Using Multicriteria Evaluation and GIS for Flood Risk Analysis in Informal Settlements of Cape Town: The Case of Graveyard Pond

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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 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. This study sought to investigate a methodology that the CTCC could use to improve flood risk assessment.

Using a case study of an informal settlement in Cape Town, this study proposed a methodology of 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 demonstrated the use of a participatory multi-criteria evaluation (MCE) for risk assessment. A questionnaire was used to collect community-based information. The shack outlines of the informal settlement were digitized using CTCC aerial imagery. 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.

Key words: Informal settlements. Flood risk management. Multicriteria Evaluation. GIS. Participation. Risk weights.

1 Introduction

1.1 Background

In the period between 1996 and 2005, floods have 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.

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 rural-urban migrations, there has been a growth of informal 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 (Barry & Rüther, 2005; SDI, 2009).

In a local context, according to the 2007 Cape Town City Council (CTCC) census report, there were approximately 109,000 families living in informal settlements in Cape Town (City of Cape Town, 2008a). A number of reports point out the extensive effect of flooding in many of these informal settlements. For instance, 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, heavy rainfall resulted in flooding that affected 8,000 households, comprising 38,000 residents, in the informal settlements of Khayelitsha and Philippi. 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. Meyer *et al* (2009) identified the two main components of flood risk management as flood risk assessment and flood risk mitigation. This paper will present a novel way of carrying out risk assessment in informal settlements.

1.2 Assessing risk

A widely accepted description of risk was offered by Crichton (1999) and cited by Kelman (2003: 7) as follows:

"Risk is the probability of a loss, and this depends on three elements, hazard, vulnerability and exposure". Hence, the following equation was put forward:

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \qquad [1]$$

Based on this description, 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 extent of 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 1, 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 therefore adopted vulnerability as an indicator of 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:

$$\text{Regional Vulnerability} = \text{Damage potential} + \text{Coping capacity} \qquad [2]$$

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 or environment);
- How the system gets exposed to the hazard; and
- The coping capacity of the system.

This study was therefore focused on assessing these prescribed indicators in an informal settlement in Cape Town. Variations in these indicators will invariably result in variations in vulnerability. For instance, if a household in an informal settlement was exposed to more hazards than another, it would have a higher level of vulnerability than the other. Similarly, variations in the forms of exposure of the households to the same hazard will cause variations in levels of vulnerability. Hence, an assessment of relative vulnerability of a household of interest to another household requires the consideration and comparison of the criteria prescribed by Turner *et al* (2003) in those particular households.

1.3 Multicriteria 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. Table 1 summarises the attributes of the various MCE methods presented by Malczewski (1999).

Table 1 Table showing comparisons of method. Source: Malczewski (1999: 190)

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

The pairwise comparison method (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.

The trade-off analysis method (TAM) has the least number of judgements, however, because the various alternatives are simply altered at the expense of the most preferred alternative. 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). 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 derived from PCM 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 Virtual 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. A critique of these studies though, is that they were done isolation. The communities around the river basins were never involved in the analysis and hence the existing risk mitigation efforts were not taken into context when assessing vulnerability. An examination of the essential requirements postulated by Turner *et al* (2003) reveals the need for the participation of the different stakeholders in the determination of 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 the community. The success of vulnerability assessment and decision making to mitigate vulnerability is therefore vested in partnerships. This study therefore adopted a participatory approach to MCE. The resulting weights were imported into a GIS environment and mapped to identify disparities in vulnerability.

1.4 Study area

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. 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 2). This specific area is the lowest part of the settlement and it can stay wet for months on end.

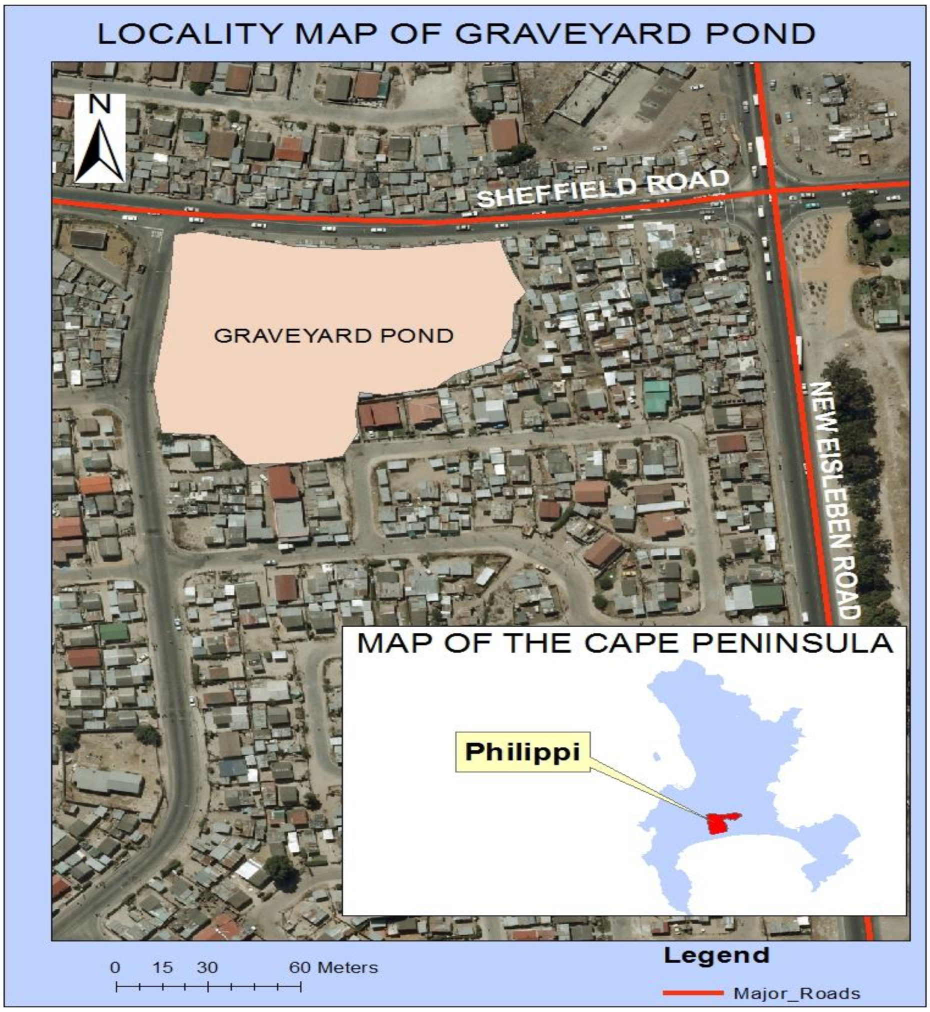

Figure 1. Location of Graveyard Pond

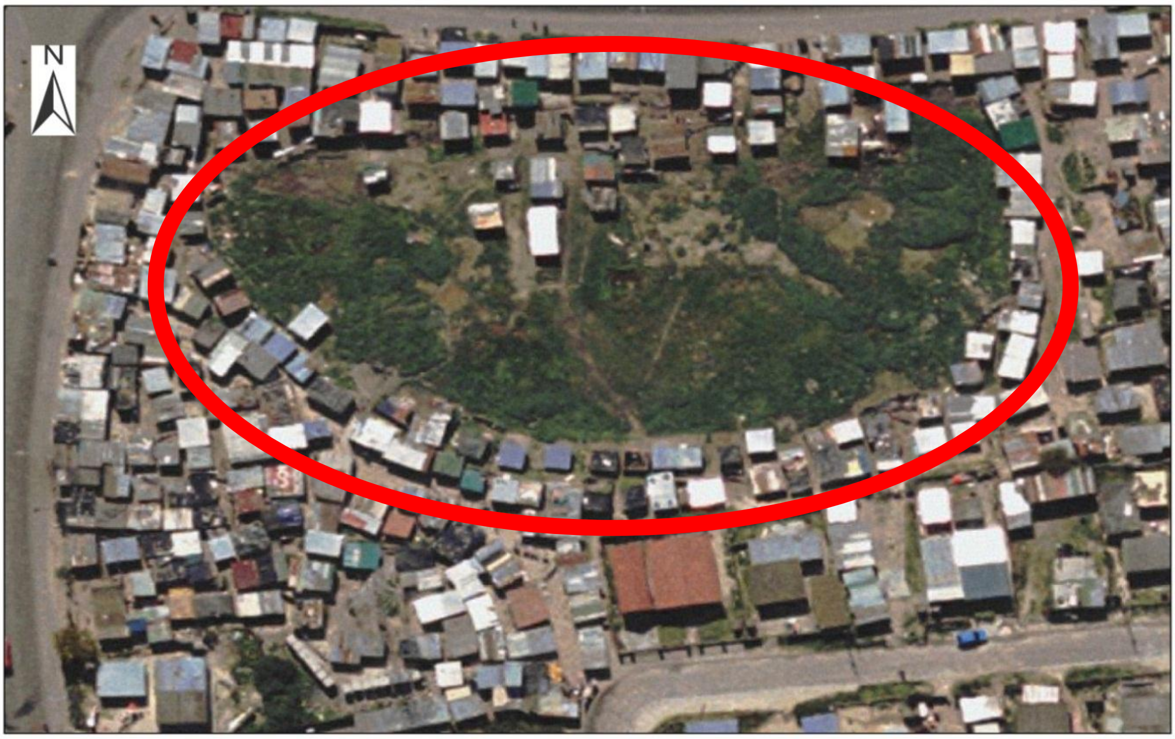

Figure 2. Graveyard Pond, September 2007 (Source: City of Cape Town, 2008)

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). 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 4 shows the state of Graveyard Pond in July, 2010.

Figure 3. Graveyard Pond, March 2009 (Source: City of Cape Town, 2010)

Figure 4. Flooding in Graveyard Pond, July 2010

2 Approach

2.1 Data collection

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 and capturing the spatial information using GIS. The social information included a basic profile of the inhabitants' education levels, employment and skills, coping mechanisms, health, and frequency of exposure to flooding. The social information was captured by means of spreadsheets, whereas the spatial information was derived from aerial imagery of Graveyard Pond. Every step of the data collection was done in partnership with the relevant stakeholders.

Firstly, some experienced enumerators from Slum Dwellers International (SDI), a Non-Government Organisation (NGO) working with informal settlements, were selected to help with the survey. In Graveyard Pond, the full team of surveyors included the SDI trained team, the community leaders, the author and a research partner. 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 and SDI surveyors was instrumental in developing the wording of the final questionnaire. In addition, the author trained the 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 had already been numbered with spray paint, and the survey teams decided to use these numbers as the shack identification numbers.

The settlement was divided into six 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 questionnaire 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.

The survey took three days and approximately 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 5 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.

Figure 5. One of the Graveyard Pond community leaders conducting a survey

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.

2.2 Data integration, analysis and verification

The questionnaire responses were captured into a spreadsheet, using the shack number as the primary identifier for each questionnaire. 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 satellite images 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. 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. 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.

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.

2.3 Multicriteria evaluation in Graveyard Pond

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 four variations were taken as the main criteria to be used in evaluating vulnerability. The following sections detail the alternatives in each of these criteria.

2.3.1 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 Graveyard Pond had been exposed to both flooding and fire, flooding was the predominant hazard. The following alternatives were derived for the types of exposure to hazards, based on the responses to the questionnaire:

- 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.

The levels of exposure to these hazards in Graveyard Pond were ranked in order of preference in partnership with the community leaders of the settlement. 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 questionnaire. For instance, if a household reported that they had not experienced either hazard, the weight for 'no exposure to hazards' 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.

2.3.2 Methods of mitigation

It was found that there were several methods being employed by the households in Graveyard Pond to cope with the hazards, and these methods were derived from the responses in the questionnaires. 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.

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 the community leaders 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 questionnaire. After each household had been allocated a weight, a vulnerability map based on efficiency of the mitigation methods 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.

2.3.3 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. 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. 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.

2.3.4 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). 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.

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. 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. 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.

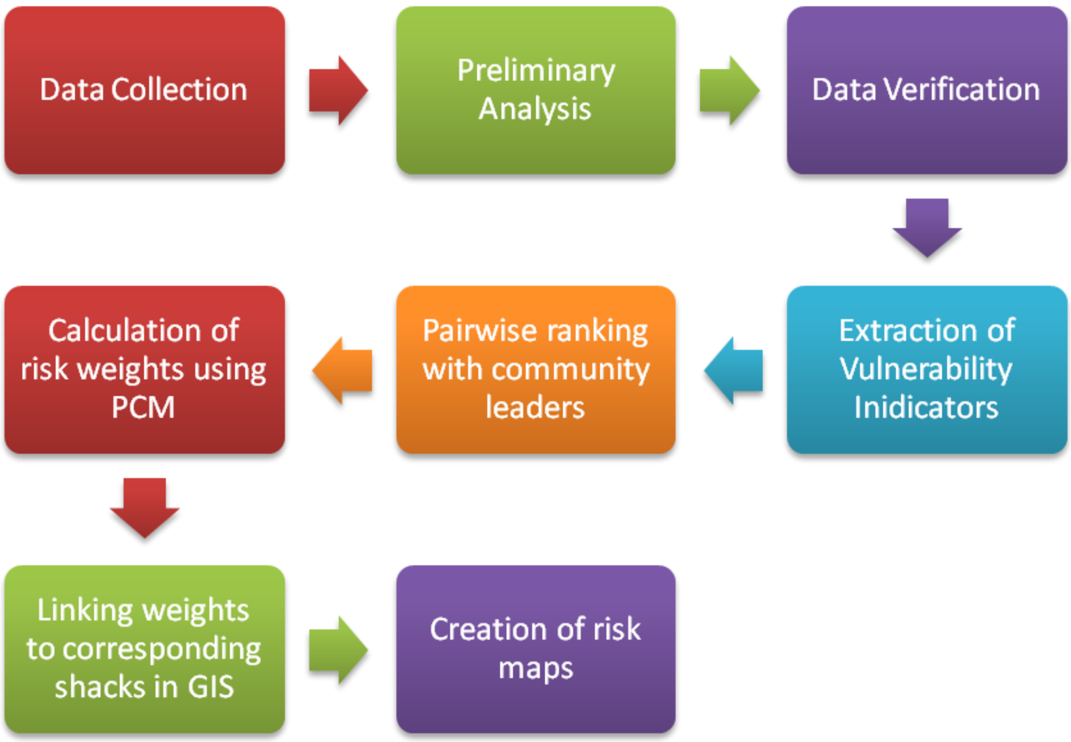

Figure 6. Steps in vulnerability analysis of Graveyard Pond

The MCE stage of the study led to the creation of vulnerability maps that showed the spatial disparities of risk within the informal settlement. 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 community. Hence, their opinion is captured in the resulting weights. The next section describes the results of the study.

3 Results

3.1 Exposure to hazards

The relative weights were calculated using PCM. The comparisons were checked for consistency and 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 2 shows the final relative weights. In this table, the magnitude of the vulnerability is inversely proportional to the magnitude of the associated weight.

Table 2. Vulnerability weights for hazard exposure

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

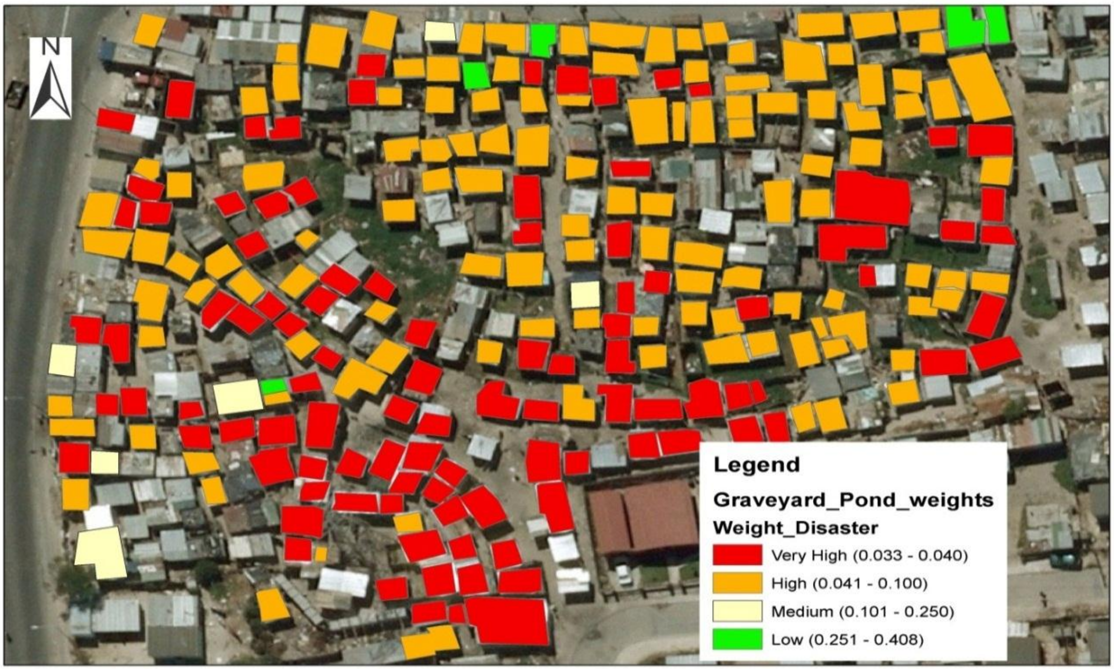

Figure 7. Map showing vulnerability based on type of exposure to a hazard

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 7). Also, 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 8).

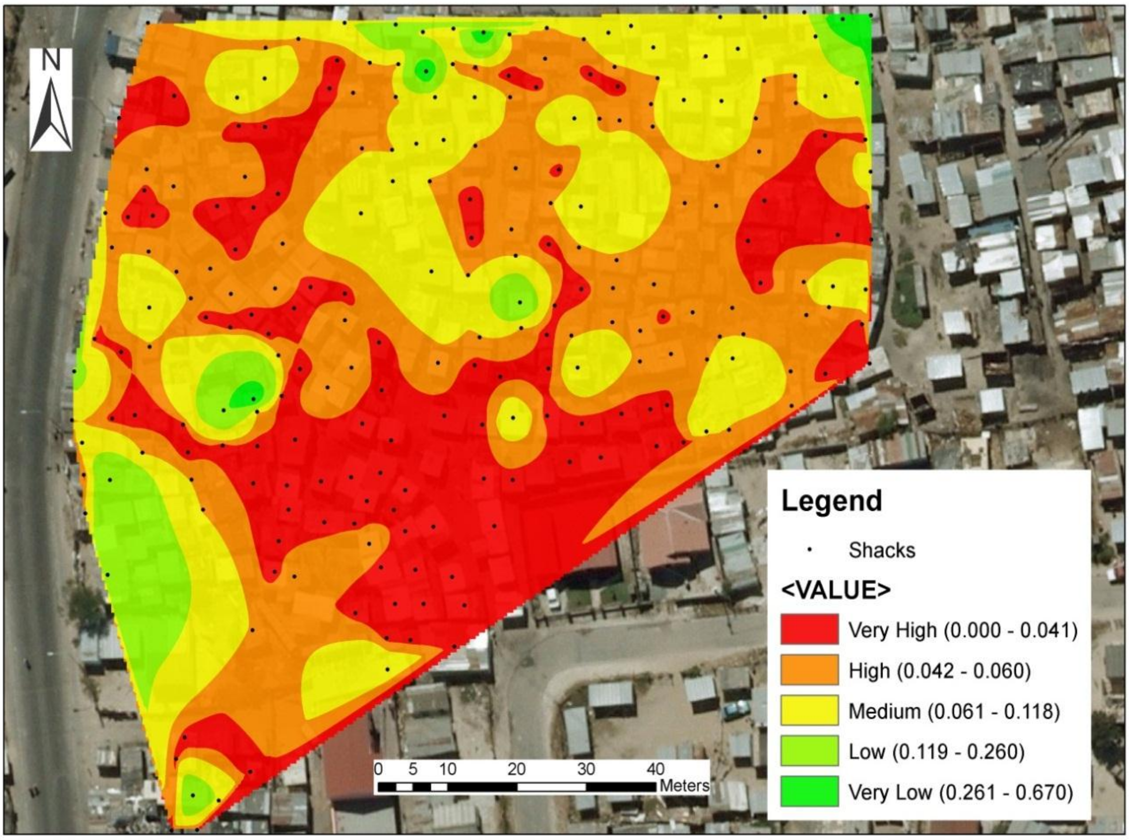

Figure 8. Raster map showing vulnerability based on type of exposure to a hazard

Figure 7 and Figure 8 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 successfully been able to channel the run-off water away from their dwellings hence they fell in the category of those with very low vulnerability. There were a few households that 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; hence, they can be regarded as anomalies. The next section describes the results on mitigation methods and vulnerability in Graveyard Pond.

3.2 Methods of mitigation

Based on the responses in the questionnaire, it was found that the most popular method of mitigation was the digging of trenches. However, given that the forms of flooding varied, the digging of trenches was not necessarily the most efficient mitigation technique.

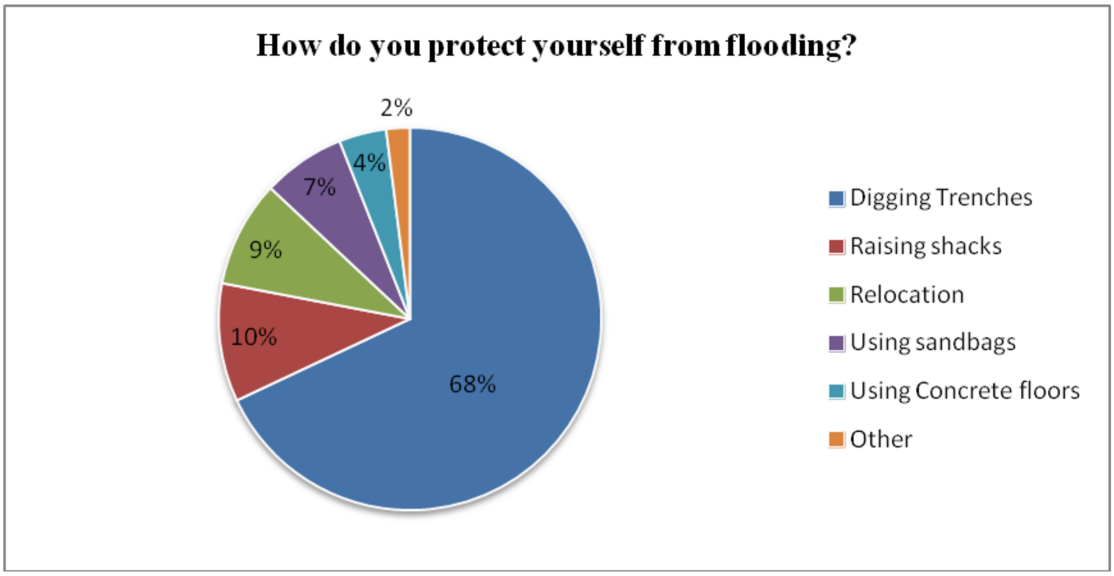

Figure 9. Methods of flood mitigation in Graveyard Pond

Table 3. Vulnerability weights for 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

Hence, the mitigation techniques were sequentially ranked based on their efficiency for every form of exposure. 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 3 shows the results of the PCM analysis. 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 10).

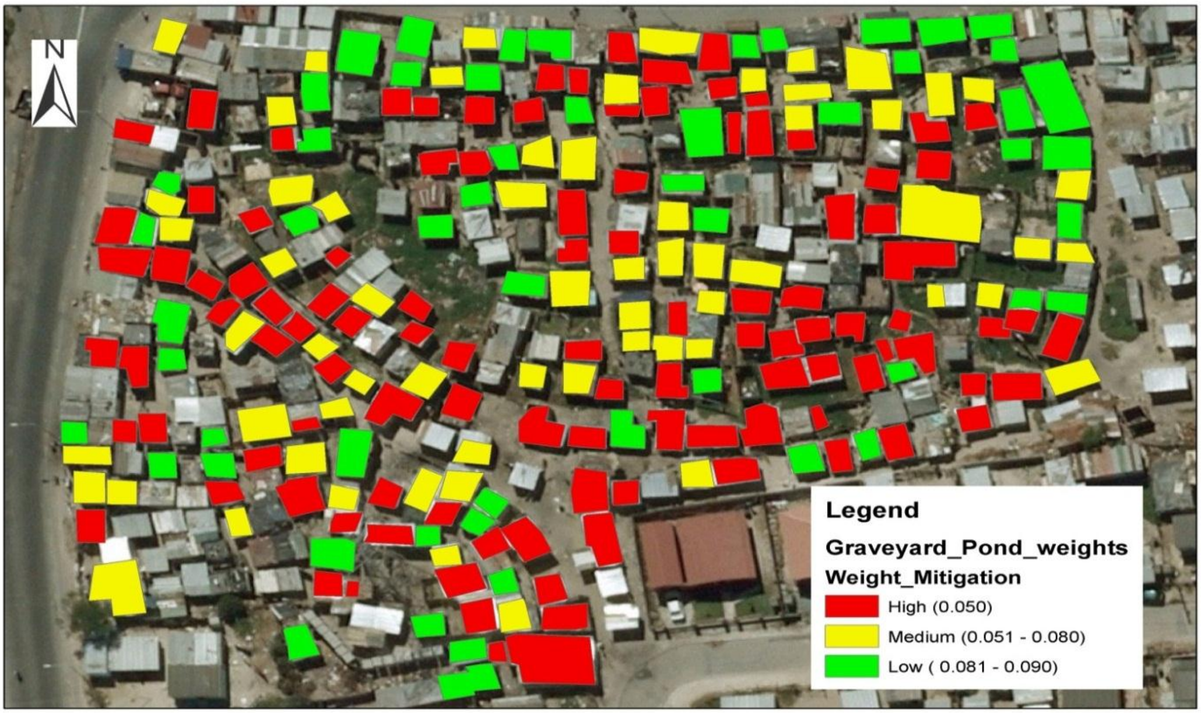

Figure 10. Map showing vulnerability based on methods of mitigation

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 11).

It was found that most households preferred to dig trenches regardless of the type of flooding they experienced. For the people that suffered predominantly from flash floods, the ideal method for mitigation was found to be digging trenches. On the other hand, those that were affected by rising water thought that raising the shacks was best (Table 3).

However on inspecting the shacks that had been raised, it was found that the water collected under the shack and either became smelly or a breeding ground for frogs. Hence, although the water did not actually enter the shacks, the flooding still affected the residents. On that note, a number of residents thought relocation was best.

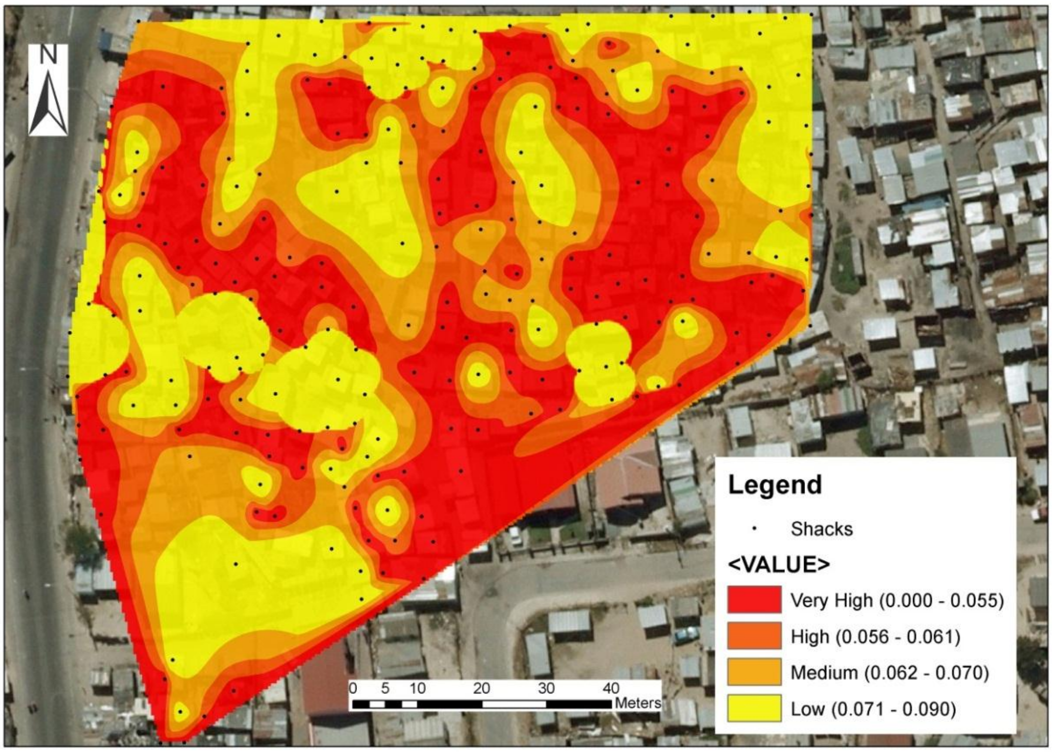

Figure 1. Raster map showing vulnerability based on efficiency of mitigation methods

An assessment of the efficiency of the various mitigation methods against the types of flooding showed that various residents got flooded regardless of their efforts at flood mitigation (Figure 11). The majority 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 11). Notably, the same areas were also the most vulnerable areas based on exposure (Figure 8). Considering the combination of high exposure and inefficient mitigation, the residents of these two areas are highly vulnerable in comparison to the rest. The next section describes the findings on sanitation and vulnerability in Graveyard pond.

3.3 Sanitation and disease

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. The rationale 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 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. Table 4 shows the final relative weights. In this table, the magnitude of vulnerability is inversely proportional to the associated weight. The reliability of the pairwise comparisons 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

Table 4. Weights for contribution of disease to vulnerability

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

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 (Table 4).

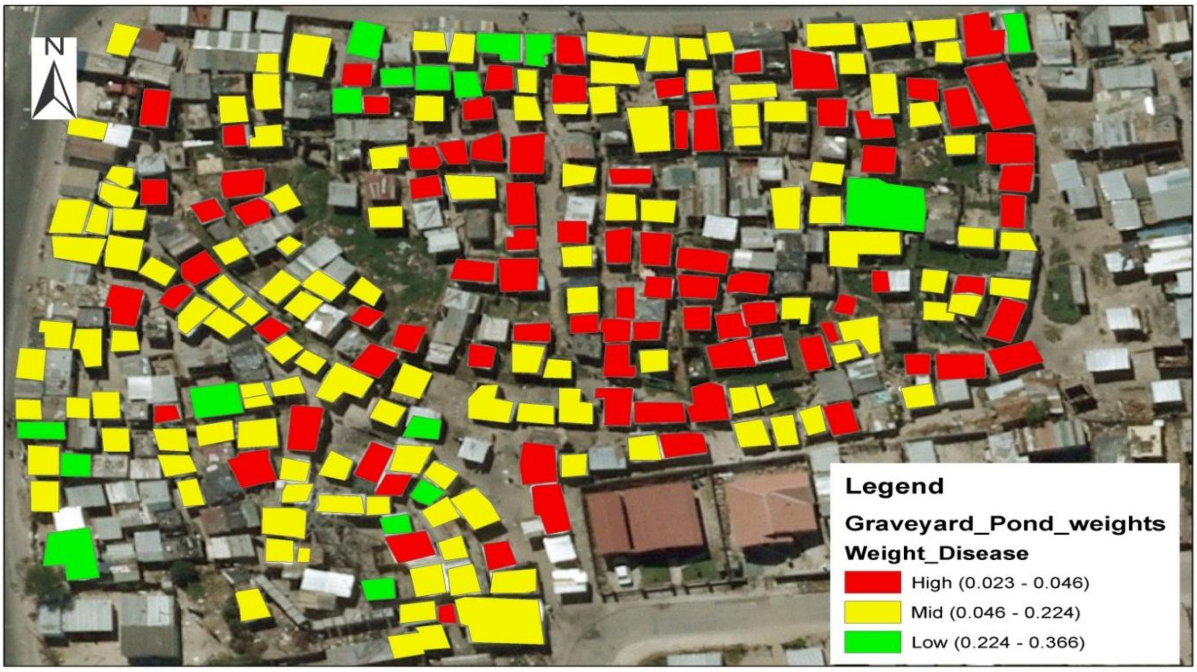

Figure 12. Map showing vulnerability based on prevalence of disease

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 12). 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 subsequent raster map (Figure 13).

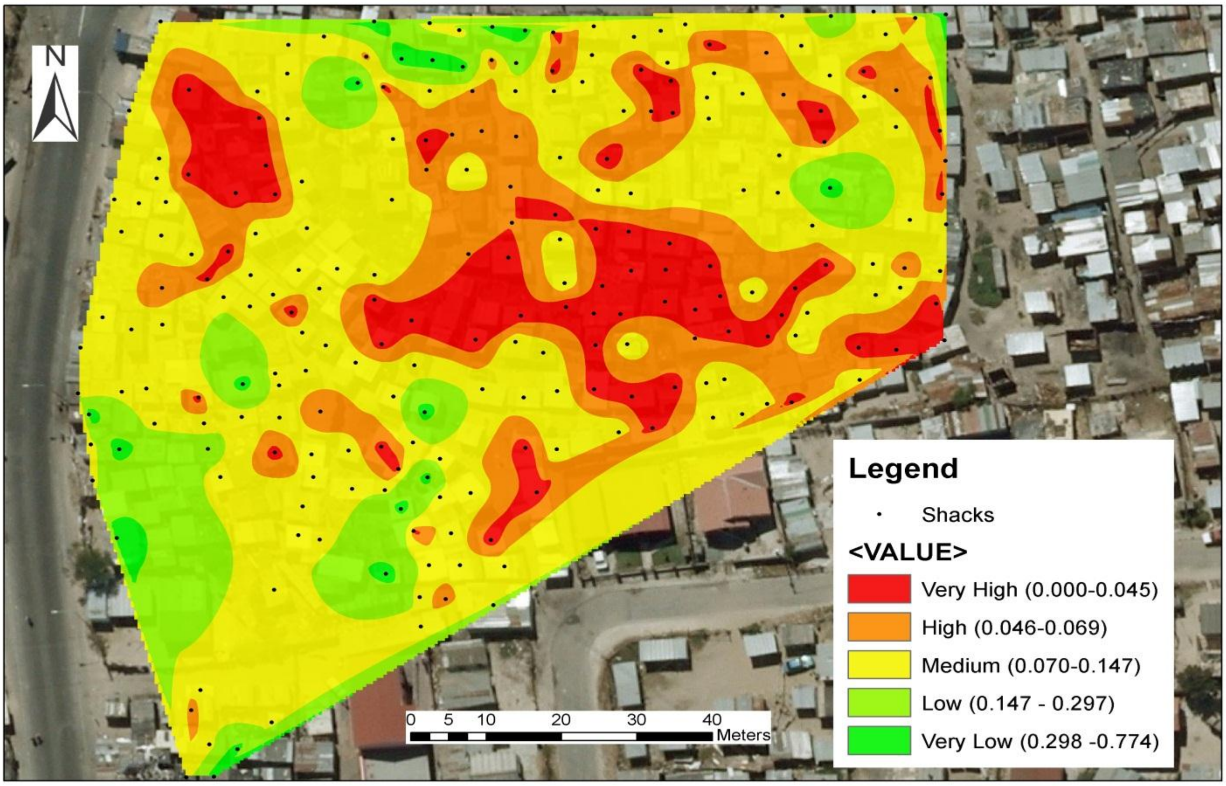

Figure 2. Raster map showing vulnerability based on prevalence of disease

During the questionnaire 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 flushing 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. Consequently, an additional map showing the relationship between the storm water drain and vulnerability to disease was created (Figure 14). Furthermore, a map showing the relationship between the type of toilets used and vulnerability to disease was created (Figure 15).

It was found that the people that suffered from both respiratory diseases and rashes were mostly located in the central part of the settlement (Figures 12 and 13) which is predominantly wet throughout the year. 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 14).

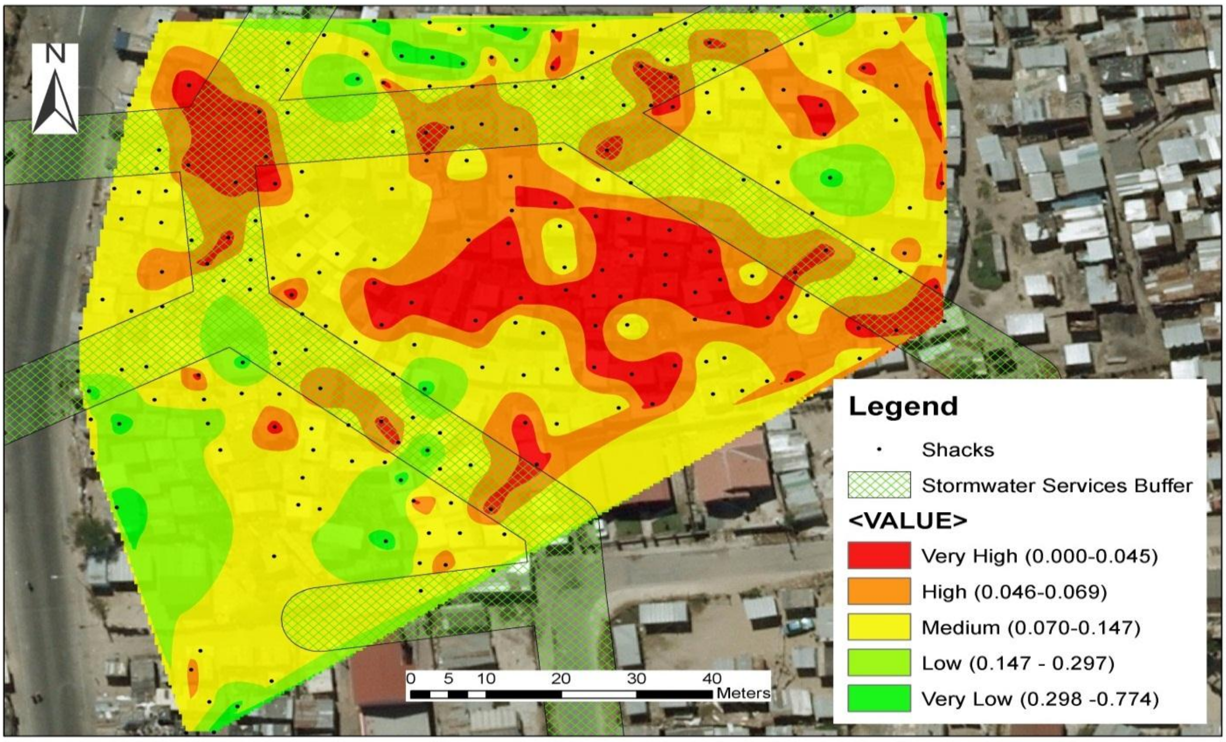

Figure 14. Vulnerability map showing location of storm water drain relative to disease prevalence

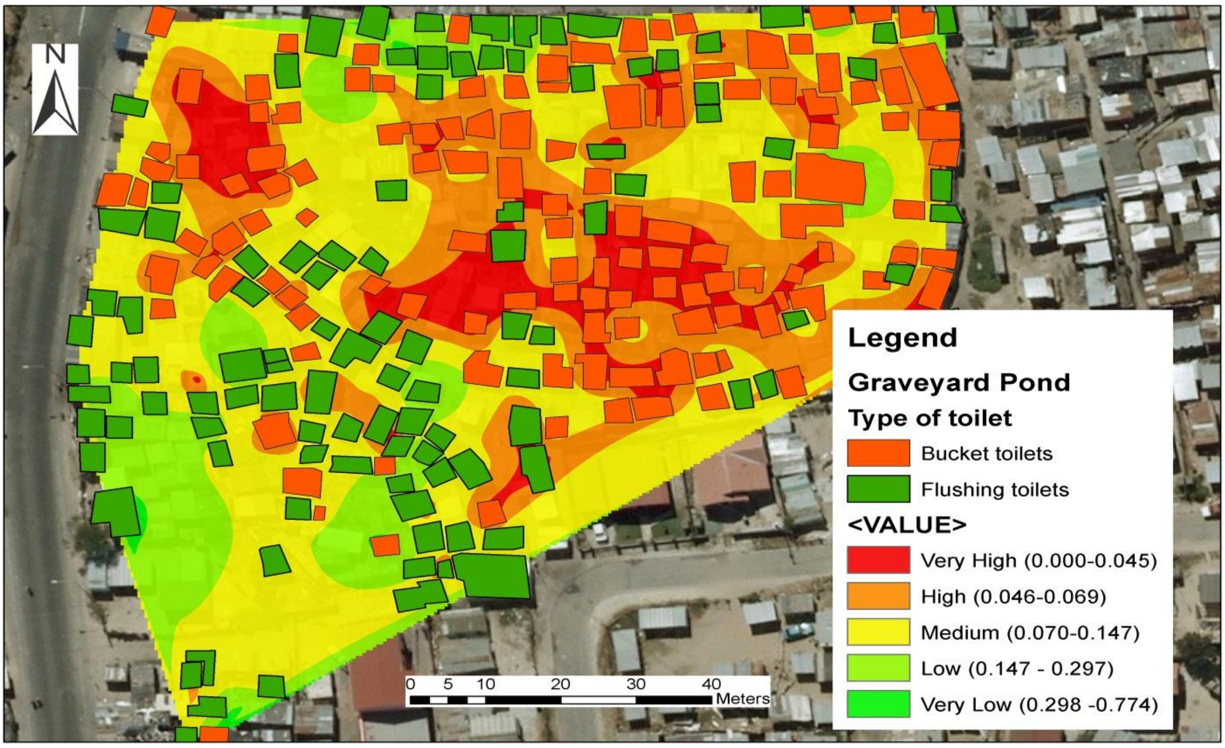

Figure 15. Vulnerability map showing the type of toilets used in Graveyard Pond relative to the prevalence of diseases

A further comparison between the choice of toilets and the prevalence of disease showed a distinct correlation (Figure 15). 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 are also pouring the excrement along with the rubbish into the marshy areas surrounding their structures (Figure 4).

The residents in the central part of the settlement are most vulnerable. This is based on the fact that they have the highest prevalence of diseases that escalate because of flooding, and the methods of mitigation in that region are highly inefficient. The next section describes the findings on income and vulnerability in Graveyard pond.

3.4 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.

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. 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.

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. Table 5 shows the final relative weights. In this table the magnitude of vulnerability is inversely proportional to the associated weight.

Table 3. Calculated weights for sources of income

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

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.

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 16).

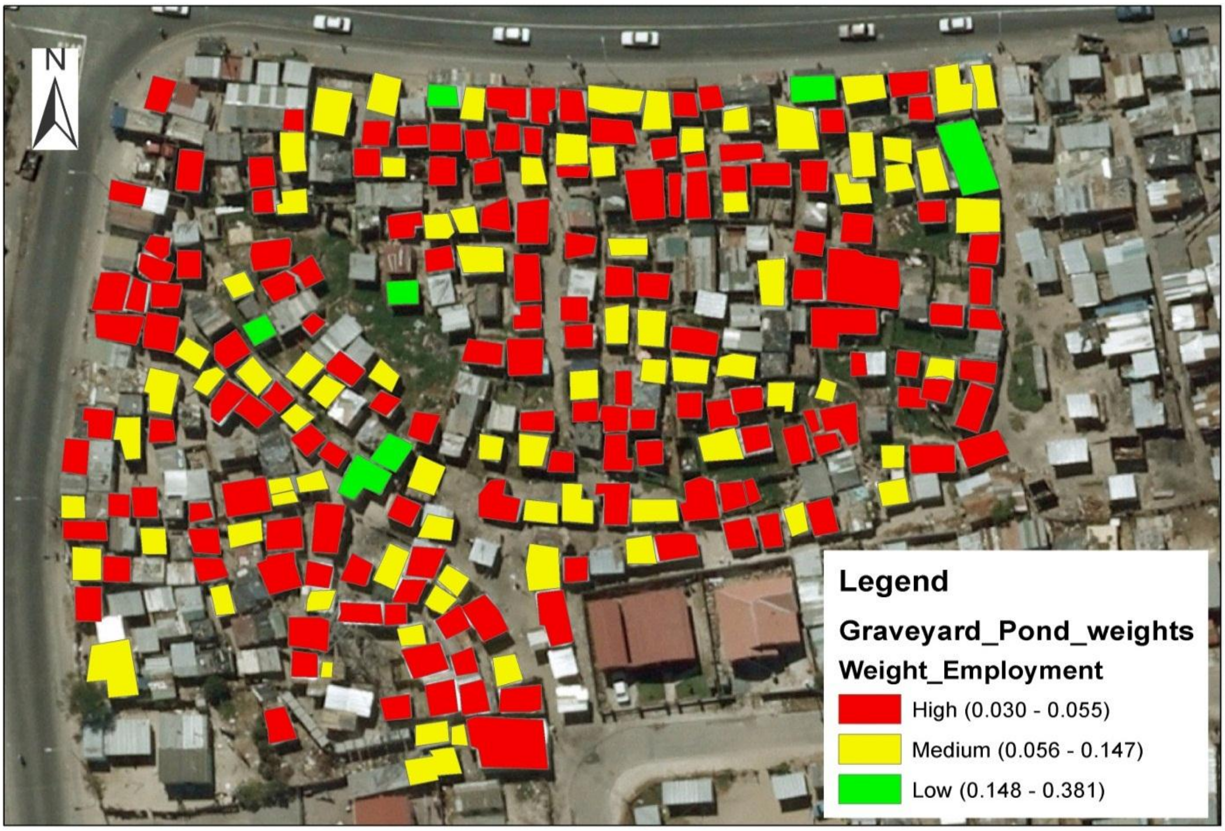

Figure 16. Map showing vulnerability based on type of income

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 17).

Based on the weights on Table 5, most households in Graveyard Pond depend solely on welfare grants (Figure 16). Also, although a number of households have part-time jobs, very few households have people who are fully or self-employed (Figure 16). Consequently, Figure 17 shows that most houses have a low income and are therefore unable to protect themselves from flooding. Hence, the low income levels in the households of Graveyard Pond have contributed significantly to their vulnerability.

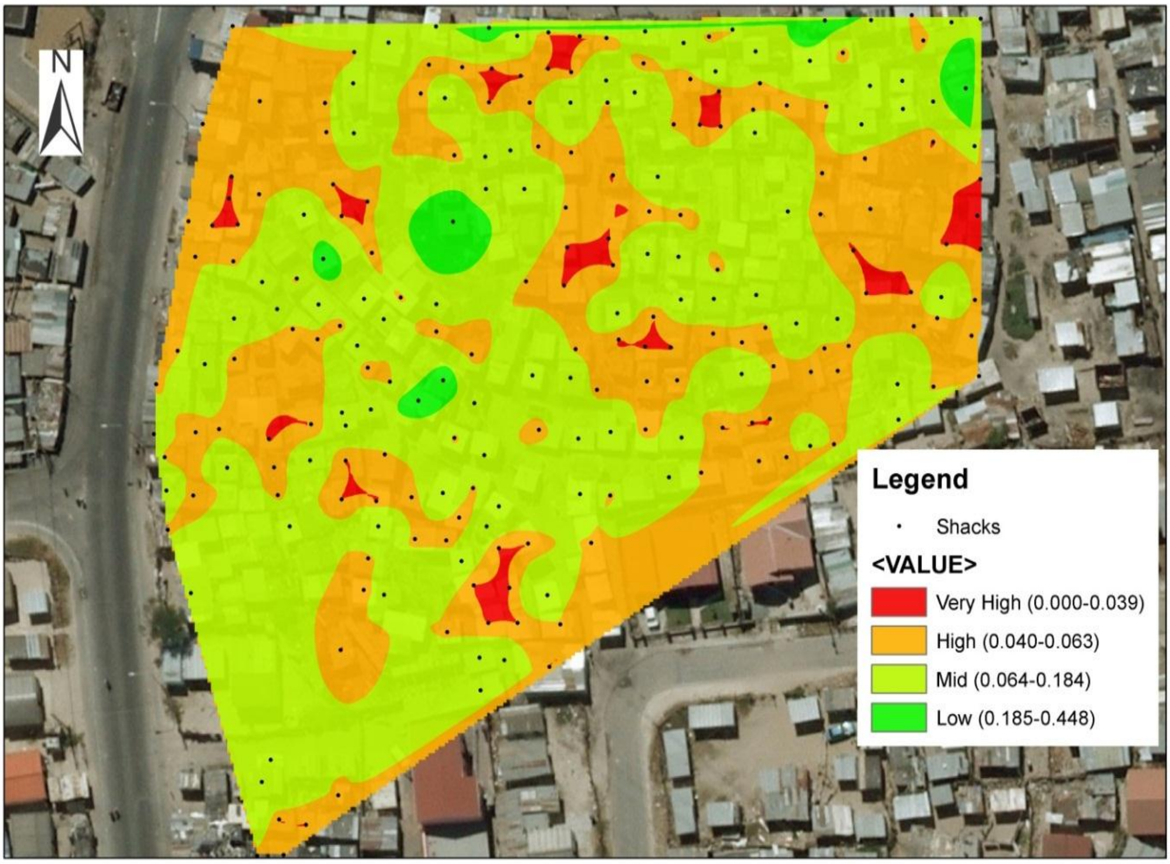

Figure17. Raster map showing vulnerability based on income levels

4 Conclusions

Multicriteria 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 sequentially compared pairs of alternatives. In other words, at any given stage of the MCE, the community leader 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. The simplicity of this method facilitated community participation in the risk assessment. Based on the results of this study, a participatory approach is recommended for risk assessment in informal settlements. The participation of the community is essential in estimating risk and identifying dynamics that may be amplifying risk. Pinpointing such dynamics can help identify potential solutions. For instance, the provision of toilets in Graveyard pond will significantly reduce flood risk.

The various maps showed that vulnerability and implicitly, risk was not homogeneous across Graveyard Pond. It was found that the central and southern sections of the settlement were most vulnerable based on exposure to both fires and flooding. Furthermore, the majority of the people in the central and southern regions of the settlement were unemployed and dependent on welfare grants. Lastly, waterborne and respiratory diseases were most prevalent in the central regions.

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