, it can also be deemed a hierarchical weighting process with good precision.

The ranking and rating approaches both require the user to award weights to the alternatives without explicitly drawing any actual comparisons between the alternatives. Hence, the number of judgements is equal to the number of alternatives; however, the weighting is neither necessarily hierarchical nor precise.

Furthermore, unlike the ranking and rating methods that have no theoretical bedrock, the PCM and TAM are developed and based on statistical and deductive theories respectively. The rating method and PCM are highly reliable, but the reliability of TAM suffers when the decisions between alternatives must be made subjectively. For instance, one user may choose a different trade-off point in comparison to another user in the very same situation. All the methods can be developed in a spreadsheet environment, but the PCM and TAM have already been incorporated into software packages, such as Expert Choice and Logical Decisions. It is also noteworthy that each of these methods can be used to interface with GIS packages by importing the spreadsheets containing the weights into the GIS. It is also worth mentioning, however, that the PCM too has been incorporated into some GIS packages, such as IDRISI.

A holistic assessment of all the attributes of the various methods reveals that the PCM and TAM are overall the best options. This is because they explicitly compare alternatives to derive their respective weights. For that reason, the magnitudes of weights can be assumed to indicate the preference of each alternative to the other. Moreover, because each alternative is assessed individually, the comparisons between the alternatives can be deemed reasonably consistent. However, drawing both methods into the context of vulnerability analysis reveals a major weakness in the TAM. It has been shown in the foregoing discussion that analysis of social vulnerability requires community engagement. The choices of coping and mitigation methods, such as new programs and policies to reduce vulnerability, are largely subjective with regard to the perceptions of risk and vulnerability within the social units. Hence, choosing between programs using the TAM would produce less reliable results than the PCM. For the purposes of vulnerability assessment, therefore, the PCM is the best option out of the four presented here. The MCE methods presented here are by no means exhaustive. For instance, other researchers have employed fuzzy methods (Jiang & Eastman, 2000; Akter & Simonovic, 2005, 2006) and MACBETH (Bana e Costa *et al*., 2004). Furthermore, a thorough review and classification of

refereed journal articles covering spatial multicriteria decision analysis can be found in Malczewski (2006).

PCM and GIS have been used together by a number of scholars (Guipponi *et al.*, 1999; Jankowski *et al.*, 2001; Kyem, 2001, 2004; Ayalew & Yamagishi, 2005; Yahaya & Abdalla, 2010). The next section reports on some relevant case studies in the application of PCM and GIS in risk and vulnerability assessment.

2.5.6 Case studies in Multi Criteria Evaluation

A study was conducted by Yalcin & Akyurek (2004) in Turkey. The study involved the vulnerability assessment of an area located between the Filyos and Bartin river basins in Northern Turkey. The research focussed on biophysical vulnerability and considered the contribution of annual rainfall, the size of the watershed, the basin slope, the gradient of the primary drainage channel, the drainage density, the land use and the soil types with regard to vulnerability in the river basins. The corresponding weights were found to be 0.26, 0.21, 0.17, 0.16, 0.10, 0.06 and 0.04 respectively. The consistency ratio was found to be 0.042, which showed an acceptable level of consistency in ranking the alternatives. The calculations were done using a Visual Basic Application (VBA) embedded in a GIS package.

The weights were then linked to the corresponding values of the seven attributes under assessment in the cells of the raster data. Thereafter, vulnerability maps were created, and the authors were able to locate the most vulnerable areas located between the two rivers.

Yahaya & Abdalla (2010) conducted a similar study into flood vulnerability in the Hadejia-Jama'are River Basin in Nigeria. Their research also focused on biophysical vulnerability, and the researchers analysed the contribution of annual rainfall, the basin's slope, drainage network, land cover and the type of soil to vulnerability in Hadejia-Jama'are. A combination of PCM and ranking methods were used to calculate the weights of these attributes.

Each attribute was compared to the others, and the PCM matrices were calculated using the MATLAB software package. After the PCM calculations had been done, the normalized weights were found to be 0.339, 0.255, 0.197, 0.152, and 0.057, for annual rainfall, the drainage network in the river basin, the basin slope, the soil type and land cover respectively. Consequently, the highest contributors to risk vulnerability in the region were found to be annual rainfall, the drainage network in the river basin and the basin slope. A check on the consistency yielded a consistency ratio of 0.0506. Since it was significantly less than 0.1, the authors found the analysis to be reasonably consistent. Yahaya & Abdalla (2010) replicated the methodology used by Yalcin & Akyurek (2004) to link the weights into the raster based GIS data and create vulnerability maps.

The studies reported here show that PCM can be used in conjunction with GIS for risk assessment. They also show that, once the weights have been introduced into the GIS, it is possible to map the values of vulnerability at a particular geographical location. The resulting

maps can be used to infer the most vulnerable places to target for risk mitigation. The final section of this chapter summarises the conceptual framework for this study.

2.6 Summary

It is clear from the foregoing discussion that the combination of increasing populations in informal settlements in Cape Town and the increasing occurrence of disasters necessitates the formulation of novel methods of flood risk management. Furthermore, flood risk assessment forms an integral part of flood risk management. Risk has often been represented as a function of hazards, vulnerability, and exposure (Equation 2.4). It has further been shown in the preceding discussion that, since the magnitude of the vulnerability affects the magnitude of the risk, an assessment of vulnerability can be used as a proxy for an assessment of risk. In addition, a holistic approach requires one to study both biophysical and social vulnerability at all scales (Figure 2.2).

However, this research will be limited to an assessment of vulnerability within the local geographical context (in this case two flood-prone informal settlements in Cape Town). The other pieces of research within the CCAA FliCCR project will look at risk management and governance at a larger scale than the limited local geographical context. The study will thus build on the methods employed by SDI (2009), Abbot (2000) and Bouchard *et al*. (2007) and add a component of Multi Criteria Evaluation based on the Pairwise Comparison Method.

In addition, this study will adopt a participatory approach and interface with various stakeholders in order to develop Pairwise Comparison weights as well as a GIS to map vulnerability in informal settlements. Moreover, the methodology developed in this study will be tested on two informal settlements of different sizes.

The next chapter introduces the two informal settlements that were used for this study.

Chapter 3
Background and Description of the Case Studies: Graveyard Pond and Europe

This chapter contextualises the two informal settlements that were used as case studies. The first settlement to be studied was Graveyard Pond, the relatively smaller settlement. It was used as a pilot study and Europe, the second and significantly larger settlement was used to test the methodologies developed in studying Graveyard Pond in a bigger context.

3.1 Background and Description of Graveyard Pond

Graveyard Pond is an informal settlement located in Philippi, a suburb of Cape Town. It lies southwest of the intersection of Sheffield Road and New Eisleben Road covering 9,426m².

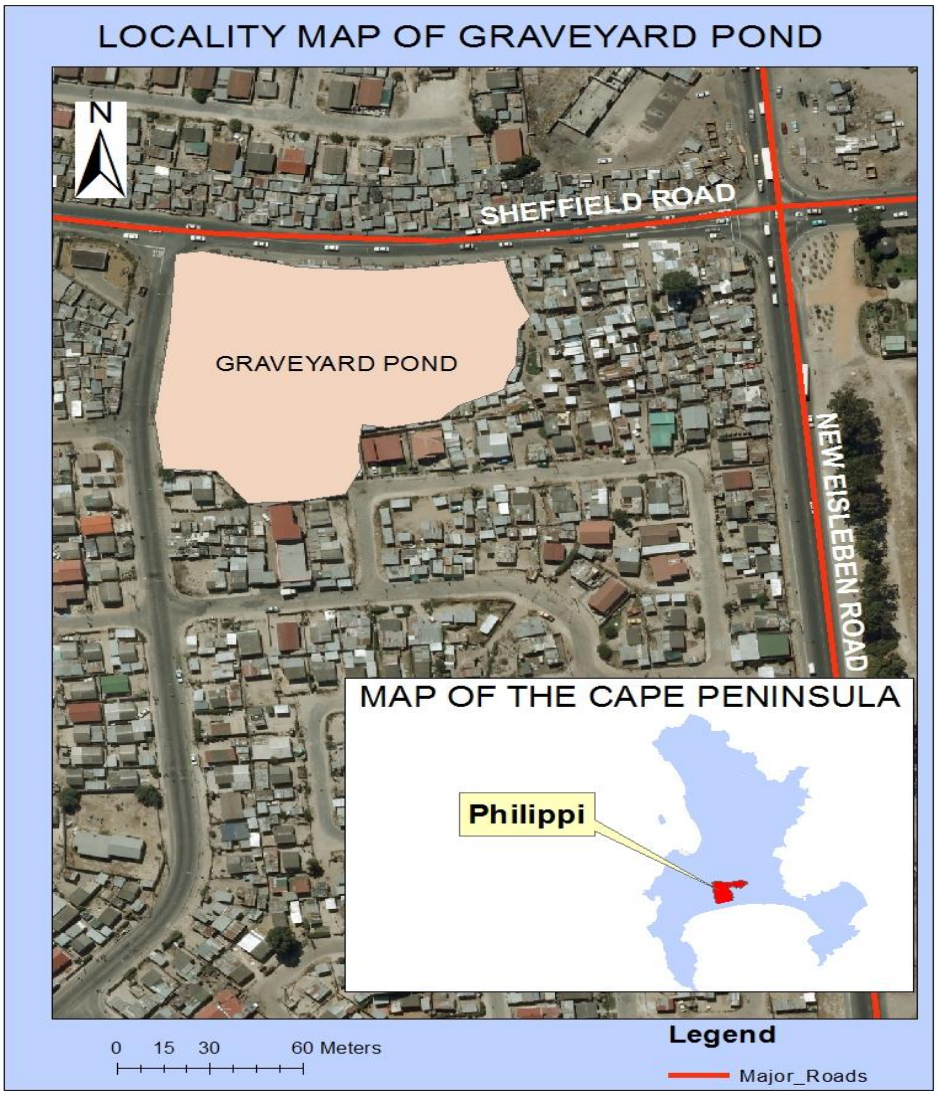

Figure 3.1 Location of Graveyard Pond

This settlement is particularly prone to flooding because it is located in an area designated as a catchment pond by the CTCC. Imagery from the CTCC captured in 2007 clearly depicts the uninhabited wetter part at the centre of the settlement (Figure 3.2). This specific area is the lowest part of the settlement and it can stay wet for months on end.

Figure 3.2 Graveyard Pond, September 2007 (Source: City of Cape Town, 2008)

In contrast, imagery from the CTCC captured in 2009, shows an increase in the number of settlements in Graveyard Pond, especially in the wetter part of the settlement (Figure 3.3). The community leader in Graveyard Pond stated that immigration into the settlement started at the periphery of the settlement, with the population growing towards the middle of the settlement. People settled in the area because they had no other place to stay, even though they knew it periodically became wet. Most people living in Graveyard Pond either relocated here from backyard shelters or from the Eastern Cape. Backyard shelters are informal dwellings located in the backyards of formal dwellings. Figure 3.4 shows the state of Graveyard Pond in July, 2010.

Graveyard Pond is a relatively new settlement. It does not appear in the census report on informal settlement dwellings released by the CTCC in 2006, but it is mentioned in the 2008 report. According to that report, Graveyard Pond contained 154 dwellings in 2007 (CTCC, 2008b). Today it has almost doubled in numbers (see Chapter 5). The inhabitants are affected by a number of problems, including flooding, unemployment, poor housing and a lack of services, to mention but a few. However, the settlement is not well connected to outside organisations

such as Non-Governmental Organisations (NGOs) and the CTCC, who could be of assistance to them.

Figure 3.3 Graveyard Pond, March 2009 (Source: City of Cape Town, 2010)

Figure 3.4 Graveyard Pond, July 2010

3.2 Background and Description of Europe

Europe is a much larger (149,719 m²) and older settlement than Graveyard Pond. It is already more than 20 years old and is located on municipal land approximately 16km east of Cape Town in the suburb of Gugulethu. The land is a former dumpsite and lies between Klipfontein Road and Nt'langano Crescent, as well as Settler's Way and Borchard's Quarry on the N2 Highway. The settlement is bordered by the Crossroads graveyard in the East, Barcelona in the North West, Boquinar Industrial Area in the West and Vukuzenzele in the South East.

Figure 3.5 Location of Europe

The 2008 report on informal dwellings by the CTCC showed that Europe had grown from 584 informal dwellings in 2002 to 831 dwellings in 2007 (CTCC, 2008b). Today, there are approximately 1700 dwellings in Europe. This settlement has also had more interaction with outside organisations such as the CTCC and SDI, an international NGO dealing with informal settlements. Incidentally, SDI works in partnership with the Community Organization Resource Centre (CORC) based in Cape Town. Any reference to CORC in the text invariably applies to SDI and vice versa.

Like Graveyard Pond, the inhabitants of Europe are mostly migrants from the Eastern Cape province. They settled in the area because they could not afford to buy or rent decent housing in Cape Town. The settlement is also run by a committee consisting of residents of Europe who control the influx of settlers and who hold discussions with outside organisations among other things. According to the community leaders, the most urgent needs are roads, electricity, streets and water.

Europe is also prone to flooding and poorly serviced. Discussions with community leaders revealed that runoff water drains towards the N2 Highway (Settler's Way). Some areas close to the N2 highway are continually flooded. The area is also very low lying and during heavy winter rainfall, there is often an upsurge of water into the dwellings. The community leaders added that the combination of the winter cold and flooding has led to the proliferation of fires and respiratory diseases.

3.3 Summary

Graveyard Pond and Europe are located in two of the top three suburbs (Khayelitsha, Philippi and Gugulethu) with the highest number of informal settlements (CTCC, 2008b). Additionally, both settlements are located on flood-prone land. With respect to services, Europe is poorly serviced and Graveyard Pond is not serviced at all. In addition, both settlements consist of poor communities that struggle to cope with flooding, fires, unemployment and other stresses. Both communities are thus significantly vulnerable and the extent of their vulnerability needed to be assessed and mapped in order to provide insight into possible solutions.

The next chapter pieces together the methodology adopted in this research and comments on the reliability of the data collected.

Chapter 4 Research Methodology

This chapter reports on how the research was conducted. The methodology used in this study applies the conceptual framework that was developed in Chapter 2. This chapter also discusses the limitations of the methodology and the adopted framework as well as the validity of the data gathered.

4.1 Research design

This research was prompted by the need to develop efficient flood risk management policies in informal settlements in Cape Town. In order to manage risk in any locality, though, it is important to know the hazards that affect such locality. It is also important to assess the vulnerability of the locality and the effectiveness of any actions taken to curb the impact of the hazards in the locality. These elements together make it possible to estimate the risks holistically, based on which mitigation measures can be proposed.

Taking vulnerability as a proxy for risk, the methodology presented herein focussed on quantifying vulnerability in a specific locality, based on the framework of Turner *et al.* (2003) shown in Figure 2.3. Of the six elements proposed by Turner *et al.* (2003) for a holistic vulnerability analysis (Section 2.3.2 of Chapter 2), three have been adopted in this research. This study on vulnerability encompassed:

- A study of all the hazards affecting the system (community and environment);
- A study of how the system is exposed to the hazard;
- The coping capacity of the system;

This study thus assessed the vulnerability of the two informal settlements before a flood event because the timeline of this particular thesis did not allow studies into vulnerability after the event. Hence the other three elements proposed by Turner *et al.* (2003), which are only relevant after a flood, could not be employed in this research. However, further studies within the CCAA FliCCR project will account for post-event elements of vulnerability, such as sensitivity of the local communities, adaptations by residents and the scale of responses, ranging from communities to local government.

Additionally, the areas studied in this research are in fact flood-prone by design, because the CTCC had designated those areas as buffers to prevent flooding in the adjacent formal settlements. The communities who moved into these buffer areas are only there out of desperation because there is nowhere else for them to go. Hence, for the purposes of this study, it was found unnecessary to carry out traditional flood determination calculations, such as hydrological modelling, rainfall calculations for volumes of run-off water, flood years, etc. Also, the environmental effects of the flooding are not part of this study either.

Research Question	Research Aims	Research Objectives	Methods Used	Underlying Literature
How can valid information be sourced from various stakeholders including local communities in informal settlements for risk assessment?	• Identify hazards and their outcomes in the community • Establish validity of information	• Conduct interviews with stakeholders e.g. NGOs, CTCC • Collect and compare datasets from the various stakeholders • Present information back to the stakeholders	• Attending CTCC meetings • Social and demographic questionnaires • Communal presentations • Comparison of social data to CTCC aerial imagery and GIS	Abbot *et al.* (1998), Abbot (2000), Bouchard *et al.* (2007), Raaijmakers *et al.* (2008), SDI (2009), Turner *et al.* (2003), Tyler (2011).
How can partnerships be developed to enhance holistic flood risk assessment in flood-prone informal settlements?	• Identify institutions and their roles in affecting the vulnerability of the system • Develop appropriate methodologies for assessing, modelling and testing vulnerability	• Use local community, CTCC and NGOs in data collection • Use local community for ranking of alternatives in MCE	• Training of community leaders in reading aerial imagery from CTCC • Face to face discussion with CTCC officials, NGOs and community leaders • Collection of data using teams of community leaders and researchers	Karanja, (2010) Malczewski (1999), SDI (2009), Turner *et al.* (2003), Tyler (2011).
How does the distribution of flood risk vary spatially within flood-prone informal settlements and what are the implications for mitigation?	• Establish differential vulnerability • Identify dynamics causing unexpected outcomes • Link analysis to potential decision making	• Calculate weights of alternatives • Present results in maps • Allow comments from stakeholders	• Creation of risk maps in GIS • Discuss results with stakeholders to assess 'cause and effect' • Open dialogue for potential solutions	Yahaya & Abdalla (2010), Yalcin & Akyurek (2004), Malczewski (1999), SDI (2009), Turner *et al.* (2003), Tyler (2011).

Table 4.1 Research Question, Objectives, Aims, Methods and Underlying Literature

Nonetheless, it was envisaged that the findings of this research could provide information for decision making around flood risk management in informal settlements. Therefore, taking these gaps into account, this vulnerability study was designed to cover all the essential elements postulated by Turner et al. (2003) to improve decision making.

Consequently, during the course of this research, three main research questions were addressed, namely:

- How can valid information be sourced from various stakeholders, including local communities in informal settlements for risk assessment?
- How can partnerships be developed to enhance holistic flood risk assessment in flood-prone informal settlements?
- How does the distribution of flood risk vary spatially within flood-prone informal settlements and what are the implications for mitigation?

Table 4.1 summarises the links between the research and the literature, the aims of this research, and the methodology developed in this research. The essential elements in vulnerability assessment by Turner *et al.* (2003) are captured in the research objectives column.

The next section expounds on Table 4.1 and details the various steps undertaken in the course of this research.

4.2 Ethics Clearance

Once the research design had been completed, it was clear that much of the research depended on interaction with people in various spheres of society. Hence, it was imperative to consider the ethical ramifications of the study. The research proposal was tabled before the ethics committee of the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town (UCT). The research was approved on condition that any confidential information provided by the stakeholders could not be presented in the research. Also, it was stated that the research could not discriminate on the grounds of age, race, ethnic group, religion, handicap or any such categorization. This research has adhered to the conditions prescribed by the committee.

After soliciting ethics approval, the next stage involved selecting flood-prone case study areas for the research.

4.3 Site Selection

The selection of the case studies for this research was done based on previous studies and various discussions with SDI/CORC. The CTCC periodically prepares reports and maps of informal settlements in Cape Town. Figure 4.1 shows the latest such map.

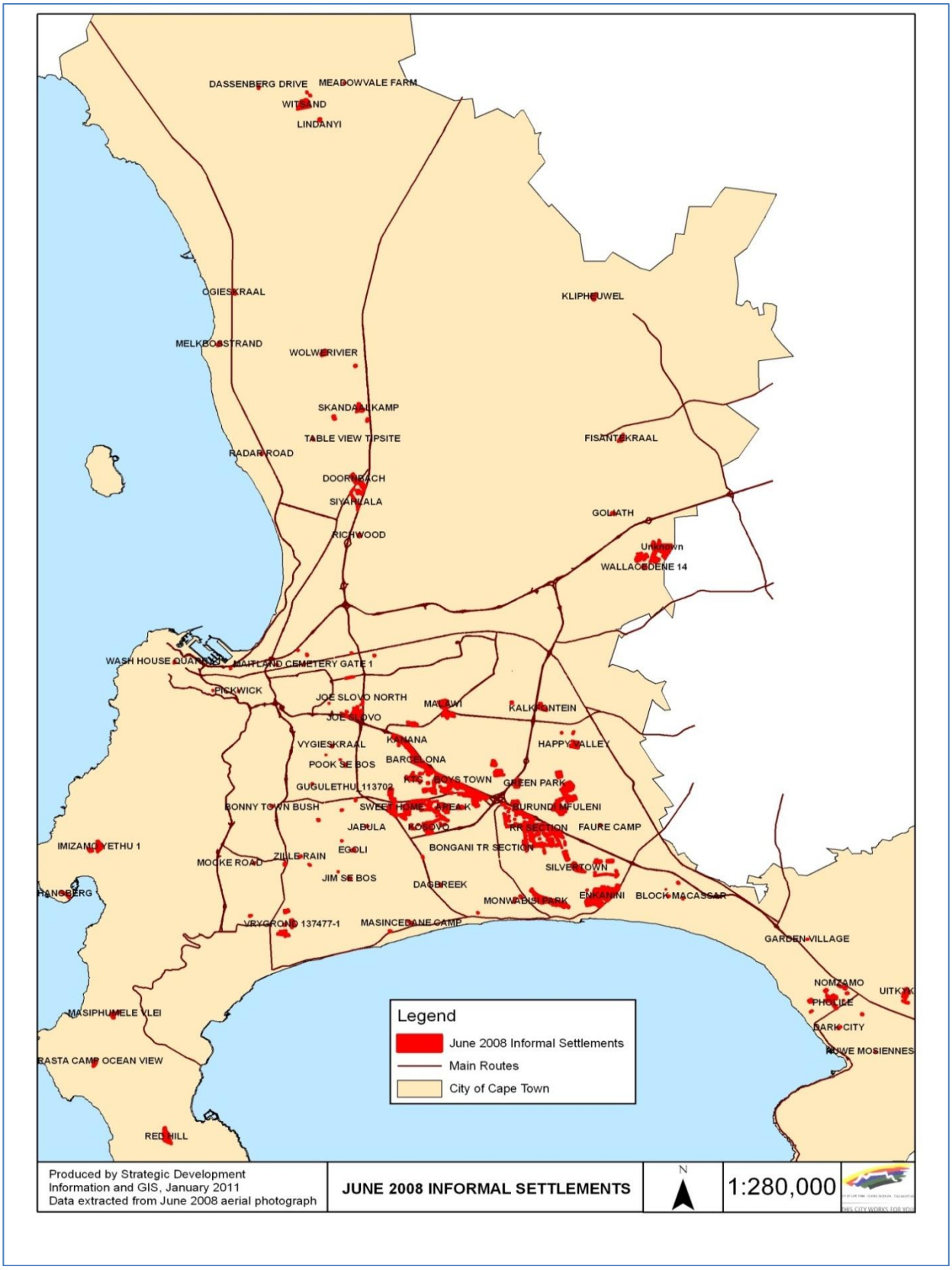

Figure 4.1 Informal Settlements of Cape Town (Source: City of Cape Town, 2011)

Based on such reports, it was found that Khayelitsha, Philippi and Gugulethu had the most flood-prone informal settlements in Cape Town (CTCC, 2008b). SDI was then approached in order to identify specific settlements within these suburbs that could be used as case studies. It was envisaged that, since SDI had already made inroads into the settlements, it would be easier to create partnerships with the informal settlements in collaboration with SDI.

Initially, SDI official were highly sceptical of the use of GIS in risk assessment of informal settlements. In the opinion of SDI officials, the complexities of GIS meant that it reduced community participation instead of enhancing it. Since SDI is essentially concerned with participating with communities in upgrading informal settlements, however, they were vehemently opposed to partnering in any GIS based research. Nonetheless, they identified a settlement in Philippi called 'Graveyard Pond' in which they had never done any work.

Later, a study into the methodology used by SDI in upgrading of informal settlements revealed an opportunity for the use of GIS technology. SDI used questionnaires to capture demographic and other social information and they drew up maps of the shacks in the informal settlement by hand. The SDI staff would also measure the dimensions of the shacks during the survey. The subsequent maps were often rudimentary and not drawn to scale. This presented problems when creating new maps of proposed shack layouts to allow the input of infrastructure to minimise the impacts of floods and fires. The author gave a presentation on the spatial strengths of GIS and reported on studies, such as those of Abbot (2000) and Bouchard *et al.* (2007), which had successfully used GIS in mapping community information. Furthermore, dummy data was entered into a GIS to show the SDI officials the potential uses of GIS in easing the restructuring of shack layouts. The presentation was successful, and SDI thus agreed to partner with the author on an impending enumeration of a flood-prone informal settlement called 'Europe' in the suburb of Gugulethu.

Once the two case study areas had been selected, the next stage involved creating partnerships in preparation for the data collection.

4.4 Preparation for Data Collection

At this stage, it was important to forge partnerships for the data collection. Firstly, the CTCC officials from the Departments of Housing; Sports and Recreation; Water and Sanitation; Roads, Transport and Storm Water; Solid Water; City Health and the Call Centre 107 were approached at a winter preparedness meeting. At this meeting, the author sought to gain clarity on the role of the CTCC in flood risk management in informal settlements. Also, the author sought to find out what datasets already existed within the CTCC database with regard to the informal settlements of interest. From interviews with the CTCC winter preparedness 2010 committee in June 2010, it was found that the CTCC was responsive rather than pre-emptive in the management of flood risks in informal settlements. Responses included the provision of blankets, sand, plastic, meals and temporary accommodation to victims of flooding in informal settlements after an event. The

CTCC officials revealed that the CTCC had spatial data on the geographical locations of the informal settlements in their GIS but no social data from these settlements.

Aerial photographs of Graveyard Pond taken in March 2009 were acquired from the CTCC. In addition, GIS maps depicting geographical data in the same area, such as roads, storm water drains, contours, sewer lines, direction of flow of ground water and cadastral data were also acquired from the CTCC. An overlay of the cadastral data on the aerial image revealed that there was no cadastral information within Graveyard Pond. This is typical of informal settlements that have not been zoned as residential areas. Abbott (2000) showed that, in informal settlements without cadastral information, the piece of land that is the most vital to individual households is that on which the accommodation structure is situated. The individual shacks were therefore adopted as the basic spatial unit to which the social and demographic information could be linked in the GIS.

Secondly, partnerships were also forged with the community leaders in Graveyard Pond and Europe. The community leaders in Graveyard Pond and Europe were identified after a series of visits to the settlement. A series of meetings was then organised to sensitise the community leaders on the aims of the study and to highlight the relevance of the risk assessment in their future negotiations with the CTCC. The author was actively involved in these discussions at Graveyard Pond, whilst SDI preferred to conduct these discussions in Europe without the author's presence. The community leaders then presented the proposed research to their constituencies and received approval for the research to proceed.

Based on various studies conducted in informal settlements (Abbot *et al.* 1998; Abbot 2000; Bouchard *et al.* 2007; SDI 2009; Tyler 2011) questionnaires were chosen as the format for data collection.

4.5 Development of the Questionnaires

Although various scholars have looked at concepts that are relevant in designing questionnaires (Hair et al., 2003), the questionnaires used in Abbot et al. (1998); Abbot (2000); Bouchard et al. (2007); SDI (2009), Tyler (2011) were modified to suit the requirements of the Turner et al. (2003) model. The questionnaire was extensive to ensure that the data obtained would be relevant to other stakeholders and that it could be used for future research within the CCAA FliCCR project. There were slight differences between the questionnaires used in Graveyard Pond and Europe (Appendices A and B respectively), because SDI required more information from Europe than was pertinent to the author. Table 4.2 tabulates the categories of the questions in the survey. The questionnaire was designed to collect information that could satisfy some of the research objectives. The following section will detail the rationale behind the questions in the survey.

It has been shown in various studies that adaptation to risk is contingent on the awareness of the severity of the consequences of the hazard (Smith, 1999). Awareness is further dependent on

criteria such as the age, gender and education (Smith, 2003; Brilly & Polic, 2005) of the household members. This warranted the first category of questions, which has been broadly named household details. It is essentially a section on demographics. This section contained questions pertaining to the age and gender of the head of the household. For ethical reasons, the Graveyard Pond enumeration designed by the author did not ask for the ID number of the head of the household, but the Europe enumeration designed by SDI did. It was envisaged that the demographic details of the various households could be used to explain the factors causing or amplifying differential vulnerability in the settlement.

CATEGORIES OF QUESTIONS IN THE QUESTIONNAIRE	QUESTIONS INCLUDED IN THE QUESTIONNAIRE
Household details	• Identity number, home language and gender of household head • His/her age • Number of families occupying the structure • Number of young people in the house • Number of people attending school • Number of adults staying in the house • Number of aged persons in the house
Employment, income and expenses	• Number of people employed in the household • Type of employment • Grants received • Monthly basic expenses • Transport and costs • Shopping options
Nature of house	• Type of house • Floor area of house • Number of rooms
Eligibility for housing subsidy	• Possibility of receiving housing subsidy • Income level with respect to housing subsidy
Disaster & relocation history	• Disasters experienced by the household • Methods of mitigation • Help from outside actors
Migration history	• Period lived in the community • Place of residence before Europe • Period lived in Cape Town
Health & sanitation	• Type of toilets available to the household • Number of people using the toilet • Collection of waste from common bins • Access to health services

Table 4.2 Survey Questionnaire (table format adapted from SDI, 2009)

The next set of questions dealt with employment, income and expenses. These questions were designed to ascertain the financial standing of the households. They queried factors, such as employment, access to welfare grants and expenses. A low household income effectively lowers the capacity of the household to cope with the consequences of a hazard. This set of questions could therefore assist in assessing the coping capacity of the households and inferring differential vulnerability.

The third section was meant to assess the type of construction material used to build the particular dwelling. The type of material can determine the capacity of the dwelling to withstand strong winds, and heavy rainfall and to reduce the impact of the winter cold. This set of questions not only addressed differential vulnerability but also examined how the households were exposed to hazards. The more susceptible the dwellings are to stresses, the more vulnerable the inhabitants are. This section also asked questions about the size of the dwelling, which were not relevant to this study but were included for the benefit of SDI. This is because SDI helps informal settlements to restructure the layout of the dwellings in order to introduce services. It is thus important for them to ensure that the total floor area of the dwellings prior to restructuring is maintained after the restructuring.

The questionnaire also enquired on eligibility of the households for housing subsidies. Access to a housing subsidy would mean that the household would be relocated by the state into a flood-free environment; hence there would be no exposure to flooding in the future for that particular household. This question was meant to identify the institutions and their roles in affecting the vulnerability of the community.

The disaster and relocation history section of the questionnaire was the most pertinent to this study. It was meant to solicit information on the hazards affecting the community, the mitigation measures in place to combat the consequences of these hazards, and the influnce of outside organisations on the vulnerability of the community.

The questions posed in the section on migration history assessed the reasons why people relocated into these flood-prone areas. The reasons investigated included proximity to family, colleagues and workplaces. It was envisioned that households with support from colleagues and family members would have more options available in coping with the hazards, such as the option of temporary relocation and potential access to borrowed income. Also, households that had relocated from other flood-prone informal settlements were more likely to perceive themselves to be less vulnerable than those relocating from outside Cape Town and moving directly into these informal settlements.

Lastly, the questionnaire contained a section on health and sanitation. It was assumed that respiratory diseases could be linked to dampness and cold and that the different types of diseases could infer differential vulnerability. These questions were meant to identify any dynamics or stresses that were causing unexpected outcomes. This section thus queried issues, such as access to proper toilets, removal of rubbish and access to health facilities. It was hoped that the information from this section could influnce potential decision makers into being cognisant of

stresses arising out of flooding as well as of the dynamics that amplify the influnce of flooding on the community, instead of a simplistic appraisal of the hazard itself.

The questions outlined in the enumeration were meant to address as many of the research objectives as possible. Also, the design of the questionnaire was meant to allow for checks on the validity of the information being provided. This issue will be addressed in a forthcoming section but the next section explains the steps taken in the data collection phase of this research.

4.6 Enumeration and Mapping

The methodology used to collect the data incorporated the methodologies used by Abbot *et al.* (1998), Abbot (2000), Karanja (2010), SDI (2009), Turner *et al.* (2003) and Tyler (2011).The data collection consisted of two main parts: capturing the social information from the communities using and capturing the spatial information using GIS. The social information was captured by means of spreadsheets, whereas the spatial information was derived from the aerial imagery. Every step of the data collection was done in partnership with the relevant stakeholders.

Firstly, some experienced enumerators from SDI were selected to help with the survey. In Graveyard Pond, the full team of surveyors included six people comprising the SDI trained team, the community leaders, the author and a research partner from the CCAA FliCCR group. In Europe, the survey team consisted of ten people comprising SDI enumerators and the community leaders. SDI preferred to act as a mediator between the author and the community of Europe hence the author did not have actually contact with the community members. In both settlements, meetings were held with all the surveyors to discuss the questionnaire so that any ambiguous or inappropriate questions could be rephrased or removed prior to conducting the survey. At these meetings, the input from the community leaders (in Graveyard Pond) and SDI surveyors (in Europe) was instrumental in developing the wording of the final questionnaire. In addition, the author trained both the Graveyard Pond and Europe survey teams in map reading, so that they could identify the dwellings where they were conducting interviews on the printed CTCC aerial images. It was noted during the first site visits that the shacks in both settlements had already been numbered with spray paint, and the teams decided to use these numbers as the shack identification numbers. Figure 4.2 shows the meeting held in Graveyard Pond with the survey team prior to the enumeration.

Each settlement was divided into sections, each of which was allocated to a particular surveyor. The surveyors were required to mark the shack number of each visited shack on a print-out of the aerial photographs, as well as on the corresponding questionnaire. In addition, any differences between the actual appearance of the shacks on the ground and the aerial image were marked on the printed aerial photographs. The questionnaires also contained the name of the enumerator so that, if two shacks in different sections had the same shack number, the individual questionnaires and the correct locations of the corresponding shacks could be distinguished by the names of the enumerators.

Figure 4.2 Initial meeting with the Graveyard Pond surveyor team

The survey took three days and 280 households were interviewed. The community leaders conducted further interviews over the weekends and in the evenings with those households where the community members were unavailable during the day because of work or other engagements. Figure 4.3 shows one of the community leaders conducting an interview with a household. In the background is an example of a shack with its identification number 'T34B' sprayed on its side with red paint.

A major setback in the data collection process was that not all respondents answered all the questions. Sometimes the heads of household were absent and the respondents did not have sufficient knowledge of the answers to the questions posed.

Figure 4.3 One of the Graveyard Pond community leaders conducting a survey

4.7 Data Integration, Analysis and Verification

The questionnaire responses were captured into a spreadsheet, using the shack number as the primary identifier for each questionnaire. In order to translate the data for analysis a coding process had to be introduced. For instance, qualitative information such as gender (question 3 in Appendix A) had to be coded as 1 (representing male) and 2 (representing female). Similar coding was done for all qualitative responses. For instance, in question 5(a)(i) of Appendix B, the responses were coded 1 for 'yes' and 2 for 'no'.

The spatial data was captured in a GIS environment using a methodology similar to that in Abbot *et al.* (1998) and Abbott (2000). After the completion of the survey, the printed aerial photographs, which the surveyors marked with the shack numbers, were used to digitise the shacks in the GIS. The shacks were digitised from the raster aerial photographs provided by the CTCC, taking into account any amendments recorded by the enumerators on the printed aerial photographs. Also, during the digitization, the shack numbers marked by the enumerators in the printed aerial photographs were used as the identifiers of the digitised shacks in the GIS. Since both the spreadsheet and the GIS had corresponding shack numbers as database identifiers, a spatial join could be carried out in the GIS software to link the questionnaires as attribute data for the corresponding shacks. Consequently, both the social data and the spatial data were located in a singular GIS database.

Some analysis was carried out on the spreadsheet in order to tease out the relevant statistics in the communities. These statistics included information on gender, age, language, employment, income, incidence of disasters, etc. The GIS data was used to create maps from the responses in the questionnaires. In Graveyard Pond, the results of the statistical analysis and the response maps were then presented by the author and another researcher to the community at the local community hall to verify that the captured data was accurate (Figure 4.4). This step was important because some of the residents might have given false information in the hope that an inflated impression of risk would yield quick responses from outside actors. Also, there was a risk that some of the enumerators could have captured the responses wrongly, hence it was important for the respondents to scrutinise the captured data.

Figure 4.4 Presenting the captured data to the Graveyard Pond community

During this meeting, the community was able to look at the data holistically, and they were able to identify trends (e.g. clusters of households with similar diseases) in some of the response maps. In areas where trends were identified, the community also debated potential causes of these trends and potential solutions. Hence the feedback meeting was also important in identifying criteria and alternatives to be assessed in the MCE. A similar verification process was conducted by SDI in Europe in conjunction with the community leaders.

4.8 Multi-Criteria Evaluation

From the response maps and community discussions, it emerged that the communities experienced both flooding and fire hazards. However, there were distinct differences in the types

of flooding, corresponding mitigation measures, income levels and diseases suffered. Hence these indicators were taken as the main criteria to be used in evaluating vulnerability. Various alternatives were identified for these criteria and ranked. The ranking process involved translating comparisons between alternatives using the codes in Table 2.3 prescribed by Malczewski (1999: 183). The next section details the alternatives in each of these criteria.

4.8.1 Exposure to Hazards

Vulnerability only exists if there is the potential for a hazard to manifest. Hence, the first stage of analysis involved identifying all the hazards affecting the settlements being studied and any disparities in the exposure of the households to such hazards. The statistics derived from the responses to the questionnaire showed that, although the households in Europe and Graveyard Pond had been exposed to both flooding and fire, flooding was the predominant hazard. The possible types of exposure ranged from 'no exposure to hazards' to 'exposure to both flooding and fire'. The levels of exposure to these hazards in Graveyard Pond were ranked in partnership with the community leaders of the settlement. A similar exercise was carried out with the SDI officials on behalf of the Europe enumeration. After the ranking had been completed, a pairwise comparison was carried out in order to derive weights for each alternative. In this analysis, the highest weight was allocated to the best case scenario and the lowest weight to the worst case scenario.

The weights were then linked to the shacks as attribute data in the GIS, based on the responses to the questions in the disaster and the relocation history section of the questionnaire (Table 4.2). For instance, if a household reported that they had not experienced either hazard, the weight for 'no exposure to flooding or fire' was allocated to that household. Once each household had been allocated a weight, a risk map based on exposure to hazards was created for the entire settlement. Also, the individual weights of each shack were interpolated to create a hazard exposure surface in order to smooth out any anomalies and tease out geographical areas that were particularly hazard-prone. A map of this surface was also created. After identifying the hazards in the community, the next stage of analysis involved identifying the corresponding methods of mitigation.

4.8.2 Methods of Mitigation

It was found that there were several methods being employed by the households in Europe and Graveyard Pond to cope with the hazards, and these methods were derived from the responses in the questionnaires. Each response was analysed against a type of hazard exposure and then ranked relative to the other responses to that type of exposure. The ranking was also done in partnership with SDI officials on behalf of Europe and the community leaders on behalf of Graveyard Pond. Based on their order of preference, a pairwise comparison was carried out on the alternatives in order to derive weights for each alternative. The highest weight was allocated to the best case scenario and the lowest weight to the worst case scenario.

As with the hazards, the weights were then linked to the shacks as attribute data in the GIS, based on the corresponding household's responses to the questions in the disaster and relocation history section of the questionnaire (Table 4.2). After each household had been allocated a weight, a vulnerability map based on mitigation was created for the entire settlement. Also, the individual weights of each shack were interpolated to create a map of a surface, showing changes in mitigation techniques across the two settlements. An analysis of the maps established whether the technique of mitigation was appropriate to the type of exposure to the hazards. Inappropriate methods of mitigation could not be deemed to reduce vulnerability.

4.8.3 Sanitation and Diseases

The rationale in assessing disease was that the dampness associated with flooding created an environment for respiratory and waterborne diseases. Consequently, the prevalence of disease could be used to gauge flooding. In Graveyard Pond, four main diseases were found to be prevalent in the community. It was reported that the community members periodically suffered from rash, running tummies, cough and flu during floods. The statistics on the prevalence of each of these diseases were used to rank the alternatives from the best case scenario (no disease) to the worst case scenario (all diseases). The ranking was done with the community leaders in Graveyard Pond and the SDI officials in charge of the Europe enumeration repectively. After the ranking had been completed, a pairwise comparison was carried out in order to derive weights for each alternative. The highest weight was allocated to the best case scenario and the lowest weight to the worst case scenario.

The weights were then linked to the shacks as attribute data in the GIS, based on the corresponding household's responses to the questions in the health and sanitation section of the questionnaire (Table 4.2). For instance, if a household reported that they did not suffer from any disease after or during flooding, the weight for 'no disease' was allocated to that household. Once each household had been allocated a weight, a vulnerability map based on disease was created for the entire settlement. Also, the individual weights of each shack were interpolated to create a surface showing the incidences of diseases across the settlements. The surface was created to smooth out any anomalies, and the subsequent map was used to tease out disease hotspots and any unusual dynamics causing particular diseases.

4.8.4 Income

Income has been used as an indicator of vulnerability in various studies on the subject. Essentially, a lower income also lowers coping capacity and increases vulnerability. Thus, the disparity in incomes can be used to assess the disparity in vulnerability to disasters. From the questionnaire and from discussions with the community leaders, it was found that household income in both settlements was dependent on employment of household members and access to welfare grants. Employment was found to be either continuous (full time employment) or intermittent (part time employment).

Based on the responses to the questionnaires the various income levels were ranked from the best household income scenario being (full time employment and access to welfare grants) to the worst case scenario (unemployment and no access to grants). Again, the ranking in Graveyard Pond was done with the community leaders, whilst the ranking in Europe was done in partnership with the SDI officials in charge of the Europe enumeration. After the ranking had been completed, a pairwise comparison was carried out in order to derive weights for each alternative. As with other factors, the highest weight was allocated to the best case scenario and the lowest weight to the worst case scenario.

The weights were then linked to the shacks as attribute data in the GIS based on the corresponding household's responses to the questions in the employment, income and expenses section of the questionnaire (Table 4.2). Once each household had been allocated a weight, a vulnerability map based on income was created for the entire settlement. Also, the individual weights of each shack were interpolated to create a surface showing the magnitude of income. This surface, when compared to the other surfaces can show how prepared a household was to cope with the dynamics, such as disease and disasters.

The MCE stage of the study led to the creation of vulnerability maps that showed the spatial disparities of risk within and between the two informal settlements. Also, a comparison between vulnerability maps was used to derive connections between the different datasets that might be aggravating vulnerability and risk. A unique attribute of this study is that the MCE was done in conjunction with the local communities and NGOs. The next section describes the problems and limitations of the methodology presented in this chapter.

4.9 Problems and Limitations of the Methodology

A holistic study of vulnerability requires the estimation of both biophysical and social vulnerability. However, research is littered with studies on biophysical vulnerability whilst social vulnerability is largely under researched. Hence the design of the CCAA FliCCR project required this study to place its emphasis on social vulnerability. Further studies will need to be conducted to ascertain the biophysical elements of vulnerability in informal settlements.

The methodology presented here was highly reliant on collecting social information through questionnaires. A major shortcoming of this methodology was that a number of households did not answer all the questions in the questionnaire. Where questions were left unanswered by some households, it was impossible to compare accurately the responses within the entire settlement. Questions were often left unanswered when minors or female spouses found alone at the dwelling did not have sufficient information to answer the questions.

In some instances, it was difficult to identify shacks from the printed aerial photographs during the enumeration and mapping phase. The shacks were sometimes located so close to each other, that their roofs appeared as one continuous roof in the aerial photographs. This led to errors in

the location of the shacks when the shack numbers were written on the printed aerial photographs.

Also, in some cases, the same enumerator visited more than one shack with the same shack number in their allocated section. In such scenarios, there would be two or more questionnaires and two or more shacks on the aerial photograph with the same number. Since the questionnaires had been captured by the same enumerator, it was impossible to determine to which shack a particular questionnaire belonged. This scenario necessitated a site visit to both shacks in order to link the data correctly.

Lastly, throughout the data collection and analysis phases of this study, the methodology presented in this research promoted partnerships with stakeholders. The collection of social data was carried out with the help of community members and the author thus could not accompany every surveyor during the enumeration. Therefore, it was difficult to completely rule out bias on the part of the respondents and the surveyors. Nonetheless, the accurate analysis of risk was contingent on the input of accurate data, hence it was important to check the integrity of the data. The next section describes the checks that were put in place to ascertain the reliability of the data.

4.10 Data Integrity

This section will describe the ways in which the reliability of the data collected from the informal settlements was checked.

4.10.1 The Questionnaire Design

The first check on the data integrity is embedded in the questionnaire design. The questionnaire was split into seven sections (Table 4.2) and the enumerator was required to ask the questions in the order laid out in the questionnaire. It was envisaged that the enumerator and the respondent would both see the sections as separate sets of questions, although some of the questions were actually interrelated. For instance, there is a correlation between the number of young people or school-going children in the household details section of the questionnaire and in the welfare grants in the next section. It would be inconsistent for a respondent to say that they have children and no form of employment, but do not collect a child welfare grant.

Similarly, there was a correlation between the questions in the employment, income and expenses section and the type of health facilities visited. It would be inconsistent for someone without any form of employment to say that they used emergency services or general practitioners when they fell sick. It is very likely that, if they used such health facilities, they must have had some form of employment. There is also a correlation between the employment, income and expenses section and the migration history section. If a respondent said that they moved to that area because of its proximity to their work place, then it is very likely that they had some form of employment and the responses in the employment section should confirm this.

There were other correlations between the migration history section and the disaster and relocation history section. The relationships between the different questionnaire sections allowed the author to identify potentially biased responses in the questionnaire. This check was meant to identify bias on the part of the respondents and surveyors.

4.10.2 Community Feedback

The second check on the data was carried out during the community feedback meeting. After the enumeration, the statistical data and the questionnaire response maps were presented to the communities for verification. At these meetings, the community members corrected any wrongly captured data as well as the initial perceptions of the author. This check was put in place to identify bias on the part of the surveyors and the author.

4.10.3 Comparisons between the Spatial and Social Data

After the community feedback had been received, the validated questionnaire responses were integrated into the GIS as attribute data of the corresponding shacks. Some responses were then checked against the aerial imagery. For instance, it was possible to confirm from the aerial imagery how long respondents said they had lived in the settlements. If a respondent claimed to have lived in the settlement for five years, the respondent's dwelling should appear in the archived aerial images from five years ago.

After carrying out all these checks, the validated data was deemed to be reliable enough for the vulnerability analysis. The MCE was only carried out on the sections that showed the least bias.

4.11 Summary

The aim of this study was to assess flood risk in informal settlements. The research questions necessitating this study were formulated as follows:

- How can valid information be sourced from various stakeholders, including local communities, in informal settlements for risk assessment?

- How can partnerships be developed to enhance holistic flood risk assessment in flood-prone informal settlements?

- How does the distribution of flood risk vary spatially within flood-prone informal settlements and what are the implications for mitigation?

The foregoing sections have described the steps in this research, from site selection to the creation of the risk maps. The steps have been summarised in the flowchart in Figure 4.5. After

obtaining ethics clearance from the faculty, informal settlement areas that are flood-prone were identified from research studies and discussions with SDI. The next stage involved setting up partnerships with the CTCC, SDI and the community leaders in the informal settlements. This was followed up with a questionnaire design phase and an enumeration and mapping phase. Some statistics and maps of the responses were derived from the captured data and verified by the communities. A number of other checks were incorporated in the study to ensure that valid information was collected.

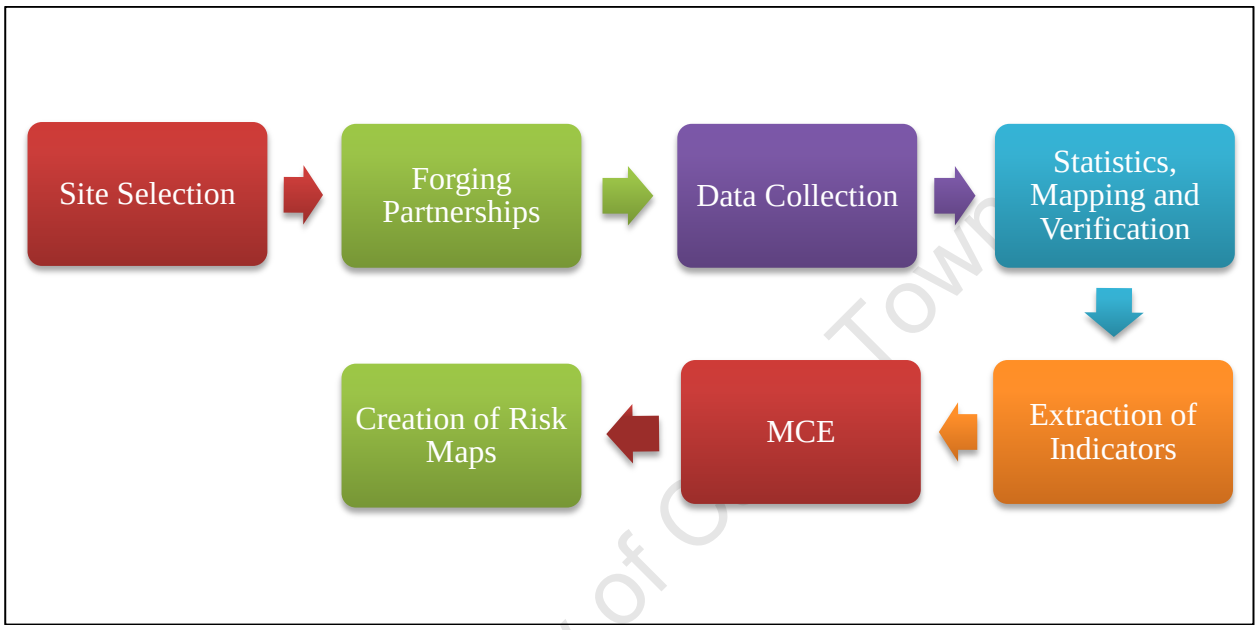

Figure 4.5 Steps used in methodology

Based on the responses to the questionnaires and in the discussions with the community leaders and NGO officials, four criteria were extracted from the questionnaires to be used in the MCE to evaluate vulnerability. The assessment of vulnerability has been limited to vulnerability prior to a flood. Hence this study is not a holistic study of vulnerability as it does not assess vulnerability after the hazard has manifested; this will be necessary to determine biophysical vulnerability. Weights were calculated using a pairwise comparison method in respect of all the alternatives. Lastly, the calculated weights were linked to the shacks in the GIS environment and vulnerability maps were created. These vulnerability maps can be regarded in this study as proxies of risk maps. These risk maps display the variance of risk within and between informal settlements.

The methodology presented in the preceding discussion differs significantly from the methodology used by the CTCC to assess risk. The CTCC neglects the social elements of vulnerability and relies on the calculations of flood lines based on terrain, water table values, rainfall predictions etc. Consequently, solutions prescribed by the CTCC are generic and often inappropriate. In contrast, the methodology presented in this chapter contextualises flood vulnerability to a specific area and presents a decision maker with additional information that can inform solutions appropriate to that particular area. The next section details the results of this study.

Chapter 5 Results

This chapter presents the findings based on analysis of the data collected from the two informal settlements of Europe and Graveyard Pond. The results include tables and graphs based on the statistical analysis of the responses to the questionnaires, as well as maps indicating the locations of respondents and the distributions of risk. The results from Graveyard Pond will be presented first, followed by the results from Europe.

In some sections, only representative results will be presented here and the rest of the calculations and results will be presented in Appendices C to J. The discussion of the results will follow in the subsequent chapter, viz. Chapter 6.

5.1 Graveyard Pond

This section presents results showing variance in risk in Graveyard Pond. The results include the statistics from the questionnaire, the questionnaire response maps, the weight calculations and the final risk maps. The statistics from the questionnaire were generated after coding the responses. The objective of this section is to expose the distribution of risk within Graveyard Pond. From the community's responses to the questionnaire and from discussions with the community leaders, four main factors were found to influence the magnitude of vulnerability in the households of Graveyard Pond. The factors were:

i. Differences in exposure to the hazards;
ii. Methods of mitigation against the hazards;
iii. Sanitation and incidence of waterborne and respiratory diseases; and
iv. Household income.

These factors will be addressed in more detail in the following sections.

5.1.1 Exposure to Hazards

Based on the statistical report generated from the, 94% of the people interviewed reported that they experienced flooding every winter. It was found that flooding was attributed to leaking roofs, an upsurge of ground water and flooding by run-off water, which respondents referred to as 'real flooding'. Of these three forms of exposure, 70% of the respondents stated that an upsurge of underground water was responsible for the flooding of their structures. A map was created to show the types of flooding relative to the positions of the shacks (Figure 5.1).
Figure 5.2 shows two areas in the centre of Graveyard Pond that are flooded for long periods of the year.

The second hazard prevalent in Graveyard Pond is fire. An analysis of the responses showed that 41% of the respondents had experienced fire. The community leaders however pointed out that

the incidence of fire was less frequent than flooding. Whilst flooding occurred perennially with the winter rains, the last fire had occurred in 2008. Figure 5.3 shows the geographical distribution of the questionnaire responses to fire.

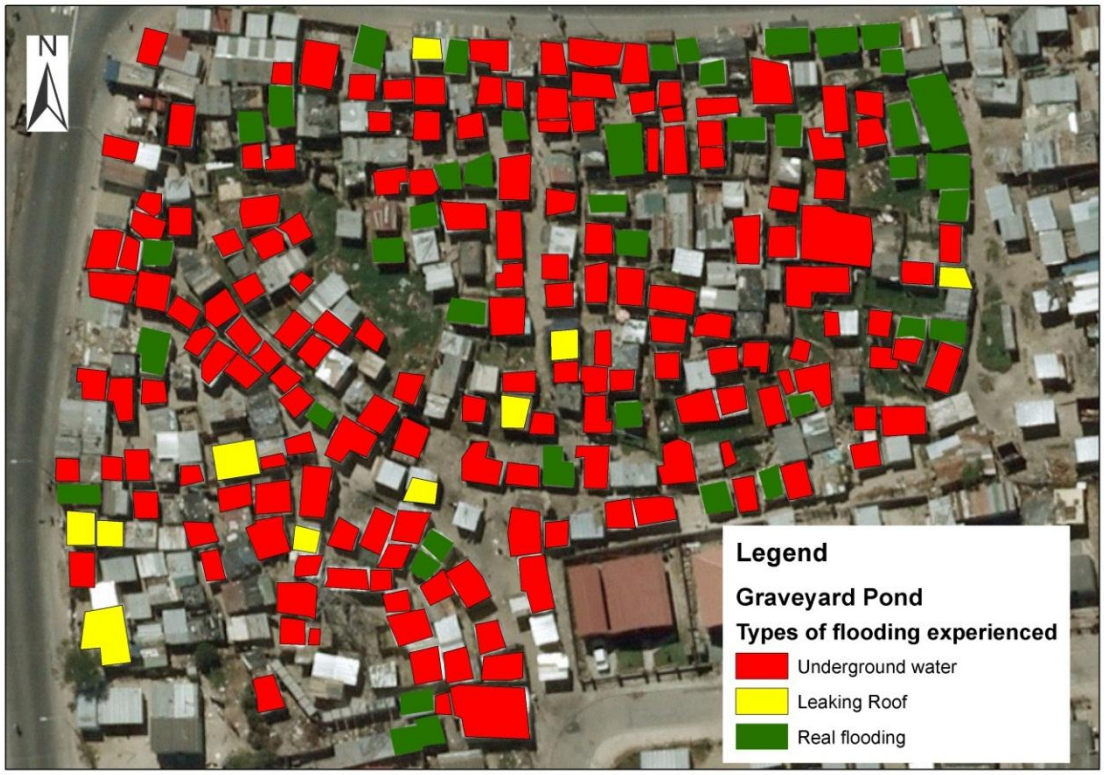

Figure 5.1 Types of flooding experienced in Graveyard Pond

Figure 5.2 Flooding from rising underground water in Graveyard Pond

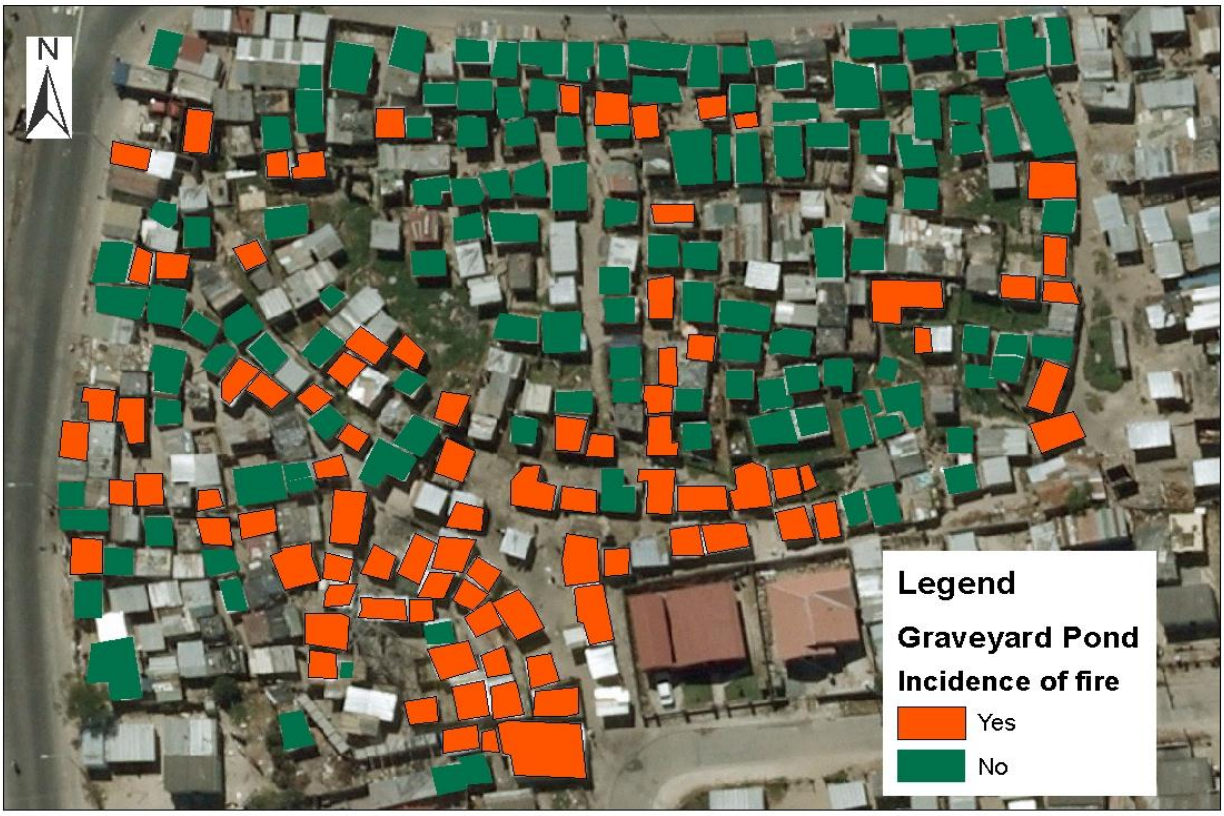

Figure 5.3 Incidence of fire in Graveyard Pond

Based on the findings for flooding and fire, the following alternatives were generated for the types of exposure to hazards:

- No exposure to hazards;
- Exposure to fire only;
- Flooding because of a leaking roof;
- Flooding caused by rising water;
- Flooding caused by flash floods; and
- Exposure to both flooding and fire.

These alternatives were ranked in order of preference through discussions with the community leaders. In this context, if an alternative was ranked higher than another, it meant that that alternative was perceived to have less of a negative consequence than the other. On opposite ends of the scale, 'no exposure to hazards' ranks higher than 'exposure to both flooding and fire'. An MCE was then employed to calculate the relative consequences of the ranked alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The full set of calculations can be found in Appendix C.

Table 5.1 shows the ranking and the pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives. The values on the right of the diagonal represent the comparisons between the alternatives based on Table 2.3. The values on the left of the diagonal represent the inverses of those comparisons. For instance, having no exposure to a

disaster is moderately preferred to flooding from a leaking roof, hence it was allocated a value of 3 (based on Table 2.3) in Table 5.1, on the right hand side of the matrix diagonal. Based on that relationship, the comparison of flooding from a leaking roof to no exposure to a disaster is 1/3 or 0.333 and it was allocated to the corresponding cell on the left hand side of the matrix diagonal. All comparisons of the relevant to themselves were allocated a weight of 1 based on Table 2.3.

PAIRWISE COMPARISON MATRIX						
Criteria	ND	LR	Ofr	FFl	RW	FF
No Disaster (ND)	1.000	3.000	4.000	5.000	6.000	7.000
Leaking Roof (LR)	0.333	1.000	2.000	4.000	5.000	6.000
Only Fire (Ofr)	0.167	0.200	1.000	3.000	4.000	5.000
Flash Floods (FFl)	0.143	0.250	0.333	1.000	3.000	4.000
Rising Water (RW)	0.167	0.200	0.250	0.333	1.000	3.000
Flood and Fire (FF)	0.143	0.167	0.200	0.250	0.333	1.000
Sum:	**1.952**	**4.817**	**7.783**	**13.583**	**19.333**	**26.000**

Table 5.1 Pairwise Comparison Matrix of exposure to disasters

Table 5.2 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX						
Criteria	ND	LR	Ofr	FFl	RW	FF
No Disaster (ND)	0.512	0.623	0.368	0.368	0.310	0.269
Only Leaking Roof (LR)	0.171	0.208	0.294	0.294	0.259	0.231
Only Fire (Ofr)	0.085	0.042	0.221	0.221	0.207	0.192
Only Flash Floods (FFl)	0.073	0.052	0.074	0.074	0.155	0.154
Only Rising Water (RW)	0.085	0.042	0.025	0.025	0.052	0.115
Flood and Fire (FF)	0.073	0.035	0.018	0.018	0.017	0.038
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table 5.2 Normalised Pairwise Comparison matrix of exposure to disasters

EXPOSURE TO HAZARDS	
Alternatives	**Weights**
No Disaster	0.408
Only Leaking Roof	0.243
Only Fire	0.161
Only Flash Floods	0.097
Only Rising Water	0.057
Flood and Fire	0.033
Sum:	**1.000**

Table 5.3 Vulnerability weights for hazard exposure

The relative weights were then calculated and the comparison was found to have a consistency ratio of 0.044. The consistency ratio was significantly less than the value of 0.1 suggested by

Malczewski (1999) as a threshold of consistency and therefore the relative weights were adopted. Table 5.3 shows the final relative weights. In this table, the magnitude of the vulnerability is inversely proportional to the magnitude of the associated weight.

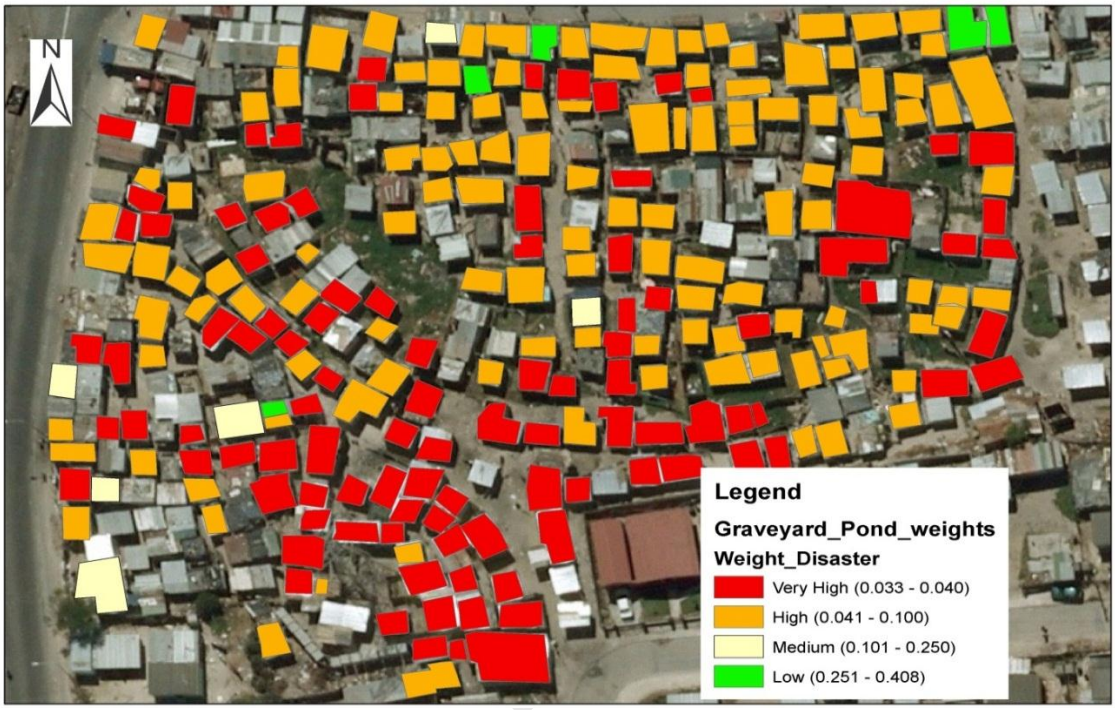

Figure 5.4 Map showing vulnerability based on type of exposure to a hazard

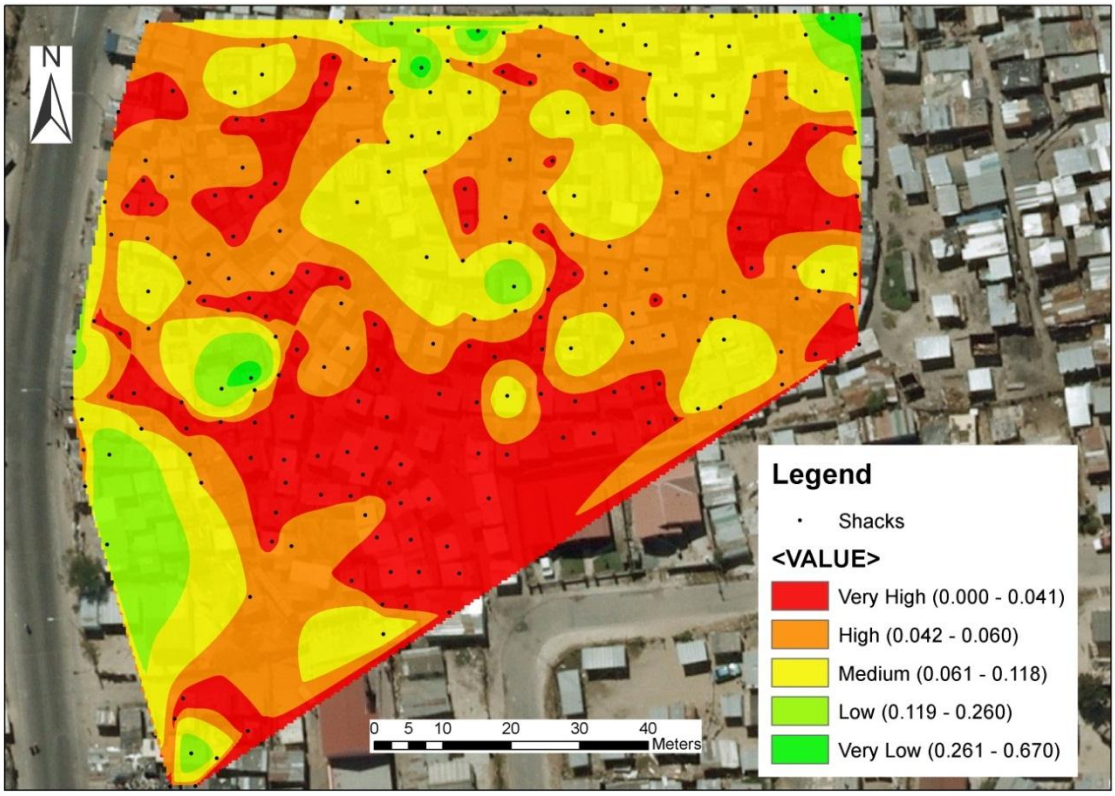

Figure 5.5 Raster map showing vulnerability based on type of exposure to a hazard

The weights were then allocated to the individual households based on their responses. For instance, if a particular household experienced both fire and floods, a weight of 0.033 was allocated to that household. The weight was added as an attribute in the same row as the corresponding shack number in the GIS. After a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.4).

Some of the shacks in Figure 5.4 do not have any of the colours in the legend because the respondents either never answered that question or were not interviewed. Hence a raster dataset denoting types of exposure was created by interpolating the weights. The natural neighbour method of interpolation was applied to the data to create the raster map (Figure 5.5).

5.1.2 Methods of Mitigation

It was found that responses to hazards varied according to the type of exposure. In this section, the emphasis was placed on responses to flooding because of the frequency of floods relative to fires. The following main responses to flooding were extracted from the questionnaires:

- Digging of trenches;
- Raising of shacks;
- Use of sandbags;
- Relocation; and
- Use of concrete floors.

Figure 5.6 shows the preferred methods of mitigation to flooding. The most popular choice of flood mitigation in Graveyard Pond is the use of trenches. The trenches are meant to channel water away from the shacks and potentially avoid the impact of flash floods. Figure 5.7 is a photograph taken during the enumeration showing an example of a trench outside one of the shacks.

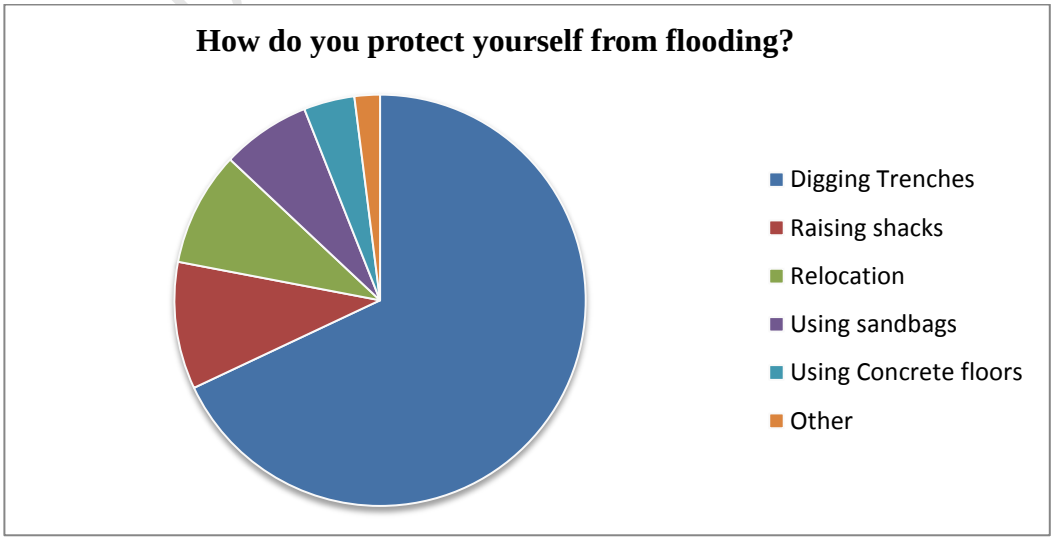

Figure 5.6 Graph showing the preferred methods of flood mitigation

Although Figure 5.6 depicts the relative preference of the mitigation methods, the individual responses were also mapped to assess the geographical distribution of the mitigation methods. Figure 5.8 shows the distribution of the main method employed by each household to mitigate against flooding. The shacks without any of the colours in the legend belong to residents who did not respond to the questions on mitigation.

Figure 5.7 Image showing the use of trenches in flood mitigation

Figure 5.8 Map showing the geographic distribution of methods of flood mitigation

The next step involved analysing the efficiency of the mitigation methods using MCE. The MCE assessed the efficiency of each type of mitigation method against the type of exposure to flooding. The rationale was that, whilst digging trenches might reduce vulnerability to flash floods, it might not be as effective at reducing flooding from rising underground water. Table 5.4 explains the alternative combinations of type of exposure and choice of mitigation.

TERM	DESCRIPTION OF CORRESPONDING RESPONSE
FF&DT	Flash Floods & Dig trenches
FF&RS	Flash Floods & Raise shacks
FF&SB	Flash Floods & Sand bags
FF&REL	Flash Floods & Relocation
FF&CF	Flash Floods & Concrete floors
LR&REL	Leaking Roof & Relocation
LR&SB	Leaking Roof & Sand bags
LR&RS	Leaking Roof & Raise shacks
LR&CF	Leaking Roof & Concrete floors
LR&DT	Leaking Roof & Dig trenches
RW&RS	Rising water & Raise shacks
RW&CF	Rising water & Concrete floors
RW&SB	Rising water & Sand bags
RW&REL	Rising water & Relocation
RW&DT	Rising water & Dig trenches

Table 5.4 Legend of criteria for mitigation

PAIRWISE COMPARISON MATRIX															
Criterion	FF&DT	FF&RS	FF&SB	FF&REL	FF&CF	LR&REL	LR&SB	LR&RS	LR&CF	LR&DT	RW&RS	RW&CF	RW&SB	RW&REL	RW&DT
FF&DT	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&RS	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&SB	0.333	0.333	1.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&REL	0.333	0.333	0.500	1.000	2.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&CF	0.250	0.250	0.333	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LR&REL	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&SB	1.000	1.000	1.000	1.000	1.000	0.500	1.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&RS	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&CF	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&DT	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.500	0.500	1.000	1.000	1.000	1.000	1.000	1.000
RW&RS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&SB	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	0.333	3.000
RW&REL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	3.000	1.000	4.000
RW&DT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.333	0.250	1.000
Sum:	12.917	12.917	17.833	19.500	24.000	12.833	14.333	16.500	16.500	21.000	14.833	14.833	18.333	12.583	24.000

Table 5.5 Pairwise comparison matrix of methods of mitigation

Table 5.5 depicts the pairwise comparisons between the alternatives. The resulting pairwise comparison matrix was normalised and the relative weights were calculated. The calculations have been detailed in Appendix D. Owing to the magnitude of the calculations, only the final weights are presented here.

METHODS OF MITIGATION	
Alternatives	**Weights**
Flash Floods & Dig trenches	0.085
Flash Floods &Raise shacks	0.085
Flash Floods & Sand bags	0.064
Flash Floods &Relocation	0.056
Flash Floods &Concrete floors	0.050
Leaking Roof &Relocation	0.081
Leaking Roof & Sand bags	0.074
Leaking Roof & Raise shacks	0.060
Leaking Roof & Concrete floors	0.060
Leaking Roof & Dig trenches	0.051
Rising Water & Raise shacks	0.069
Rising Water & Concrete floors	0.069
Rising Water & Sand bags	0.060
Rising Water & Relocation	0.087
Rising Water & Dig trenches	0.050
Sum:	**1.000**

Table 5.6 Vulnerability weights for methods of mitigation

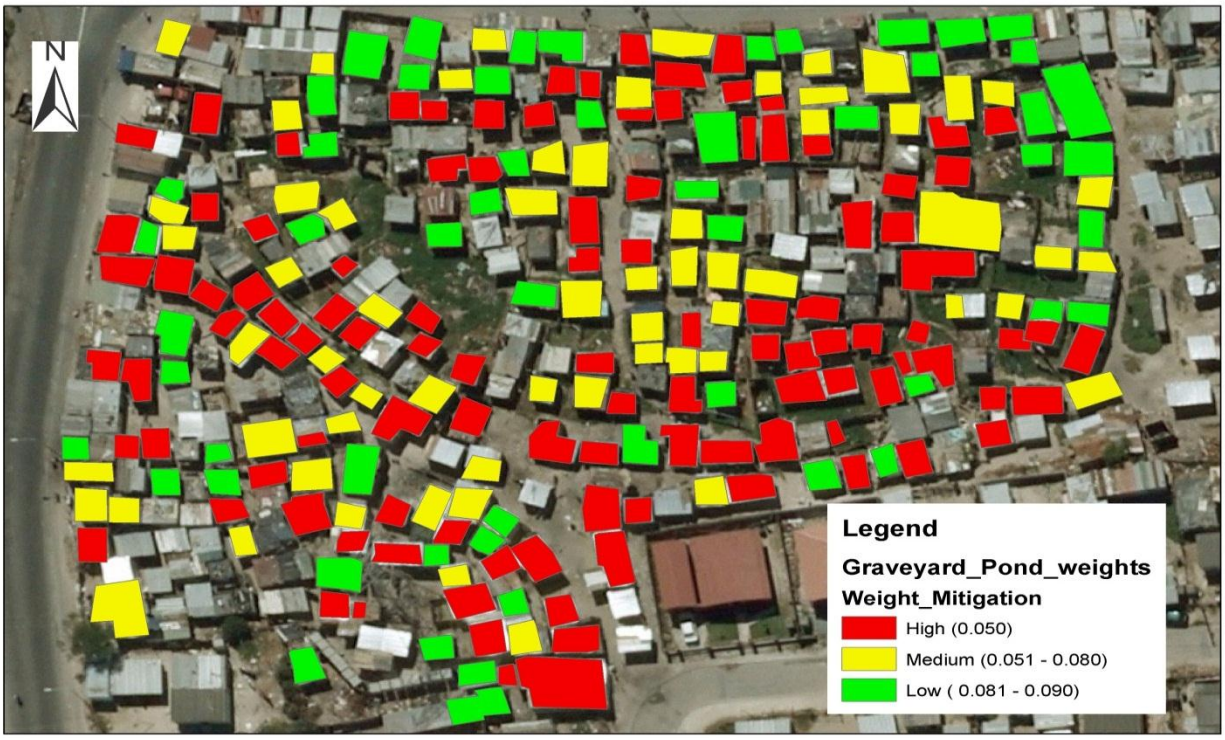

Figure 5.9 Map showing vulnerability based on methods of mitigation

The relative weights were found to have a consistency ratio of 0.054. Since the consistency ratio was significantly less than the value of 0.1, the relative weights were adopted. Table 5.6 shows the final relative weights. In this table, the magnitude of the vulnerability is inversely proportional to the magnitude of the associated weight.

The weights were then allocated to the individual households based on their responses. For instance, if a particular household experienced flooding from rising water and opted to dig trenches, a weight of 0.050 was allocated to that household. This weight was added as an attribute in the same row as the corresponding shack number in the GIS. Once a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.9).

A raster dataset denoting efficiency of mitigation methods was also created by interpolating the weights. The natural neighbour method of interpolation was applied to the data to create the raster map (Figure 5.10). The next section will show the results of investigation into sanitation and disease.

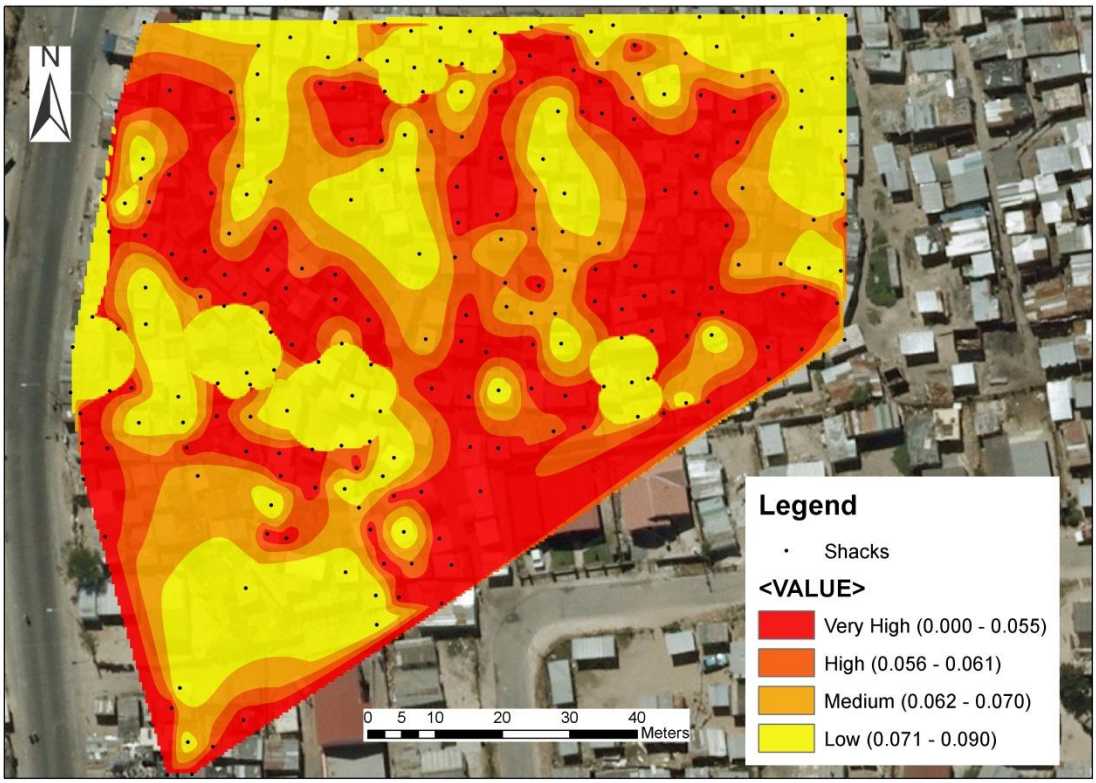

Figure 5.10 Raster map showing vulnerability based on efficiency of mitigation methods

5.1.3 Sanitation and Incidence of Diseases

This section reports on the relevance of sanitation and diseases in amplifying vulnerability to flooding. During the enumeration design, the author was informed that there are no toilets in Graveyard Pond. Hence, approximately 52% of the residents use buckets for toilets whilst the rest use toilets in neighbouring settlements. The refuse is often poured into an open storm water

drain in the settlement since it is laborious for residents in the centre of the settlement to walk to those toilets. Figure 5.11 shows the locations and types of toilets used by the households.

Figure 5.11 Map showing types of toilets used in Graveyard Pond

Figure 5.12 Incidence of rashes in Graveyard Pond

The residents reported a number of respiratory diseases, such as coughs, flu and tuberculosis, which they associated with flooding. It was also found that 15% of the residents were afflicted

by rashes and 28% suffered from running stomachs. A map was created to show the location of residents afflicted by rashes relative to the open storm water drain (Figure 5.12). A five meter buffer was created around the storm water drain in Figure 5.12.

Based on the statistical finding on diseases in Graveyard Pond, the following alternatives were generated:

- No incidence of diseases;
- Running tummy;
- Respiratory diseases;
- Rashes;
- Running tummy and respiratory diseases;
- Rashes and respiratory diseases; and
- All diseases (respiratory diseases, rashes and running tummy)

These alternatives were ranked in order of preference based on discussions with the community leaders. An MCE was then used to calculate the relative consequences of the alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The full set of calculations can be found in Appendix E.

TERM	DESCRIPTION
ND	No Disease
Rsh	Only Rash
RT	Only Running Tummy
Co/F	Only Cough/Flu
RT&Rsh	Running Tummy and Rash
Co&Rsh	Cough and Rash
RT&Co	Running Tummy and Cough
All	All

Table 5.7 Legend of criteria for mitigation

PAIRWISE COMPARISON MATRIX								
Criteria	ND	Rsh	RT	Co/F	RT&Rsh	Co&Rsh	RT&Co	All
ND	1.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
Rsh	0.333	1.000	3.000	4.000	5.000	5.000	6.000	6.000
RT	0.250	0.333	1.000	3.000	4.000	4.000	5.000	6.000
Co/F	0.200	0.200	0.250	1.000	2.000	3.000	4.000	5.000
RT&Rsh	0.167	0.167	0.250	0.500	1.000	2.000	3.000	4.000
Co&Rsh	0.143	0.200	0.250	0.333	0.500	1.000	2.000	3.000
RT&Co	0.125	0.167	0.200	0.250	0.333	0.500	1.000	2.000
All	0.111	0.167	0.167	0.200	0.250	0.333	0.500	1.000
Sum:	2.329	5.233	9.117	14.283	19.083	22.833	29.500	36.000

Table 5.8 Pairwise comparison matrix of incidence of diseases

Table 5.7 explains the alternative combinations of type of exposure and choice of mitigation. Table 5.8 summarises the pairwise comparisons between the alternatives.

INCIDENCE OF DISEASES	
Alternatives	**Weights**
No Disease	0.367
Rash	0.224
Running Tummy	0.151
Cough/Flu	0.092
Running Tummy and Rash	0.065
Cough and Rash	0.046
Running Tummy and Cough	0.032
All	0.023
Sum:	1.000

Table 5.9 Weights for contribution of disease to vulnerability

The resulting pairwise comparison matrix was normalised and the relative weights were calculated. Table 5.9 shows the final relative weights. In this table, the magnitude of vulnerability is inversely proportional to the associated weight. The reliability of the pairwise comparison was calculated and the consistency ratio was found to be 0.050. Given that the overall value was supposed to be less than 0.1, these weights were adopted. There were eight criteria and the random inconsistency index for eight criteria is 1.41 (from Table 2.6).

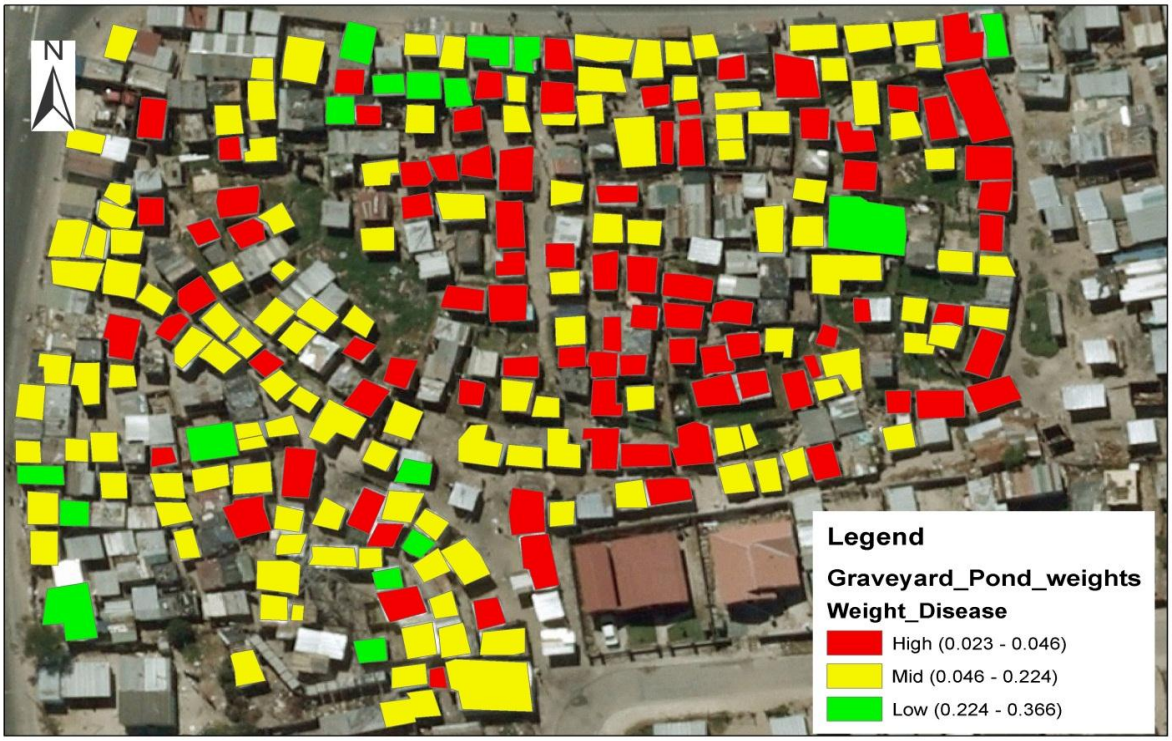

Figure 5.13 Map showing vulnerability based on prevalence of disease

The weights were then allocated to the individual households based on their responses. For instance, if a particular household experienced only coughs and rashes, a weight of 0.046 was allocated to that household. The weight was added as an attribute in the same row as the

corresponding shack number of the respondent in the GIS. Once a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.13).

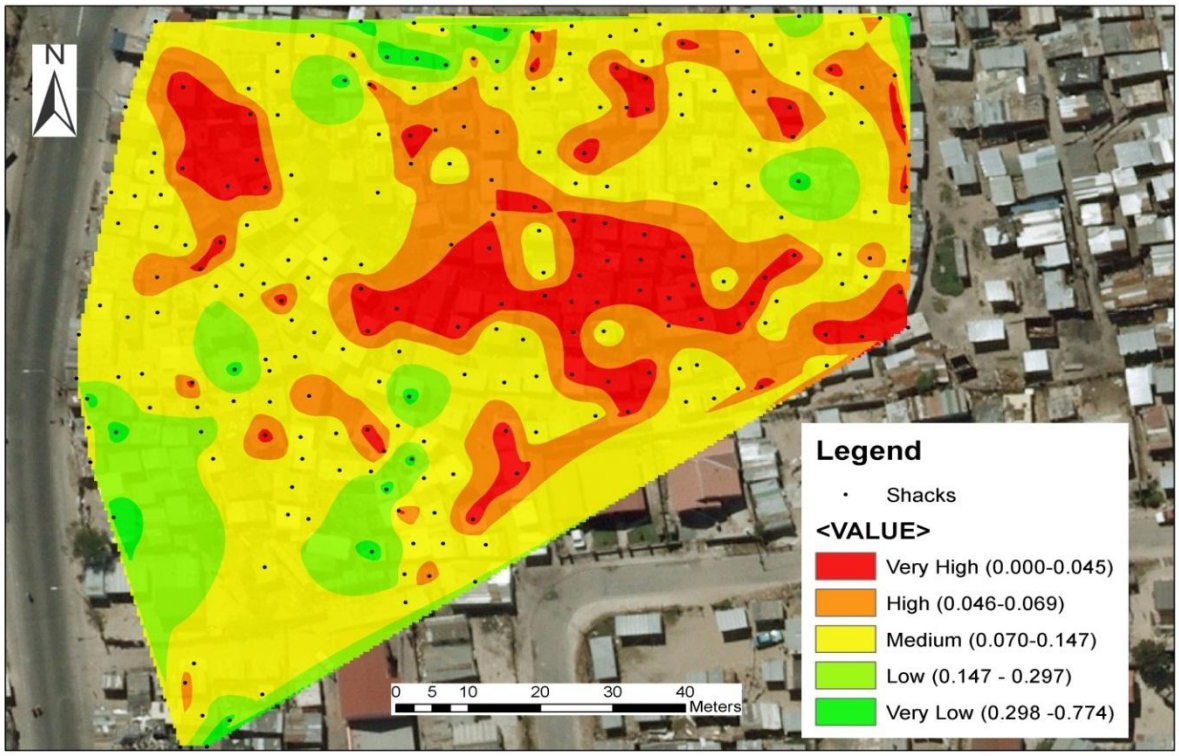

Figure 5.14 Raster map showing vulnerability based on prevalence of disease

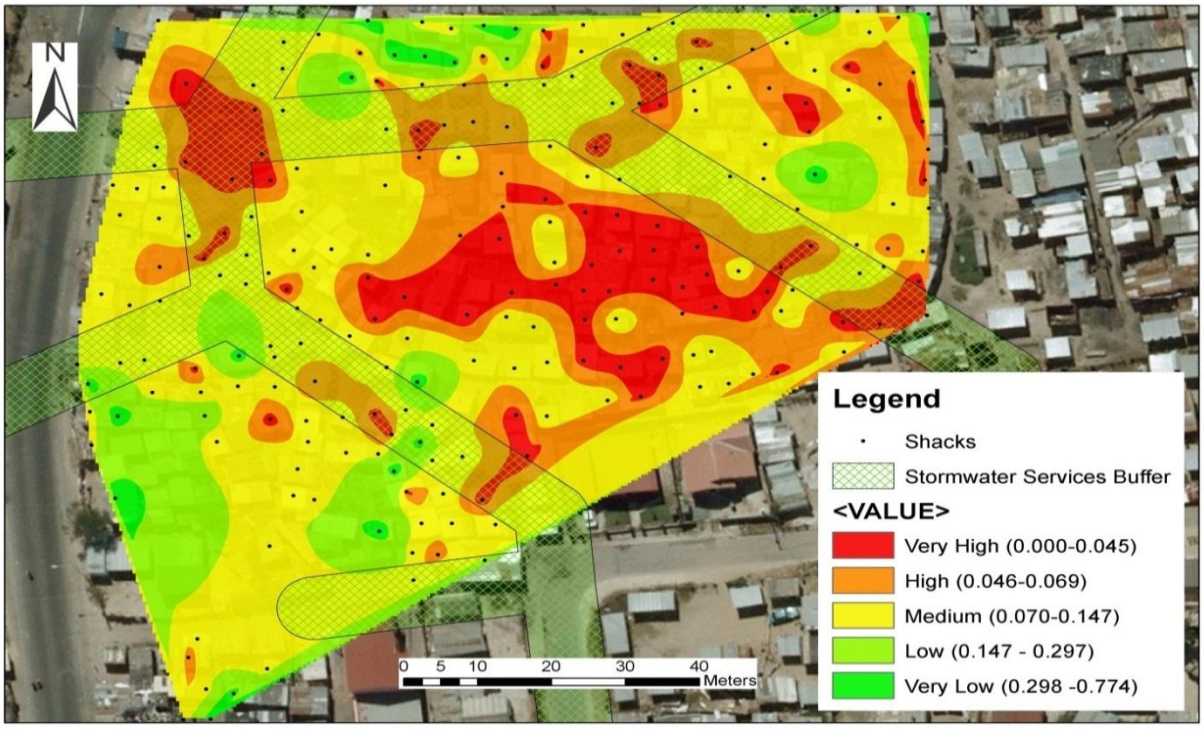

Figure 5.15 Vulnerability map showing location of storm water drain relative to disease prevalence

A raster dataset denoting the role of disease in amplifying vulnerability was also created by interpolating the weights. The natural neighbour method of interpolation was applied to the data to create the raster map (Figure 5.14).

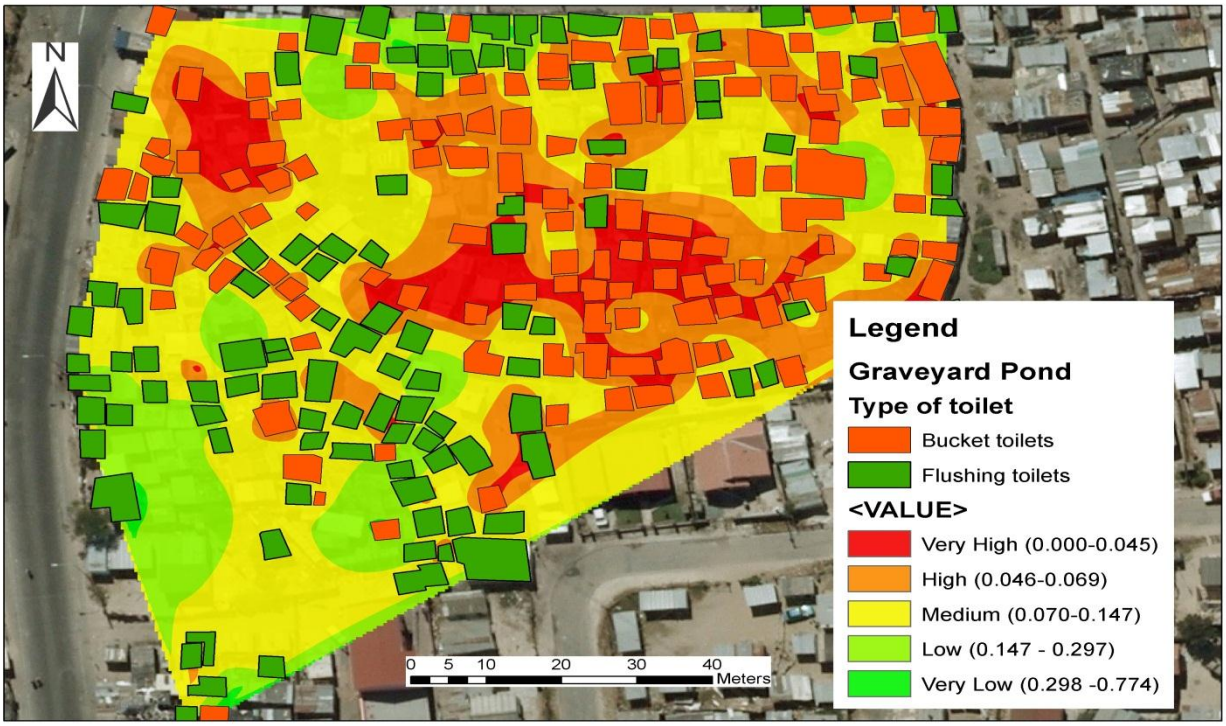

Figure 5.16 Vulnerability map showing the type of toilets used in Graveyard Pond relative to the prevalence of diseases

An additional map showing the relationship between the storm water drain and vulnerability to disease was created (Figure 5.15). Furthermore, a map showing the relationship between the type of toilets used and vulnerability to disease was created (Figure 5.16).

The following section contexualises the role of income in reducing vulnerability.

5.1.4 Household Income

It was found that 63.7% of the households interviewed in this survey had at least one person with some form of employment. In addition, in 8.1% of the households interviewed two or more people were employed. Of the people who reported being employed, most have part-time jobs (Figure 5.17). Figure 5.18 shows an interview of a self-employed resident and Figure 5.19 shows the number of people employed in the Graveyard Pond households.

Furthermore, 45% of the households in Graveyard Pond receive welfare grants from the government. It was found that the majority of these grants are child support grants. Figure 5.20 shows the types of welfare grants being accessed in Graveyard Pond. The various alternative forms of income extracted from the responses to the questionnaires were as follows:

- Full-time or self-employment;

- Full-time or self-employment and welfare grants;
- Part-time employment and welfare grants;
- Part-time employment;
- Only welfare grants; and
- No income at all.

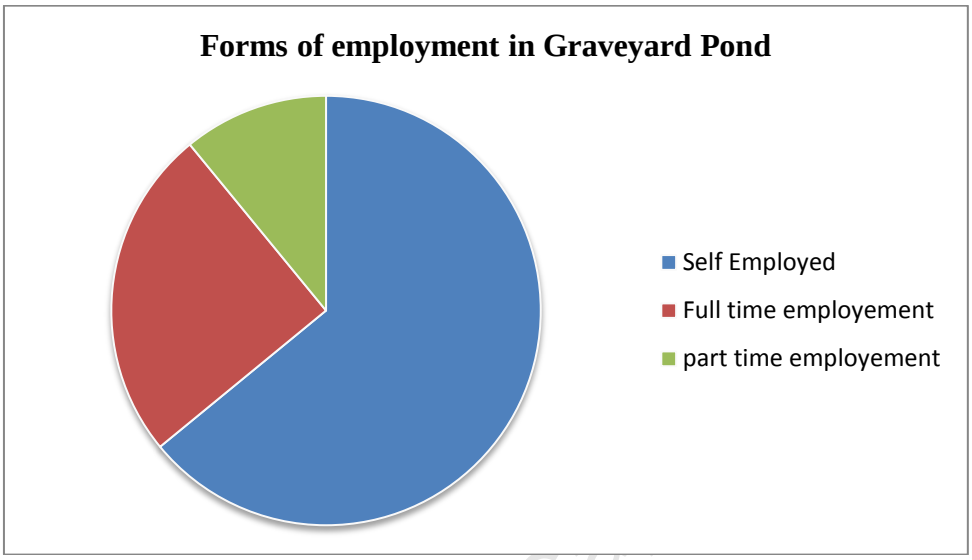

Figure 5.17 Forms of employment in Graveyard Pond

Figure 5.18 An example of self-employment in Graveyard Pond

Figure 5.21 shows the number of people with an income including welfare grants. Discussions were conducted with the community leaders in order to rank these alternatives. The rationale was

that, if an alternative was ranked higher than another, it meant that that alternative was perceived to reduce vulnerability more than the other. An MCE was then employed to calculate the relative consequences of the alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The weight calculations can be found in Appendix F.

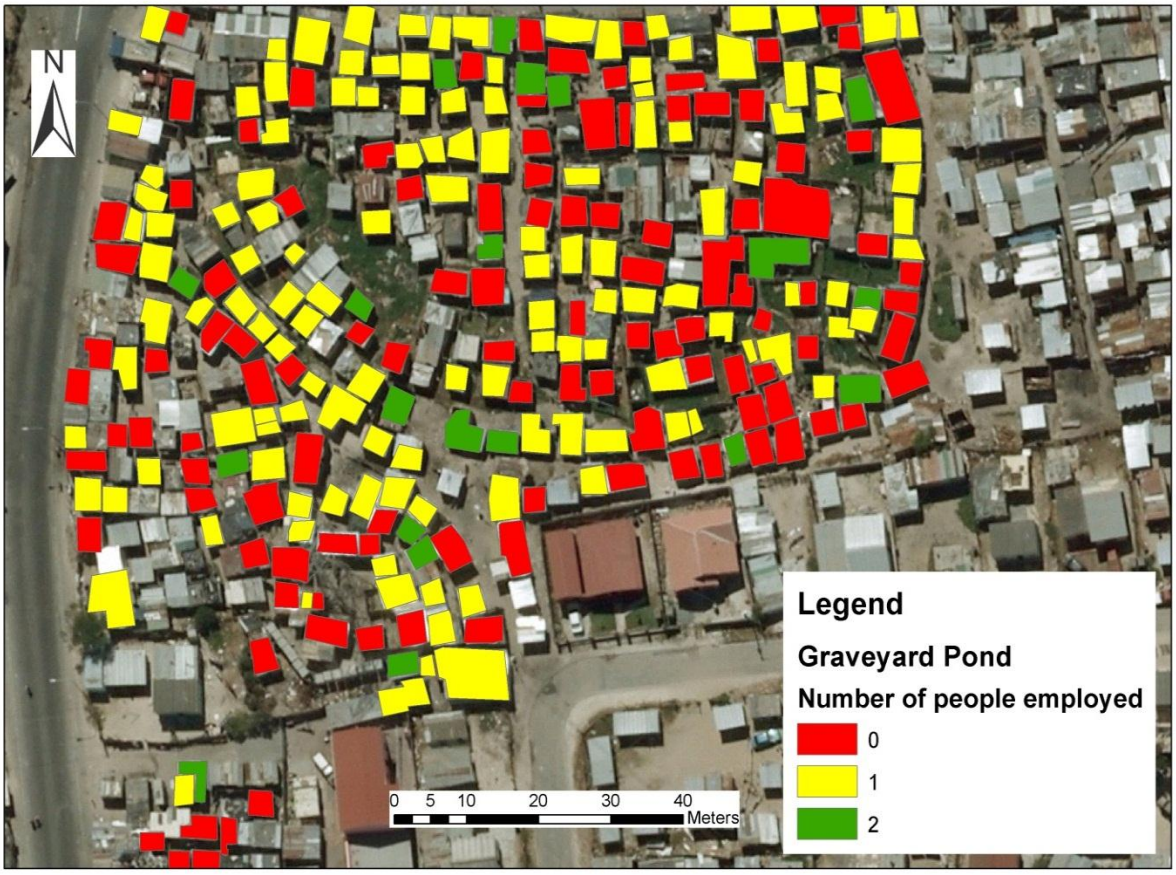

Figure 5.19 Number of people employed in the households of Graveyard Pond

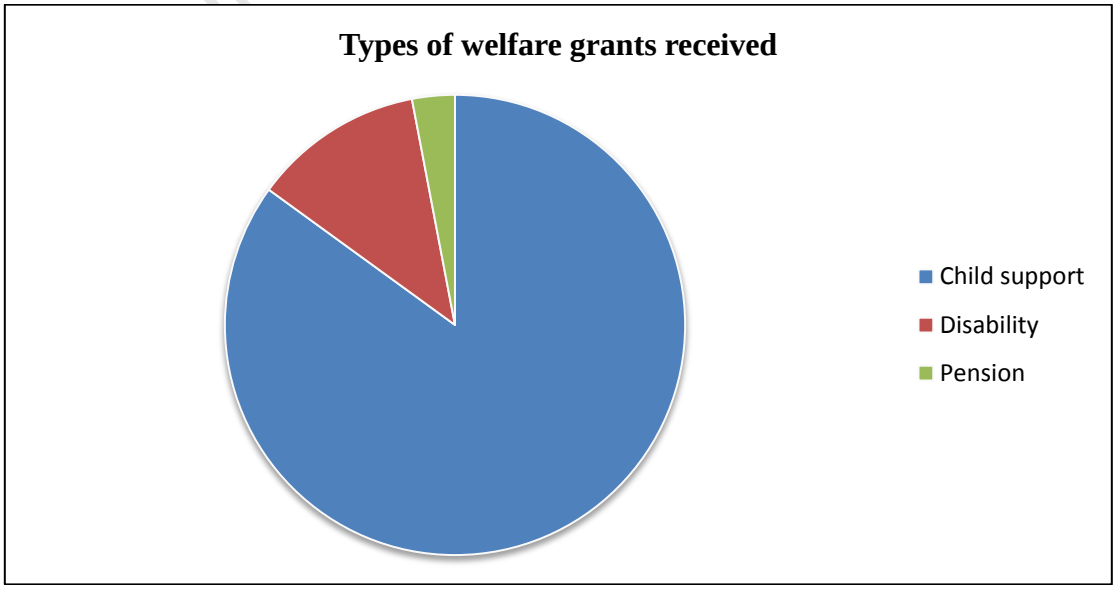

Figure 5.20 Types of welfare grants received in Graveyard Pond

TERM	DESCRIPTION
FE&G	Full-time/Self Employment and receiving a Grant
FE	Full-time Employment
PE&G	Part-time Employment and Grant
PE	Part-time Employment
UE&G	Unemployed and receiving a Grant
UE	Unemployed and not receiving a Grant

Table 5.10 Legend of types of income

PAIRWISE COMPARISON MATRIX						
Criteria	FE&G	FE	PE&G	PE	UE&G	UE
FE&G	1.000	2.000	3.000	5.000	5.000	6.000
FE	0.500	1.000	3.000	4.000	5.000	6.000
PE&G	0.200	0.200	1.000	2.000	4.000	5.000
PE	0.167	0.250	0.500	1.000	3.000	4.000
UE&G	0.200	0.200	0.250	0.333	1.000	2.000
UE	0.167	0.167	0.200	0.250	0.500	1.000
Sum:	**2.233**	**3.817**	**7.950**	**12.583**	**18.500**	**24.000**

Table 5.11 Pairwise comparison matrix of types of income

Table 5.10 explains the alternative sources of income and Table 5.11 shows the pairwise comparisons between the alternatives. The pairwise comparison matrix was normalised and the relative weights were calculated. Table 5.12 shows the final relative weights. In this table the magnitude of vulnerability is inversely proportional to the associated weight. The consistency of the pairwise comparison was calculated and the consistency ratio was found to be 0.032. The overall value is required to be less than 0.1 and so these weights were adopted. There were six alternatives and the random inconsistency index for six criteria is 1.24 (from Table 2.6).

SOURCES OF INCOME	
Alternatives	**Weights**
Full-time/Self Employment and receiving a Grant	0.381
Full-time Employment	0.274
Part-time Employment and Grant	0.147
Part-time Employment	0.105
Unemployed and receiving a Grant	0.055
Unemployed and not receiving a Grant	0.038
Sum:	**1.000**

Table 5.12 Calculated weights for sources of income

The calculated weights were allocated to the individual households based on their responses. For instance, if a particular household had no form of employment and received no grants, a weight of 0.038 was allocated to that household. The weight was added as an attribute in the same row

as the corresponding shack number of the respondent in the GIS. Once a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability based on income (Figure 5.22).

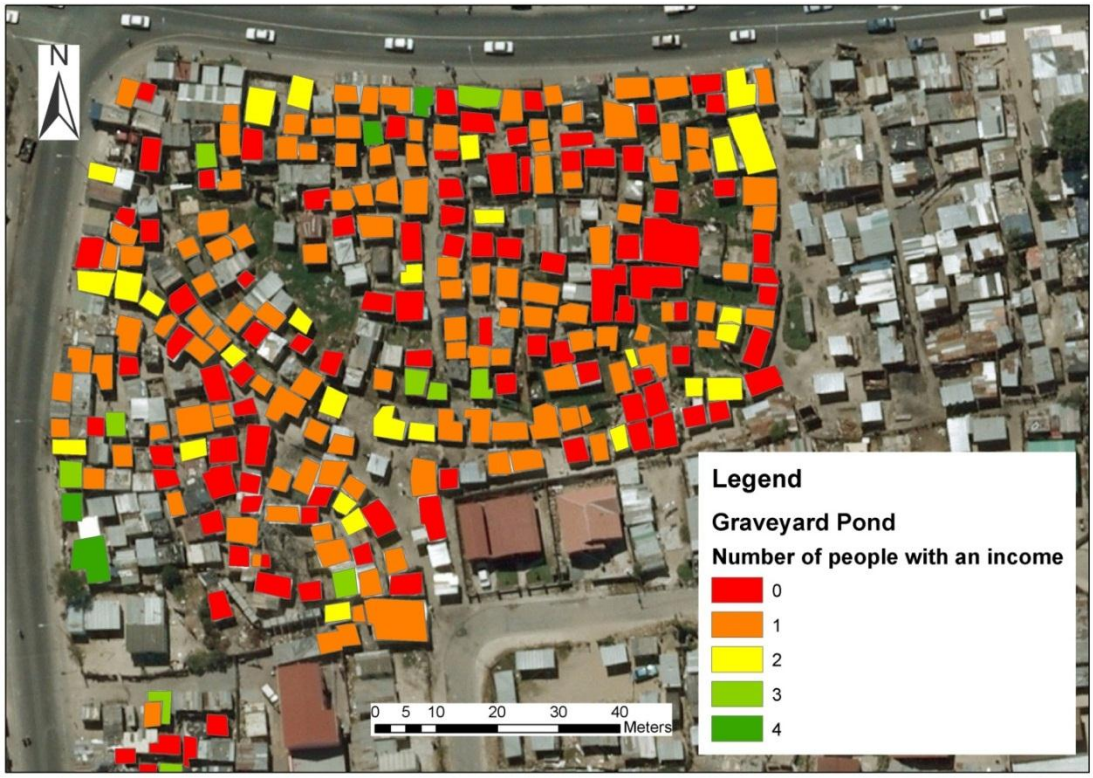

Figure 5.21 Number of people with an income in the households of Graveyard Pond

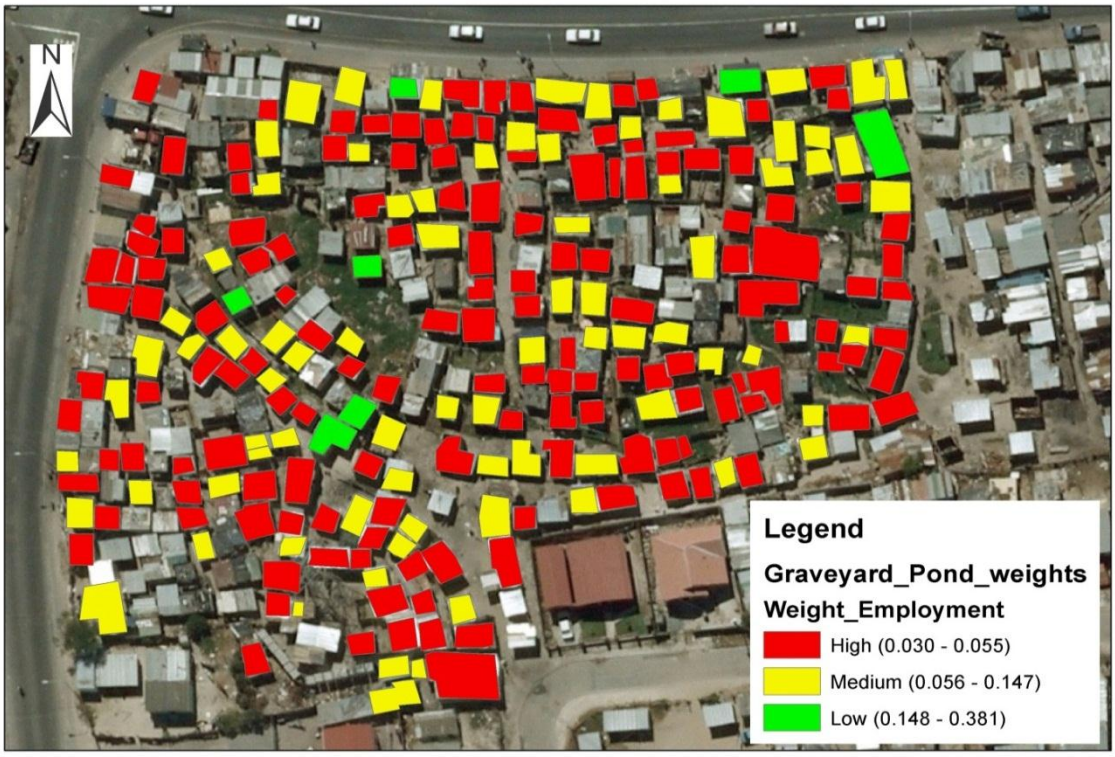

Figure 5.22 Map showing vulnerability based on type of income

A raster dataset depicting vulnerability based on income was also created by interpolating the weights. Again, the natural neighbour method of interpolation was applied to the data to create the raster map (Figure 5.23).

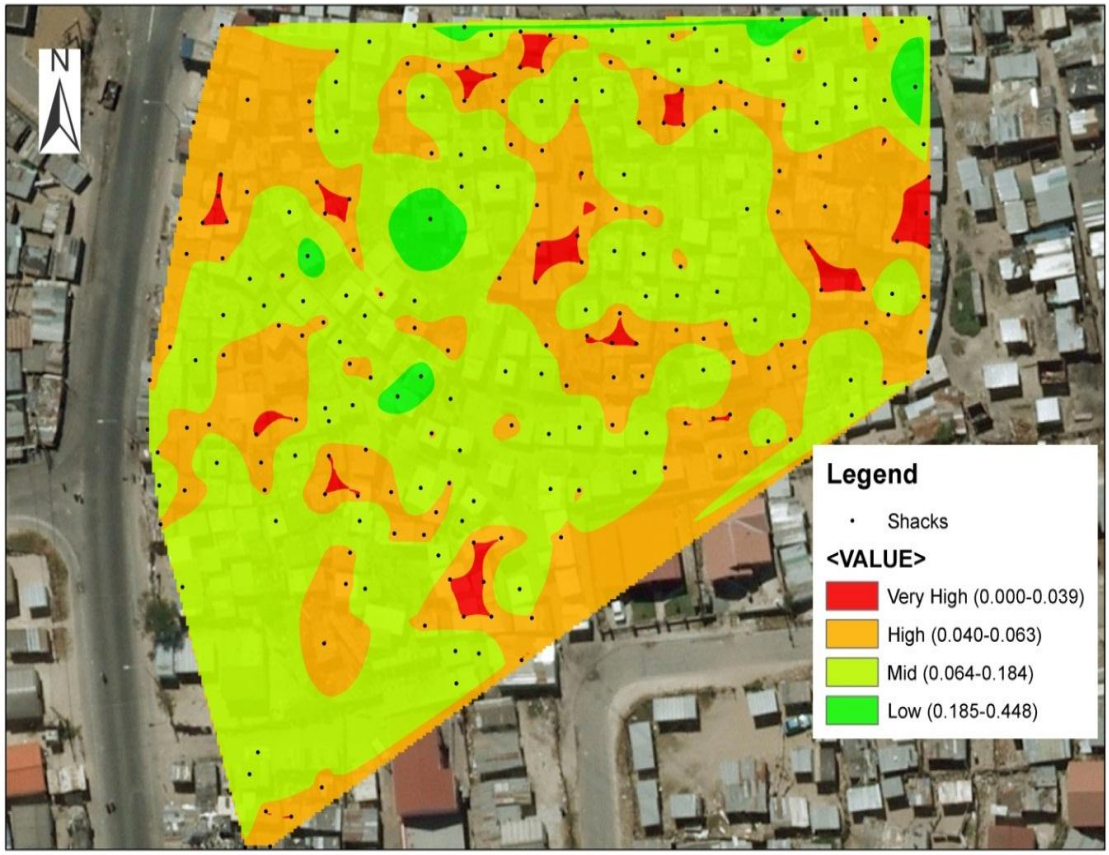

Figure 5.23 Raster map showing vulnerability based on income levels

The results of data analysis from Graveyard Pond have been presented in the foregoing sections. The aim of the analysis was to establish the variance in risk in Graveyard Pond, as well as any dynamics amplifying vulnerability. The results presented here have included the relevant statistics from the questionnaire, the relevant questionnaire response maps, the weight calculations and the final risk maps. The results are based on four main factors that, based on discussions with residents and community leaders, were found to influence the magnitude of vulnerability in the households of Graveyard Pond. The next section presents results of the average of all the indicators for each household.

5.1.5 Average Weights

An additional map was created depicting the average weights from all four vulnerability indicators (Figure 5.24). Subsequently, a raster map was created from the average weights (Figure 5.25).

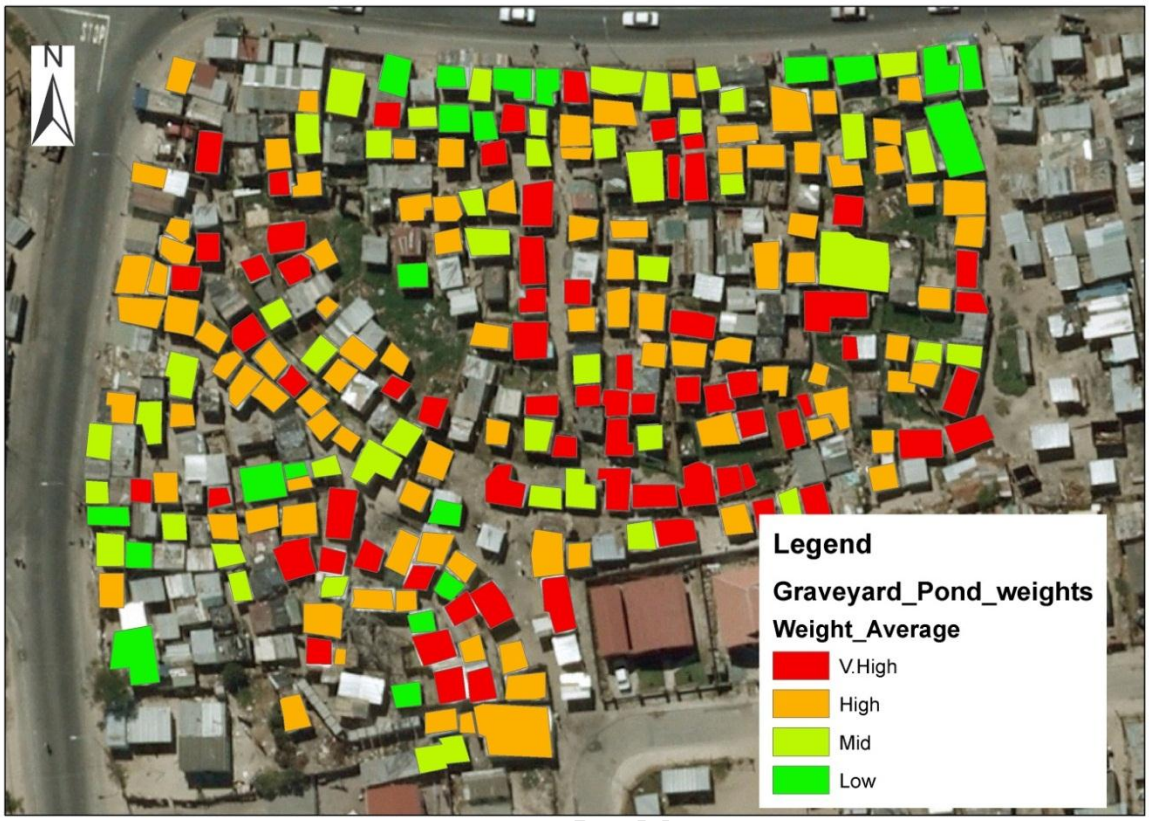

Figure 5.24 Map showing the average of the weights for each household

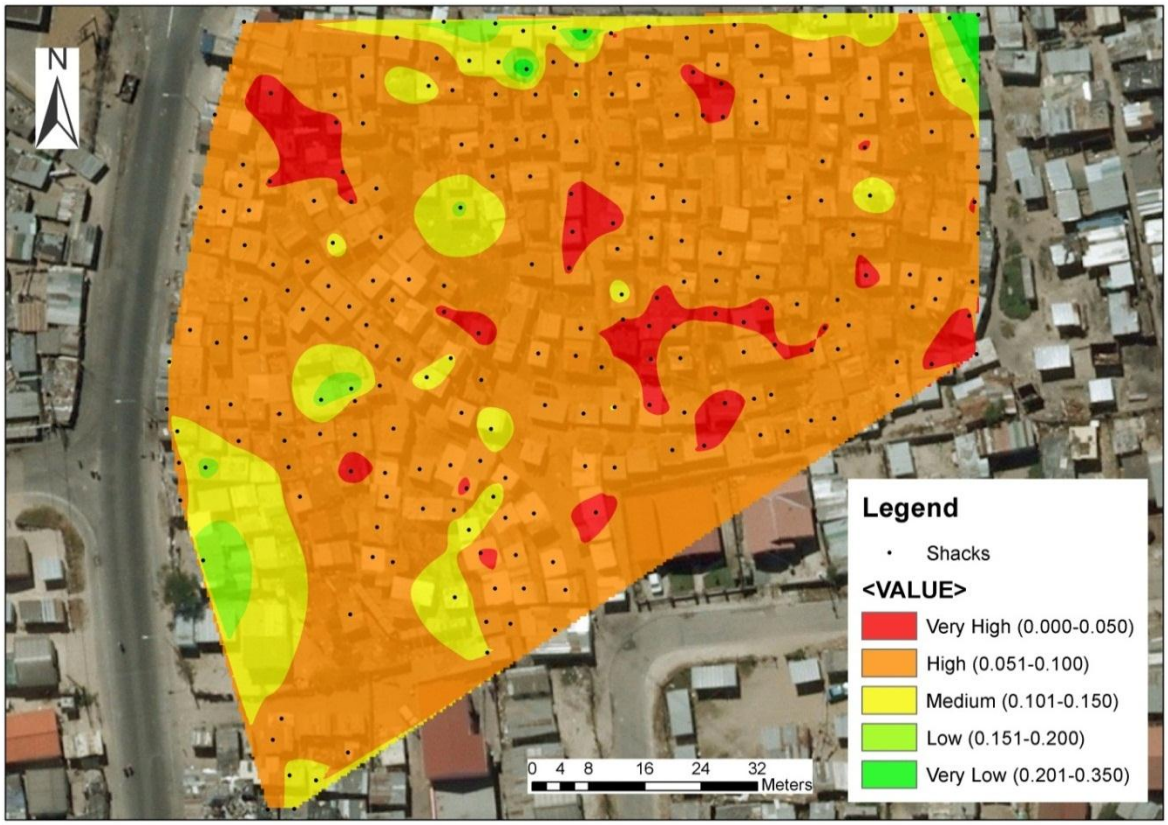

Figure 5.25 Raster map showing vulnerability based on an average of all the weights

The following section presents the results from Europe informal settlement.

5.2 Europe

This section presents results showing the variance in risk in Europe informal settlement in Gugulethu. The results of the analysis presented here consist of the statistics from the questionnaire, the questionnaire response maps, the weight calculations and the final risk maps. The objective of this chapter is to expose the variance of risk within Europe and identify any unforeseen dynamics that might amplify risk in the settlement. Based on the questionnaire and on the discussions with the SDI officials, the four main factors assessed in Graveyard Pond have been applied here to assess the magnitude of vulnerability in the households of Europe.

5.2.1 Exposure to Hazards

It was found that 81% of the residents in Europe had experienced flooding. The responses to the questionnaire revealed similar forms of flooding to those in Graveyard Pond. It was found that flooding was also attributed to leaking roofs, an upsurge of ground water and flooding by run-off water. Sixty percent of the respondents who had suffered flooding cited flooding from an upsurge of ground water. Although in Graveyard Pond, the respondents only highlighted the most significant forms of flooding, the respondents in Europe reported some combinations in the forms of flooding. Figure 5.26 shows the various forms of flooding in Europe.

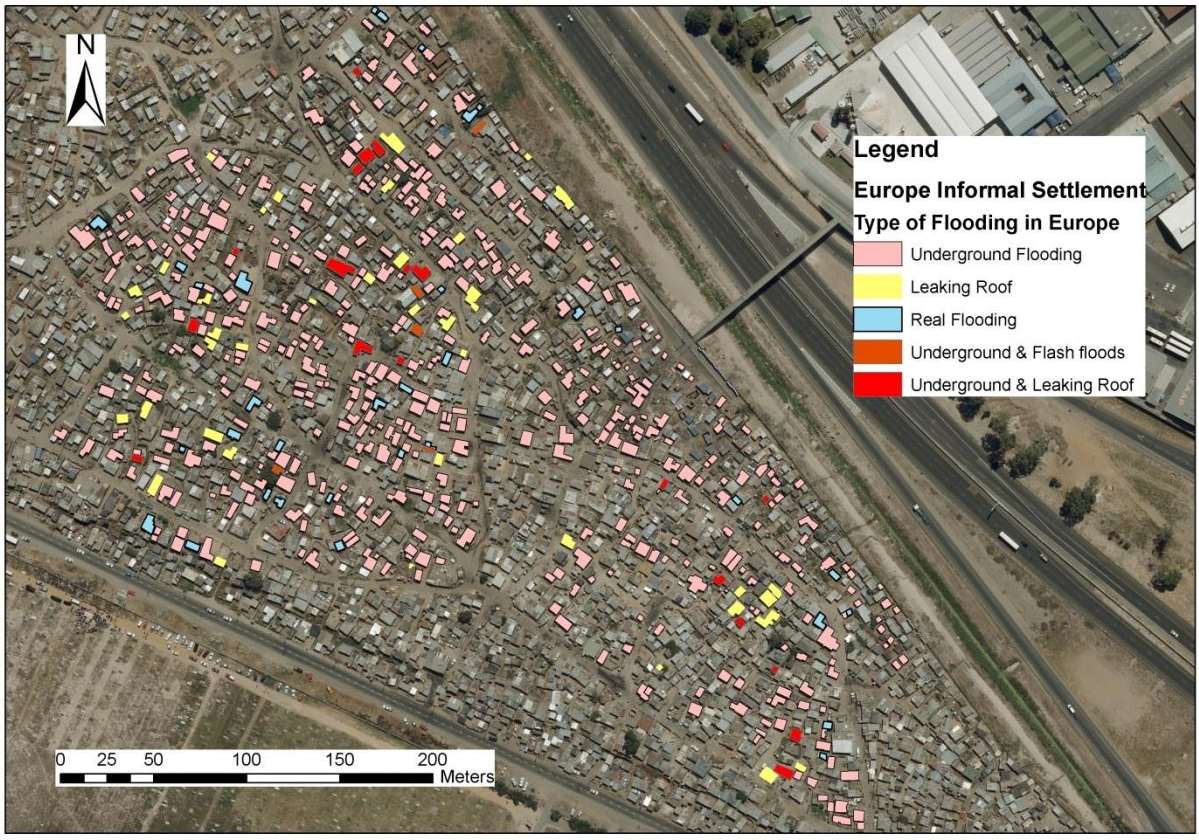

Figure 5.26 Types of flooding experienced in Europe

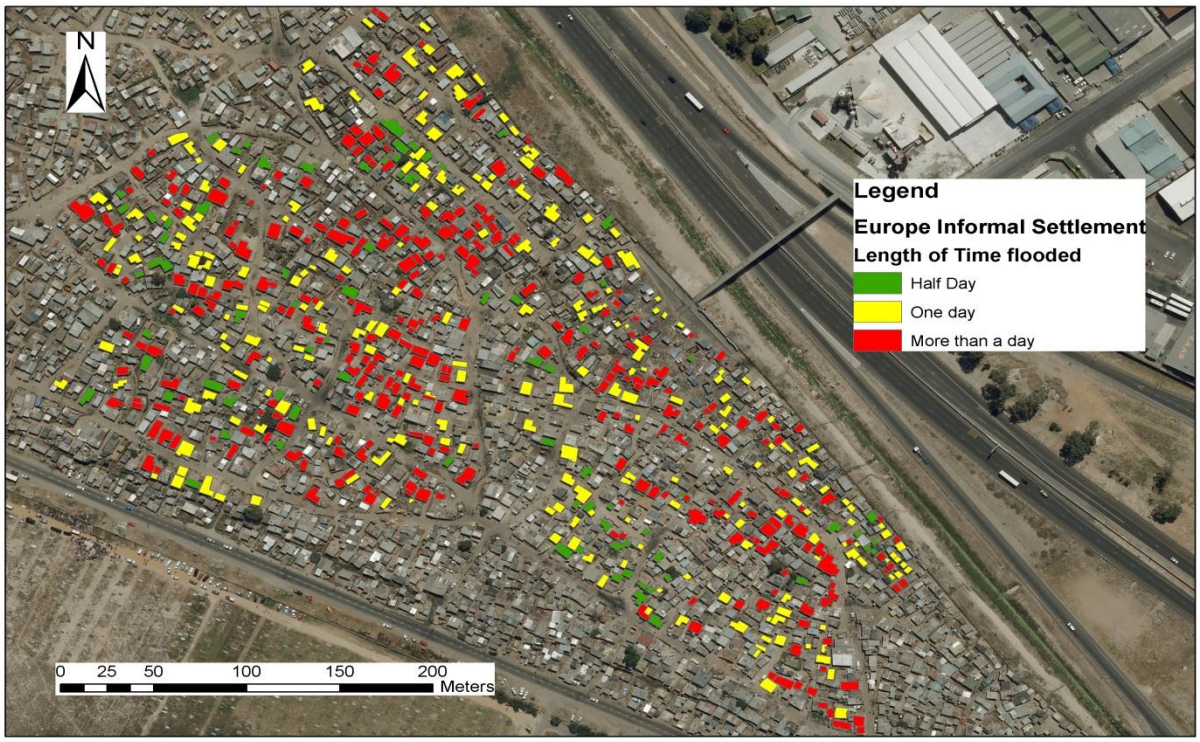

Figure 5.27 Length of time that households remain flooded

In addition, maps were also created to show the length of time for which a particular area remained flooded (Figure 5.27).

It was also found that some residents had been affected by fires. An analysis of the responses showed that 267 households, comprising 19% of the population, had experienced fires. The frequency of fires was significantly less than that of flooding. Figure 5.26 shows the locations of respondents who had been affected by fires.

Based on the findings for flooding and fire, the following alternatives were generated for the types of hazard exposure:

- No exposure to hazards;
- Exposure to fire only;
- Flooding because of a leaking roof;
- Flooding caused by rising water;
- Flooding caused by flash floods;
- Flooding from both flash floods and leaking roof;
- Flooding from flash floods and rising water;
- Flooding from leaking a leaking roof and rising water; and
- Exposure to both flooding and fire.

These alternatives were ranked in order of preference through discussions with the SDI officials. If an alternative was ranked higher than another, it meant that that alternative was perceived to

have less of a negative consequence than the other. An MCE was then employed to calculate the relative consequences of the alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The full set of calculations is located in Appendix G.

Figure 5.28 Incidences of fire in Europe

The relative weights were calculated based on PCM and the comparison was found to have a consistency ratio of 0.048. Since the consistency ratio was significantly less than the value of 0.1, the relative weights were endorsed. Table 5.13 shows the final relative weights. In this Table, the higher the weight value, the lower the associated vulnerability.

EXPOSURE TO HAZARDS	
Alternatives	**Weights**
No Disaster	0.309
Flash Floods	0.205
Only Fire	0.160
Leaking Roof	0.110
Rising Water	0.077
Flash Floods & Leaking Roof	0.055
Leaking Roof & Rising Water	0.038
Flash Floods & Rising Water	0.026
Flood and Fire	0.019
Sum:	**1.000**

Table 5.13 Legend of types of exposure to hazards in Europe

The calculated weights were subsequently allocated to the individual households based on their responses. For instance, if a particular household experienced both fire and floods, a weight of

0.019 was allocated to that household. The weight was added as an attribute in the same row as the corresponding shack number in the GIS. After a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.29).

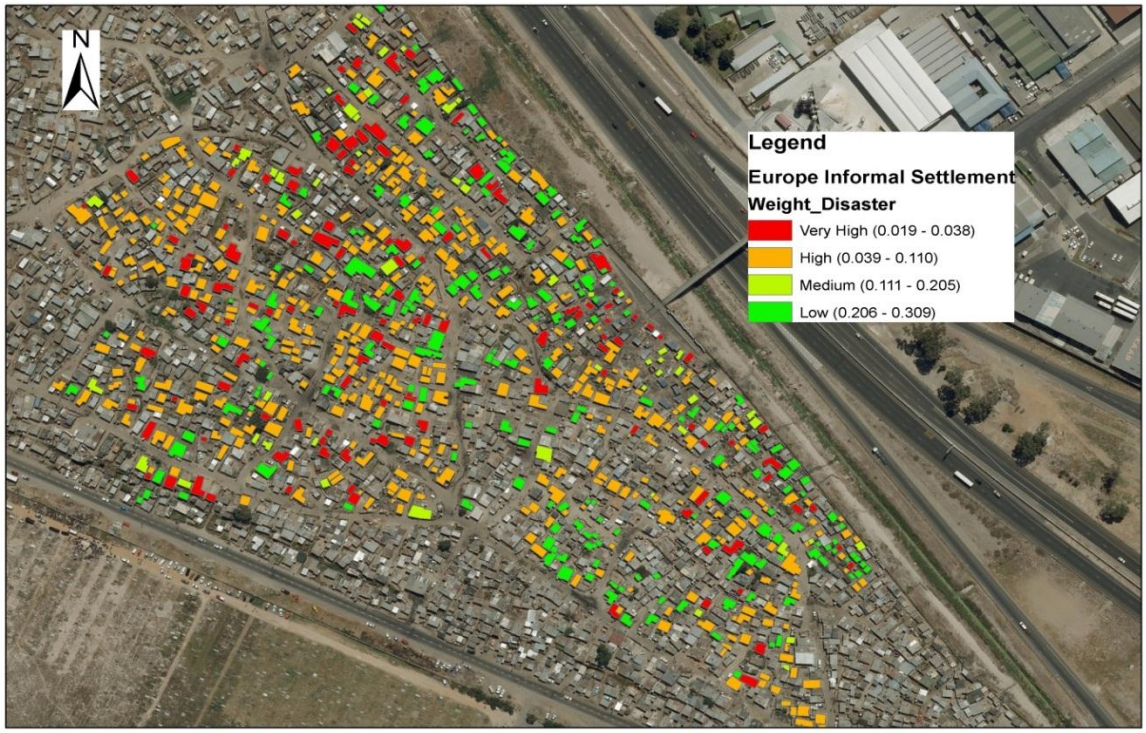

Figure 5.29 Map showing vulnerability based on type of exposure to a hazard

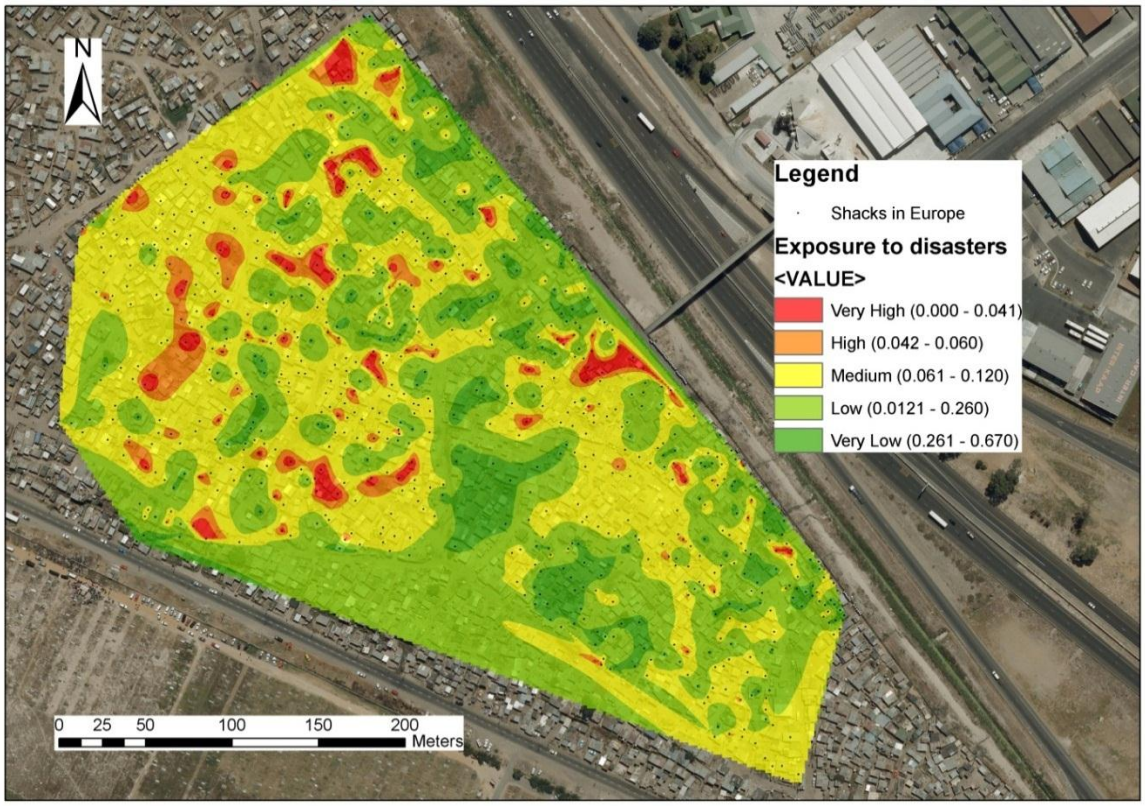

Figure 5.30 Raster map showing vulnerability based on type of exposure to a hazard

A raster dataset denoting types of exposure was created by interpolating the weights using the natural neighbour method of interpolation (Figure 5.30).

5.2.2 Methods of Mitigation

It was found that the residents in Europe had developed a number of ways of mitigating the consequences of the hazards in Europe. The study on mitigation methods focussed on flooding because of the high frequency of floods relative to fires. The following main responses to flooding were extracted from the questionnaires:

- Digging of trenches;
- Raising of shacks using wood or stones;
- Use of sandbags;
- Relocation; and
- Use of concrete floors.

The most popular method is the digging of trenches. It was found that some households employed more than one method and the combinations have also been included in Figure 5.31.

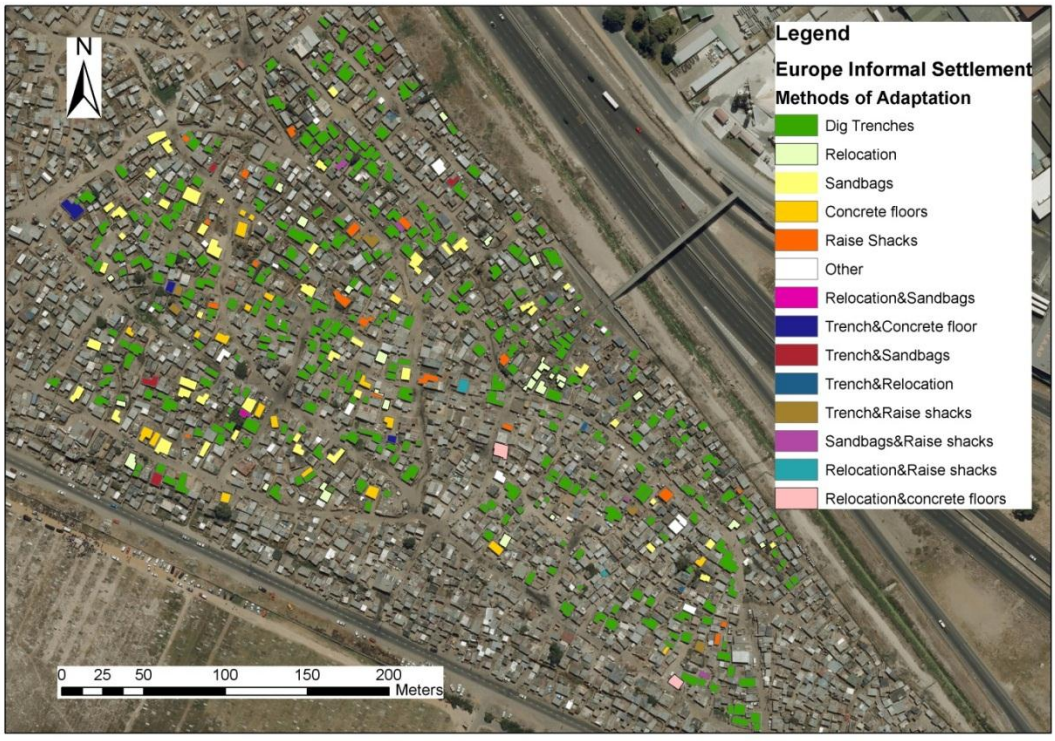

Figure 5.31 Map showing the geographic distribution of methods of flood mitigation

These alternatives were ranked in order of preference through discussions with the SDI officials. Again, if an alternative was ranked higher than another, it meant that that alternative was perceived to have less of a negative consequence than the other. An MCE was then employed to calculate the relative consequences of the alternatives. A pairwise comparison was carried out

between each of the alternatives in order to generate a set of preference weights. The full set of calculations can be found in Appendix H. Table 5.14 shows the calculated weights.

METHODS OF MITIGATION	
Alternatives	**Weights**
Flash Floods & Dig trenches	0.085
Flash Floods & Raise shacks	0.085
Flash Floods & Sand bags	0.064
Flash Floods & Relocation	0.056
Flash Floods & Concrete floors	0.050
Leaking Roof & Relocation	0.081
Leaking Roof & Sand bags	0.074
Leaking Roof & Raise shacks	0.060
Leaking Roof & Concrete floors	0.060
Leaking Roof & Dig trenches	0.051
Rising water & Raise shacks	0.069
Rising water & Concrete floors	0.069
Rising water & Sand bags	0.060
Rising water & Relocation	0.087
Rising water & Dig trenches	0.050
Sum:	1.000

Table 5.14 Vulnerability weights for methods of mitigation.

After the weight calculations, the relative weights were found to have a consistency ratio of 0.054. The consistency ratio was significantly less than the threshold value of 0.1 and the relative weights were accepted. Table 5.14 shows the final relative weights. In Table 5.14, the higher the weight value, the more effective it is in reducing vulnerability to a particular form of exposure.

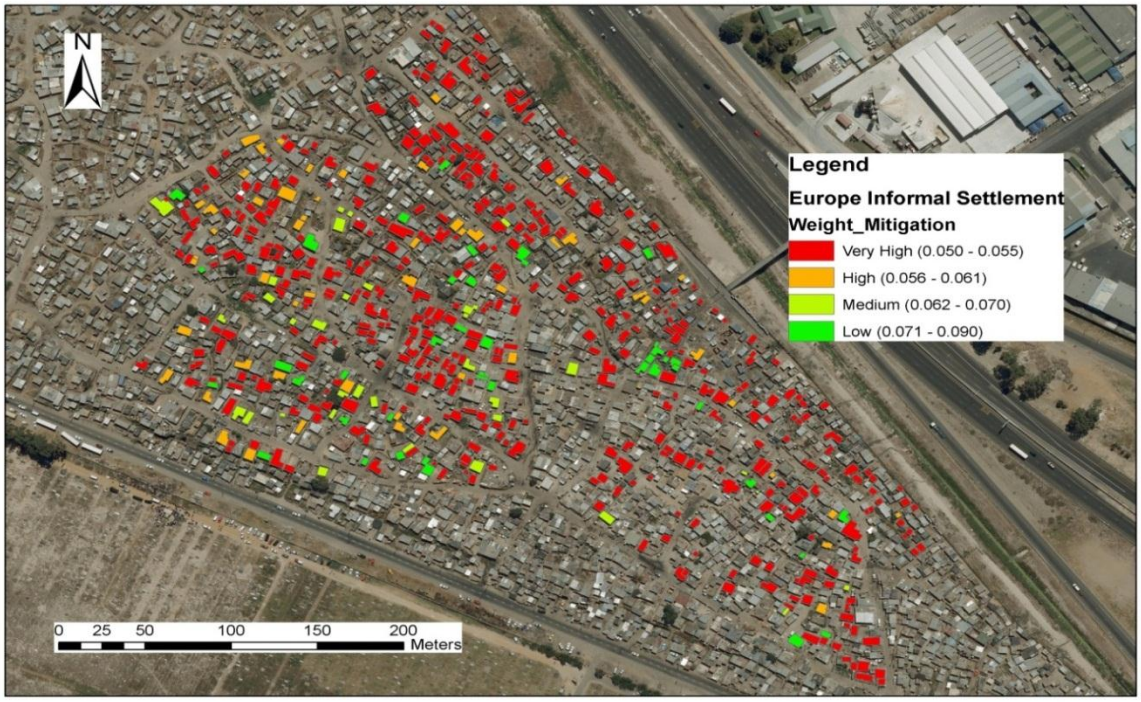

Figure 5.32 Map showing vulnerability based on methods of mitigation

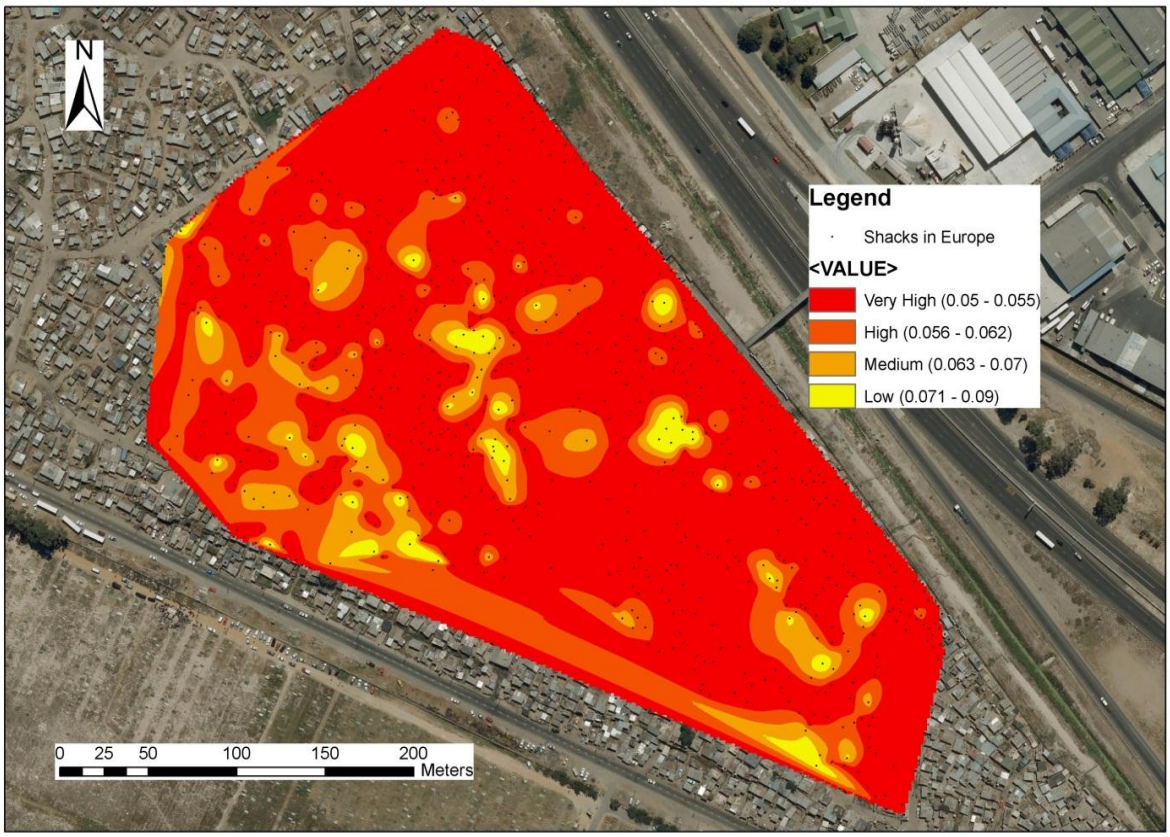

Figure 5.33 Raster map showing vulnerability based on efficiency of mitigation methods

The weights were allocated to the individual households based on their responses. For instance, if a particular household experienced flooding from flash floods and opted to use concrete floors, a weight of 0.050 was allocated to that household. The weight was added as an attribute in the same row as the corresponding shack number in the GIS. Once a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.32).

A raster dataset denoting types of exposure was also created by interpolating the weights. The interpolation was based on the natural neighbour method of interpolation. Figure 5.33 shows the resulting map. The next section will show the results of analysis relating to the issues of sanitation and disease.

5.2.3 Sanitation and Incidence of Diseases

This section will explore the role of sanitation and diseases in amplifying vulnerability to flooding. Discussions with the SDI official revealed that there are 40 chemical toilets and 10 pit latrines in Europe informal settlement. The questionnaires revealed that only 4% of the population use these toilets, whilst 96% of the population uses bucket toilets. In addition, a number of diseases are prevalent in Europe. Figure 5.34 shows the various flood-related diseases experienced in the settlement. Respiratory diseases were found to be most common.

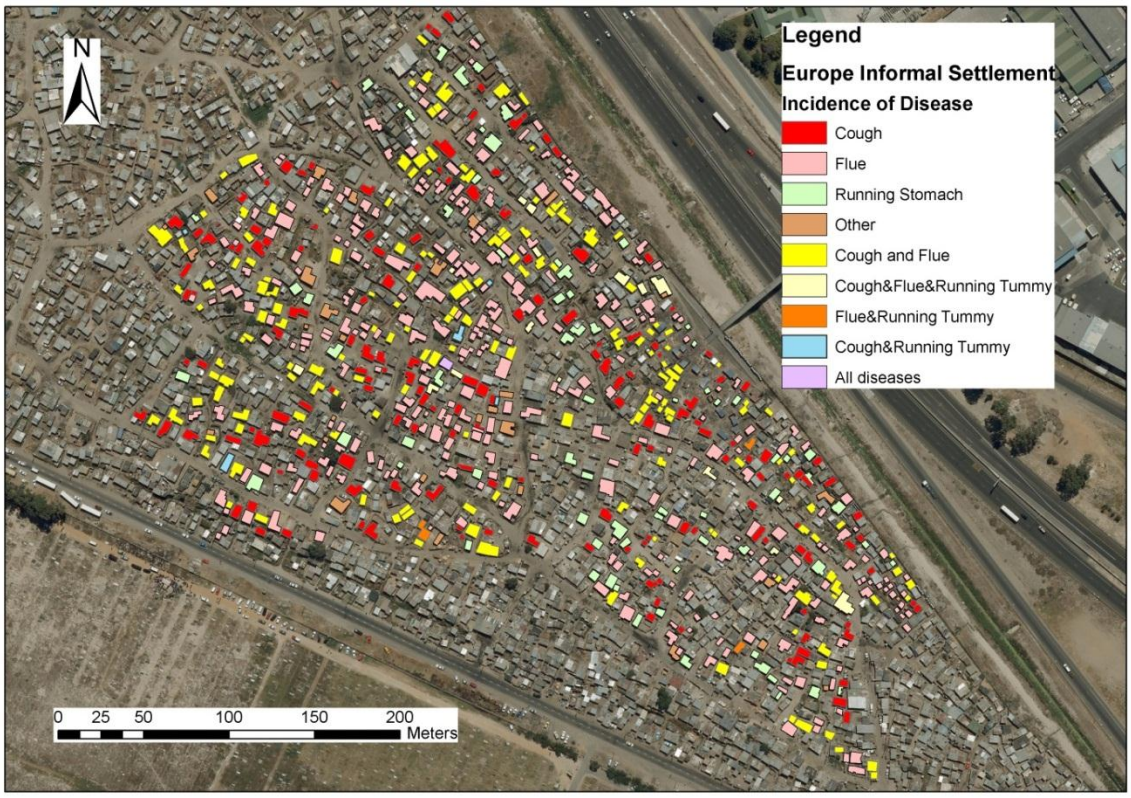

Figure 5.34 Incidence of diseases in Europe

Based on the responses in the questionnaire on diseases in Europe, the following alternatives were derived:

- No incidence of diseases;
- Running tummy;
- Respiratory diseases;
- Other diseases e.g. Rash;
- Running tummy and respiratory diseases;
- Other diseases and respiratory diseases; and
- More than two diseases

Subsequently, these alternatives were ranked in order of preference based on discussions with the liaisons at SDI. The logic behind the ranking was that, if an alternative was ranked higher than another, it meant that that alternative was perceived to have less of a negative consequence than the other. An MCE based on PCM was then employed to calculate the relative consequences of the alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The full set of calculations can be found in Appendix I.

Table 5.15 shows the calculated weights. The magnitude of vulnerability as a result of the disease is inversely proportional to the associated weight. Consistency ratio calculations were used to check the precisions of the pairwise comparisons. The overall value is supposed to be

less than 0.1 and this comparison yielded a value of 0.054, hence the calculated weights were accepted. There were twelve criteria and the random inconsistency index for twelve criteria is 1.41 (from Table 2.6).

INCIDENCE OF DISEASE	
Alternatives	**Weights**
No Disease	0.233
Other (e.g. Rash etc.)	0.192
Running Tummy	0.154
Cough	0.105
Flu	0.077
Other and Running Tummy	0.062
Other and Cough	0.054
Other and Flu	0.040
Running Tummy and Cough	0.031
Running Tummy and Flu	0.022
Flu and Cough	0.017
More than two diseases	0.013
Sum:	**1.000**

Table 5.15 Calculated weights for contribution of disease to vulnerability

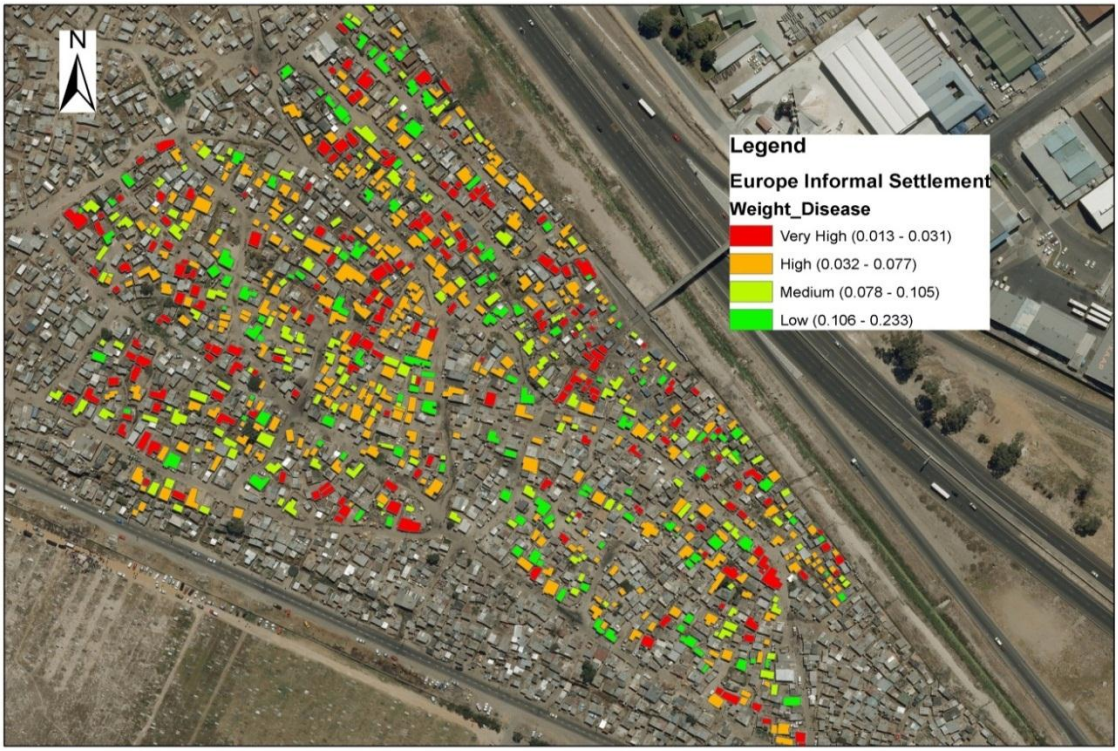

Figure 5.35 Map showing vulnerability based on prevalence of disease

The weights were then allocated to the individual households based on their responses. For example, if a particular household experienced only coughs, a weight of 0.105 was allocated to that household. The weight was added as an attribute in the same row as the corresponding

shack number of the respondent in the GIS. Once a weight had been allocated to each shack, a map was created to show the geographical distribution of the vulnerability (Figure 5.35)

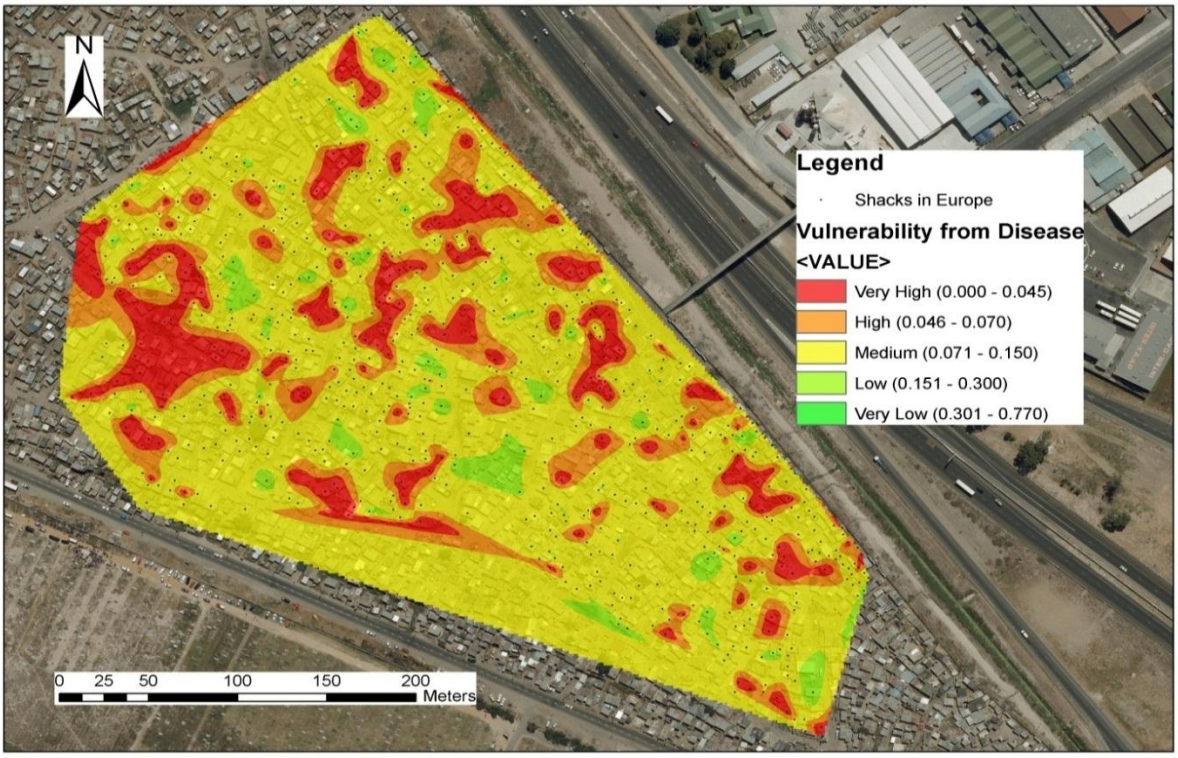

Figure 5.36 Raster map showing vulnerability based on prevalence of disease

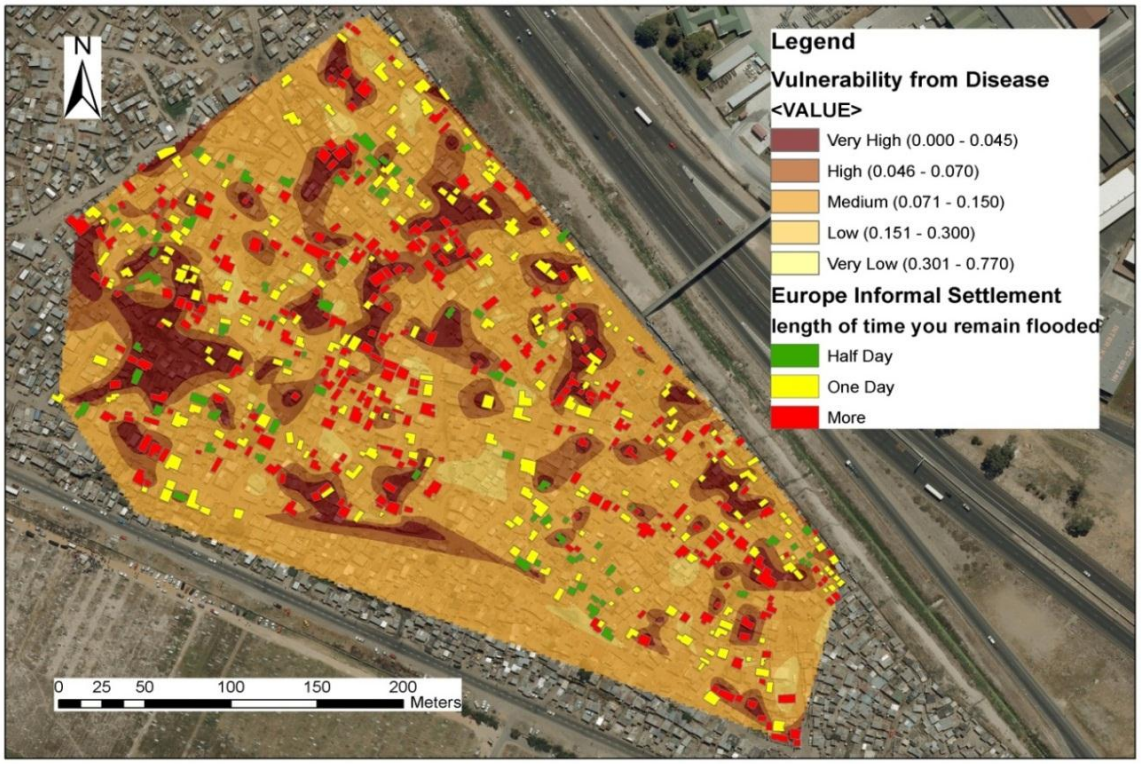

Figure 5.37 Map showing vulnerability based on prevalence of disease relative to length of time households remain flooded

A raster dataset denoting the role of disease in amplifying vulnerability was also created by interpolating the weights. The natural neighbour method of interpolation was applied to the weights to create the raster map denoting the areas that were most influenced by disease (Figure 5.36).

An additional map was created, showing the relationship between the length of time for which dwellings remain flooded and vulnerability from disease (Figure 5.37).

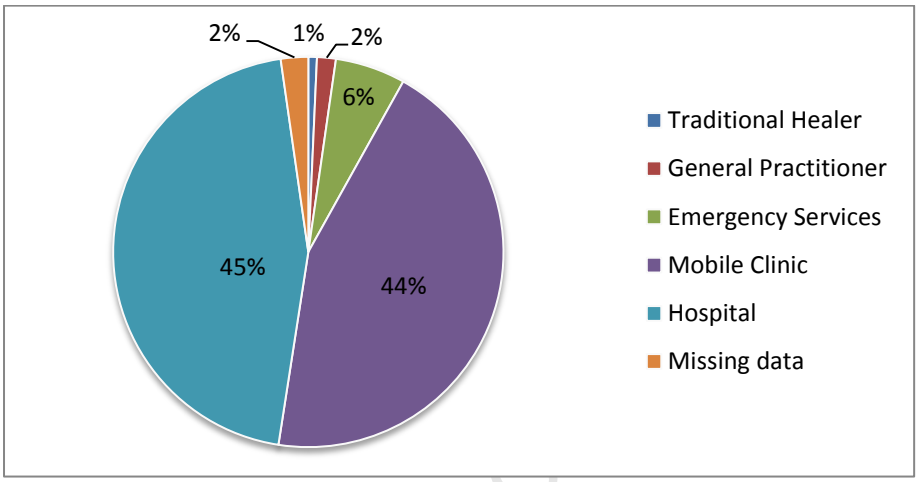

Figure 5.38 Access to health services by households in Europe

It was found that households accessed different facilities for health services. Figure 5.38 shows the services accesed by households in Europe. From this it is clear that most households have access to public hospitals and mobile clinics.

The following section investigates the role of income in reducing vulnerability.

5.2.4 Household Income

It was found that 30% of the households interviewed in Europe had at least one person with some form of employment. Of the people who reported being employed, most have full-time jobs (Table 5.16). Figure 5.39 shows the number of people employed in these households.

Form of employment	Percentage (%)
Self employed	12
Part-time	39
Full-time	49
Total	**100**

Table 5.16 Forms of employment in Europe

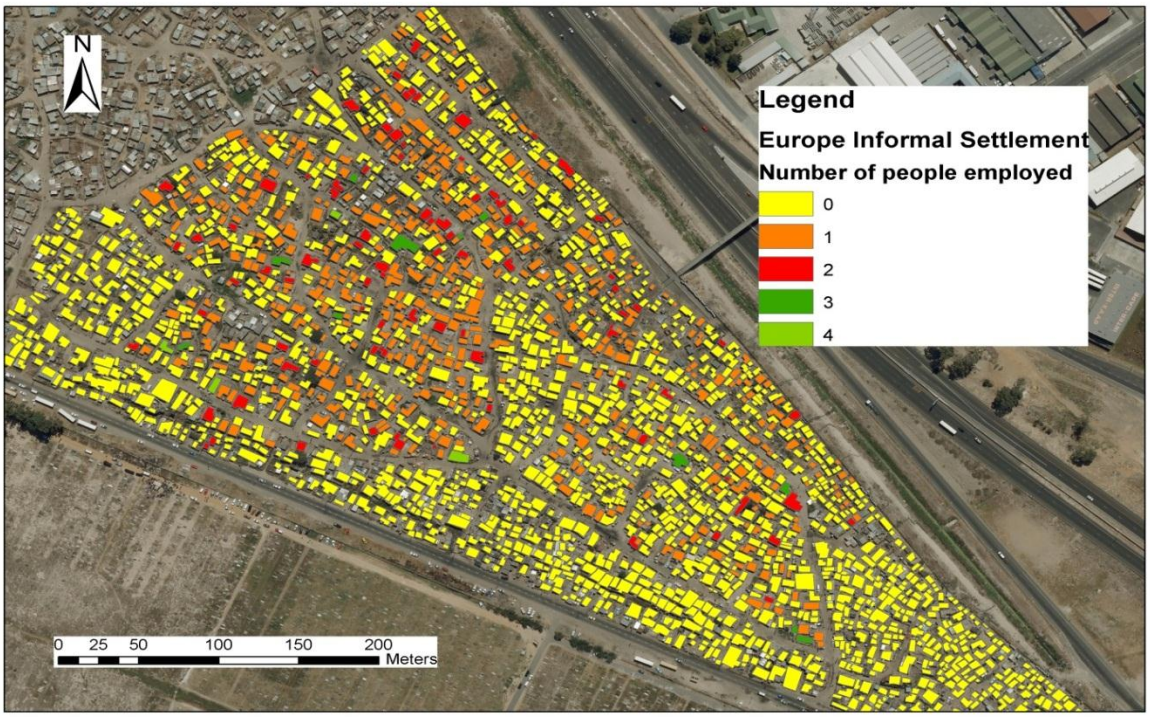

Figure 5.39 Number of people employed in households in Europe

In addition, 25% of the households in Europe receive welfare grants from the government. Fifty percent of these households rely solely on welfare grants as a source of income. It was found that the majority of these grants are child support grants. Table 5.17 shows the types of welfare grants being accessed in Europe.

Type of Grant	**Frequency**	**Percentage of total respondents (%)**
Disability	83	1.88
Child Support	961	21.78
Pension	39	0.88
Refugee	6	0.14
Other	21	0.48
Total recipients	1110	25.15
Total population	**4413**	

Table 5.17 Welfare grants accessed in Europe

An analysis of the responses in the questionnaire showed that the various alternative forms of income were as follows:

- Full-time or self-employment;
- Full-time or self-employment and welfare grants;
- Part-time employment and welfare grants;
- Part-time employment;
- Only welfare grants; and
- No income at all.

These alternatives were ranked in conjunction with the SDI liaisons. The reasoning in the ranking was that, if an alternative was ranked higher than another, it meant that that alternative was perceived to reduce vulnerability more than the other. An MCE based on PCM was employed to calculate the relative consequences of the alternatives. A pairwise comparison was carried out between each of the alternatives in order to generate a set of preference weights. The full set of calculations can be found in Appendix J.

Table 5.18 shows the final relative weights. The magnitude of vulnerability is inversely proportional to the associated weight. The precision of the pairwise comparison was calculated and the consistency ratio was found to be 0.032. Since it was less than 0.1, the weights were adopted. There were six alternatives and the random inconsistency index for six criteria is 1.24 (from Table 2.6).

SOURCES OF INCOME	
Alternatives	**Weights**
Full-time/Self Employment and receiving a Grant	0.381
Full-time/ Self Employment	0.274
Part-time Employment and Grant	0.147
Part-time Employment	0.105
Unemployed and receiving a Grant	0.055
Unemployed and not receiving a Grant	0.038
Sum:	**1.000**

Table 5.18 Calculated weights for sources of income

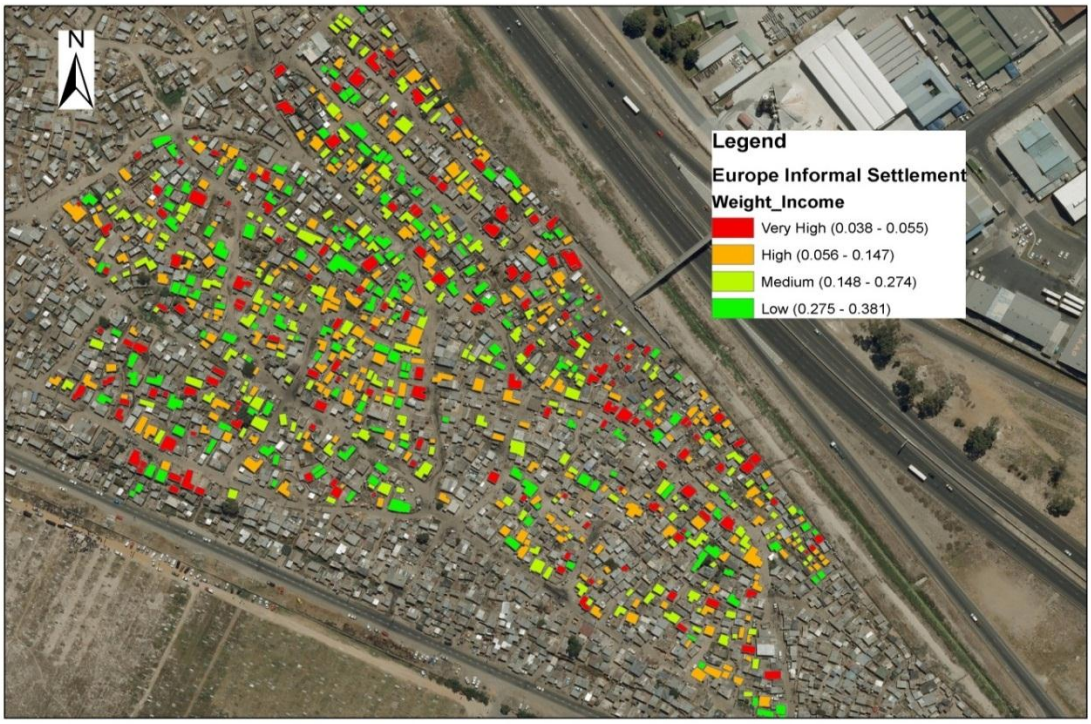

Figure 5.40 Map showing vulnerability based on type of income of households in Europe

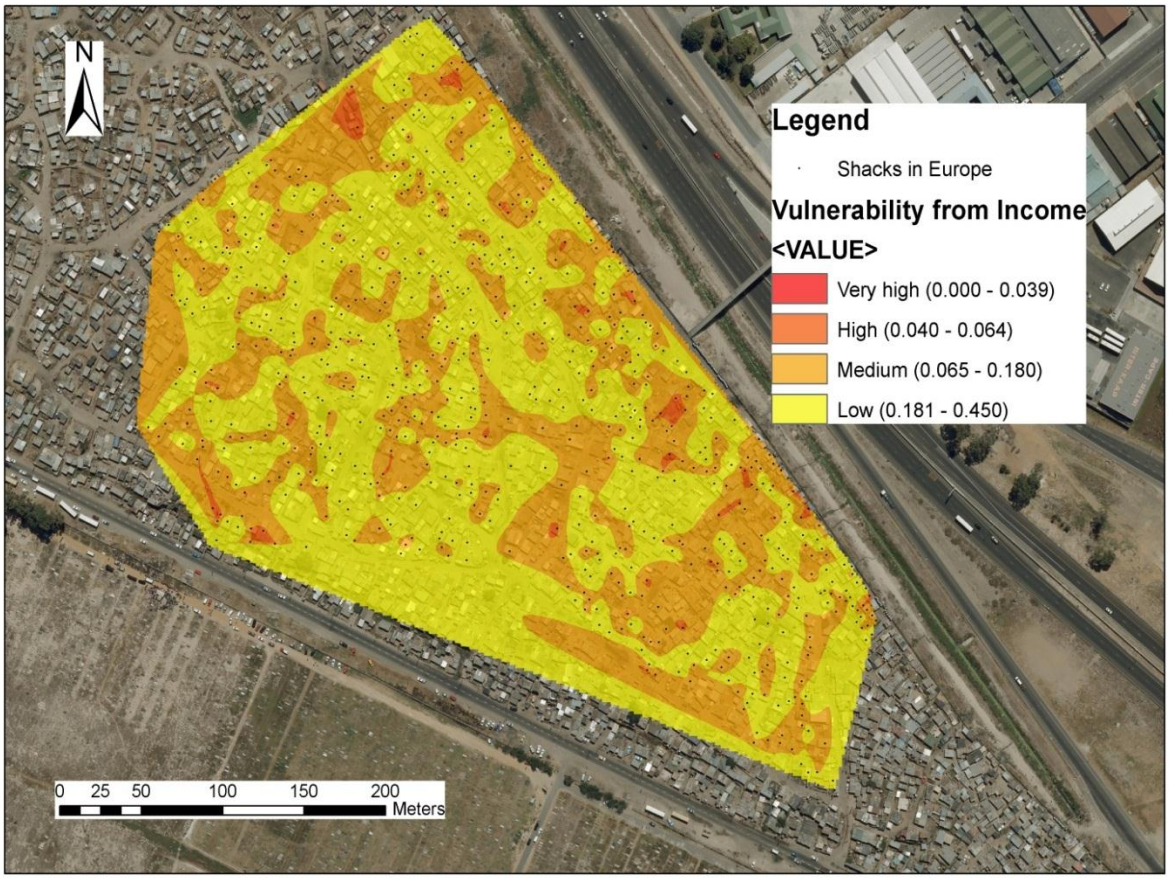

Figure 5.41 Raster map showing vulnerability based on income levels

The weights were then allocated to the individual households based on their responses. For instance, if a particular household had someone with part-time employment and no welfare grant, a weight of 0.105 was allocated to that household. The weight was added as an attribute in the same row as the corresponding shack number of the respondent in the GIS. Subsequently, a map was created to show the geographical distribution of the vulnerability based on income (Figure 5.40).

In addition, a raster dataset of vulnerability based on income was also created by interpolating the weights. Again, the natural neighbour method of interpolation was applied to the data to create the raster map (Figure 5.41).

5.2.5 Average Weights

An additional map was created depicting the average weights from all four vulnerability indicators (Figure 5.42). Subsequently, a raster map was created from the average weights (Figure 5.43).

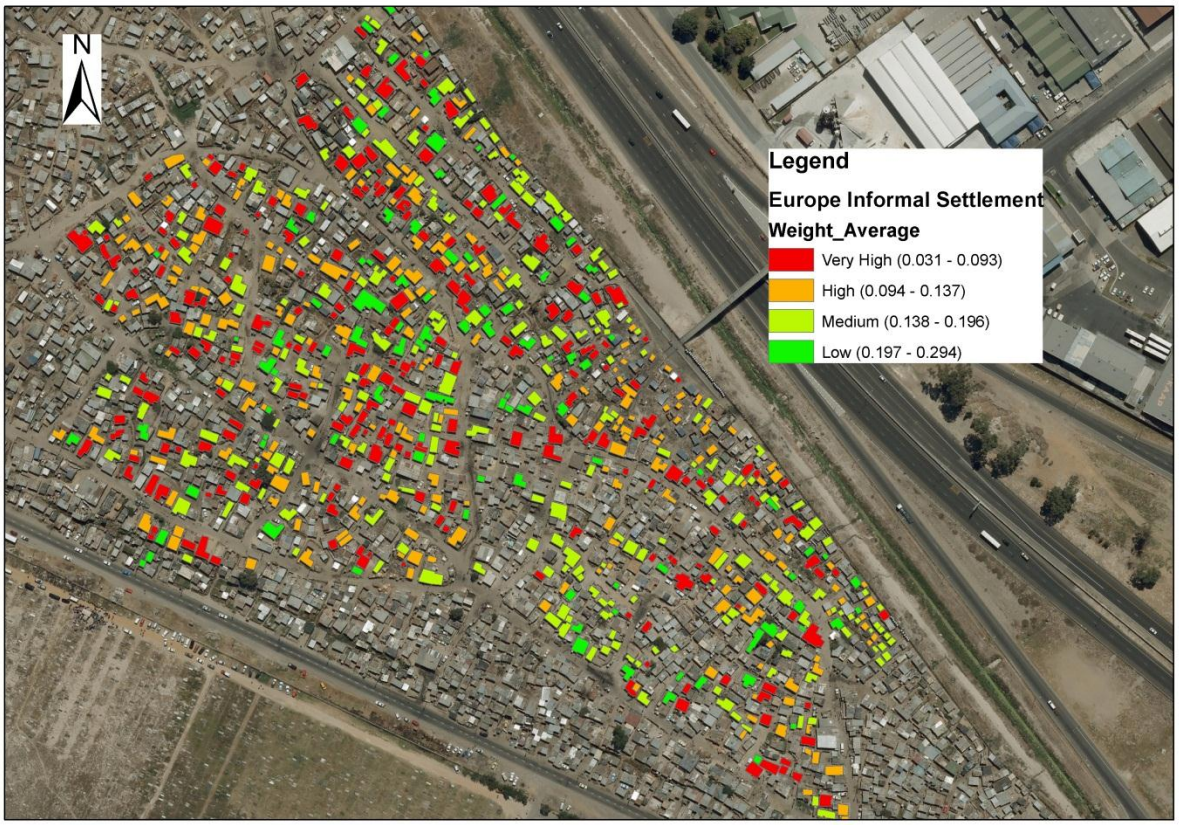

Figure 5.42 Map showing the average of the weights for each household

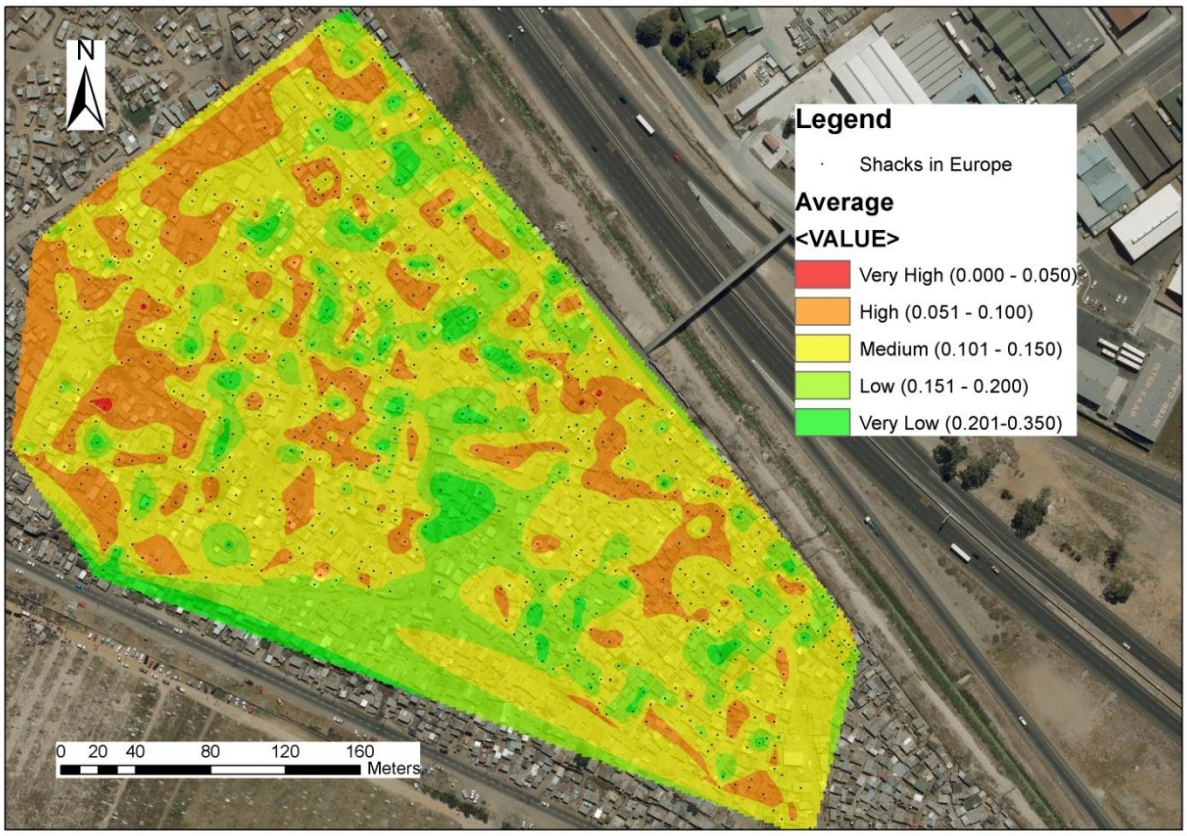

Figure 5.43 Raster map showing vulnerability based on an average of all the weights

5.3 Spatial Autocorrelation

The foregoing sections have presented a number of maps that were created after interpolation of data. The underlying logic is that the closer spatial units are to each other, the higher the likelihood of similarity. In the context of risk assessment, one would expect shacks in close proximity to each other to manifest similar levels of vulnerability. However, it is important to verify that the data being interpolated is actually similar. Hence, a spatial autocorrelation using Moran's *I* analysis, was carried out on the risk weights of each criterion, for all the households in Graveyard Pond and Europe. A positive Moran's *I* index indicates similarity or clusters.

5.3.1 Spatial Autocorrelation in Graveyard Pond

It was found that all the criteria had positive autocorrelations indicating that adjacent spatial units were more alike. However, a random distribution was found for household income. This indicates that there is no particular trend in settlement based on income. Hence, the analysis of the influence of income on vulnerability can only be drawn from the surveyed households.

Criteria	Moran's *I* Index	Z-score	Distribution
Household Income	0.01	0.38	Random
Exposure to Hazards	0.13	4.19	Clustered
Sanitation and Incidence of Diseases	0.16	5.30	Clustered
Methods of Mitigation	0.03	1.15	Clustered/Random

Table 5.19 Spatial Autocorrelation in Graveyard Pond

5.3.2 Spatial Autocorrelation in Europe

It was also found that all the criteria had positive autocorrelations indicating that contiguous spatial units were more alike. However, like Graveyard Pond, a random distribution was found for household income (Table 5.20).

Criteria	Moran's *I* Index	Z-score	Distribution
Household Income	0.01	0.47	Random
Exposure to Hazards	0.08	3.75	Clustered
Sanitation and Incidence of Diseases	0.67	3.28	Clustered
Methods of Mitigation	0.17	7.91	Clustered

Table 5.20 Spatial Autocorrelation in Europe

5.4 Summary

The foregoing sections have presented the statistical and spatial results of data analysis from the data collected in Graveyard Pond and Europe informal settlements. The aim of the analysis was to investigate factors contributing to the variance in risk in both settlements. In addition, this chapter was meant to identify any underlying factors amplifying vulnerability in these

settlements. The four main factors assessed in this chapter were selected based on discussions with the officials at SDI and with the leadership at Graveyard Pond. The following chapter presents discusses the results.

Chapter 6 Discussion

This chapter discusses and interprets the findings that were presented in Chapter Five. In addition, the discussion will explicitly show the application of the vulnerability research framework deliberated in Chapter 2 within this study. The methodology used in this research will also be assessed. Lastly, possible solutions for risk mitigation in both settlements will be discussed.

6.1 Application of the Conceptual Framework

This study on vulnerability was founded on the framework presented in Turner *et al.* (2003). The framework has been summarised in Figures 2.2 and 2.3. The so-called 'vulnerability of places framework' (Figure 2.3) is focussed on assessing vulnerability within a particular geographic area, in this case, two informal settlements (Graveyard Pond and Europe) in two suburbs (Philippi and Gugulethu respectively) of Cape Town. The framework considers exposure, sensitivity and resilience as the three key aspects of vulnerability analysis. These key aspects were integrated into the questionnaire design presented in Section 4.5 (Chapter 4). The application of this framework in this research will be discussed in more detail in the following sections.

6.1.1 Exposure

The vulnerability of places framework prescribed an assessment of how an area of interest is exposed to hazards (Figure 2.3). Similar recommendations were advanced by Cardona (2004) and Kumpulainen (2006). In keeping with the vulnerability of places framework, an investigation was carried out into the hazards affecting both Graveyard Pond and Europe. Initial discussions with the SDI officials (acting on behalf of Europe) and the leadership of Graveyard Pond were used to ascertain the various hazards in the two settlements. It was found that both fires and flooding were prevalent in both settlements. A specific section on 'disaster and relocation history' in the questionnaire was designed to capture characteristics of these hazards. The characteristics included information on the frequency, magnitude and duration of these hazards. The questionnaire also sourced information on the forms of flooding in the two settlements.

The second issue related to exposure in terms of Figure 2.3 looks at the components of the system being studied. In other words, who or what is being exposed to the hazards? Turner *et al.* (2003) and Kumpulainen (2006) argue that vulnerability cannot exist unless there is human or environmental interaction with a hazard in the place of analysis. The components of the system could include individuals, households, ecosystems etc. The demographic section of the questionnaires used in this study was designed to capture the components of the two settlements being exposed to the hazards. The section on household details in the questionnaire queried specifics such as gender, age groups and number of people per household. Based on the

responses to such questions, it was possible to estimate the number of people being exposed to the various hazards as well as the different variations of flooding. It was also possible to distinguish between the different demographic groupings, such as age groups and gender, with regard to exposure to hazards.

6.1.2 Sensitivity

Turner *et al.* (2003) also prescribed the need for an analysis of a system's sensitivity when assessing vulnerability. Sensitivity is essentially a function of the state of the system. In Figure 2.3, sensitivity is divided into human and environmental conditions that prevail before a flood, such as economic and biophysical structures respectively. A number of sections in the questionnaire investigated the sensitivity of the two informal settlements. The section on employment, income and expenses in the questionnaires assessed the financial standing of the households in the two settlements. It was found that, the lower the income, the more sensitive a household is to the impact of the hazard.

The 'nature of the dwelling' and 'eligibility for housing subsidy' sections in the questionnaire investigated the role of the dwelling structure in reducing sensitivity to hazards. Poor dwelling structures can let in water during heavy rains and eventually cause flooding. If households replied that they were eligible for housing subsidies, it meant that the current structure was only temporary and that residents might be able to relocate to serviced residential areas. Generally, poor dwelling structures increase sensitivity to flooding, whilst proper dwelling structures reduce sensitivity to flooding.

The health and sanitation section of the questionnaires was designed to query sensitivity to disease in the two informal settlements. Poor sanitation can lead to the proliferation of diseases. The incidence of diseases can affect the finances of a household, especially when the breadwinner falls sick. Any impact of diseases on household income can subsequently limit the capacity of the household to cope with a hazard.

Lastly, the questionnaire investigated the institutions working in the informal settlements. The 'disaster and relocation history' as well as the 'migration history' sections investigated any prevailing partnerships with the communities of the two settlements. Partnerships with outside organisations, such as the municipality and NGOs can lead to remedies that can reduce the sensitivity of the community to hazards and disasters.

6.1.3 Resilience

Analysing the resilience of the two communities was essential for understanding their vulnerability to hazards. Firstly, the existing flood mitigation techniques employed by the community were queried in the 'disaster and relocation history' section of the questionnaire. The role of the municipality in the settlements after flooding was also determined from interviews and from the same section of the questionnaires.

Secondly, the impact of the floods on the community was investigated. For example, an investigation was carried out into the correlation of flooding and disease. The last section of resilience in Figure 2.3 on adjustment and adaptation after flooding is beyond the scope of this research, which is based on the design of the CCAA FliCCR project. However, the findings of this research will pinpoint possible adjustments that can potentially increase resilience and lower vulnerability. The general framework recommended by Turner *et al.* (2003) on vulnerability applies the vulnerability of places framework to regional and global scales (Figure 2.2). This particular study has focused only on vulnerability in a specific and limited locality, viz. two informal urban settlements. Owing to the project design, the analysis of new programs and the influence of policies at a regional level on these two communities are covered in another CCAA FliCCR study.

6.2 Stakeholder Involvement

The development of partnerships in risk assessment was an important aspect of this study. Most of the studies highlighted in Section 2.4, such as Abbott *et al.* (1998), Abbott (2000), Roux and Barry (2001), Quan *et al.* (2001), Barry and Ruther (2005), Iuliana and Eugen (2009), Karanja (2010), and Tyler (2011), are founded on partnerships. A number of these studies have been detailed in Section 2.4. A common thread in all these studies was the assertion that partnerships between stakeholders are essential in developing sustainable solutions.

6.2.1 Partnerships in this study

This study emphasized the development of partnerships at every stage of the risk analysis. Figure 6.1 shows the various stakeholders involved in this study.

SDI was instrumental in developing the questionnaires and identifying suitable flood-prone informal settlements for the study. However, the initial interactions with SDI were frosty. Initially, SDI was vehemently opposed to a GIS based approach to vulnerability assessment. It was found that SDI was using hand drawn maps for informal settlement upgrading. However, these maps were crude and the scale was inconsistent. The author used this shortcoming in the SDI methodology to show how GIS could be used in the SDI mapping process. It was shown that GIS not only ensured a faster turnaround in data collection but also improved the design phase of the informal settlement upgrading. SDI subsequently changed their policy and adopted GIS as an integral part of their methodology.

Nonetheless, although SDI was very helpful in the vulnerability analysis of Europe, they maintained a ‘gatekeeper’ mentality when dealing with the author. SDI did not allow actual contact between the author and the communities and preferred to act as a proxy for the community leaders. The partnership with SDI in Europe extended through the data collection, MCE and analysis phases of vulnerability in that settlement. In Graveyard Pond, the partnership with SDI included identification of the settlement and the community leaders.

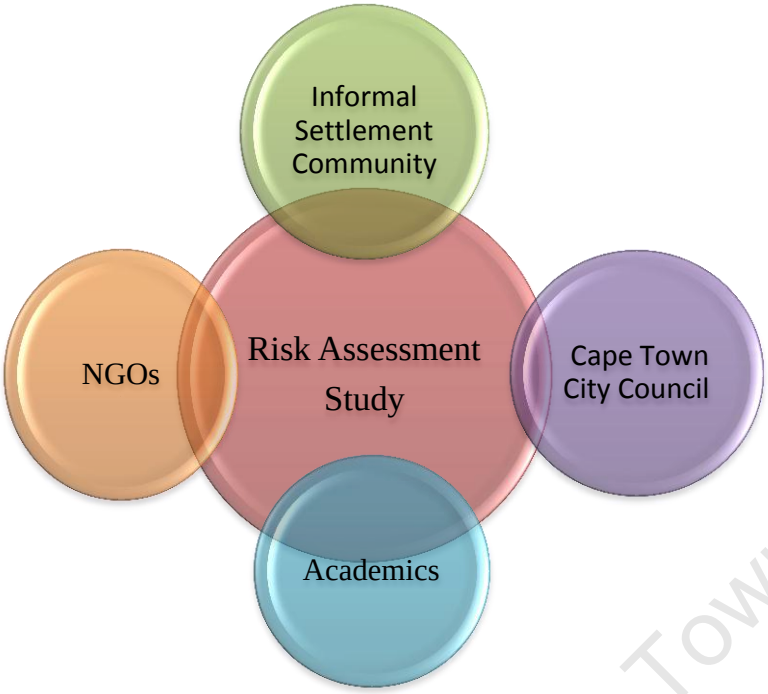

Figure 6.1 Partnerships created in this study

Partnerships were also created with the community leaders in Graveyard Pond. It is worth noting that, although the community leaders were initially difficult to track down, they were very keen on the research. The community leaders played a huge role in the discussion of the problems in the settlement and development of the questionnaire. They also took part in the pre-enumeration briefing and the actual survey. Also, the community leaders helped with the MCE and the analysis of the results from the MCE.

The CTCC is responsible for risk mitigation in Cape Town; hence, it had a major stake in this research. In fact, the CTCC has two members on the steering committee of the CCAA FliCCR research group. The CTCC provided insight into the flood risk management policies in informal settlements as well as access to their GIS data. The CTCC will also be involved in the adaptation and adjustment studies at a regional scale within the CCAA FliCCR project.

Lastly, every stage of research was carried out in partnership with fellow academics in the CCAA FliCCR project at the University of Cape Town.

6.2.2 Strengths and Weaknesses of the Partnerships in this study

The partnerships used in this study yielded certain strengths and weakness in the course of this research. The positives based on the partnerships were as follows:

- The reliability of the data collected benefited from the participation of the local communities.

- The silos of information resulting from the data collection allowed the residents to analyse the problems in the settlement holistically.
- There was a transfer of skills in map reading and GIS to the local community and the NGOs respectively.
- The reliability of the MCE and vulnerability analysis benefited from the participation of the local communities and the NGOs.
- A new methodology of supplementary data collection managed by the communities was developed for potential use by the CTCC.

Conversely, there were some problems arising out of the involvement of various stakeholders. The problems were as follows:

- The forging of partnerships was time consuming. Several meetings were conducted with the NGOs and community leaders before they committed to the vulnerability study. In addition, the community leaders and SDI officials needed training in map reading and basic GIS in the course of the data collection and integration respectively.
- Since the local community members were being used to do the interviews, there was a risk that they could influence the opinions of the respondents.
- In some cases, the questions were poorly asked and the responses were either inappropriate or questions were left unanswered altogether.

Nevertheless, the various partnerships shown in Figure 6.1 significantly improved the quality of risk assessment in the two informal settlements. Notably, the academics, NGOs and informal settlement communities have traditionally been excluded from the risk assessment process in Figure 6.1. It was found that partnership could only be formed when there was something to be gained by the various stakeholders. Hence, the different agendas of the stakeholders can sometimes frustrate the entire process. Since the municipality holds the greatest responsibility in risk mitigation, the onus lies with the CTCC to reach out and forge partnerships with the various stakeholders.

6.3 Multi-criteria Evaluation

Multi-criteria Evaluation (MCE) has been at the root of various statistical studies. The MCE methods include, among others, ranking, rating, PCM and TAM (Malczewski, 1999); fuzzy methods (Jiang & Eastman, 2000; Akter & Simonovic, 2005, 2006); and MACBETH (Bana e Costa *et al*., 2004). This study employed PCM because of its simplicity. Particular emphasis was placed on the involvement of the informal settlement communities in every stage of the assessment. The PCM method is simply a multi-dimensional ranking method. In the PCM method, the community leader or the SDI official sequentially compared pairs of alternatives. In other words, at any given stage of the MCE, the community leader or SDI official had to assess between only two alternatives. This made the ranking significantly simpler than assessing all the alternatives at once. By assessing the relative importance of all the alternatives in relation to a particular alternative, the various alternatives were implicitly ranked against each other. For

instance, given four alternatives A, B, C and D, if A is of equal importance to D, but moderately preferred to B and highly preferred to C, then the order of preference is A and D followed by B and C.

The PCM method was also preferred because of the built-in checks. The method is recursive; hence, not only is one required to compare A to B, then C and D in the example above, but also B to C and D, as well as C to D. For that reason, there is a check on the consistency of the comparisons and the eventual ranking. Therefore, the subsequent weights truly represent the relative levels of preference between the alternatives.

6.4 Vulnerability in Graveyard Pond

This section discusses the results of the findings on vulnerability in Graveyard Pond. The discussion is divided into three sections, namely, exposure, sensitivity and resilience, in line with the model prescribed by Turner *et al.* (2003).

6.4.1 Exposure

It was found that the residents of Graveyard Pond had been exposed to flooding and fire. This finding was consistent with that of other studies in different informal settlements (SDI, 2009; Tyler, 2011). Figure 5.1 shows the geographical distribution of the various flood types. From the map, it was noted that approximately 59% of the shacks prone to flooding from run-off water were located on the periphery of the settlement, close to the roads and adjacent to formalised developments. During heavy rainfall, water tends to collect in the channels along the roads and built surfaces of the neighbouring formal developments. This water subsequently flows into the settlement, first flooding the shacks on the periphery of the settlement and then flowing into the centre of the settlement. Since the centre of the settlement lies at a lower altitude than the periphery, the run-off water collects in the valley; hence, the residents reported flooding by rising underground water. Discussions with the community leaders revealed that the area in the centre of the settlement could remain wet due to ponding for long periods of the year, even when the rains have stopped (Figure 5.2).

The geographical location of the households prone to flooding reveals a flaw in the biophysical approach to vulnerability assessment currently employed by the CTCC. The CTCC considers elevation to be a major indicator of areas prone to flooding; the logic being that areas at lower altitudes are more susceptible to flooding. In Graveyard Pond, the floor levels of the households at the periphery of the settlement are approximately three meters higher than the floor levels of the households in the centre of the settlement. Based on the prevailing logic, one would not expect the households on the periphery of the settlement to flood. However, Figure 5.1 shows that even the dwellings on the periphery flood, albeit in a different way to those at the lower altitudes.

It is also noteworthy that some of the forms of flooding reported in Graveyard Pond are not captured in the classifications of flooding prescribed by Douglas *et al.* (2008) in Section 2.1. The suggested classifications of flooding do not include flooding caused by poor dwelling structures and upwelling of underground water. Similarly, the study by Satterthwaite *et al.* (2007) on the causes of flooding in urban areas did not extend to flooding in informal settlements (Section 2.1).

The southern area of Graveyard Pond is particularly prone to fires (Figure 5.3). It was noted during the interviews that most households in Graveyard Pond do not have electricity. The majority of the households with electricity were located in the southern and south-western area of the settlement. There is a formal settlement located south-east of Graveyard Pond and the Graveyard Pond residents in the periphery of the formal settlement were illegally tapping into the electricity supply of the formal settlement. These illegal connections have been responsible for the incidences of fire in the southern and south-western area of Graveyard Pond. Some fires in other areas of the settlement were attributed to arson.

Figures 5.4 and 5.5 consider the impact of both flooding and fire on the households of Graveyard Pond. It was found that the southern area is prone to both flooding and fire, and hence the residents of that area were the most vulnerable. The residents at the centre of Graveyard Pond were highly vulnerable because that area remains flooded for long periods of the year. Vulnerability generally decreased towards the north of the settlement. Some of the households adjacent to Sheffield Road in the north had been able to channel the run-off water successfully away from their dwellings and hence they fell into the category of those with very low vulnerability. A few households stood out in the centre of the settlement for having low levels of vulnerability. The residents of those households had recently moved into the settlement and had not experienced flooding yet, and thus they can be regarded as anomalies.

6.4.2 Sensitivity

Household income was used as the primary indicator for sensitivity in this study. Most households in Graveyard Pond had at least one person employed (Figure 5.19). It was noticed during the survey that there are many children in Graveyard Pond. It was subsequently found that 267 school going children and that 45% of the households in Graveyard Pond either supplemented their income or depended entirely on child support welfare grants. Figure 5.21 takes access to welfare grants into account when considering the number of people contributing to household income. Based on the weights on Table 5.12, approximately 25% of the households in Graveyard Pond depend solely on welfare grants (Figure 5.22). Also, although a number of households did have part-time jobs, very few households have people who are fully or self-employed (Figure 5.22). Figure 5.23 shows that up to 68% of the households have a low income and are therefore unable to protect themselves against flooding. Consequently, the low income levels in the households of Graveyard Pond have contributed significantly to their vulnerability.

It was also found that there were low levels of sanitation in Graveyard Pond. Approximately 54% of the respondents were using buckets as toilets. Figure 5.11 shows the types of toilets being used in Graveyard Pond. The residents on the periphery of the settlements were using

toilets in the neighbouring settlements; hence, they reported using flushing toilets. However, the residents in the centre of the settlement use buckets, which they empty into the two open northern nodes of a storm water drain located in the settlement. The absence of toilets has left the residents prone to diseases. The prevalence of disease has a detrimental effect on household income and subsequently makes the household more sensitive to the effects of flooding.

6.4.3 Resilience

This study assessed the efficiency of the prevailing flood mitigation methods in Graveyard Pond. It was found that most households preferred to dig trenches regardless of the type of flooding they experienced (Figures 5.6 and 5.8). For the people that suffered predominantly from flash floods, the ideal method for mitigation was found to be digging trenches. Conversely, those who were affected by rising water thought that raising the shacks was the best option (Table 5.6). However, on inspecting the shacks that had been raised, it was found that the water collected under the shack and became either smelly or a breeding ground for frogs. Hence, although the water did not actually enter the shacks, the flooding still affected the residents negatively. On that note, a number of residents thought that relocation was best.

An assessment of the efficiency of the various mitigation methods against the types of flooding showed that various residents were flooded, regardless of their efforts at flood mitigation (Figure 5.9). Sixty eight percent of the residents with successful mitigation methods were located on the periphery of the settlement, where the residents chose to dig trenches in response to flash floods. The least efficient responses were found to be in the central and southern part of the settlement (Figure 5.10). Notably, the same areas were also the most vulnerable areas based on exposure (Figure 5.5). Considering the combination of high exposure and inefficient mitigation, the residents of these two areas are highly vulnerable in comparison to the rest.

An additional assessment was done on the interaction of flooding and disease. The prevalence of respiratory diseases indicates dampness. Dampness implicitly indicates either high exposure or poor mitigation methods. Discussions with the community leaders revealed that the storm water drains periodically overflowed. Considering that the storm water drain was being used as an avenue to damp excrement and refuse, an investigation was carried out into the diseases manifesting around the storm water drains. It was found that 15% of the respondents had suffered from rashes and most of them were located around the storm water drain (Figure 5.12). Furthermore, the people who suffered from both respiratory diseases and rashes were mostly located in the central part of the settlement (Figures 5.13 and 5.14), which is predominantly wet throughout the year. It was found that, other than the central part of the settlement, the two northern nodes of the storm water drain, where excrement and rubbish were being dumped, were also disease hotspots (Figure 5.15). A further comparison between the choice of toilets and the prevalence of disease showed a distinct correlation (Figure 5.16). It was found that the areas where the residents were using buckets were highly prone to disease. Hence, it is possible that the residents of those households were also pouring the excrement and rubbish into the marshy areas surrounding their structures (Figure 5.2).

The residents in the central part of the settlement have the lowest resilience because they have the highest prevalence of diseases that escalate because of flooding, and the methods of mitigation in that region are highly inefficient.

6.4.4 Summary and possible solutions

With regard to exposure, it was found that the central and southern sections of the settlement were exposed to fires and the longest periods of flooding. The analysis of sensitivity further showed that, although there was no geographical trend in the distribution of household income levels, the majority of the people in the central and southern regions of the settlement were unemployed and dependent on welfare grants. Lastly, the central and southern regions of the settlement were the least resilient. Since vulnerability is a function of exposure, sensitivity and resilience, based on the model prescribed by Turner *et al.* (2003), it makes sense that the central and southern regions of Graveyard Pond are the most vulnerable sections of the settlement.

In view of the fact that the central part of the settlement is marshy throughout the year, the only plausible solution for the residents of that section is relocation. This option is further justified by the fact that even those residents who raised their shacks still had smelly and frog-infested waters underneath their shacks. For the residences on the periphery of the settlement, the provision of toilets and electricity will reduce their sensitivity to diseases and fires and implicitly reduce their vulnerability. Also, the cleaning of the drains along the roads and the storm water drains will reduce the incidences of flash floods.

Furthermore, there is a need for sensitisation of the community members on the impact that dumping rubbish into the marshy areas of the settlement has on their health. The general improvement of sanitation can have an impact in reducing the prevalence of diseases and vulnerability.

This study on vulnerability in Graveyard Pond derived a separate weight for each of the vulnerability indicators for each household. A number of studies on vulnerability have preferred a single value that is often derived from a weighted mean of different indicators (Bana e Costa *et al*., 2004; Ayalew & Yamagishi, 2005; Yahaya & Abdalla, 2010). A similar approach was taken in this study to derive a mean weight and produce Figures 5.24 and 5.25. These figures theoretically reflect the most vulnerable areas of Graveyard Pond, taking into consideration all the factors. Despite its aesthetic appeal, this approach masks the underlying problems in Graveyard Pond. Hence, the resulting maps do not provide the information required to derive sustainable risk management solutions. An analysis of the separate risk maps presents a better prospect of deriving solutions. The next section discusses the issue of vulnerability in Europe.

6.5 Vulnerability in Europe

This section contains a discussion of the results of the findings on vulnerability in the informal settlement of Europe. The discussion is also divided into three sections, namely, exposure, sensitivity and resilience, in line with the model prescribed by Turner *et al.* (2003).

6.5.1 Exposure

The residents of Europe reported being affected by both flooding and fire. The majority of the residents who were affected by flooding cited an upwelling of underground water (Figure 5.26). Several residents were also flooded because their poor dwelling structures could not keep out the heavy rains. Although Europe's terrain generally falls from the centre of the settlement towards Settlers Way and Klipfontein Road, a number of residents reported that their dwellings could remain flooded for days after the rains had stopped. Figure 5.27 shows that some households can remain flooded for more than a day. Unlike Graveyard Pond, where the ponding was in the low-lying centre of the settlement, the households that remain flooded are located at different elevations across the settlement. Again, this finding contradicts the assumption by the CTCC that only points at lower elevations are flood-prone.

A map of the households prone to flooding is presented in Figure 5.28. The dwellings that have suffered fires are mostly clustered together. This is because the dwellings in informal settlements are often built so close to each other. Hence, if one catches fire, several neighbouring shacks will very likely also be gutted by fire. The residents of Europe do not have access to electricity and so they use paraffin lamps for lighting and paraffin stoves for cooking. Discussions with the SDI officials revealed that the fires are often caused by accidents involving unattended paraffin stoves or lamps.

It was found that the most vulnerable people based on exposure to hazards were those who experienced both fires and floods (Table 5.13). In addition, because the areas that suffered from flooding because of rising underground water remained marshy the longest, the households reporting upwelling of water were also considered exceedingly vulnerable. From Figures 5.29 and 5.30 it can be seen that that, in general, the western half of Europe is highly vulnerable.

6.5.2 Sensitivity

Household income can influence sensitivity to the impact of hazards. Approximately 30% of the households in Europe had at least one person employed (Figure 5.39). Most of the employed residents were either fully employed or self-employed. This means that, although few people are employed, they do have a consistent flow of income.

It was subsequently found that 1110 households, approximately 25% of the entire population in Europe, had access to welfare grants. Eighty-seven percent of these recipients receive child support welfare grants. It was found that a number of households depended solely on these welfare grants and were therefore very highly sensitive to the impacts of hazards (Figure 5.40).

In general, however, several households had at least one person with consistent employment and a number of households were thus found to have medium levels of vulnerability. Lastly, the households that had people who were fully employed and accessing welfare grants were deemed to be the least vulnerable (Figures 5.40 and 5.41).

However, these results have to be assessed critically because the information on income in Europe was found to be incomplete. This is because some residents in Europe did not respond to the questions on income. It is therefore difficult to distinguish between those households that did not respond to the question and those that have residents with no form of employment whatsoever. Therefore, an assumption was made that those that were interviewed but did not respond to the questions on income could be deemed to be unemployed. Nonetheless, the vulnerability maps were derived from the households that responded to the questions on vulnerability.

6.5.3 Resilience

This study assessed the effectiveness of the prevailing flood mitigation methods in Europe. It was found that the most popular strategy for flood mitigation was the digging of trenches. A number of people also tried combinations of strategies in a bid to stem the effects of flooding (Figure 5.31). Considering that many residents had reported flooding from rising water, it was noted that digging trenches was an ineffective way of dealing with the flooding. Hence, in Figures 5.32 and 5.33, it was noted that the resilience to flooding was generally low in Europe.

In addition, there was a high prevalence of respiratory diseases around Europe. Most residents suffered from cough and flu (Figure 5.34). The prevalence of respiratory diseases is an indicator of dampness, which in turn exposes the inefficiency of the flood mitigation strategies. The high incidence of diarrhoea (running stomach) also pinpoints poor sanitation. It was noted that certain areas were disease hotspots, with residents being afflicted by two or more diseases (Figures 5.35 and 5.36). The relationship between these hotspots and dampness was explicitly assessed in Figure 5.37. It was found that the residents who suffered from several diseases at a time were largely located in the areas that remained damp for more than a day. Most of the residents of Europe visit hospitals and mobile clinics for treatment (Figure 5.38).

The low efficiency of the mitigation methods and the incidence of water-borne and respiratory diseases both point to low resilience in Europe.

6.5.4 Summary and Possible Solutions

With regard to exposure, it was found that certain sections of Europe remained marshy for days after the rains have stopped. However, outside of the winter months, most sections of Europe do dry. These findings suggest that the introduction of proper drainage channels in Europe might reduce the impact of flooding. Current community-driven efforts have focussed on digging trenches, but the run-off water is not being channelled into a single canal and hence it inevitably soaks into the ground. Given that Europe is located on an old dumpsite, the ground easily

becomes water logged and the water rises through the floors of the shacks. It is plausible, therefore, that if the water is properly channelled into canals, it could reduce the amount of water soaking into the ground and reduce the flooding from rising water.

Although the incidences of fire in Europe are sporadic, the underlying cause is the lack of electricity. The fires could be traced back to illegal electricity connections and the use of paraffin. If the residents could receive electricity, it would negate the need for paraffin lamps and stoves and reduce the incidences of fire. It was further noted that the fires easily spread because of the proximity of the dwellings to each other. Thus, the community should agree to leave gaps between their dwellings during construction, which may act as firebreaks.

The analysis of sensitivity further showed that 53% of the residents were unemployed and dependent on welfare grants. The low levels of resilience coupled with the high sensitivity and exposure to hazards makes many of the residents of Europe highly vulnerable. However, mitigating the flooding will certainly reduce the incidences of diseases and implicitly increase resilience. It is noteworthy that only 32% of the community felt that relocation was the only solution to the flooding problem. Most residents felt that the provision of better housing material and proper drainage would alleviate their problems.

The risk analysis for Europe was more demanding than that of Graveyard Pond. All the communications and analysis had to be done with SDI who acted on behalf of the community of Europe. It is the author's opinion that contact with the actual community would have yielded more insight into the dynamics amplifying risk in Europe. Nonetheless, the interaction with SDI was enlightening. For instance, the relationship between the author and SDI could be replicated by the CTCC. Various NGOs periodically collect information from communities in informal settlements across Cape Town, depending on their agendas. The data collection phase constitutes the most time-consuming part of the methodology proposed in this research. Given the number of households in the various informal settlements across Cape Town, the CTCC may regard the methodology presented here as impractical. However, if the CTCC developed partnerships with reputable NGOs already working in these communities, the data collection phase could be expedited. The additional information would certainly provide the CTCC with more sustainable options in risk mitigation. Also, the implementation of the solutions could be done with the support of the communities and NGOs.

It is notable that the solutions to the problems in Graveyard Pond differ from those in Europe. In large portions of Graveyard Pond, the threshold for adaptation has already been breached and relocation is the only plausible solution. The issues surrounding sanitation in Graveyard Pond also amplify the levels of risk within the settlement. In Europe, despite facing similar hazards, better drainage infrastructure will adversely reduce flood risk. Hence, a decision maker must treat the two settlements on their own merit when proposing solutions to the risks. In other words, the solutions applied in Graveyard Pond cannot simply be replicated in Europe and vice versa.

6.6 Summary

The goal of this study was to develop an alternative methodology for risk assessment in informal settlements; one that allowed community participation. It was envisaged that community participation was necessary in order to establish all the hazards manifesting in the community as well as their outcomes. In the course of the study it was found that appropriate tools had to be developed in order to facilitate community participation. Notably, various authors such as Iuliana & Eugen (2009), Bird (2009), Abbot *et al.* (1998), Abbot (2000), Bouchard *et al.* (2007), Raaijmakers *et al.* (2008), Roux & Barry (2001), Barry & Rüther (2005) and Rambaldi *et al.* (2006) had conducted studies into methods of facilitating community participation. This particular study adopted questionnaires but even more innovative methods such as the use of mobile phones could be adopted in other informal settlements. However, it is important to ensure that the information collected is not biased. In this study, spatial information was also solicited from the CTCC and cross-referenced against the information sourced from the community in order to identify anomalies. In this regard, the involvement of a second stakeholder enhanced the quality of the baseline information for the risk assessment.

During the course of the study, it was found that the information sourced from the community was often qualitative in nature. Hence, the responses of the community members had to coded in order to capture the data quantitatively. The collection of qualitative data allowed the community members to provide information comfortably whilst the coding of the data allowed that information to be used for statistical analysis. Based on the information, it was subsequently found that there were several factors creating differential vulnerability within the community. This study chose to use MCE to assess these factors. However, it was found that the methods used in MCE are often too complex to be adopted by local communities. Hence, a method of MCE was chosen that allowed the community leaders to rank the factors affecting vulnerability qualitatively (Table 2.3). A coding process was subsequently used to translate the responses to quantitative information and in order to develop relative weights (Table 2.3). The relative weights were then linked to the corresponding shacks and mapped in order to spatially depict variations in vulnerability within the two settlements. In addition, cross-referencing the vulnerability maps with the spatial information from the CTCC identified other dynamics that were affecting vulnerability in the settlement. Consequently, the participation of the various stakeholders in the risk analysis led to the identification of potential solutions. The next section presents the conclusions of this research.

Chapter 7 Conclusions and Recommendations

This chapter summarises the developments and findings of this study. It also makes recommendations for future research in flood risk assessment in informal settlements.

7.1 Conclusions

7.1.1 Flooding and Flood Risk Assessment

Traditional approaches to flood risk assessment have often focussed on assessing the physical damage after the manifestation of a flood. This approach is in part based on the traditional understanding of floods. This study found that the traditional definitions and causes of flooding provided by flood risk scholars are deficient. The definitions of flooding must be extended to include flooding as a result of poor infrastructure and flooding from rising underground water. In addition, physical damage assessments must be coupled with social vulnerability assessments in order to get a holistic picture of vulnerability in a geographical space. Since risk is directly proportional to vulnerability, any assessment of vulnerability will implicitly assess risk.

From the findings of this research, it is clear that a holistic approach should be taken in assessing risk. It is important to assess all the hazards that are relevant in a geographical location. The manifestation of multiple hazards in an environment will inevitably increase the magnitude of risk in that environment. Therefore, studying flooding in isolation masks the contribution of other hazards in amplifying flood risk, and consequently the solutions may be deficient or inappropriate.

7.1.2 Developing Partnerships

Various authors have called for the development of partnerships, but without describing how such partnerships can be developed in practice. During the course of this study, it was found that several organisations were already actively participating in flood risk management in informal settlements. These included NGOs and religious groups. However, since most informal settlements are located on municipal land, any long-term mitigation measures must be implemented in partnership with the CTCC. It is important to identify all the stakeholders in a particular geographical location before starting the data collection and risk assessment.

7.1.3 Partnerships in Data Collection and Validity

The methodology used in this study relied on collecting data from various stakeholders. It was found that flood risk assessment in informal settlements has predominantly been carried out by the CTCC, solely based on information sourced by a number of departments within the CTCC. This study showed that sustainable solutions must include information from other stakeholders, such as NGOs and the community itself. The involvement of the local communities, NGOs and the CTCC in this study was instrumental in identifying all the hazards manifesting in the case

study informal settlements. Based on the findings of this study, the CTCC should consider developing partnerships in data collection and implementation of solutions with local communities through NGOs.

A key element of collecting data through partnerships is the process of data validation. It was found that the involving several stakeholders in the data collection process facilitated cross-referencing of information. In this study, the validation was developed through the careful design of questionnaires; the use of local residents as surveyors; collection of spatial data from the CTCC; and a holistic comparison of the individual datasets received from the different stakeholders.

7.1.4 Partnerships in Risk Assessment

The risk assessment employed in this research involved using MCE and GIS to map vulnerability. A distinctive attribute of this assessment is that the local communities and the NGOs were actively involved in developing the risk weights in the MCE as well as the vulnerability assessment in the subsequent GIS. In this regard, even the risk assessment was done in partnership with the stakeholders. This research therefore demonstrated a novel participatory approach to GIS and MCE in the context of risk assessment. It was found that involving the local communities provided insight into the 'cause and effect' dynamics in the settlements and implicitly pinpointed potential solutions to the problems in the settlements.

The method of choice in the MCE was the pairwise comparison method. This method was chosen for its simplicity when dealing with technically challenged stakeholders and for its robustness in identifying inconsistent ranking of preferences. It was well suited to this study because community leaders simply had to rank two preferences at a time.

The methodology developed in this study was used in two informal settlements of different sizes. Based on the findings in both settlements, the methodology was found to be adaptable to settlements of different scales. Hence, this method can be used by the CTCC in conjunction with local community representatives or NGOs to assess various indicators of vulnerability in other informal settlements.

7.1.5 Distribution of Vulnerability

Vulnerability is a function of exposure, sensitivity and resilience. It was found that the forms of exposure to hazards differed spatially within the two settlements studied. Also, sensitivity and resilience differed spatially across the households of the settlements used in this study. For instance, the households at the centre of Graveyard Pond were significantly more vulnerable than were those on the outskirts of the settlements. Inherent dynamics, such as poor sanitation and low income levels, were also found to exacerbate the levels of risk. Therefore, vulnerability and implicitly, risk, cannot be deemed to be homogeneous within an informal settlement.

If vulnerability varies spatially within a settlement, it makes sense that the required solutions will also vary spatially within the settlement. Therefore, when dealing with informal settlements, the CTCC should not simply replicate solutions within informal settlements. Additionally, a solution to the problems in a particular settlement may not necessarily be the same solution for similar problems in another settlement. Rather, the CTCC must treat each settlement separately and develop solutions in partnerships with the local communities.

Also, it was found that contrary to prevailing assumptions, flood risk did not necessarily depend on elevation. The households on the periphery of Graveyard Pond reported a different form of flooding than those on the lower ground in the centre of the settlement. Hence, in spite of their elevation, they were still flood-prone. Similarly, the households in Europe located on higher ground were still prone to flooding from rising water. These findings show that the traditional use of GIS to determine flood lines based on elevation and water flows is insufficient when dealing with risk assessment in informal settlements.

7.2 Recommendations

This section presents the recommendations for further research, based on the findings of this study.

7.2.1 Methodologies in Data Collection

Although the use of questionnaires was a successful approach to data collection in the local communities, the data collected is static. This method of data collection will require several iterations in order to assess vulnerability periodically in such settlements. Further studies need to be carried out into developing methodologies in which data can be captured from communities in real-time. A possible approach could be the use of cell phones to collect data from communities.

7.2.2 Up-Scaling of Risk Assessment

This assessment of risk was focussed on the vulnerability of places, based on the prescriptions of Turner *et al.* (2003). Further studies need to be carried out at a regional level on the external factors that influence vulnerability in the local communities. Such studies could include assessment of institutions such as the CTCC that develop risk management policies. An understanding of the governance structures surrounding risk management will potentially pinpoint linkages that need to be created for the development of long-term solutions.

7.2.3 Assessment of Linkages between Flooding and Disease

A thorough assessment of the linkages between the flooding, sanitation and poor health in informal settlements is urgently required. Similar trends in flooding and prevalence of disease were found in both Graveyard Pond and Europe. In general, the areas that stayed flooded the longest reported the highest incidence of diseases. An assessment of the health implications of

flooding may determine solutions that will hopefully decrease vulnerability within the settlements.

7.2.4 Multi-criteria evaluation and GIS

Several studies have reported on the use of MCE and GIS in various contexts. Whilst some authors have prescribed participatory approaches to GIS development, there has been little research on the participatory approaches to MCE. This study demonstrated the merger of participatory MCE and GIS using the pairwise comparison method. Further studies should investigate other methods of MCE that may be suited to getting local communities involved in risk assessment.

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Appendices

Appendix A. Graveyard Pond Questionnaire

This appendix shows the actual questionnaire used during the enumeration at Graveyard Pond Informal settlement.

GRAVEYARD POND ENUMERATION

This enumeration survey collects information on housing conditions, expenditures (and income if possible), employment and sanitation in your community. Please co-operate with the enumerator to fill in this questionnaire.
This form asks for the following:

- Basic information about the people who are living in your house
- Specific information about this house and its occupancy
- Specific information about flooding, sanitation services and health conditions.

Thank you for your co-operation.

Household Details and (Data)

1) **Shack Number** ☐

Occupant <u>of structure:</u>
Surname _____ **Names** _____

2) Age ☐

3) Gender of the head of the household: **Male** ☐ **Female** ☐

4) Home Language _____

5) How many people stay in your house? ☐ **1** ☐ **2** ☐ **3+**

6 -10) How many people in the house are… **0 - 6 years** ☐ **18 – 35 years** ☐
7 – 17 years ☐ **36 – 64 years** ☐
65 + years ☐

11) How many people attend school? ☐

Employment, Income & Expense

12) How many people are employed in the house?

0 ☐ **1** ☐ **2** ☐ **3** ☐

13) What type of employment are they involved in?

Self Employed ☐ Part time/Casual ☐ Full Time ☐

If unemployed list skills (If any):_____

14) Do you receive any kind of a welfare grant? **Yes** ☐ **No** ☐

15) What kind of grant do you receive?

Disability ☐ Child support ☐ Pension ☐

Refugee ☐ Other ☐

16) How many people have any form of income in your house?

0 ☐ **1** ☐ **2** ☐ **3** ☐

17 -19) How much are the main expenses per month?

1. Food R ☐ **2.** Electricity R ☐

3. Transport R ☐

20) What type of transport do you use when going to work?

Walk ☐ **Private** ☐ **Taxi/ Bus** ☐ **Train** ☐

21) How far is the place of employment (or where the household head gets the income)?

(Hours, Minutes of TRAVEL or WALK) ☐ ____ Hrs ____

Nature of house

22) Use of structure: **Residential only** ☐ **Church** ☐ **school** ☐

Spaza **Other** ☐ ☐

23) How many rooms does your house have?

1 ☐ **2** ☐ **3** ☐ **4 +** ☐

24) Do you own a car? Yes ☐ **No** ☐

Eligibility for Housing Subsidy

25) Were you ever approved for a housing subsidy? **Yes** ☐ **No** ☐

26) Would you like to state your income level for the purpose of understanding how many households in the community can apply for subsidies?

R _____

Disaster & Relocation History

Disaster History

Have you ever experienced the following disasters when staying at this settlement?

27) Fire Disaster Yes ☐ **No** ☐

28) Flooding Yes ☐ **No** ☐

29) Evictions Yes ☐ **No** ☐

30) If your answer to 5.1 (a) (ii) was YES, what type of flooding affects you?

Under ground water ☐ **Leaking roof/wall** ☐ **Real flooding** ☐

31) for how long does your house remain flooded?

½ day ☐ **One day** ☐ **more than one day** ☐

32) if you have experienced flooding, which of these mechanisms are the most effective:

Dig Trenches ☐ **Relocate to family/shelter** ☐ **Concrete Floors** ☐

Raise Shack on stones or wood ☐ **Other** _____

33) If your answer to 29 was NO, do you think you are at risk to flooding? _____

If yes, why? _____

34) Has the community tried anything to reduce the effect of flooding?

If yes, what? Dig Trenches ☐ **Use Sand** ☐ **Raise structures** ☐

Other: _____

35) Have you ever received any warnings or help when flooding**? Yes** ☐ **No** ☐

If yes, from who? **Municipality** ☐ **NGO** ☐ **The community leaders** ☐

Neighbors ☐ **Others**_____

37) Do you call any authority during a flood**? Yes** ☐ **No** ☐ If yes, who? _____

38) What do you think could be done to reduce the effect of flooding?
Dig more Trenches ☐ **Provide sand** ☐ **Provide building material** ☐

Relocation ☐ **Other** _____

Migration History

39) How long have you lived in this settlement? ☐ Year/s

40) Where were you living before you came here? _____

41) How long have you lived in Cape Town? ☐ Foreign National? ☐

42) Why did you choose this area? Close to family ☐ Close to friends ☐ Close to work ☐

Other _____

Health & Sanitation

43) Which toilet do you use**?**
Bucket System Toilet ☐ **Water System (Flushed)** ☐ **Other** ☐

44) How many people use this toilet? ☐ About _____ people

45) **What health facilities do you have access to?** Traditional Healer ☐ Clinic ☐
Other ☐

46) What health problems have you or your family suffered after a flood?

Cough ☐ Flu ☐ Running Stomach ☐ TB ☐ Other _____

49) Do you have any other things you want to say? Please give a comment:_____

Please Note: *All Enumerators have to write their names including dates during the process.*

THANK you! ENKOSI! DANKIE!

ENUMERATOR:_____
CODE:_____ **DATE:____/ _____/ 2010**

Appendix B. Europe Questionnaire

This appendix shows the actual questionnaire used in partnership with SDI/CORC during the enumeration at Europe Informal settlement.

COMMUNITY ORGANIZATION RESOURCE CENTRE (CORC) EUROPE ENUMERATION

This enumeration survey collects information on housing conditions, expenditures (and income if possible), employment and sanitation in your community. Please co-operate with the enumerator to fill in this questionnaire.
This form asks for the following:

- Basic information about the people who are living in your house
- Specific information about this house and its occupancy
- Specific information about sanitation services and health conditions.

Thank you for your co-operation.

1. Household Details and (Data)

1.1 Owner of structure: **Shack/House Number** ☐

Surname _____ **Names** _____

ID number (only if you wish to provide it)**:** _____

Age of structure Owner ☐

Gender of the head of the household: **Male** ☐ **Female** ☐

1.2 Occupant of structure:

Surname _____ **Names** _____

ID number (only if you wish to provide it)**:** _____

Gender of the occupant: **Male** ☐ **Female** ☐ **Home Language** _____

1.3 The relationship between the owner and the occupant;

Structure owner ☐ nt Relat ☐ owner ☐

1.4 How many families stay in your house? **1** ☐ **2** ☐ ☐

1.5 How many people in the house are… **(i) 0 - 6 years** ☐ **(iv) 18 – 35 years** ☐

(ii) 7 – 14 years ☐ **(v) 36 – 64 years** ☐

(iii) 15 –17 years ☐ **(vi) 65 + years** ☐

1.6 How many people attend school? ☐

Crèche ☐ **Primary school** ☐ **Secondary/High School** ☐

Tertiary ☐

1.7 How do you travel to school? **Bus/Train** ☐ **walk** ☐

2. Employment, Income & Expense

2.1 How many people are employed in the house?

1 ☐ **2** ☐ **3** ☐ **4 +** ☐

2.2 What type of employment are they involved in?

How many Self Employed ☐ How many Part time/Casual ☐ How many Full Time ☐

If unemployed list skills (If any):_____

2.3 Do you receive any kind of a welfare grant? **Yes** ☐ **No** ☐

2.4 What kind of grant do you receive?

Disability ☐ Child support ☐ Pension ☐

Refugee ☐ Other ☐

2.5 How many people have any form of income in your house?

1 ☐ **2** ☐ **3** ☐ **4+** ☐

2.6 How much are the main expenses per month?

1. Food	R	**2.** Electricity	R
3. Transport	R	**4.** Rent/Maintenance	R
5. School fees	R	**6.** Clothing	R

7. Water R **8.** Other items R

2.7 What type of transport do you use when going to work?

Private **Taxi** **Bus** **Train**

2.8 How far is the place of employment (or where the household head gets the income)?

(Hours, Minutes of TRAVEL or WALK) ____ Hrs ____

2.9 How much do you pay per day in transport? **R**

2.9.1 Where do you do your shopping?

1. Goal Shopping Mall **2. Philippi** Shoprite Shopping Mall

3. Nyanga Junction Shopping Mall **4.** Other: _____

3. Nature of house

3.1 Type of house**:**

Independent Shack **Backyard dwelling**

3.2 Use of structure: **Residential only** **Church** **Pre –school**

Spaza **Other**

3.3 What is the size of your house? **MT** **X** **MT** **[e.g. 3.50 mt x 2.95 mt]**

3.4 How many rooms does your house have?

1 **2** **3** **4 +**

3.6 Do you own a car? **Yes** **No**

3.7 If yes, where do you park? (i) Private garage **(ii) Drive Way** **(iii) Other**

4. Eligibility for Housing Subsidy

4.1 Were you ever approved for a housing subsidy? **Yes** **No**

4.2 Would you like to state your income level for the purpose of understanding how many households in the community can apply for subsidies?

R

5. Disaster & Relocation History

5.1 Disaster History

(a) Have you ever experienced the following disasters when staying at Never-Never settlement?

(i) Fire Disaster **Yes** ☐ **No** ☐ **how many times?** ☐

(ii) Flooding **Yes** ☐ **No** ☐ **how many times?** ☐

(iii) Evictions **Yes** ☐ **No** ☐ **how many times?** ☐

(iv) If your answer to 5.1 (a) (ii) was YES, what type of flooding affects you?

Under ground water ☐ **Leaking roof/wall** ☐ **Real flooding** ☐

(v)for how long does your house remain flooded?

½ day ☐ **One day** ☐ **more than one day** ☐

(vi) How do you protect yourself from flooding?

Dig Trenches ☐ **Relocate to family/shelter** ☐ **Use Sandbag** ☐ **Concrete Floors** ☐

Raise Shack on stones or wood ☐ **Other** _____

(vii) If your answer to 5.1 (a) (ii) was NO, do you think you are at risk to flooding? _____

If yes, why? _____

(viii) Has the community tried anything to reduce the effect of flooding?

If yes, what? Dig Trenches ☐ **Use Sandbags** ☐ **Raise structures** ☐

Other: _____

(ix) Have you ever received any warnings about flooding**? Yes** ☐ **No** ☐

If yes, from who? **Municipality** ☐ **NGO** ☐ **Other** _____

(x) Do you call any authority after a flood**? Yes** ☐ **No** ☐

If yes, who? **Municipality** ☐ **NGO** ☐ **Other** _____

(xi) What do you think could be done to reduce the effect of flooding?

Dig more Trenches ☐ **provide Sandbags** ☐ **Provide building material** ☐

Relocation ☐ **Other** _____

(x) Do you ever use coastal resources? Yes ☐ **No** ☐ **If yes, do you use the coast for**
Relaxing at the beach ☐ **fishing** ☐ **getting sand for building** ☐ **Other** _____

(xii) Has any change of the sea affected your house, work or path? Yes ☐ **No** ☐

5.2 Migration History

(i) How long have you lived in Europe? ☐ Year/s

(ii) Where were you living before you came here? _____

(iii) How long have you lived in Cape Town? ☐ **iv) Foreign** National? ☐

(iv) Why did you choose this area?

Close to family ☐ Close to friends ☐ Close to work ☐

Other _____

6. Health & Sanitation

6.1 Which toilet do you use**?**

(i) Bucket System Toilet ☐ **(ii) How many people use this toilet?** About ☐

(iii) Water System (Flushed) ☐ **(iv) Bush** ☐

(iv) How often is the bucket being emptied? _____times

6.2 How many times is the refuse (Black Bags) collected in your community**?**

Once a Week ☐ **twice a week** ☐ **3 times a week** ☐

Once a month ☐ **twice a month** ☐ **or NEVER?** ☐

6.3 What health facilities do you have access to?

Traditional Healer ☐ General Practitioner ☐ Emergency Services ☐

Mobile Clinic ☐ Hospital ☐

(ii) Are all your health problems solved at this facility?

Yes ☐ No ☐

6.4 What health problems have you or your family suffered after a flood?

Cough ☐ Flu ☐ running stomach ☐ Other _____

Please Note: *All Enumerators have to write their names including dates during the process.*

THANK YOU! ENKOSI! DANKIE!

ENUMERATOR:_____

CODE:_____ **DATE:____/ _____/ 2010**

Appendix C. PCM calculations for Exposure to Hazards in Graveyard Pond

This section shows the weight calculations for the exposure to hazards. Table C.1 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

PAIRWISE COMPARISON MATRIX						
Criteria	ND	LR	Ofr	FFl	RW	FF
No Disaster (ND)	1.000	3.000	4.000	5.000	6.000	7.000
Leaking Roof (LR)	0.333	1.000	2.000	4.000	5.000	6.000
Only Fire (Ofr)	0.167	0.200	1.000	3.000	4.000	5.000
Flash Floods (FFl)	0.143	0.250	0.333	1.000	3.000	4.000
Rising Water (RW)	0.167	0.200	0.250	0.333	1.000	3.000
Flood and Fire (FF)	0.143	0.167	0.200	0.250	0.333	1.000
Sum:	**1.952**	**4.817**	**7.783**	**13.583**	**19.333**	**26.000**

Table C.1 Pairwise Comparison matrix of exposure to disasters

Table C.2 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX						
Criteria	ND	LR	Ofr	FFl	RW	FF
No Disaster (ND)	0.512	0.623	0.368	0.368	0.310	0.269
Only Leaking Roof (LR)	0.171	0.208	0.294	0.294	0.259	0.231
Only Fire (Ofr)	0.085	0.042	0.221	0.221	0.207	0.192
Only Flash Floods (FFl)	0.073	0.052	0.074	0.074	0.155	0.154
Only Rising Water (RW)	0.085	0.042	0.025	0.025	0.052	0.115
Flood and Fire (FF)	0.073	0.035	0.018	0.018	0.017	0.038
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table C.2 Normalised Pairwise Comparison matrix of exposure to hazards

Table C.3 shows the final relative weights. In this table the magnitude of the vulnerability is inversely proportional to the associated weight.

EXPOSURE TO HAZARDS	
Alternatives	**Weights**
No Disaster	0.408
Only Leaking Roof	0.243
Only Fire	0.161
Only Flash Floods	0.097
Only Rising Water	0.057
Flood and Fire	0.033
Sum:	**1.000**

Table C.3 Vulnerability weights for hazard exposure

Table C.4 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value of 0.044. There were six criteria and the Random Inconsistency index for six criteria is 1.24 (from Table 2.6).

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
2.843	6.961	0.055
1.575	6.488	
0.964	5.978	**Consistency Ratio**
0.575	5.932	0.0442
0.347	6.061	
0.208	6.223	
Lambda:	6.274	

Table C.4 Calculations for consistency in ranking exposure to hazards

Appendix D. PCM Calculations for Methods of Mitigation in Graveyard Pond

This section shows the weight calculations for the methods of mitigation. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table D.1 is a legend and Table D.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
FF&DT	Flash Floods & Dig trenches
FF&RS	Flash Floods & Raise shacks
FF&SB	Flash Floods & sand bags
FF&REL	Flash Floods & Relocation
FF&CF	Flash Floods & Concrete floors
LR&REL	Leaking Roof & Relocation
LR&SB	Leaking Roof & sand bags
LR&RS	Leaking Roof & Raise shacks
LR&CF	Leaking Roof & Concrete floors
LR&DT	Leaking Roof & Dig trenches
RW&RS	Rising water & Raise shacks
RW&CF	Rising water & Concrete floors
RW&SB	Rising water & sand bags
RW&REL	Rising water & Relocation
RW&DT	Rising water & Dig trenches

Table D.1 Legend of criteria for mitigation

PAIRWISE COMPARISON MATRIX															
Criterion	FF&DT	FF&RS	FF&SB	FF&REL	FF&CF	LR&REL	LR&SB	LR&RS	LR&CF	LR&DT	RW&RS	RW&CF	RW&SB	RW&REL	RW&DT
FF&DT	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&RS	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&SB	0.333	0.333	1.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&REL	0.333	0.333	0.500	1.000	2.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&CF	0.250	0.250	0.333	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LR&REL	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&SB	1.000	1.000	1.000	1.000	1.000	0.500	1.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&RS	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&CF	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&DT	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.500	0.500	1.000	1.000	1.000	1.000	1.000	1.000
RW&RS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&SB	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	0.333	3.000
RW&REL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	3.000	1.000	4.000
RW&DT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.333	0.250	1.000
Sum:	**12.917**	**12.917**	**17.833**	**19.500**	**24.000**	**12.833**	**14.333**	**16.500**	**16.500**	**21.000**	**14.833**	**14.833**	**18.333**	**12.583**	**24.000**

Table D.2 Pairwise comparison matrix of methods of mitigation

Table D.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX															
Criterion	**FF&DT**	**FF&RS**	**FF&SB**	**FF&REL**	**FF&CF**	**LR&REL**	**LR&SB**	**LR&RS**	**LR&CF**	**LR&DT**	**RW&RS**	**RW&CF**	**RW&SB**	**RW&REL**	**RW&DT**
FF&DT	0.077	0.077	0.168	0.154	0.167	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&RS	0.077	0.077	0.168	0.154	0.167	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&SB	0.026	0.026	0.056	0.103	0.125	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&REL	0.026	0.026	0.028	0.051	0.083	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&CF	0.019	0.019	0.019	0.026	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
LR&REL	0.077	0.077	0.056	0.051	0.042	0.078	0.140	0.121	0.121	0.143	0.067	0.067	0.055	0.079	0.042
LR&SB	0.077	0.077	0.056	0.051	0.042	0.039	0.070	0.121	0.121	0.143	0.067	0.067	0.055	0.079	0.042
LR&RS	0.077	0.077	0.056	0.051	0.042	0.039	0.035	0.061	0.061	0.095	0.067	0.067	0.055	0.079	0.042
LR&CF	0.077	0.077	0.056	0.051	0.042	0.039	0.035	0.061	0.061	0.095	0.067	0.067	0.055	0.079	0.042
LR&DT	0.077	0.077	0.056	0.051	0.042	0.026	0.023	0.030	0.030	0.048	0.067	0.067	0.055	0.079	0.042
RW&RS	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.109	0.040	0.125
RW&CF	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.109	0.040	0.125
RW&SB	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.034	0.034	0.055	0.026	0.125
RW&REL	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.135	0.135	0.164	0.079	0.167
RW&DT	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.022	0.022	0.018	0.020	0.042
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table D.3 Normalised pairwise comparison matrix of methods of mitigation

METHODS OF MITIGATION	
Alternatives	**Weights**
FF&Dig trenches	0.085
FF&Raise shacks	0.085
FF&sand bags	0.064
FF&Relocation	0.056
FF&Concrete floors	0.050
LR&Relocation	0.081
LR&sand bags	0.074
LR&Raise shacks	0.060
LR&Concrete floors	0.060
LR&Dig trenches	0.051
RW&Raise shacks	0.069
RW&Concrete floors	0.069
RW&sand bags	0.060
RW&Relocation	0.087
RW&Dig trenches	0.050
Sum:	**1.000**

Table D.4 Vulnerability weights for methods of mitigation

Table D.4 shows the final relative weights. In this table the magnitude of vulnerability is inversely proportional to the associated weight.

Table D.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value of 0.054. There were fifteen criteria and the Random Inconsistency index for fifteen criteria is 1.59 (from Table 2.6)

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
1.391	16.419	0.086
1.391	16.419	
1.043	16.264	**Consistency Ratio**
0.905	16.137	0.054
0.802	16.005	
1.297	15.990	
1.183	16.009	
0.974	16.149	
0.974	16.149	
0.836	16.254	
1.116	16.262	
1.116	16.262	
0.973	16.328	
1.405	16.218	
0.804	16.183	
Lambda :	16.203	

Table D.5 Calculations for consistency in ranking efficiency of mitigation methods

Appendix E. PCM Calculations for Sanitation and Disease in Graveyard Pond

This section shows the weight calculations for the influence of sanitation and diseases on vulnerability. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table E.1 is a legend and Table E.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
ND	No Disease
Rsh	Only Rash
RT	Only Running Tummy
Co/F	Only Cough/Flu
RT&Rsh	Running Tummy and Rash
Co&Rsh	Cough and Rash
RT&Co	Running Tummy and Cough
All	All

Table E.1 Legend of criteria for disease

PAIRWISE COMPARISON MATRIX								
Criteria	**ND**	**Rsh**	**RT**	**Co/F**	**RT&Rsh**	**Co&Rsh**	**RT&Co**	**All**
ND	1.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
Rsh	0.333	1.000	3.000	4.000	5.000	5.000	6.000	6.000
RT	0.250	0.333	1.000	3.000	4.000	4.000	5.000	6.000
Co/F	0.200	0.200	0.250	1.000	2.000	3.000	4.000	5.000
RT&Rsh	0.167	0.167	0.250	0.500	1.000	2.000	3.000	4.000
Co&Rsh	0.143	0.200	0.250	0.333	0.500	1.000	2.000	3.000
RT&Co	0.125	0.167	0.200	0.250	0.333	0.500	1.000	2.000
All	0.111	0.167	0.167	0.200	0.250	0.333	0.500	1.000
Sum:	**2.329**	**5.233**	**9.117**	**14.283**	**19.083**	**22.833**	**29.500**	**36.000**

Table E.2 Pairwise comparison matrix of incidence of diseases

NORMALISED PAIRWISE COMPARISON MATRIX								
Criteria	**ND**	**Rsh**	**RT**	**Co/F**	**RT&Rsh**	**Co&Rsh**	**RT&Co**	**All**
ND	0.429	0.573	0.439	0.350	0.314	0.307	0.271	0.250
Rsh	0.143	0.191	0.329	0.280	0.262	0.219	0.203	0.167
RT	0.107	0.064	0.110	0.210	0.210	0.175	0.169	0.167
Co/F	0.086	0.038	0.027	0.070	0.105	0.131	0.136	0.139
RT&Rsh	0.072	0.032	0.027	0.035	0.052	0.088	0.102	0.111
Co&Rsh	0.061	0.038	0.027	0.023	0.026	0.044	0.068	0.083
RT&Co	0.054	0.032	0.022	0.018	0.017	0.022	0.034	0.056
All	0.048	0.032	0.018	0.014	0.013	0.015	0.017	0.028
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table E.3 Pairwise comparison matrix of incidence of diseases

Table E.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

INCIDENCE OF DISEASES	
Alternatives	**Weights**
No Disease	0.367
Rash	0.224
Running Tummy	0.151
Cough/Flu	0.092
Run.Tummy and Rash	0.065
Cough and Rash	0.046
Run.Tummy and Cough	0.032
All	0.023
Sum:	1.000

Table E.4 Calculated weights for contribution of disease to vulnerability

Table E.4 shows the final relative weights. In this table the magnitude of vulnerability is inversely proportional to the associated weight. Table E.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value of 0.050. There were eight criteria and the Random Inconsistency index for eight criteria is 1.41 (from Table 2.6).

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
3.278	8.940	0.070
2.052	9.148	
1.334	8.810	**Consistency Ratio**
0.759	8.288	0.050
0.527	8.131	
0.377	8.120	
0.259	8.165	
0.192	8.347	
Lambda :	8.493	

Table E.5 Calculations for consistency in ranking contribution of diseases to vulnerability

Appendix F. PCM Calculations for Income in Graveyard Pond

This section shows the weight calculations for the influence of income on vulnerability. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table F.1 is a legend and Table F.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
FE&G	Full-time/Self Employment and receiving a Grant
FE	Full-time Employment
PE&G	Part-time Employment and Grant
PE	Part-time Employment
UE&G	Unemployed and receiving a Grant
UE	Unemployed and not receiving a Grant

Table F.1 Legend of types of income

PAIRWISE COMPARISON MATRIX						
Criteria	**FE&G**	**FE**	**PE&G**	**PE**	**UE&G**	**UE**
FE&G	1.000	2.000	3.000	5.000	5.000	6.000
FE	0.500	1.000	3.000	4.000	5.000	6.000
PE&G	0.200	0.200	1.000	2.000	4.000	5.000
PE	0.167	0.250	0.500	1.000	3.000	4.000
UE&G	0.200	0.200	0.250	0.333	1.000	2.000
UE	0.167	0.167	0.200	0.250	0.500	1.000
Sum:	**2.233**	**3.817**	**7.950**	**12.583**	**18.500**	**24.000**

Table F.2 Pairwise comparison matrix of types of income

Table F.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the relative ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX						
Criteria	**FE&G**	**FE**	**PE&G**	**PE**	**UE&G**	**UE**
FE&G	0.448	0.524	0.397	0.397	0.270	0.250
FE	0.224	0.262	0.318	0.318	0.270	0.250
PE&G	0.090	0.052	0.159	0.159	0.216	0.208
PE	0.075	0.066	0.079	0.079	0.162	0.167
UE&G	0.090	0.052	0.026	0.026	0.054	0.083
UE	0.075	0.044	0.020	0.020	0.027	0.042
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table F.3 Normalised pairwise comparison matrix of types of income

Table F.4 shows the final relative weights. In Table F.4 the magnitude of vulnerability is inversely proportional to the associated weight. Table F.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each pair of alternatives. The overall value is supposed to be less than 0.1 and this comparison yielded a

value of 0.032. There were six criteria and the Random Inconsistency index for six criteria is 1.24 (from Table 2.6).

SOURCES OF INCOME	
Alternatives	**Weights**
Full-time/Self Employment and receiving a Grant	0.381
Full-time Employment	0.274
Part-time Employment and Grant	0.147
Part-time Employment	0.105
Unemployed and receiving a Grant	0.055
Unemployed and not receiving a Grant	0.038
Sum:	**1.000**

Table F.4 Calculated weights for sources of income

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
2.398	6.291	0.039
1.829	6.682	
0.898	6.093	**Consistency Ratio**
0.628	5.997	0.032
0.334	6.024	
0.230	6.093	
Lambda:	6.197	

Table F.5 Calculations for consistency in ranking contribution of income to vulnerability in Graveyard Pond

Appendix G. PCM calculations for Exposure to Hazards in Europe

This section shows the weigh calculations for the exposure to hazards in Europe. Table G.1 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
ND	No Disaster
FF	Flash Floods
Ofr	Only Fire
LR	Leaking Roof
RW	Rising Water
FF&LR	Flash Floods & Leaking Roof
LR&RW	Leaking Roof & Rising Water
FF&RW	Flash Floods & Rising Water
Fl&Fr	Flood and Fire

Table G.1 Legend of types of exposure to hazards in Europe

PAIRWISE COMPARISON MATRIX									
Criteria	ND	FF	Ofr	LR	RW	FF&LR	LR&RW	FF&RW	Fl&Fr
ND	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
FF	0.500	1.000	2.000	3.000	4.000	4.000	5.000	6.000	7.000
Ofr	0.333	0.500	1.000	2.000	4.000	4.000	5.000	6.000	6.000
LR	0.250	0.333	0.500	1.000	2.000	3.000	4.000	5.000	6.000
RW	0.200	0.250	0.250	0.500	1.000	2.000	3.000	4.000	5.000
FF&LR	0.167	0.250	0.250	0.333	0.500	1.000	2.000	3.000	4.000
LR&RW	0.143	0.200	0.200	0.250	0.333	0.500	1.000	2.000	3.000
FF&RW	0.125	0.125	0.167	0.200	0.250	0.333	0.500	1.000	2.000
Fl&Fr	0.111	0.111	0.167	0.167	0.200	0.250	0.333	0.500	1.000
Sum:	**2.829**	**4.769**	**7.533**	**11.450**	**17.283**	**21.083**	**27.833**	**35.500**	**43.000**

Table G.2 Pairwise Comparison Matrix of exposure to hazards

Table G.3 shows the normalised pairwise comparison matrix for the alternatives listed in Table G.1. The criteria column shows the ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX									
Criteria	ND	FF	Ofr	LR	RW	FF&LR	LR&RW	FF&RW	Fl&Fr
ND	0.353	0.419	0.398	0.349	0.289	0.285	0.251	0.225	0.209
FF	0.177	0.210	0.265	0.262	0.231	0.190	0.180	0.169	0.163
Ofr	0.118	0.105	0.133	0.175	0.231	0.190	0.180	0.169	0.140
LR	0.088	0.070	0.066	0.087	0.116	0.142	0.144	0.141	0.140
RW	0.071	0.052	0.033	0.044	0.058	0.095	0.108	0.113	0.116
FF&LR	0.059	0.052	0.033	0.029	0.029	0.047	0.072	0.085	0.093
LR&RW	0.050	0.042	0.027	0.022	0.019	0.024	0.036	0.056	0.070
FF&RW	0.044	0.026	0.022	0.017	0.014	0.016	0.018	0.028	0.047
Fl&Fr	0.039	0.023	0.022	0.015	0.012	0.012	0.012	0.014	0.023
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table G.3 Normalised Pairwise Comparison matrix of exposure to hazards

Table C.3 shows the final relative weights. In this table the magnitude of the vulnerability is inversely proportional to the associated weight.

EXPOSURE TO HAZARDS	
Alternatives	**Weights**
No Disaster	0.309
Flash Floods	0.205
Only Fire	0.160
Leaking Roof	0.110
Rising Water	0.077
Flash Floods & Leaking Roof	0.055
Leaking Roof & Rising Water	0.038
Flash Floods & Rising Water	0.026
Flood and Fire	0.019
Sum:	**1.000**

Table G.4 Vulnerability weights for hazard exposure

Table G.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value of 0.048. There were nine criteria and the Random inconsistency index for nine criteria is 1.45 (from Table 2.6).

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
3.005	9.726	0.069
2.020	9.848	
1.577	9.859	**Consistency Ratio**
1.053	9.538	0.048
0.710	9.271	
0.504	9.089	
0.346	8.993	
0.234	9.041	
0.176	9.222	
Lambda:	9.555	

Table G.5 Calculations for consistency in ranking exposure to hazards

Appendix H. PCM Calculations for Methods of Mitigation in Europe

This section shows the weight calculations for the methods of mitigation. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table H.1 is a legend and Table H.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
FF&DT	Flash Floods & Dig trenches
FF&RS	Flash Floods & Raise shacks
FF&SB	Flash Floods & sand bags
FF&REL	Flash Floods & Relocation
FF&CF	Flash Floods & Concrete floors
LR&REL	Leaking Roof & Relocation
LR&SB	Leaking Roof & sand bags
LR&RS	Leaking Roof & Raise shacks
LR&CF	Leaking Roof & Concrete floors
LR&DT	Leaking Roof & Dig trenches
RW&RS	Rising water & Raise shacks
RW&CF	Rising water & Concrete floors
RW&SB	Rising water & sand bags
RW&REL	Rising water & Relocation
RW&DT	Rising water & Dig trenches

Table H.1 Legend of criteria for mitigation

PAIRWISE COMPARISON MATRIX															
Criterion	FF&DT	FF&RS	FF&SB	FF&REL	FF&CF	LR&REL	LR&SB	LR&RS	LR&CF	LR&DT	RW&RS	RW&CF	RW&SB	RW&REL	RW&DT
FF&DT	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&RS	1.000	1.000	3.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&SB	0.333	0.333	1.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&REL	0.333	0.333	0.500	1.000	2.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FF&CF	0.250	0.250	0.333	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LR&REL	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&SB	1.000	1.000	1.000	1.000	1.000	0.500	1.000	2.000	2.000	3.000	1.000	1.000	1.000	1.000	1.000
LR&RS	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&CF	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000
LR&DT	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.500	0.500	1.000	1.000	1.000	1.000	1.000	1.000
RW&RS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	0.500	3.000
RW&SB	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	0.333	3.000
RW&REL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	3.000	1.000	4.000
RW&DT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.333	0.333	0.333	0.250	1.000
Sum:	**12.917**	**12.917**	**17.833**	**19.500**	**24.000**	**12.833**	**14.333**	**16.500**	**16.500**	**21.000**	**14.833**	**14.833**	**18.333**	**12.583**	**24.000**

Table H.2 Pairwise comparison matrix of methods of mitigation

Table H.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX															
Criterion	FF&DT	FF&RS	FF&SB	FF&REL	FF&CF	LR&REL	LR&SB	LR&RS	LR&CF	LR&DT	RW&RS	RW&CF	RW&SB	RW&REL	RW&DT
FF&DT	0.077	0.077	0.168	0.154	0.167	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&RS	0.077	0.077	0.168	0.154	0.167	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&SB	0.026	0.026	0.056	0.103	0.125	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&REL	0.026	0.026	0.028	0.051	0.083	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
FF&CF	0.019	0.019	0.019	0.026	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.055	0.079	0.042
LR&REL	0.077	0.077	0.056	0.051	0.042	0.078	0.140	0.121	0.121	0.143	0.067	0.067	0.055	0.079	0.042
LR&SB	0.077	0.077	0.056	0.051	0.042	0.039	0.070	0.121	0.121	0.143	0.067	0.067	0.055	0.079	0.042
LR&RS	0.077	0.077	0.056	0.051	0.042	0.039	0.035	0.061	0.061	0.095	0.067	0.067	0.055	0.079	0.042
LR&CF	0.077	0.077	0.056	0.051	0.042	0.039	0.035	0.061	0.061	0.095	0.067	0.067	0.055	0.079	0.042
LR&DT	0.077	0.077	0.056	0.051	0.042	0.026	0.023	0.030	0.030	0.048	0.067	0.067	0.055	0.079	0.042
RW&RS	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.109	0.040	0.125
RW&CF	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.067	0.067	0.109	0.040	0.125
RW&SB	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.034	0.034	0.055	0.026	0.125
RW&REL	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.135	0.135	0.164	0.079	0.167
RW&DT	0.077	0.077	0.056	0.051	0.042	0.078	0.070	0.061	0.061	0.048	0.022	0.022	0.018	0.020	0.042
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table H.3 Normalised pairwise comparison matrix of methods of mitigation

METHODS OF MITIGATION	
Alternatives	**Weights**
Flash Floods & Dig trenches	0.085
Flash Floods & Raise shacks	0.085
Flash Floods & sand bags	0.064
Flash Floods & Relocation	0.056
Flash Floods & Concrete floors	0.050
Leaking Roof & Relocation	0.081
Leaking Roof & sand bags	0.074
Leaking Roof & Raise shacks	0.060
Leaking Roof & Concrete floors	0.060
Leaking Roof & Dig trenches	0.051
Rising water & Raise shacks	0.069
Rising water & Concrete floors	0.069
Rising water & sand bags	0.060
Rising water & Relocation	0.087
Rising water & Dig trenches	0.050
Sum:	**1.000**

Table H.4 Vulnerability weights for methods of mitigation

Table H.4 shows the final relative weights. In this Table the magnitude of vulnerability is inversely proportional to the associated weight.

Table H.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value of 0.054. There were fifteen criteria and the Random Inconsistency index for fifteen criteria is 1.59 (from Table 2.6)

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
1.391	16.419	0.086
1.391	16.419	
1.043	16.264	**Consistency Ratio**
0.905	16.137	0.054
0.802	16.005	
1.297	15.990	
1.183	16.009	
0.974	16.149	
0.974	16.149	
0.836	16.254	
1.116	16.262	
1.116	16.262	
0.973	16.328	
1.405	16.218	
0.804	16.183	
Lambda :	16.203	

Table H.5 Calculations for consistency in ranking efficiency of mitigation methods

Appendix I. PCM Calculations for Sanitation and Disease in Europe

This section shows the weight calculations for the influnce of sanitation and diseases on vulnerability. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table I.1 is a legend and Table I.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
ND	No Disease
Oth	Other (Rash, TB, etc)
RT	Running Tummy
C	Cough
Flu	Flu
O&RT	Other and Running Tummy
O&C	Other and Cough
O&F	Other and Flu
RT&C	Running Tummy and Cough
RT&F	Running Tummy and Flu
F&C	Flu and Cough
All	More than two diseases

Table I.1 Legend of criteria for disease

PAIRWISE COMPARISON MATRIX												
Criteria	ND	Oth	RT	C	Flu	O&RT	O&C	O&F	RT&C	RT&F	F&C	All
ND	1.000	2.000	2.000	3.000	4.000	5.000	6.000	7.000	7.000	8.000	8.000	9.000
Oth	0.500	1.000	2.000	3.000	4.000	4.000	5.000	6.000	6.000	7.000	8.000	9.000
RT	0.500	0.500	1.000	2.000	3.000	4.000	5.000	5.000	6.000	7.000	7.000	8.000
C	0.333	0.333	0.500	1.000	2.000	3.000	3.000	4.000	4.000	5.000	6.000	7.000
Flu	0.250	0.250	0.333	0.500	1.000	2.000	3.000	3.000	3.000	4.000	5.000	6.000
O&RT	0.200	0.250	0.250	0.333	0.500	1.000	2.000	3.000	3.000	3.000	5.000	6.000
O&C	0.167	0.200	0.200	0.333	0.333	0.500	1.000	2.000	3.000	4.000	5.000	6.000
O&F	0.143	0.167	0.200	0.250	0.333	0.333	0.500	1.000	2.000	3.000	4.000	5.000
RT&C	0.143	0.167	0.167	0.250	0.333	0.333	0.333	0.500	1.000	2.000	3.000	4.000
RT&F	0.125	0.143	0.143	0.200	0.250	0.333	0.250	0.333	0.500	1.000	2.000	3.000
F&C	0.125	0.125	0.143	0.167	0.200	0.200	0.200	0.250	0.333	0.500	1.000	2.000
All	0.111	0.111	0.125	0.143	0.167	0.167	0.167	0.200	0.250	0.333	0.500	1.000
Sum:	**3.597**	**5.246**	**7.061**	**11.176**	**16.117**	**20.867**	**26.450**	**32.283**	**36.083**	**44.833**	**54.500**	**66.000**

Table I.2 Pairwise comparison matrix of incidence of diseases

NORMALISED PAIRWISE COMPARISON MATRIX												
Criteria	ND	Oth	RT	C	Flu	O&RT	O&C	O&F	RT&C	RT&F	F&C	All
ND	0.278	0.381	0.283	0.268	0.248	0.240	0.227	0.217	0.194	0.178	0.147	0.136
Oth	0.139	0.191	0.283	0.268	0.248	0.192	0.189	0.186	0.166	0.156	0.147	0.136
RT	0.139	0.095	0.142	0.179	0.186	0.192	0.189	0.155	0.166	0.156	0.128	0.121
C	0.093	0.064	0.071	0.089	0.124	0.144	0.113	0.124	0.111	0.112	0.110	0.106
Flu	0.070	0.048	0.047	0.045	0.062	0.096	0.113	0.093	0.083	0.089	0.092	0.091
O&RT	0.056	0.048	0.035	0.030	0.031	0.048	0.076	0.093	0.083	0.067	0.092	0.091
O&C	0.046	0.038	0.028	0.030	0.021	0.024	0.038	0.062	0.083	0.089	0.092	0.091
O&F	0.040	0.032	0.028	0.022	0.021	0.016	0.019	0.031	0.055	0.067	0.073	0.076
RT&C	0.040	0.032	0.024	0.022	0.021	0.016	0.013	0.015	0.028	0.045	0.055	0.061
RT&F	0.035	0.027	0.020	0.018	0.016	0.016	0.009	0.010	0.014	0.022	0.037	0.045
F&C	0.035	0.024	0.020	0.015	0.012	0.010	0.008	0.008	0.009	0.011	0.018	0.030
All	0.031	0.021	0.018	0.013	0.010	0.008	0.006	0.006	0.007	0.007	0.009	0.015
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table I.3 Normalised pairwise comparison matrix of incidence of diseases

Table I.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the ranks of the alternatives.

INCIDENCE OF DISEASE	
Alternatives	**Weights**
No Disease	0.233
Other (Rash, TB, etc)	0.192
Running Tummy	0.154
Cough	0.105
Flu	0.077
Other and Running Tummy	0.062
Other and Cough	0.054
Other and Flu	0.040
Running Tummy and Cough	0.031
Running Tummy and Flu	0.022
Flu and Cough	0.017
More than two diseases	0.013
Sum:	**1.000**

Table I.4 Calculated weights for contribution of disease to vulnerability

Table I.4 shows the final relative weights. In this Table the magnitude of vulnerability is inversely proportional to the associated weight. Table I.5 shows the calculations for precision. The aim of these calculations was to check the consistency of the comparisons between each alternative. The overall value is supposed to be less than 0.1 and this comparison yielded a value

of 0.054. There were twelve criteria and the Random Inconsistency index for twelve criteria is 1.41 (from Table 2.6).

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
3.106	13.319	0.079
2.588	13.493	
2.086	13.542	**Consistency Ratio**
1.411	13.433	0.054
1.035	13.374	
0.816	13.073	
0.675	12.624	
0.495	12.366	
0.378	12.258	
0.276	12.266	
0.205	12.285	
0.158	12.460	
Lambda:	12.874	

Table I.5 Calculations for consistency in ranking contribution of diseases to vulnerability in Europe

Appendix J. PCM Calculations for Income in Europe

This section shows the weight calculations for the influnce of income on vulnerability. The calculations followed the steps in section 2.5.3. Firstly the alternatives were ranked and then preferences were allocated based on Table 2.3. Table J.1 is a legend and Table J.2 shows the ranking and preference comparisons for each of the alternatives based on Table 2.3.

TERM	DESCRIPTION
S/FE&G	Full-time/Self Employment and receiving a Grant
S/FE	Full-time/ Self Employment
PE&G	Part-time Employment and Grant
PE	Part-time Employment
UE&G	Unemployed and receiving a Grant
UE	Unemployed and not receiving a Grant

Table J.1 Legend of types of income

PAIRWISE COMPARISON MATRIX						
Criteria	**S/FE&G**	**S/FE**	**PE&G**	**PE**	**UE&G**	**UE**
S/FE&G	1.000	2.000	3.000	5.000	5.000	6.000
S/FE	0.500	1.000	3.000	4.000	5.000	6.000
PE&G	0.200	0.200	1.000	2.000	4.000	5.000
PE	0.167	0.250	0.500	1.000	3.000	4.000
UE&G	0.200	0.200	0.250	0.333	1.000	2.000
UE	0.167	0.167	0.200	0.250	0.500	1.000
Sum:	**2.233**	**3.817**	**7.950**	**12.583**	**18.500**	**24.000**

Table J.2 Pairwise comparison matrix of types of income

Table J.3 shows the normalised pairwise comparison matrix for the alternatives listed above. The criteria column shows the relative ranks of the alternatives.

NORMALISED PAIRWISE COMPARISON MATRIX						
Criteria	**S/FE&G**	**S/FE**	**PE&G**	**PE**	**UE&G**	**UE**
S/FE&G	0.448	0.524	0.397	0.397	0.270	0.250
S/FE	0.224	0.262	0.318	0.318	0.270	0.250
PE&G	0.090	0.052	0.159	0.159	0.216	0.208
PE	0.075	0.066	0.079	0.079	0.162	0.167
UE&G	0.090	0.052	0.026	0.026	0.054	0.083
UE	0.075	0.044	0.020	0.020	0.027	0.042
Sum:	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table J.3 Normalised pairwise comparison matrix of types of income

Table J.4 shows the final relative weights. In Table J.4 the magnitude of vulnerability is inversely proportional to the associated weight. Table J.5 shows the calculations for precision. These calculations were meant to check the consistency of the comparisons between each pair of alternatives. The overall value is supposed to be less than 0.1 and this comparison yielded a

value of 0.032. There were six criteria and the Random Inconsistency index for six criteria is 1.24 (from Table 2.6).

SOURCES OF INCOME	
Alternatives	**Weights**
Full-time/Self Employment and receiving a Grant	0.381
Full-time/ Self Employment	0.274
Part-time Employment and Grant	0.147
Part-time Employment	0.105
Unemployed and receiving a Grant	0.055
Unemployed and not receiving a Grant	0.038
Sum:	**1.000**

Table J.4 Calculated weights for sources of income

CONSISTENCY CALCULATIONS		
Matrix product	**Consistency Vector**	**Consistency Index**
2.398	6.291	0.039
1.829	6.682	
0.898	6.093	**Consistency Ratio**
0.628	5.997	0.032
0.334	6.024	
0.230	6.093	
Lambda:	6.197	

Table J.5 Calculations for consistency in ranking contribution of income to vulnerability in Europe