Participatory Multi-Criteria Evaluation and GIS: An Application in Flood Risk Analysis

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SUMMARY

Many of the rural-urban migrants in Cape Town have settled in informal settlements because they cannot afford to rent or buy decent housing. A number of these settlements are however located on poorly drained land that is often prone to flooding after prolonged rainfall. However, 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 inadequate information about the levels of flood risk within the individual informal settlements the CTCC has often implemented inappropriate remedies within such settlements. This study sought to investigate a participatory methodology that the CTCC could use to improve flood risk assessment in informal settlements.

This study responded to calls in various research papers calling for the adoption of participatory methodologies in developing a Geographic Information System (GIS). Using a case study of an informal settlement in Cape Town, this study proposed a methodology involving sourcing and integrating of community-based information into a GIS that can be used by the CTCC for risk assessment. Also, this research demonstrated the use of a participatory multi-criteria evaluation (MCE) for risk assessment. The MCE method of choice was the pairwise comparison method. Risk weights were subsequently calculated using pairwise comparisons for each household and mapped in the GIS to show the spatial disparities in risk between the households.

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).

In Cape Town, 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, 2008). 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. 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 participatory 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. Drawing from the arguments of the United Nations Department of Humanitarian Affairs (1992), Wilde (1994), Crichton (1999), Etkin (1999), Kelman (2001), Cardona (2004) and Kumpulainen (2006) 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.

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.

Turner *et al* (2003) developed a framework for vulnerability that identified exposure, sensitivity and resilience as the three main contributors to magnitude of vulnerability. This study was therefore focused on assessing these prescribed contributors in an informal settlement in Cape Town. Variations in these indicators will invariably result in variations in vulnerability.

1.3 Multi-criteria evaluation

Multi Criteria Evaluation (MCE) involves analysing a series of alternatives or objectives with a view to ranking them from the most preferable to the least preferable using a structured approach. The end product 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. Alternatively, they may 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).

A holistic assessment of all the attributes of the various methods reveals that the pairwise comparison method (PCM) and Trade-off analysis method (TAM) are overall the best options. 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) and it was therefore adopted in this study. Other MCE methods include fuzzy methods (Jiang & Eastman, 2000; Akter & Simonovic, 2005, 2006) and MACBETH (Bana e Costa *et al*, 2004). A thorough review and classification of refereed journal articles covering spatial multi-criteria decision analysis can be found in Malczewski (2006).

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

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 1). This specific area is the lowest part of the settlement and it can stay wet for several months.

Figure 1. Graveyard Pond, September 2007 (Source: City of Cape Town, 2008)

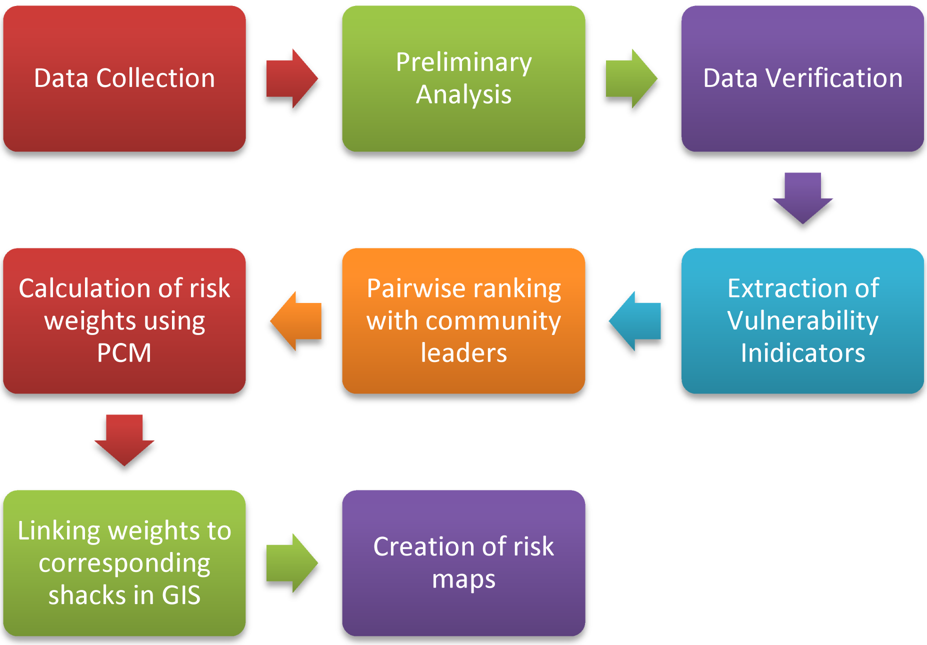
In contrast, imagery from the CTCC captured in 2009, shows an increase in the number of settlements in Graveyard Pond, especially in the wetter part of the settlement (Figure 2).

Figure 2. Graveyard Pond, March 2009 (Source: City of Cape Town, 2010)

2 APPROACH

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 questionnaires and capturing the spatial information using GIS. The questionnaire contained questions investigating exposure, sensitivity and resilience. Figure 3 summarises the methodology

Figure 3. Steps in vulnerability analysis of Graveyard Pond



From initial discussions with community leaders, 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 differential vulnerability. Various alternatives of these four criteria were drawn based on the responses to the questionnaires. The alternatives were ranked from the best case scenario being to the worst case scenario through discussions with the community leaders. 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 alternative preferred by the corresponding household. Once each household had been allocated a weight, a vulnerability map was created for each criterion in the entire settlement.

3 RESULTS

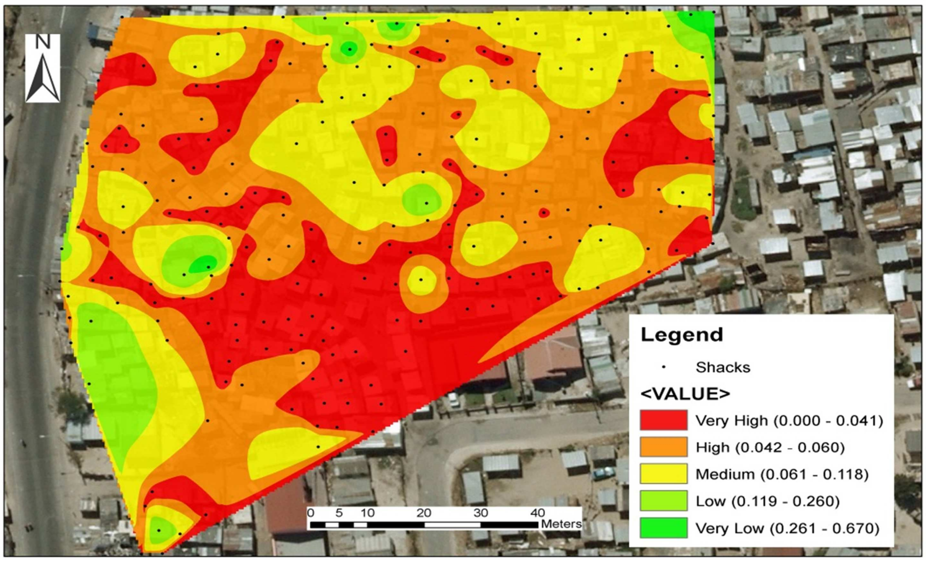
3.1 Exposure to hazards

Table 2 shows the derived relative weights for the forms of exposure to hazards in the settlement. The magnitude of the vulnerability is inversely proportional to the magnitude of the associated weight. The weights were allocated to the individual households based on their responses and a map was subsequently created to show the geographical distribution of the vulnerability (Figure 4).

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



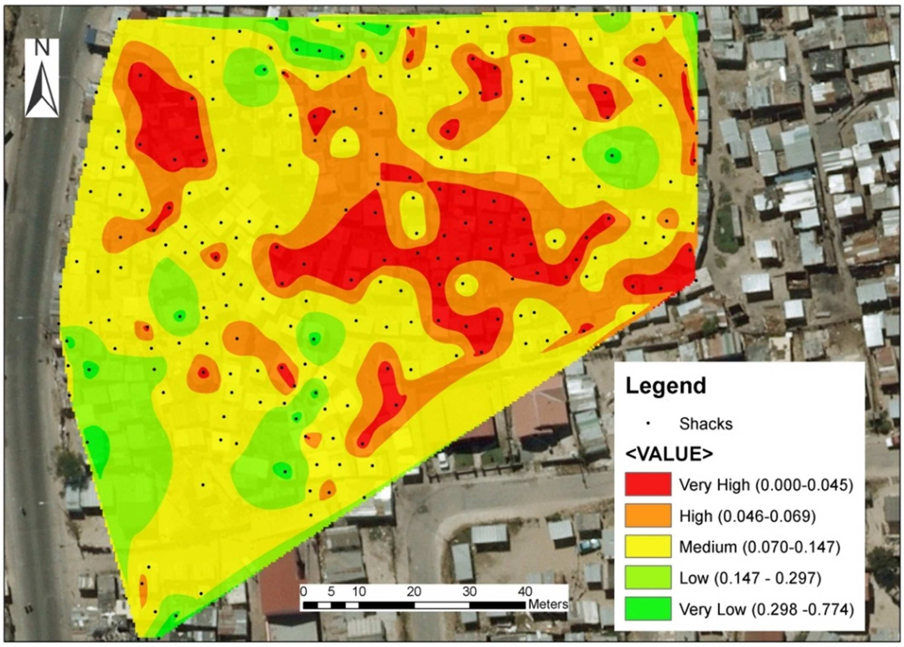
3.2 Sanitation and disease

Table 4 shows the final calculated weights for disease and sanitation. The weights were then allocated to the individual households based on their responses. For instance, if a particular household experienced no disease, a weight of 0.367 was allocated to that household. Figure 5 shows the resulting map.

Table 4. Weights for contribution of disease to vulnerability

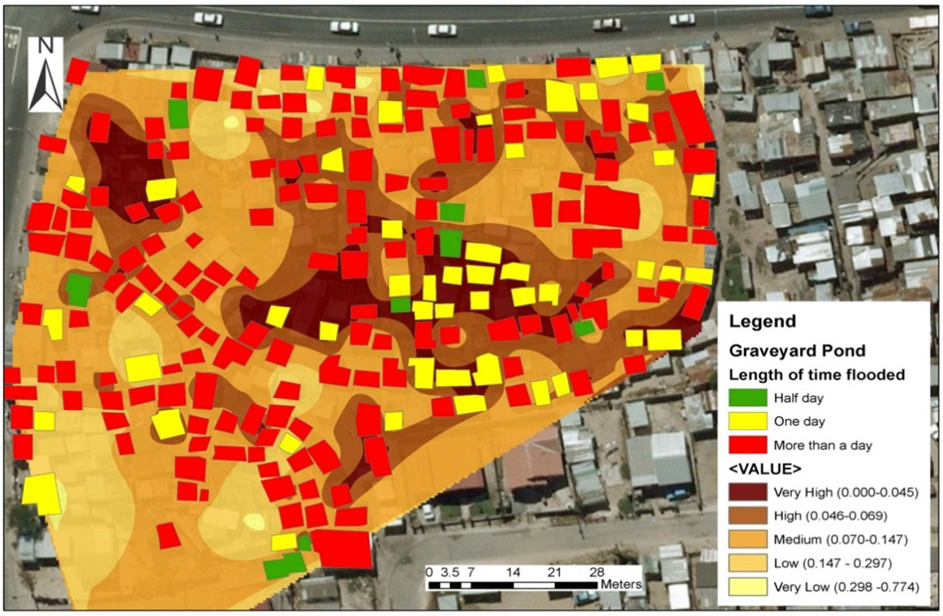
INCIDENCE OF DISEASES	
Alternatives	**Weights**
No Disease	0.367
Rash	0.224
Running Tummy	0.151
Cough/Flu	0.092
Running Tummy and Rash	0.065
Cough and Rash	0.046
Running Tummy and Cough	0.032
All	0.023
Sum:	1.000

Figure 5. Map showing vulnerability based on prevalence of disease



An additional map was created to assess the correlation between the length of time a household remained flooded and incidence of disease (Figure 6).

Figure 6. Map showing correlation between prevalence of disease and length of time flooded



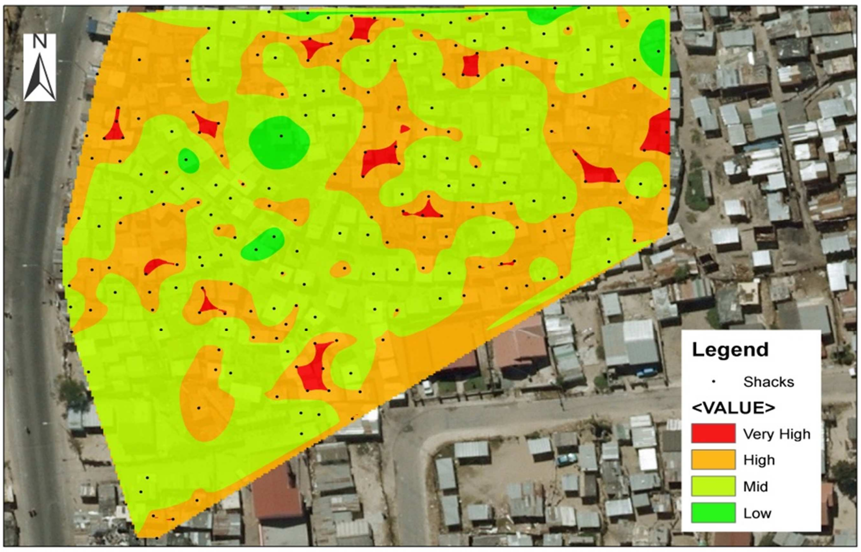
3.3 Income

Table 5 shows the final weights for the alternatives in income. Figure 7 shows the corresponding map.

Table 5. 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

Figure 7. Map showing vulnerability based on type of income



3.4 Methods of mitigation

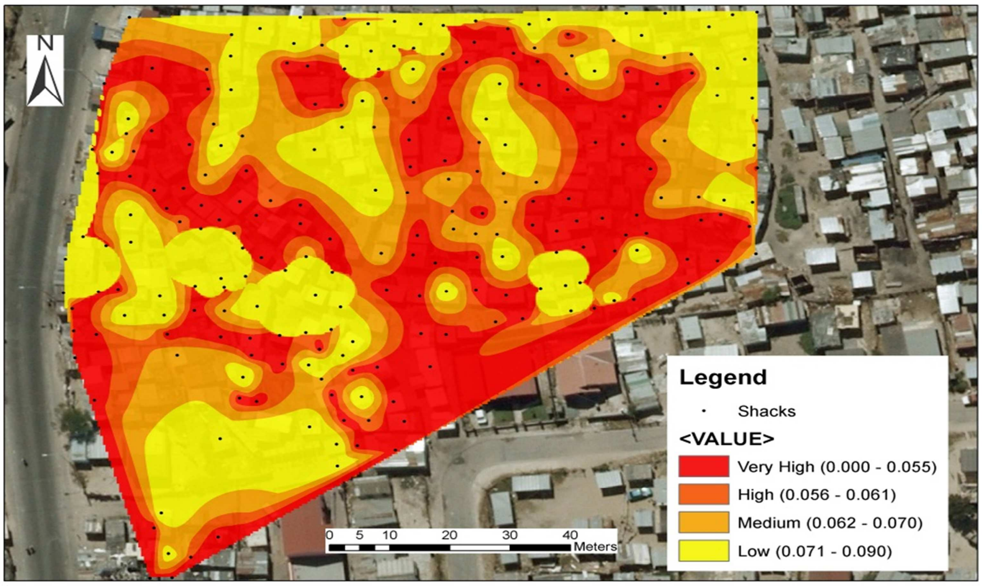
Table 6 shows the results of the PCM analysis based on discussions with the community leaders.

Table 6.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

It was found that although the households were individually applying various forms of mitigation against flooding, some were more efficient than others. The mitigation techniques were sequentially ranked based on their efficiency in mitigating the various forms of exposure to flooding. Figure 8 shows the resulting map.

Figure 8. Map showing vulnerability based on methods of mitigation



An assessment of income showed that most households are unable to protect themselves from flooding (Figure 7). Also, 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 8). The least efficient responses were found to be in the central and southern part of the settlement. Notably, the same areas were also the most vulnerable areas based on exposure to hazards (Figure 4) and disease (Figures 5 and 6). Figures 5 and 6 also showed a correlation between the length of time a household stays flooded and the prevalence of disease in that household. Therefore the households in the central and southern part of the settlement are the most vulnerable.

4 CONCLUSIONS

Multi-criteria Evaluation (MCE) has formed the crux 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 its simplicity favours community participation. From the results of this study, a participatory approach to risk assessment in informal settlements is plausible. The participation of the community is essential in estimating risk and pinpointing dynamics that may be amplifying risk.

The various maps showed that vulnerability and implicitly, risk was not homogeneous across Graveyard Pond. Based on the assessment of various vulnerability indicators, the central and southern parts of the settlement were most vulnerable.

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