INTEGRATING LOCAL, INDIGENOUS KNOWLEDGE AND GEOGRAPHICAL INFORMATION SYSTEM IN MAPPING FLOOD VULNERABILITY AT QUARRY ROAD WEST INFORMAL SETTLEMENT IN DURBAN, KWAZULU-NATAL

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A thesis submitted to the School of Agricultural, Earth and Environmental Sciences, at the University of KwaZulu-Natal, in fulfilment of the academic requirements for the degree of Doctor of Philosophy (PhD) in Environmental Science

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ABSTRACT

Reducing flood vulnerability is crucial in reducing flood impacts, and mapping flood vulnerability is one of the most useful options for reducing flood vulnerability. This is because it helps locate where the vulnerable households or areas are, which in turn, supports policy and strategic interventions. However, the complex nature of flood vulnerability, especially in informal settlements requires holistic consideration of the dweller's experiential, contextual, and situational knowledge in mapping flood vulnerability. This study sought to establish a methodological approach for integrating Local, Indigenous Knowledge and Geographical Information System to map flood vulnerability in Quarry Road West informal settlement in Durban, South Africa. A convergent parallel mixed methods approach which involved a digital household survey (n=359), interviews with key informants (n=10), focus group discussions (n=2) and a global positioning system was used in the study. Descriptive and inferential statistics were used to analyse the quantitative data while thematic analysis was used to analyse the qualitative data. The findings reveal that using Local and Indigenous Knowledge that community members possess, generated context-specific indicators for mapping flood vulnerability in Quarry Road West informal settlement. The findings also reveal that the proximity of houses to the Palmiet River and the main roads, the nature of the soil and the type of materials people were using to build their houses hugely contributed to the vulnerability of people to flooding in the study area. The study further showed that flood vulnerability in the study area was a result of socio-economic, physical and institutional challenges. Using the Analytical Network Process helped to foster community participation and comprehensively integrated Local and Indigenous Knowledge with Geographical Information System in mapping flood vulnerability in Quarry Road West informal settlement. Flood vulnerability in the informal settlement exhibited spatial differentiations. Households along the Palmiet River were highly vulnerable to flooding and a section of the settlement called Mcondo 1 was highly vulnerable to flooding while maMsuthu had low flood vulnerability. The study concludes that using community members' Local and Indigenous Knowledge to select indicators was crucial for mapping flood vulnerability in an informal settlement, as it provided a more nuanced understanding of flood vulnerability. The methodological approach presented in this study can help decision-makers and other stakeholders to have sight of sustainable

solutions and context-specific strategies that could be employed to increase the resilience of people at local levels to flooding.

PREFACE

The research work described in this thesis was conducted in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, from February 2020 to May 2022, under the supervision of Professor Maheshvari Naidu (School of Social Sciences, University of KwaZulu-Natal; UKZN, South Africa) and Professor Onisimo Mutanga (School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal; UKZN, South Africa)

I would like to declare that the research work reported in this thesis has never been submitted in any form for any degree or diploma to any tertiary institution. It, therefore, represents my original work. Where use has been made of the work of other authors or organizations it is duly acknowledged within the text and references chapter.

Signed: [redacted] Date: 5-06-2022
Garikai Martin Membele

As the candidate's supervisors, we certify the aforementioned statement and have approved this thesis for submission.

Supervisor: [redacted] Date: 5-06-2022
Professor M. Naidu

Co-supervisor: [redacted] Date: 5-06-2022
Professor O. Mutanga

DECLARATION -1 PLAGIARISM

I, GARIKAI MARTIN MEMBELE, declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

(ii) This thesis has not been submitted for any degree or examination at any other university.

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DECLARATION 2- PUBLICATION AND MANUSCRIPTS

1. **Membele, G. M.,** Naidu, M., & Mutanga, O. (2021). Integrating Indigenous Knowledge and Geographical Information System in mapping flood vulnerability in informal settlements in a South African context: a critical review. *South African Geographical Journal*, 1-21. https://doi.org/10.1080/03736245.2021.1973907

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DEDICATION

"Unto Him, who is able to do exceedingly abundantly above all we ask or think according to the power that worketh in us"

To my family and my mother-in-law for the prayers.
Special thanks to my wife Tamara and the girls Nyasha and Akatentendaka for giving me the space to do this.

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I would like to thank the BDSS UKZN for the scholarship to pursue my PhD studies at UKZN.

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LIST OF ACRONYMS

AHP	Analytic Hierarchical Process
ANP	Analytic Network Process
BDSS	Big Data for Science and Society
CENAPRED	National Center for the Prevention of Disasters
DEM	Digital Elevation Model
FEWS	Forecast Early Warning System
FGD	Focus Group Discussion
FRI	Flood Risk Index
GIS	Geographical Information Systems
GPS	Global Positioning System
HH	Household
LIDAR	Light Detection and Ranging
MCA	Multi-Criteria Analysis
MCDM	Multi-Criterial Decision Making
MCE	Multi-Criteria Evaluation
MOVE	Method for the Improvement of Vulnerability Assessment in Europe
PCA	Principal Component Analysis
PGIS	Participatory Geographical Informal Systems
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRRP	Palmiet River Rehabilitation Project
RRA	Rapid Rural Appraisal
SAR	Synthetic Aperture Radar
SMCE	Spatial Multi-Criteria Evaluation
STRM	Shuttle Radar Topography Mission
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TV	Television
UAVs	Unmanned Aerial Vehicles
VGI	Volunteered Geographical Information
WGS	World Geodetic System
WLC	Weighted Linear Combination
WOA	Weighted Overlay Analysis
WoS	Web of Science

CHAPTER 1: GENERAL INTRODUCTION

This Chapter provides a synoptic view of the research background and outlines the objectives and the structure of the thesis.

1.1 Flood vulnerability in informal settlements

Many cities across the world are rapidly becoming urbanized (United Nations, 2015). In 2018, 55 per cent of the population in the world was living in urban areas. By 2050, almost 70 per cent of the entire population in the world will be living in cities and almost 90 per cent of this increase will be from Asia and Africa (United Nations, 2019). Over one billion people are currently living in informal settlements across the world and in 2050, this number is expected to increase to three billion by 2050 (United Nations, 2022). Zerbo et al. (2020) assert that Sub-Saharan Africa has the highest number of people living in informal settlements due to its high rate of urbanization. In South Africa, close to 5 million people are living in informal settlements (International Budget Partnership, 2021; Nkonki-Mandleni et al., 2021).

Informal settlements have been labelled differently with different terms, which are used interchangeably in some contexts (Abunyewah et al., 2018). These terms include low-income settlements (Marutlulle, 2017); unplanned settlements (Abunyewah et al., 2018; Han et al., 2017); slums (Mahabir et al., 2016); shacks (Amoako, 2018; Drivdal, 2016); shantytowns (Han et al., 2017); and squatter settlements (Barry & Rüther, 2005). According to Jones (2017, p. 2), the interchangeable use of these terms is still a subject of academic debate. In the South African context, some terms like slum connote ideological baggage hence, the term informal settlement is preferred because it is considered less pejorative (Marx & Charlton, 2003; Zerbo et al., 2020) and has less divisive original connotations (Gilbert, 2007). The UN-Habitat (2015) define informal settlements by highlighting the human-environment relationships. This relationship is critical in this research. The UN-Habitat (2015, p. 1), defines informal settlements as "residential areas where inhabitants have no security of tenure for the land, they lack basic services and the housing may not comply with current planning and building regulations. They are often situated in geographically and environmentally hazardous areas".

In South Africa and many other developing countries, informal settlements are located in hazardous areas (Abunyewah et al., 2018; Le Quéré et al., 2020; Williams et al., 2019). According to Satterthwaite and Bartlett (2017), the location of informal settlements in environmentally hazardous areas like wetlands and floodplains make them more exposed and susceptible to floods and the dwellers more vulnerable to flood hazards and stormwater events. Floods cause damage to infrastructure, health problems, displacements and loss of lives and livelihood. Climate change and its effects have made the situation worse (Cobbinah & Kobugabe, 2019). Hence, Kasei et al. (2019) argue that over 3.2 million urban dwellers will be at risk of flooding by 2050 and informal settlements dwellers will be the most affected. This is not only because of their location but because of their socio-demographic and economic factors as well as their low adaptive capacity to flooding (Cutter et al., 2003; Deria et al., 2020). Therefore, there is a need to establish the factors responsible for causing flood vulnerability in a particular area before implementing meaningful flood risk reduction measures.

In many urban areas, efforts have been made to reduce the impacts of flooding mainly by improving infrastructures such as drainages, sea walls and high-tech flood early warning systems (Hiwasaki et al., 2014). However, in most informal settlements, these infrastructural developments are limited largely because the informal settlements are considered illegal (Satterthwaite et al., 2007; Williams et al., 2018). Satterthwaite et al. (2007), argue that since most municipalities in the global south consider informal settlements to be illegal, they cast a blind eye on implementing strategies that can reduce flood vulnerability in these areas. This has prompted informal settlement dwellers to use locally-based strategies to deal with floods (Musungu et al., 2016). Hence, Parsons et al. (2016) argue that informal settlement dwellers are not 'helpless" victims of floods, as they have been using their experiential knowledge to reduce flood impacts in their settlements.

Furthermore, while the technical or infrastructural interventions are important in urban areas as they help to save people's lives and property during a flood event, the social, cultural and human factors that cause communities to be vulnerable to floods should not be ignored (Dintwa et al., 2019; Wu et al., 2002). According to Wisner et al. (2004), these factors should not be overlooked because they contribute to making a hazard become a disaster. Kasei et al. (2019) and Dube and Munsaka (2018) contend that there is a paucity of knowledge on the use of Indigenous Knowledge for reducing flood vulnerability in urban areas. This is mainly because Indigenous Knowledge is considered undocumented, and outdated. Reducing flood vulnerability has been identified to be one of the most useful options for reducing flood impacts (Apraku et al., 2018; United Nations, 2016).

1.2 Mapping flood vulnerability

Vulnerability is defined differently depending on the area of study. For instance, in economics, vulnerability is defined as a consequence of a process and how a particular household responds to risk due to their inherent characteristics (Alwang et al., 2001). In disaster risk studies, Merz et al. (2007) defined vulnerability as elements at risk, damage potential and loss. According to Van Westen (2013), vulnerability is the susceptibility of a community to hazard impacts caused by their physical, social, economic and environmental conditions. In this study, flood vulnerability is defined as the increased susceptibility of a community or household to flood impacts caused by their physical, social, economic and environmental conditions (United Nations, 2016; Van Westen, 2013). According to Nethengwe (2007) and Wu et al. (2002), people's vulnerability to flooding in a particular area is spatially differentiated. This is because people tend to have different coping and adaptive capacities to flood hazards, as such they are affected by floods differently. Mapping flood vulnerability is one of the crucial ways of identifying the most vulnerable people or households in a particular community (Hoque et al., 2019). Mapping flood vulnerability also helps to have an in-depth understanding of the major factors that influence people's flood vulnerability (Hung & Chen, 2013; Jha & Gundimeda, 2019). It also provides a base upon which decision-makers can intervene by formulating policies and implementing strategic actions to reduce people's vulnerability to flooding (Ardiansyah & Sumunar, 2020). Reducing flood vulnerability in informal settlements is crucial because it contributes to achieving Sustainable Development Goals (SDGs), particularly number 11 which relates to making cities and human settlements safer, resilient and sustainable (United Nations Development Programme, 2016).

Geographical Informal System (GIS) has been widely used for mapping floods at various scales. This is because of its inherent capabilities which enable it to store, manage, analyse, visualize geographical data and support decision-making (Khan, 2014; Tripathi & Bhattarya, 2004). GIS has for a long time been used for tracking, modelling and predicting flood disaster trends and mitigating risks and damages in many areas (Chan et al., 2022). However, GIS has been criticized for being too 'technical expert' oriented, as it alienates community members from many mapping processes (Manap et al., 2013). However, several scholars (Brandt et al., 2019; Canevari-Luzardo et al., 2017) argue that one way of limiting the role of the 'technical expert' in using GIS is by having adequate community participation during the mapping process. According to de Brito et al. (2018) community participation is very important because it enhances the legitimacy and reliability of flood vulnerability maps.

Furthermore, GIS has been combined with other approaches to map flood vulnerability (Canevari-Luzardo et al., 2017; Hung & Chen, 2013). Of all these approaches, the indicator-based approach has been widely used, especially in developing countries (Balica et al., 2009; de Brito & Evers, 2016; Nasiri et al., 2016). The indicator-based approach has also been encouraged by United Nations agencies (United Nations International Strategy for Disaster Reduction, 2005). This is because the approach is considered flexible, transparent, and helps in raising public awareness as well as depicting priority factors for reducing flood vulnerability in a particular area (Nasiri et al., 2016). According to Balica et al. (2009), the indicator-based approach allows for the combination of components or factors that make people and places vulnerable to flooding, thereby providing a proper understanding of the flood vulnerability problem in an area. However, Salvati et al. (2021) warn that indicators selected for mapping flood vulnerability influence the quality of the final maps. Chan et al. (2022), also contend that the indicator-based approach has challenges when it comes to weighting, standardization and aggregation.

Several scholars (de Brito et al., 2018; Eini et al., 2020; Niyongabire & Rhinane, 2019) mapped flood vulnerability at a city level using indicators generated from the literature while others (Chen et al., 2019; Muller et al., 2011; Musungu et al., 2012) used both indicators from the literature and expert knowledge to map flood vulnerability at community levels. However, a few studies (Lefulebe et al., 2014; Musungu et al., 2012) selected indicators using Local and Indigenous Knowledge for mapping the vulnerability in informal settlement contexts. The use of indicators from the literature and expert knowledge is problematic in our view. This is because it overgeneralizes flood vulnerability and as such, it may not be easy to accurately identify people who may need urgent help. Furthermore, using indicators that were not generated from a specific area may not appropriately depict flood vulnerability in an area because factors that influence flood vulnerability may be different from place to place (Nethengwe, 2007; Wu et al., 2002).

Musungu et al. (2012) used combined residents' experiential knowledge of floods, GIS and Multi-Criteria Evaluation to map disparities of flood vulnerability in Graveyard Pond informal settlement in Cape Town. However, only one community leader was involved in assessing the generated alternatives. Community members only participated in mapping flood vulnerability by merely responding to questionnaires given to them. However, Hedelin et al. (2017) argue that adequate community participation is crucial in reducing flood risks and promoting sustainable development in any particular area. Furthermore, Musungu et al. (2012) only considered exposure and did not consider the sensitivity and adaptive capacity. Sensitivity and adaptive capacity are important dimensions of flood vulnerability (Hung & Chen, 2013; Yuan et al., 2016). Musungu et al. (2012) used the Analytical Hierarchical Process (AHP) to map flood vulnerability in the Graveyard Pond informal settlement. However, the AHP has been criticized for its failure to take into account interdependent criteria (de Brito & Evers, 2017; Li et al., 2011). Hence, the Analytical Network Process (ANP) has been recommended (de Brito et al., 2018; Ghorbanzadeh et al., 2018). The ANP has however not been used for mapping flood vulnerability in informal settlement settings in South Africa and other countries.

Lefulebe et al. (2014) combined Indigenous Knowledge and stakeholder perspectives in upgrading an informal settlement called Monwabisi Park in Cape Town. Participatory GIS and Multi-Criterial Evaluation were used to produce the flood vulnerability maps. However, this study did not adequately demonstrate how Indigenous Knowledge was used in the analysis and mapping of flood vulnerability in Monwabisi Park informal settlement. Furthermore, Musungu et al. (2012) and Lefulebe et al. (2014) did not validate nor check the robustness of the flood vulnerability maps. The failure to validate and check the sensitivity of the flood vulnerability maps limits their usefulness for decision-making (Ouma & Tateishi, 2014; Rincón et al., 2018). The lack of validated flood vulnerability maps is not just a problem in South Africa, it is also a recurring problem in studies conducted in other developing countries (de Brito et al., 2018). Several data sets are required for mapping flood vulnerability.

However, the lack of updated and fine-resolution spatial data has been identified as one of the major problems associated with mapping flood vulnerability in informal settlements (Kienberger, 2014; Muller et al., 2011; Zerbo et al., 2020). This situation, therefore, hinders the identification of highly vulnerable people or households in informal settlements. It also hampers the formulation and implementation of strategic interventions to reduce people's flood vulnerability.

Local and Indigenous Knowledge has been identified as crucial for reducing the data challenge in informal settlements (Hazarika et al., 2018; Romanescu et al., 2018). Local and Indigenous Knowledge also provides context-specific, cost-effective, culturally appropriate and socially inclusive approaches for fostering resilience at local levels (Khan, 2014; Muyambo et al., 2017; Wisner et al., 2004).

1.3 Integrating Local and Indigenous Knowledge in mapping flood vulnerability

Over the years, there has been a debate on what constitutes Local and Indigenous Knowledge (Apraku et al., 2018; Nkomwa et al., 2014; Nyadzi, 2021). In this study, Local Knowledge is defined as the knowledge people acquired as a result of them residing in a particular area or community for some time (Langill, 1999; Naess, 2013), while Indigenous Knowledge is defined as skills, practices, values, beliefs and norms accumulated over generations (Alexander et al., 2019; Ngwese et al., 2018; UNEP, 2008). Indigenous knowledge is specific to a defined geographical area or community; hence it is crucial in localising interventions, and policies (Apraku et al., 2018; Nkomwa et al., 2014; Nyadzi, 2021). Ossai (2011) argues that Indigenous Knowledge is not static but is adaptable hence it undergoes changes due to internal experimentation and external knowledge.

Mercer et al. (2010) contend that Local and Indigenous Knowledge should be considered in any flood risk reduction effort at a local level. This is because they help in developing mitigation and adaptive measures that are generated from the community, thereby promoting sustainability (Brandt et al., 2019; Peters-Guarin et al., 2012). Local and Indigenous Knowledge also help to have an extensive understanding of the factors that cause flood vulnerability and the extent of the damages caused by floods in a specific area (Mavhura et al., 2013; Musungu et al., 2012). Hence, international organisations and individual nations have recognised the significance of Local and Indigenous Knowledge in disaster risk reduction (Ebi, 2012; Republic of South Africa, 2002; UNDRR, 2005, 2015). However, despite these critical advances demonstrating the significance of Local and Indigenous Knowledge in disaster risk reduction, there are no studies as far as one can discern that are more robust, participatory and comprehensively consider community members' Local and Indigenous knowledge to map flood vulnerability in informal settlements in South Africa and other developing countries.

1.4 Aim and objectives

The overall aim of this study was to develop a methodological approach for integrating Local, Indigenous Knowledge and GIS in mapping flood vulnerability in Quarry Road West informal settlement in Durban, South Africa. The specific objectives of the study were as follows:

1. To provide a detailed overview of approaches and the state of knowledge in literature on the integration of Indigenous Knowledge and Geographical Information System in mapping flood vulnerability
2. To investigate the main factors that cause flood vulnerability in Quarry Road West informal settlement
3. To determine local context-specific indicators using Local and Indigenous Knowledge for mapping flood vulnerability in Quarry Road West informal settlement
4. To develop a methodological approach that integrates the community members' Local and Indigenous Knowledge and GIS for mapping flood vulnerability in an informal settlement.

1.5 Research questions

The research questions for the specific objectives are as follows:

1. What is the state of knowledge in integrating Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa?
2. What methodological approaches are used for mapping flood vulnerability in developing countries?
3. What context-specific factors are responsible for causing flood vulnerability in Quarry Road West informal settlement?

4. What Local and Indigenous Knowledge-based criteria are appropriate for mapping flood vulnerability in Quarry Road West informal settlement?
5. To what extent can an approach that integrates Local or Indigenous Knowledge be used to select context-specific criteria for mapping flood vulnerability in the study area?
6. To what extent can an approach that integrates Local, Indigenous Knowledge and GIS-based MCDM using ANP be used to map flood vulnerability in an informal settlement?
7. How well does the ANP display flood vulnerability in Quarry Road West informal settlement?
8. What areas in the study area experience low, moderate and high flood vulnerability?

1.6 Description of the study area

Quarry Road West informal settlement is one of the over 560 informal settlements dotted around Durban. The informal settlement is located between Latitudes -29.809 S and -29.779 S and Longitudes 30.964 E and 30.971 E. It is about 9.5 km from the Durban Central Business District (CBD). Quarry Road West informal settlement is composed of three sections namely Mcondo 1, Mcondo 2, maSuthu and Mapondweleni (Figure 1.1). The settlement is considered illegal because it is on land that belongs to various state institutions and a private landowner (Sim et al., 2019; Wiltgen Georgi et al., 2021). Therefore, the residents are not allowed to build permanent structures. The informal settlement was established in 1984 (Sutherland, Roberts, et al., 2019). According to Williams et al. (2019), the settlement rapidly expanded between 2012 and 2013. Rural-urban migration is the primary cause of the rapid expansion of Quarry Road West informal settlement (Mazeka et al., 2019; Williams et al., 2018). There are now over 2400 people living in Quarry Road West informal settlement (Mazeka et al., 2019). The settlement is characterised by poor drainages, poor housing conditions, poverty, unemployment, high population density and a lack of basic services (Mazeka et al., 2019; Williams et al., 2018).

Quarry Road West informal settlement dwellers have strong social ties and well organised political structures (Sim et al., 2019). According to Williams et al. (2018), interactions between the residents and the municipality are very low, hence the residents are hardly involved in any form of planning or decision-making.

The Palmiet River cuts informal settlement and the settlement is within a 1:100 year flood line, hence it is prone to flood hazards (Mazeka et al., 2019). Like other areas in Durban, Quarry Road West informal settlement experiences a sub-tropical climate with mild, dry winters and hot wet summers (Roberts & O'Donoghue, 2013; Sutherland, Roberts, et al., 2019). Unlike many suburbs in Durban, Quarry Road West informal settlement is located in a relatively flat area (Mazeka et al., 2019; Williams et al., 2019). The average rainfall is over 1,000 mm and the highest amount of rain is between October to March (Williams et al., 2018). Floods experienced in May 2016, April 2019 and April 2022 have been some of the worst and most devastating floods in the settlement, as they resulted in a loss of property, washing away of houses and massive displacements.

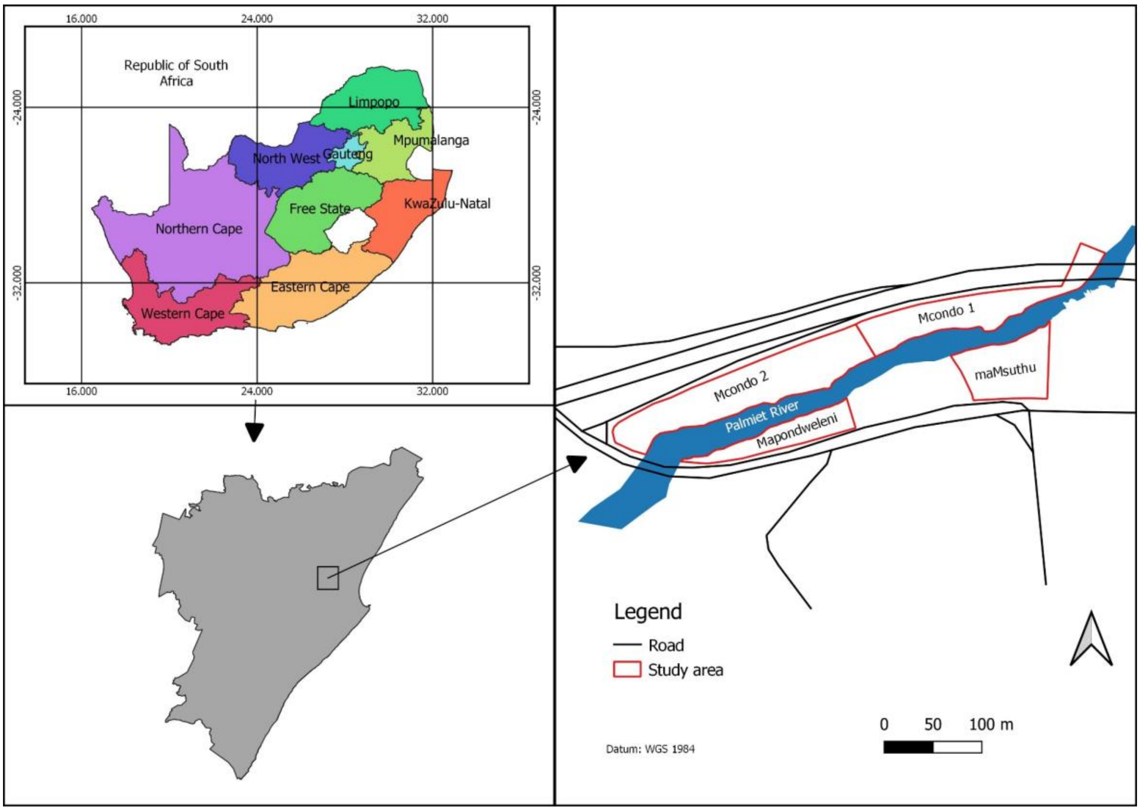

Figure 1.1 Location of the Quarry Road West informal settlement

(Source: Authors)

1.7 Thesis outline

This thesis is composed of five chapters. Chapters two to four have been written as stand-alone papers. In these chapters, three papers have been published online in peer-reviewed journals. The paper in chapter four is under peer review in an international journal. Although each paper stands alone, they were drawn from one overall research objective hence, some repetition may be observed especially in the introduction and method sections.

Chapter 1 of this thesis gives a general background and scope of the study. It also highlights the research problem, objectives and research questions addressed in the study.

Chapter 2 contains the literature review. The first paper gives context to the study by critically reviewing the literature relating to integrating Indigenous Knowledge and Geographical Information System (GIS) in mapping flood vulnerability in South Africa.

Chapter 3 is also a literature review paper. The paper in this chapter takes a global perspective by providing a detailed analysis of the elements, components, scale and settings, criteria selection methods, data, the purpose of the maps, analytical approaches, sensitivity analysis and validation techniques that were used for mapping flood vulnerability in countries in the global south.

Chapter 4 presents the results of using Local and Indigenous Knowledge in selecting indicators for mapping the vulnerability of people to flood hazards in the Quarry Road West informal settlement. This paper highlights the main causes of flood vulnerability in Quarry Road West informal settlement. It also provides context-specific indicators for mapping flood vulnerability in Quarry Road West informal settlement.

Chapter 5 operationalises the indicators identified in chapter 4. The chapter also shows the areas that have a high, moderate and low vulnerability to flooding in the study area. The chapter further shows how community participation and the Analytic Network Process approach can be used for mapping flood vulnerability in an informal settlement context.

The final part of this study is presented in chapter 6. This chapter summarizes and presents the major finding of this study. It ends by giving a conclusion based on the proceeding chapters and makes recommendations for future research on the integration of local and indigenous and GIS in mapping flood vulnerability in informal settlements.

A single reference list is provided at the end of the thesis.

CHAPTER 2: LITERATURE REVIEW

This chapter is based on the following:

Membele, G. M., Naidu, M., & Mutanga, O. (2021). Integrating Indigenous Knowledge and Geographical Information System in mapping flood vulnerability in informal settlements in a South African context: a critical review. *South African Geographical Journal*, 1-21. https://doi.org/10.1080/03736245.2021.1973907

Abstract

Climate change and the multidimensional nature of flood vulnerability, necessitate an in-depth consideration of experiential knowledge in reducing flood vulnerability in geospatial environments such as informal settlements. The objective of this paper is to provide a critical review of literature and scholarship in the context of the integration of Indigenous Knowledge and Geographical Information System in mapping flood vulnerability in South Africa. Keywords were searched in two databases for empirical studies that integrated Indigenous Knowledge and Geographical Informal System in mapping flood vulnerability in South Africa. The search extended to literature cited in the papers identified from the databases. The studies were thematically analysed and synthesized. The findings reveal that flood vulnerability in South Africa is mainly considered from an integrated perspective. Approaches used to integrate Indigenous Knowledge and Geographical Information Systems in mapping flood vulnerability are fragmented. There is a lack of sensitivity analysis and map validation, limited use of Indigenous Knowledge as well as inadequate community participation in the mapping of flood vulnerability in informal settlements. This critical review demonstrates the need for a comprehensive, explicit and participatory approach for integrating Indigenous Knowledge and Geographical Information System that genuinely utilize the special characteristics that each of them possesses.

Keywords: Indigenous knowledge; geographical information system; integration; flood vulnerability; South Africa

2.1 Introduction

This critical review paper explores literature and scholarship in the context of integrating Indigenous Knowledge (IK) and Geographical Information Systems (GIS) in mapping flood vulnerability in informal settlements in South Africa.

The phenomenon of informal settlements in South Africa is complex (Barry & Rüther, 2005; Huchzermeyer & Karam, 2006; Hunter & Posel, 2012; Marutlulle, 2017). Historically, the apartheid regime legally compelled those classified as black Africans to move to marginalized settlements and restricted their movements (Hunter & Posel, 2012; Iliffe, 1987). In the 1970s, the apartheid system in place allowed for the influx of black Africans into informal settlements due to the economic boom (Barry & Rüther, 2005). Rural-urban migration (Marutlulle, 2017), population growth (Marutlulle, 2017) and the influx of migrants both legal and illegal, from neighbouring countries (Barry & Rüther, 2005; Marutlulle, 2017). People moving between provinces, for instance, from the Eastern Cape to the Western Cape (Bekker, 2001) have also contributed to the increase in informal settlements in South Africa. The number of households in informal settlements has also increased. From 1,170,902 in 1995 to 1,294,904 in 2011, there are now about 1,300,000 households in South Africa, which represents almost five million people living in informal settlements (Nkonki-Mandleni et al., 2021; Statistics South Africa, 2016). Over the years, informal settlements have become densely populated and have increased both in number and size (Jeffery, 2010). For instance, the number of informal settlements increased from 1,176 in 2004 to over 2,700 in 2012 (The Housing Development Agency, 2012). The latest Government reports indicate that by May 2020, there were about 3,200 informal settlements in South Africa. Most informal settlements in South Africa are located in sensitive and fragile environments such as steep slopes, wetlands, flood plains and poorly drained land, susceptible to hydro-meteorological hazards (Barry & Rüther, 2005; Le Quéré et al., 2020; Musungu et al., 2016; Williams et al., 2019).

Planning interventions from the municipality are generally limited in informal settlements. Climate change and its effects such as frequent and intense storm surge events, rising water tables and rising seawater levels in coastal areas have worsened the situation (Apraku et al., 2018; Ofosu et al., 2020; Ziervogel et al., 2016). Williams et al. (2019) state that in South Africa, people in informal settlements are vulnerable to flood hazards because they live in hazardous areas and have poor socio-economic conditions. Drivdal (2016) contends that the non-existence of drainage systems in informal settlements significantly make residents vulnerable to flood hazards. According to Sutherland (2019), flood vulnerability in informal settlements in South Africa is not only a result of the residents' exposure to natural hazards but is also a result of social, political and economic marginalization. We, therefore, contend that flood vulnerability is multidimensional and complex as it has many facets. We agree with Cutter et al. (2003) who state that flood vulnerability of a place is because of interactions and accumulation of biophysical vulnerability as well as social vulnerability. Füssel (2007) defines biophysical vulnerability as a function of exposure and sensitivity to a hazard, while social vulnerability relates to the factors that determine the hazard outcome and peoples' ability to respond such as income, population structure, age and education. There is generally an agreement among scholars (Bulkeley & Tuts, 2013; Preston & Stafford-Smith, 2009; Yuan et al., 2016) that flood vulnerability is characterized by exposure, sensitivity and adaptive capacity. Nethengwe (2007) and Dintwa et al. (2019) assert that reducing vulnerability to flood hazards requires a proper understanding of the physical, economic, environmental, social and cultural attributes of individuals or communities. The United Nations Office for Disaster Risk Reduction (UNISDR), the World Conference on Disaster Reduction (UNISDR, 2005 held in Hyogo, Japan) and later the Sendai Framework for Disaster Risk Reduction 2015–2030 called for the integration of Indigenous Knowledge in disaster risk reduction to help build resilience and protection of people in high-risk areas (UNDRR, 2005, 2015). Indigenous Knowledge is defined as the specific system of knowledge and practices that are uniquely developed and confined to a particular culture or society and is transmitted over time from generation to generation orally, through demonstration, imitation from earlier years and learnt by repetition (UNEP, 2008). Several scholars assert that GIS can help to map flood vulnerability in particular geographical areas (Hambati & Yengoh, 2018; Li et al., 2011; Musungu et al., 2012). A major characteristic of GIS lies in its capability to combine data from various sources, analysing and producing spatial overlay maps. Integrating Indigenous Knowledge and GIS can help provide a broader and cost-effective understanding of the human-environment relationship of flood vulnerability at localized scales such as informal settlements (Khan, 2014). Abunyewah et al. (2018) state that reducing vulnerability is one of the most proactive ways of disaster risk reduction. The

International Strategy for Disaster Reduction (2002) defines disaster risk reduction as the application of strategies and practices to minimize vulnerability and disaster risks in society and to avoid or limit adverse hazard impacts, within the context of sustainable development.

The term vulnerability has different definitions depending on the discipline or field of study. In disaster risk reduction, the United Nations provides a more universally acceptable definition of vulnerability by defining it as 'the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards' (United Nations, 2016, p. 24). This definition emphasizes the community's capacity to prepare, respond and recover from hazards to be critical in determining vulnerability.

According to Musungu et al. (2011), most municipalities in South Africa implement inappropriate measures for reducing flood vulnerability. We contend that this could be because most municipalities fail to consider flood vulnerability as a multifaceted and complex phenomenon, which takes into account the physical, environmental, economic, social and cultural factors of communities. Cho and Chang (2017) further contend that the social relations and characteristics of informal settlements make urban systems complex, such that it is not easy to assess the level of exposure and sensitivity of places and people to flood risks. GIS-based approaches have been widely used for mapping floods in informal settlements not only in South Africa but across the world (Musungu et al., 2012; Ngie, 2012; Roy & Blaschke, 2013; Yahaya et al., 2010). However, Aloj et al. (2012) argue that GIS on its own is not able to explain the human factors that cause flood vulnerability. We are of the view that while technical-based approaches are valuable in dealing with flood vulnerability, integrating knowledge community members have acquired over generations can provide a situational and enhanced approach to dealing with the complexity of flood vulnerability. Khan (2014) asserts that integrating Indigenous Knowledge and GIS can help provide a broader and cost-effective understanding of the human-environment relationship of flood vulnerability at localized scales. Furthermore, Musungu et al. (2016) argue that the challenges of infrastructure in most informal settlements have prompted informal settlement residents to use their strategies for dealing with floods. We are therefore of the view that combining Indigenous Knowledge and GIS can provide contextual, experiential and situational knowledge that is crucial for understanding and mapping vulnerability to flood hazards in informal settlements. Therefore, the objective of this review paper is to provide a critical review of literature and scholarship in the context of the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa.

This critical review paper has four sections. The first section is the methodology, which highlights the databases and keywords used for searching for literature used in conducting the critical review. The second section reviews the literature on the characteristics of Indigenous Knowledge and GIS that are helpful in contextually understanding and mapping flood vulnerability. The third section critically reviews studies that have in varying degrees integrated Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa. The fourth and final section highlights the gaps in knowledge emanating from the review and recommends areas for future research. This section ends by providing a conclusion

2.2 Methodology

We searched for empirical studies conducted in English in Web of Science, Science Direct, JSTOR, Wiley Online Library, ProQuest Dissertations & Theses Global, SA ePublications and Google Scholar using key terms: 'Indigenous Knowledge', 'Indigenous Knowledge systems', 'informal settlements', 'Shacks' 'Unplanned settlements', 'flood vulnerability', 'mapping' and 'Geographical Information Systems'. This was to establish the existing body of research and to provide a strong foundation for this review. To critically review studies conducted on the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa, two databases namely SA ePublication and Google Scholar were searched using keywords: 'knowledge co-production OR 'inter-disciplinary' OR 'Indigenous Knowledge' AND 'GIS' AND 'flood vulnerability' OR 'flood*' AND 'informal settlement' OR 'unplanned settlement' AND 'South Africa'. These keywords helped identify relevant literature to achieve the objective of this review paper. Studies conducted in English from 2000 to 2020 were considered in this review. The search of the two databases retained 624 articles. Figure 2.1 shows the flow diagram for the literature selection process. Of the accessed articles, 587 of them were found to be unsuitable for the topic or were not conducted in South Africa. During the screening process duplicates (8) were removed and the abstracts for the remaining articles were read. At this point, 20 articles were excluded. The selected articles (9) were read in full and one additional article Tyler (2011) cited from the selected articles was found to be relevant for this critical review. Therefore, to provide a critical review of literature and scholarship in the context of the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa, 10 studies were reviewed in-depth.

The characteristics of the reviewed studies shown in Table 2.1 were analysed using descriptive statistics.

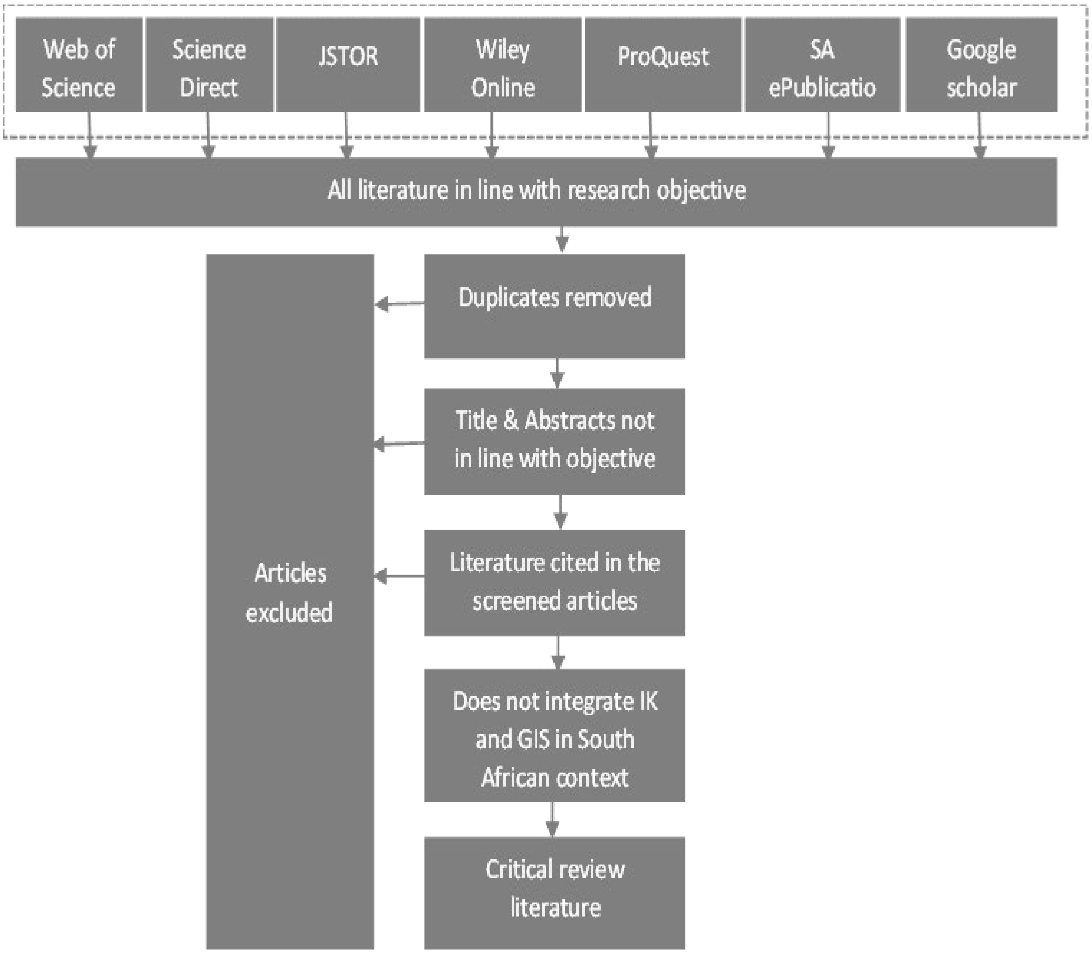

Figure 2.1 Flow diagram of the literature selection process

2.3 Indigenous Knowledge and Geographical Information System

In South Africa, legislative and policy provisions provided the impetus for research and utilization of Indigenous Knowledge in disaster risk reduction. For instance, the Disaster Management Act No. 57 of 2002 and the National Disaster Management Framework of

2005 acknowledge and highlight the need to consider Indigenous Knowledge in disaster risk reduction. The Indigenous Knowledge Systems Policy of 2004 also provides an important step in recognizing, affirming, developing and promoting Indigenous Knowledge in the country. The United Nations Environment Programme (UNEP) defines Indigenous Knowledge in a way that applies to the South African context. UNEP (2008) defines Indigenous Knowledge as the specific system of knowledge and practices that are uniquely developed and confined to a particular culture or society and is transmitted over time from generation to generation orally, through demonstration, imitation from earlier years and learnt by repetition. Sillitoe (2007) adds that Indigenous Knowledge is rooted in 'culture', and his view is also shared by Fabiyi and Oloukoi (2013) who assert that Indigenous Knowledge in Africa 'is strongly linked to local culture and past experiences' (p. 3). Indigenous Knowledge encompasses skills, practices and beliefs that enable people to achieve stable livelihoods in their locality (Senanayake, 2006; Trogrlić et al., 2019; UNEP, 2008). Flavier et al. (1995) state that Indigenous Knowledge is not static; it changes when influenced by internal creativity and experimentation intertwined with external knowledge.

Furthermore, Danladi et al. (2018) argue that Indigenous Knowledge is a source of resilience to flooding and other natural disasters in many communities, as it utilizes past learning and experiences of natural hazards to mitigate and cope with flood hazards. In South Africa, Indigenous Knowledge continues to be helpful in weather forecasting and climate prediction (Zuma-Netshiukhwi et al., 2013); predicting rainfall patterns and floods (UNEP, 2008); disaster prevention and preparation (Maferetlhane, 2013); it is social capital for the poor before and after disaster strikes (Hart & Vorster, 2006). It is also helpful in ensuring that people especially the poor and illiterate have access to information and building community resilience to flood disasters (Muyambo et al., 2017). Additionally, Indigenous Knowledge provides a context-specific, cost-effective, culturally appropriate, socially inclusive and participatory approach to reducing flood vulnerability (Apraku et al., 2018; Dekens, 2007; Maferetlhane, 2013; Muyambo et al., 2017; Zuma-Netshiukhwi et al., 2013). According to Mavhura et al. (2013), Indigenous Knowledge empowers local communities to deal with problems in local contexts. Several studies (Apraku et al., 2018; Dekens, 2007; Maferetlhane, 2013; Muyambo et al., 2017; Zuma-Netshiukhwi et al., 2013) seem to suggest that Indigenous Knowledge is only prevalent in rural settings. We, however, contend that people can also access Indigenous

Knowledge in the urban context due to their familiarity and intergenerational knowledge of their place of settlement. According to Jordaan (2001) and Maila and Loubser (2003), both rural and urban communities possess Indigenous Knowledge. Furthermore, in South Africa, most residents of informal settlements are involved in 'circulatory migration' which makes them retain strong links to their original rural homes (Le Quéré et al., 2020; Mazeka et al., 2019; Posel & Marx, 2013; Williams et al., 2018). Therefore, Kasei et al. (2019, p. 186) lament that, 'IK [Indigenous Knowledge] is under-documented in urban studies' and further submit that Indigenous Knowledge in urban settings needs special consideration. Dube and Munsaka (2018) state that practitioners in Africa have oftentimes shunned Indigenous Knowledge in reducing community disaster risks because some practitioners argue that the knowledge system is not existent in all generations, it lacks documentation and cannot be validated scientifically. Wu et al. (2002) assert that flood vulnerability displays some spatial differentiation. In agreeing with Wu et al. (2002) we contend that GIS, well informed by context-specific and social-cultural knowledge can help to visualize the patterns and quantitative levels of flood vulnerability to the extent that it is easier to identify the most vulnerable people in the community. Additionally, it is our view that spatial differentiation of flood vulnerability can help to understand the underlying causes of flood vulnerability in informal settlements. Several scholars assert that GIS can help to map flood vulnerability in particular geographical areas (Hambati & Yengoh, 2018; Li et al., 2011; Musungu et al., 2012). A major characteristic of GIS lies in its capability to combine data from various sources to analyse it and produce spatial overlay maps. This feature makes GIS an important tool for mapping. Furthermore, GIS has helped predict, model floods as well as visualize flooded areas and their extent at different spatial scales. Elalem and Pal (2015) state that GIS helps to produce a synoptic view of flood vulnerability at a localized scale.

Mapping flood vulnerability at a local scale like an informal settlement is very important in South Africa in that it helps to provide an understanding of the context-specific interactions of flood vulnerability determinants. According to Ardiansyah and Sumunar (2020), this provides a basis upon which government and other stakeholders can develop appropriate policies, projects and programmes to reduce or prevent flood vulnerability. Preston and Stafford-Smith (2009) are of the view that using GIS to map flood vulnerability helps in engaging stakeholders and educating the public on how human and environmental systems interact, as well as the reality of climate change and its effects.

Preston et al. (2011) however, warn that the use of maps in vulnerability mapping should be after a critical examination of the map itself, the data and underlying assumptions. They further argue that this is to avoid false conclusions and over-confidence among stakeholders (community members or policymakers) and avoid the impression that once a map is available, adequate information is there for effective decision-making.

GIS has however received some criticism. Manap et al. (2013) for instance, argue that GIS tends to privilege 'technical experts' over 'local' people in communities. Although this assertion is true in that even where GIS tools involve the participation of the community, the 'technical expert' will still be involved in training the community because GIS is technical. It is, however, our considered view that the privilege of the 'technical expert' can be contextualized and his or her knowledge and expertise seen as relational to the knowledge embedded in the community, by effectively and adequately engaging community members through participatory GIS approaches from the beginning to the end of the mapping process. Tripathi and Bhattarya (2004) argue that GIS provides a modern framework for documenting and storing Indigenous Knowledge. Khan (2014) further asserts that using GIS as a platform for integrating Indigenous Knowledge allows for quick and effortless analysis and retrieval of stored information, as well as management of information in a fast and accurate manner, yet preserving the cultural and local context. In our opinion, this means that using GIS and Indigenous Knowledge to map flood vulnerability is one way of documenting and storing Indigenous Knowledge especially given that Indigenous Knowledge exists in human memory and is transmitted orally from one generation to the next. Some scholars (Gaillard & Mercer, 2013; Melore & Nel, 2020; Wilson et al., 2014) have propagated the need to integrate Indigenous Knowledge and GIS. These scholars argue that Indigenous Knowledge and GIS when used separately do not provide adequate answers for solving flood vulnerability challenges in informal settlements. Aloj et al. (2012) claim that GIS on its own is not able to explain the human factors that cause flood vulnerability. These human factors include cultural norms, values, skills or practices, which Indigenous Knowledge has. Harris et al. (2011) submit that people share innate traits that allow them to share their experiences of space and place. Khan (2014) argues that Indigenous Knowledge of flood vulnerability is unwritten. It exists in human memory shared from one generation to the other orally, through demonstration and learnt by imitation (UNEP, 2008). Khan (2014) asserts that integrating Indigenous Knowledge and GIS can help provide a broader and cost-effective understanding of the human-environment relationship of flood vulnerability at localized scales such as informal settlements. We contend that the 'cost-effectiveness' and deep value of Indigenous Knowledge lie in its reliance on the rich human experiences and contextual knowledge that local communities have acquired over generations, which are not expensive to assemble and obtain. According to UNDRR (2005), Indigenous Knowledge is cost-effective and valuable in dealing with flood vulnerability because it strengthens the coping and adaptive capacities of local communities. Therefore, Indigenous Knowledge and GIS can complement each other. In this review paper, integration, therefore, means merging by jointly utilizing the inherent attributes or insights of Indigenous Knowledge and GIS at the same time (Figure 2.2).

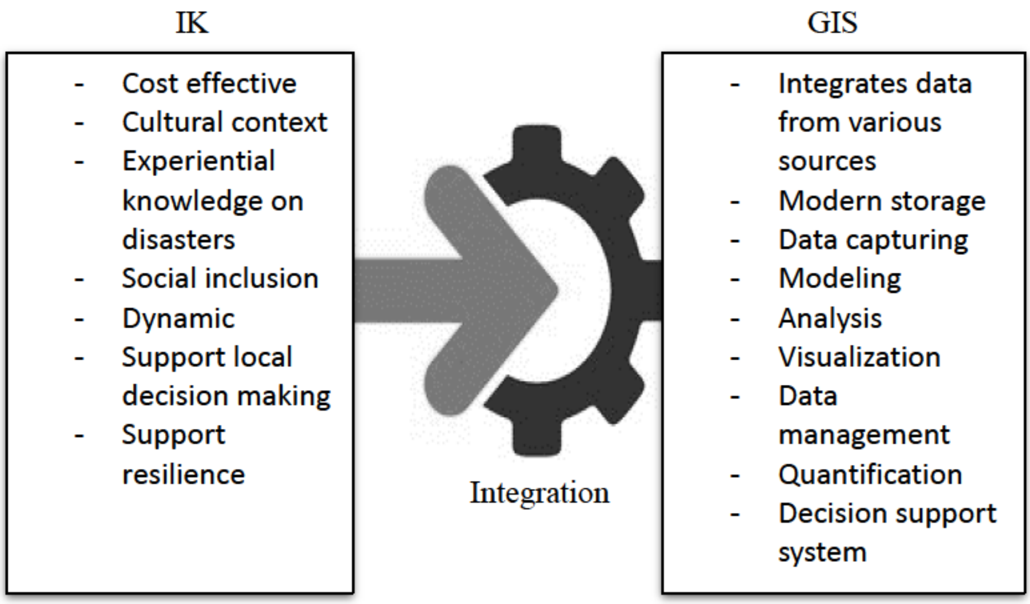

Figure 2.2 Characteristics of Indigenous Knowledge and GIS

Wisner et al. (2004) submit that the integration of Indigenous Knowledge and GIS promotes 'social inclusion'. Social inclusion in mapping flood vulnerability in informal settlements is crucial because it brings on board people who have for a long time been marginalized, because of them being considered illegal dwellers. Arguably, social inclusion is also important because it promotes social justice in dealing with flood vulnerability in informal settlements. According to Scott and Oelofse (2005) social justice advocates for fair involvement of the marginalized such as people living in informal settlements. Moreover, some authors (Gaillard & Mercer, 2013; Islam et al., 2018; Mercer & Kelman, 2009) contend that the spatial nature of Indigenous Knowledge allows its integration with GIS in supporting decision-making processes. Indigenous Knowledge is considered spatial because it is inherently linked to particular geographical localities and it considers the spatial relationship of phenomena in nature (Pierotti & Wildcat, 2000). According to Preston et al. (2011) and Dintwa et al. (2019) increased flooding due to climate change and its effects has contributed to the growing interest in mapping flood vulnerability at local scales among both public and private stakeholders. Further, Dekens (2007) submits that the desire for bottom-up approaches, more context-specific, socially inclusive and culturally appropriate solutions to deal with challenges in informal settlements has led to an increased focus on Indigenous Knowledge in disaster risk reduction initiatives in many countries. This has led to a growing interest to integrate Indigenous Knowledge with GIS in mapping flood vulnerability.

2.4 Integration of IK and GIS in mapping flood vulnerability

This section shows the studies that integrated Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa. The reviewed studies were presented thematically and then synthesized. The themes include context, methodology, key findings, integration of Indigenous Knowledge, community participation, mapping levels of flood vulnerability, sensitivity analysis and map validation (Table 2.1). In this paper, the context points out the objectives, location and components of flood vulnerability used in the reviewed studies. The methodology highlights the various methodological approaches which were used. Integration of Indigenous Knowledge checks whether or not Indigenous Knowledge was used in the studies. Mapping levels of vulnerability assess whether or not the levels of flood vulnerability were displayed or mapped. Sensitivity analysis assesses the extent to which results are affected by changes in methods, models, values and assumptions and map validation examines whether or not the flood vulnerability maps were assessed against another data source that is considered true or accurate.

.

Table 2.1 Summarized content of reviewed studies

Author, Year of publication	Context	Methodology	Key finding	Integration with IK	Community participation	Mapped levels of vulnerability	Sensitivity analysis	Map validation
(Nethengwe, 2007)	To integrate historical and contemporary flood experiences into a traditional GIS to study differential household flood vulnerability in Milaboni and Dzingahe villages in Thulamela Municipality. Combined physical, social and economic factors	Mental maps, interviews, GPS, transect walks, oral narratives, FGDs and PGIS	The interaction between physical and socio-economic factors produced differentiated flood vulnerability	No - Local knowledge	Limited to data collection	Yes	-	-
(Tyler, 2011)	To find out how physical vulnerability in Masiphumelele informal settlement in Cape Town varied across the settlement Combined physical, social and economic factors	PGIS, aerial, GPS, GIS photographs, transect walks and survey questionnaires	Even among people residing in a wetland, there are different levels of flood vulnerability	No - Local knowledge	Limited to data collection	Yes	-	-
(Ngie, 2012)	To test the hypothesis that a combined approach for identifying and mapping flood vulnerable areas was better than independent approaches in Diepsloot Township in Johannesburg Combined physical, social and economic factors	GIS using 1:50 and 1:100 years flood lines and social surveys	Indigenous Knowledge helped to find additional flood vulnerability areas that the GIS modelling process alone had failed to reveal	Yes	Limited to data collection	No	-	-

(Musungu et al., 2012)	To investigate a methodology that the Cape Town City Council could use to improve flood risk assessment Combined physical and social factors	Multi-Criteria Evaluation, Pairwise Comparison Method, Analytical Hierarchical Process, GIS and household interviews	It is credible to use participatory approaches to assess risk in informal settlements	Yes	Limited to data collection	Yes	-	-
(Ogundeji et al., 2013)	To evaluate the impact of climate change on flood damage assessment and the influence it might have on flood mitigation options in Soweto-on-sea informal settlement in Mandela Metropolitan Municipality Combined physical, social and economic factors	Benefit-cost analysis	An economic approach alone is insufficient in protecting or improving the quality of life of flood victims	No	Nil	No	-	-
(Lefulebe et al., 2014)	To demonstrate the integration of Indigenous Knowledge and other stakeholder perspectives in upgrading Monwabisi Park informal settlement in Cape Town Combined physical, social and economic factors	Multi-Criteria Evaluation, PGIS, GIS, GPS, thematic mapping, buffers, distance mapping, Thiessen polygons and questionnaires	Integrating IK and GIS provided important information in making scientific and alternate decisions during the process of upgrading an informal settlement	Yes	Not limited to data collection	No	-	-
(Siyongwana et al., 2015)	To investigate flood vulnerability and coping mechanisms of low-income communities living in Missionvale in Port Elizabeth Combined physical, social and economic factors	Structured face-to-face interviews and field observations	Insufficient institutional support, weak social resources, poorly built houses and limited infrastructure cause flood vulnerability in the Missionvale community	Yes	Limited to data collection	No	-	-

(Ziervogel et al., 2016)	To identify bottlenecks to collaborative governance that needed to be overcome to help build a holistic flood management strategy in Cape Town Combined physical, social, political and institutional factors	Interviews and workshops	Over-reliance on technocratic strategies, lack of particular skills, political contestation and short-termism and their failure to share risks are the major barriers to collaborative flood management in the City of Cape Town	No	Not involved	No	-	-
(Musungu et al., 2016)	To analyse the interaction between researchers, local communities, local government and Non-governmental Organizations in Graveyard and Europe informal settlements in Cape Town Combined physical, social, political and institutional factors	Reflect on the data collection process in Graveyard Pond and Europe informal settlements	Collaboration and the use of different knowledge systems are crucial in reducing flood vulnerability and sustainable change in informal settlements	No	Limited to data collection	No	-	-
(Drivdal, 2016)	To investigate contexts for engaging in collaborations that help to improve flood adaptation in Graveyard Pond, Egoli, and Kosovo informal settlements in Cape Town Combined physical, social and economic factors	Interviews, community meetings and field visits	Coping strategies at the household level are not adequate, because the common space continues to be flooded	No	Limited to data collection	No	-	-

2.5 Context of mapping flood vulnerability

This review shows that the majority (80%) of the studies mapped flood vulnerability in an informal settlement context. Further, all the studies that mapped flood vulnerability combined several factors. These included physical, social, economic and environmental factors. This shows that there has been a growing interest in mapping flood vulnerability in informal settlements in South Africa. This can be attributed to the devastating impacts floods have on informal settlement dwellers, especially under climate change scenarios. Flood vulnerability in South Africa is mainly being mapped in an integrated and multi-disciplinary manner. Mapping flood vulnerability from an integrated point of view is very important because it helps in providing a real picture of flood vulnerability in a particular area. However, a critical review of Nethengwe (2007) and Tyler (2011) reveals that they did not incorporate other important considerations for vulnerability such as soil type, drainage, rainfall and elevation. In our view, they did not accurately depict flood vulnerability in the study area

2.6 Methodological approaches for mapping flood vulnerability

Several methodological approaches are being used to map flood vulnerability. These approaches range from mental maps to aerial photographs, Participatory GIS and GIS-based Multi-Criterial Evaluation (Lefulebe et al., 2014; Musungu et al., 2012; Nethengwe, 2007). Questionnaires and interviews are being used to collect flood-based information from the community. In all the studies where maps were made GIS is being used. However, this review shows fragmentation of the methods used for mapping flood vulnerability. For instance, Tyler (2011) did not jointly analyse physical and socio-economic vulnerability, instead, they were independently analysed and mapped. Moreover, the utilization of experiential knowledge in mapping flood vulnerability by Tyler (2011) was only limited to data collection, while the analysis and dissemination of the information were ‘technical expert’ oriented. Similarly, Ngie (2012) separately analysed Indigenous Knowledge and GIS-based data on flood vulnerability and simply compared the two results at the end. Further, Nethengwe (2007) incorporated mental maps, which represented people’s perception of flooded locations in the study areas into a GIS. However, the implication of using mental maps is that the resultant map generated in a GIS was only as good as the quality of the mental maps used. The approach used by

Nethengwe (2007) therefore, has very limited use in establishing strategic and policy interventions to reduce flood vulnerability, because the mental maps used in the study were not drawn to scale hence, they suffer from positional inaccuracy (Aram et al., 2019), as they cannot accurately pinpoint where the most vulnerable people are located. Hence, we contend that the methodological approach used by Nethengwe (2007) to map flood vulnerability in Milaboni and Dzingahe villages was also not comprehensive. Musungu et al. (2012) used the Analytical Hierarchical Process in establishing priority and assigning weights to criteria mainly because of its simplicity and flexibility in analysing and integrating large and different types of data Chen et al. (2010). However, Li et al. (2011) contend that the Analytical Hierarchical Process has a limitation, in that it assumes that criteria are independent, even if they are interdependent. Ghorbanzadeh et al. (2018) also reveal that the Analytical Hierarchical Process is limited because it does not consider multiple alternatives at a time. To overcome this weakness, de Brito et al. (2018) recommend the use of the Analytical Network Process. They argue that the Analytical Network Process is ideal for considering interdependent criteria and other complex relationships. Ghorbanzadeh et al. (2018), state that with the Analytical Network Process, it is easy to assess the reliability of the interdependence of criteria. However, Ghorbanzadeh et al. (2018), state that one weakness associated with the Analytical Network Process is its reliance on expert decisions, which propagate uncertainty and marginalize community members. We contend that in this context, having an integrated approach for mapping flood vulnerability means jointly using Indigenous Knowledge and GIS in the analysis and generation of results.

2.7 Integration of Indigenous Knowledge in mapping flood vulnerability

A majority (60%) of the studies reviewed show that Indigenous Knowledge and Local Knowledge are being integrated with GIS to map flood vulnerability in informal in South Africa. However, critical analysis shows that only 40% of the studies involved Indigenous Knowledge. In our view, Indigenous Knowledge and Local Knowledge differ. We consider Local Knowledge to do with people who have lived in a particular area for a long time (Langill, 1999) and Indigenous Knowledge is seen to be broader and relates to a body of knowledge embedded in people’s way of thinking, skills, technology, culture and social practices that have been passed on from one generation to the next (UNEP, 2008). On this basis, we consider Indigenous Knowledge to be far more beneficial in mapping flood vulnerability than Local Knowledge. Community participation is important in reducing flood risks at local levels.

2.8 Community participation

This review shows that community participation in mapping flood vulnerability in South Africa is inadequate. A critical analysis shows that the community mainly (70%) participated in data collection generally by responding to questionnaires or interviews administered to them. The rest of the stages were conducted by 'technical experts'. Of all the reviewed studies, only (Lefulebe et al., 2014) involved community participation in the preparation and interpretation of vulnerability maps. We however notice that Lefulebe et al. (2014) did not involve the community in the dissemination of the flood vulnerability information. Musungu et al. (2012) only involved one community leader in assessing alternatives during the mapping process. This is an anomaly and shows a lack of adequate inclusion and community participation in flood vulnerability mapping. Moreover, a single community leader may have biases, which can hinder the real depiction of flood vulnerability in the community. Therefore, more than two community leaders would have been more helpful. It is our considered view that while the participation of community members in the collection of information on flood risk is important, their participation in the weighting criteria and dissemination of this information is crucial in effectively communicating to the community matters of flood risks. We, therefore, agree with Tyler (2011) who argues that a holistic approach is needed to effectively communicate flood risk in informal settlements. Enhanced community participation in dealing with flood risks is crucial in reducing flood vulnerability and increasing resilience in informal settlements (Williams et al., 2018). Community participation helps to create a sense of ownership, empowers the community and may consequently lead to more cost-effective, locally based and sustainable solutions to deal with flood vulnerability and disaster risk management in general (Botha & van Niekerk, 2013; Hedelin et al., 2017). In mapping flood vulnerability, the levels of vulnerability are important to take into account.

2.9 Mapping levels of flood vulnerability

This review shows that very few (30%) studies mapped the levels of flood vulnerability. For instance, Ngie (2012) only established the extent of flood vulnerability in the study area but did not map the levels of vulnerability within the study area. This is of concern because it gives an impression that all the households within the study area had the same level of flood vulnerability. According to Nethengwe (2007), people experience differentiated flood vulnerability because their coping and adaptive capacities are different. We believe that the failure to visually map and classify flood vulnerability for instance, as low, medium and high makes it difficult to implement strategic interventions aimed at reducing flood vulnerability in a particular community. There is a need to assess if sensitivity analysis and validation were conducted on the vulnerability maps.

2.10 Sensitivity analysis and validating of vulnerability maps

The review has shown that none of the studies that mapped flood vulnerability in South Africa conducted sensitivity analysis or validated the maps. The lack of sensitivity analysis and validation of flood vulnerability maps in South Africa breeds misgivings about the extent to which the maps can be used. Accurate and reliable flood vulnerability maps are fundamental for decision-making (Rincón et al., 2018). It is however important to note that while it is easy to validate biophysical vulnerability, assessing the accuracy of social vulnerability is challenging. This is because many facets have to be taken into account, some of which include income, education, demographic structure and cultural norms, values, skills as well as practices. Therefore, we are of the view that high-resolution satellite images, which provide an inventory of flooded areas as well as census data, which provide the socio-economic outlook of an area, can be useful in conducting accurate assessments of flood vulnerability maps. From these studies, some recommendations and conclusions can be drawn.

2.11 Recommendations for future research

This review enabled us to identify gaps in knowledge relating to the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa. The review (Musungu et al., 2012; Nethengwe, 2007; Ngie, 2012; Tyler, 2011) shows that there is a fragmentation of approaches used to integrate Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa. Future research should therefore seek to use a comprehensive approach that integrates Indigenous Knowledge and GIS by way of jointly utilizing the inherent attributes of Indigenous Knowledge and GIS at the same time.

Furthermore, the critical review has shown that there is a lack of adequate community participation in mapping flood vulnerability in informal settlements in South Africa. Most of the studies only involved community members at the data collection stage mainly by way of them (community members) responding to questionnaires or interviews administered to them (Musungu et al., 2012; Nethengwe, 2007; Ngie, 2012; Tyler, 2011; Ziervogel et al., 2017). Therefore, future research should aim at finding ways that elicit the effective participation of community members living in informal settlements from the beginning to the end of the flood vulnerability mapping process.

This critical review has also revealed that sensitivity analysis and accuracy assessments are lacking in flood vulnerability maps done in South Africa. Therefore, future research should endeavour to conduct sensitivity analysis and accuracy assessments to promote their reliability and use in supporting decision-making.

CHAPTER 3: EXAMINING FLOOD VULNERABILITY MAPPING APPROACHES IN DEVELOPING COUNTRIES

This chapter is based on the following:

Membele, G. M., Naidu, M., & Mutanga, O. (2022). Examining flood vulnerability mapping approaches in developing countries: A scoping review. *International Journal of Disaster Risk Reduction*, 69(2022), 1-25. https://doi.org/10.1016/j.ijdrr.2021.102766

Abstract

In the face of climate change, mapping flood vulnerability has become important. This is because it helps to identify vulnerable people in particular communities and provides a better understanding of the causes of their vulnerability. The objective of this scoping literature review paper is to describe the components, elements, criteria selection methods, scale and settings, data, analytical approaches, the purpose of the maps, sensitivity analysis and accuracy assessment techniques used for mapping flood vulnerability in developing countries. A search over the last decade (2010 and 2020) was conducted on Web of Science and Scopus using the keywords: "flood vulnerability" OR "Spatial Modelling" AND "developing country". The results reveal that flood vulnerability mapping in developing countries was integrated and multi-disciplinary and the mapping was mainly done at a community level or local level. Indicator-based multi-criteria analysis approaches and Geographical Information Systems (GIS) were commonly used in mapping flood vulnerability. The selection of criteria or indicators was mostly based on the existing literature and expert knowledge. Stakeholder participation and the use of Indigenous Knowledge in producing the flood vulnerability maps were limited in the reviewed studies. Sensitivity analysis was hardly done and the lack of reliable, updated and high-resolution data adversely affected the validation and usability of the flood vulnerability maps. Since a significant number of people especially in urban areas are expected to be vulnerable to flooding due to climate change, validated and accurate flood vulnerability maps are crucial in supporting decision-making and strategic interventions aimed are reducing flood risks.

Keywords: Vulnerability, flooding, developing countries, mapping, geospatial analysis

3.1 Introduction

According to UNDRR (2018), of all the disasters experienced in the world, floods frequently occur and have affected the largest number of people. Aderogba (2012) asserts that floods are a natural hazard that seriously threatens sustainable development. According to Paul and Routray (2010, p. 505) floods also cause environmental damages. It is also well-known that floods usually destroy people’s houses and property, cause displacements, and loss of life, pose health risks and adversely affect people’s livelihoods thereby accentuating poverty. With the advent of climate change, floods have been projected to increase in frequency and intensity in many parts of the world (Jonkman & Dawson, 2012; Ouma & Tateishi, 2014). This situation will have a huge impact on people living in developing countries especially the urban poor due to where they live, their population density, socio-economic conditions and institutional marginalisation (Dintwa et al., 2019; Maheu, 2016).

Asiedu (2020) argues that increased precipitation, high imperviousness and inadequate or unavailability of drainages are to blame for floods in many developing countries. Asiedu (2020) adds that poor solid waste management, sedimentation, and construction of houses in low-lying areas contribute to flooding. Adelekan (2010, p. 217) contends that the consequences of floods in developing countries are exacerbated by poor development control, while Tran et al. (2008) and Peters-Guarin et al. (2012) argue that developing countries are vulnerable to flood hazards due to inadequate human and financial resources to prevent, mitigate and respond to floods. It has also been argued that most developing countries are rapidly urbanising mainly due to rural-urban migration and the population is rapidly increasing as a result, disaster risks have also advanced (Adelekan et al., 2015; Chakraborty et al., 2005; Satterthwaite et al., 2007). Patel et al. (2015, p. 187) contend that risks are ‘urbanising’ such that most people especially the poor are increasingly becoming exposed to hazards such as floods.

According to Kienberger (2012, p. 2001) information on the hazard incidents, their distribution as well as the spatial distribution of vulnerability, are crucial in addressing risks. The Intergovernmental Panel on Climate Change (IPCC) recommends adequate participation of stakeholders at appropriate spatial scales when conducting vulnerability assessments. This is to foster a sense of ownership among community members in disaster risk reduction undertakings. Isunju et al. (2015) contend that flood vulnerability is context-specific and is fashioned by local conditions. Therefore, a locally based approach is ideal for dealing with flood vulnerability. Indigenous knowledge among community members is important in fostering participation.

According to Bernatchez et al. (2011, p. 631), Indigenous Knowledge helps to provide an understanding of the spatial pattern and factors that cause varying flood levels and the degree of flood damage in a particular community. Indigenous Knowledge is defined as a dynamic place-based knowledge and practices rooted in a local culture that is transmitted from one generation to the next by word of mouth, demonstration, imitation and repetition (Alexander et al., 2019; Orlove et al., 2009; Sillitoe, 2007; UNEP, 2008). The World Conference on Disaster Reduction held in Hyogo, Japan and the Sendai Framework for Disaster Risk Reduction 2015–2030 have been very instrumental in calling for the use of Indigenous Knowledge in reducing vulnerability, fostering resilience and protecting people living in high-risk areas (UNDRR, 2005, 2015). However, Dube and Munsaka (2018) and Kasei et al. (2019) contend that Indigenous Knowledge is underutilised in dealing with flood vulnerability in developing countries, especially in urban studies. Vulnerability is defined differently depending on the field of study.

The United Nations (2016, p. 24) in disaster risk reduction define vulnerability as physical, social, economic and environmental conditions that increase an individual, a community, assets or system's susceptibility to the impacts of hazards. Flood vulnerability is multi-faceted and complex because it considers the constant interaction of physical, social, environmental and economic components or factors (Cutter et al., 2003; Dintwa et al., 2019). The physical dimension includes aspects of geography, location, settlement patterns, physical structures and infrastructure located in hazard-prone areas (Balica et al., 2009; Cardona & van Aalst, 2012). The economic dimension relates to the susceptibility of people’s economic well-being and the social dimension relates to demography, social groups, health, education, people’s well-being, culture, institutions, and governance aspects (Cardona & van Aalst, 2012). The environmental dimension is related to the possibility of harm and disruption of people’s livelihoods or other societal processes due to the degradation of environmental services and functions (Birkmann, 2013).

According to Hoque et al. (2019, p. 2), mapping flood vulnerability is important for decision-makers because it helps to visualise levels of vulnerability in a particular geographical area. It also helps to understand the factors responsible for causing vulnerability in an area [44, 48, 49]. Furthermore, mapping flood vulnerability helps produce management and strategic plans aimed at preventing and reducing flood impacts. Flood vulnerability mapping is important in that it promotes the participation of various stakeholders at various levels (Diagne, 2007; Scheuer et al., 2013; Wilk et al., 2018).

Therefore, there is a need for more studies on flood vulnerability to produce flood vulnerability maps that depict the spatial distribution or patterns and levels of vulnerability (low, medium or high). This will help to identify people or asserts that are more vulnerable to floods in particular geographical areas as well as ensure that flood vulnerability maps are used for decision-making and policy intervention. Several scholars (Anik & Khan, 2012; Birkmann, 2007; Hoque et al., 2019) argue that the components, elements, criteria selection methods, scale and settings, data and analytical approaches in mapping flood vulnerability should be carefully considered if the maps are to be used for support decision-making and policy interventions. Some scholars (Chen et al., 2019; de Brito et al., 2019; Ghorbanzadeh et al., 2018) contend that the flood vulnerability maps should also be examined on whether or not sensitivity analysis and validation or accuracy assessments were undertaken. In our view, these considerations are important because they determine the accuracy and validity of flood vulnerability maps. In this paper, accuracy is considered to be the closeness of the flood vulnerability maps to what is obtained on the ground while validity relates to the confidence or credibility one has in the maps (Birkmann, 2007; Fekete et al., 2009; Wang et al., 2011). Since many developing countries are grappling with floods, there is a need for a comprehensive analysis of studies on flood vulnerability mapping to identify gaps and areas of improvement to ensure that the studies are more helpful in supporting decision-making and flood risk reduction interventions at different spatial scales.

The predisposition of a community to be negatively affected by floods comprises three elements: exposure, sensitivity or susceptibility to hazards and adaptive capacity or ability to cope during or after a flood (Akukwe & Ogbodo, 2015; Hung & Chen, 2013; Yuan et al., 2016). Exposure is generally considered a major element of vulnerability and it is defined as the probability that people or physical items will be impacted by floods (Hung & Chen, 2013; Sadeghi-Pouya et al., 2017). The people's struggle against flood vulnerability is largely a function of their level of exposure and their abilities to cope with the flood. According to Paul and Routray (2010), exposure tends to be seen as a physical factor when an integrated perspective is considered. Sensitivity refers to the fragility of a system or community to the impact of flood hazards (Jha & Gundimeda, 2019; Yankson et al., 2017). Adaptive capacity or ability to cope is defined as the abilities people or a community have to withstand or recover from the negative consequences of floods (Kienberger, 2012; Muller et al., 2011). The selection of criteria to be used for mapping flood vulnerability determines the indicators that will be used for producing the maps and the quality of the final output. Criteria selected with the participation of various stakeholders including community members help to produce context-specific and locally appropriate flood vulnerability maps (Hazarika et al., 2018; Hung & Chen, 2013; Kienberger, 2012). According to Schmeltz and Marcotullio (2019, p. 14) scale is one of the most significant considerations in producing flood vulnerability maps, because it determines the accuracy of results and detail of the maps. Flood vulnerability maps can be produced from a community level or local scale with a fine-scale resolution to regional and global levels with low-scale resolution (Birkmann, 2007). The setting relates to the localities (rural or urban) where flood vulnerability maps were done (Dube & Munsaka, 2018; Kasei et al., 2019; Mutasa, 2015). This is important because floods have catastrophic effects in both urban and rural settings but urban settings tend to experience the worst effects (Satterthwaite et al., 2007). Data relates to the spatial and non-spatial data that was used for analysing and producing flood vulnerability maps. Data affects the scale and accuracy of the maps (Hoque et al., 2019; Kienberger, 2012; Muller et al., 2011). Thabane et al. (2013, p. 2) define sensitivity analysis as an examination of the robustness and the extent to which results are affected by changes in assumptions, values, models and methods. Validation or accuracy assessment compares the flood vulnerability maps with another data source that is considered ground truth data or accurate (Fekete, 2009). Rincón et al. (2018) argue that validation improves the legitimacy of flood vulnerability maps for decision-making. Unvalidated flood vulnerability maps have low legitimacy; hence their usability is limited. Therefore, the objective of this scoping literature review paper is to describe the components, elements, criteria selection methods, scale and setting, data, analytical approaches, the purpose of the maps, sensitivity analysis and validation techniques used for mapping flood vulnerability in developing countries. The rapid increase of people without proper housing and drainage infrastructure, as well as the occupation flood-prone areas such as floodplains and wetlands, high population densities, poor socioeconomic conditions and marginalisation of informal settlement dwellers because they are considered illegal by most municipalities, has increased the interest in mapping flood vulnerability in developing countries.

3.2 Methods

This scoping review is based on a search of research articles on mapping flood vulnerability in developing countries conducted between 2010 and 2020. Web of Science and Scopus databases were searched to provide the relevant peer-reviewed papers or studies. The search criteria that were used in Web of Science were TOPIC: (("flood vulnerability")) OR TOPIC: (("spatial modelling")) AND TOPIC: (("developing country")) while in Scopus the following keywords were used: ("flood vulnerability") OR ("Spatial Modelling") AND ("developing country") This search yielded 547 papers in Web of Science and 2002 in Scopus. A total number of 708 papers were excluded from both Web of Science and Scopus on account of not having been published between 2010 and 2020. Some papers (306) were excluded from the output because they were not book chapters or research articles. Only book chapters and research articles written in English were included in this scoping review paper, hence, 28 papers were excluded because they were written in other languages. A number (845) of studies were excluded from this review because they were not conducted in a developing country. Furthermore, 421 papers were excluded because they were found to have an irrelevant title, topic or abstract. Therefore, 241 papers from both Web of Science and Scopus were imported into Endnote and further filtered. Some duplicates (19) were found and removed and this resulted in 222 papers. These papers were then skimmed through to check if they mapped flood vulnerability or had a flood vulnerability map as one of the outputs in the paper. Several scholars (Samu & Kentel, 2018; Solín et al., 2018; Zare & Talebbeydokhti, 2018) argue that mapping flood vulnerability is crucial in preventing and mitigating floods. This exercise led to the exclusion of 92 papers. Therefore, 130 papers or studies were read in full and examined in this scoping review paper. The details synthesised from the 130 papers included the components, elements, criteria selection methods, scale and settings, data, analysis or analytical approaches and purpose of the maps used in mapping flood vulnerability in developing countries. The selected papers were also examined to check if sensitivity and validation of the final flood vulnerability maps were conducted. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) extension for scoping reviews propagated by Tricco et al. (2018) was used to conduct the analysis (Figure 3.1).

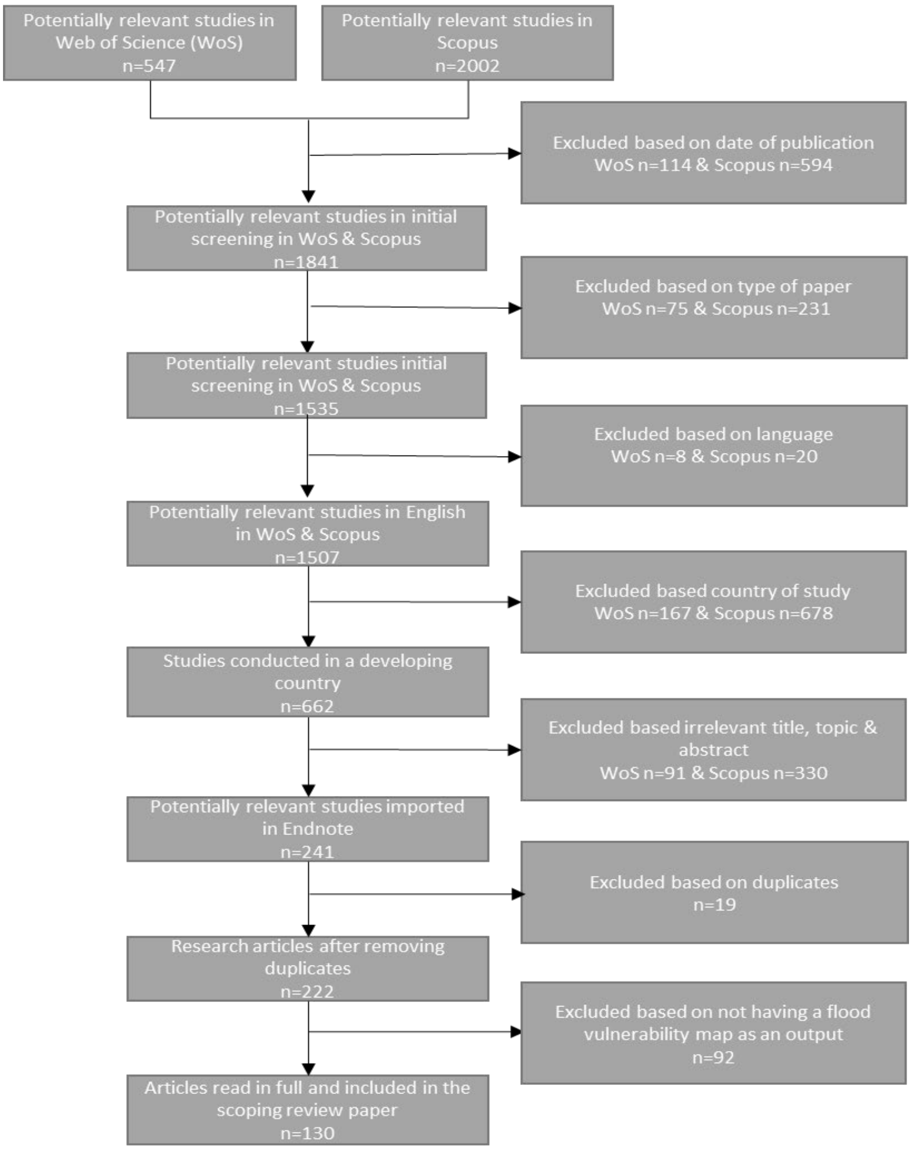

Figure 3.1 Flow diagram of the selection process based on PRISMA Tricco et al. (2018)

3.3 Results

A total of 2549 research papers were identified from Web of Science and Scopus and then screened. By considering years of publications and those written in English, book chapters and research articles, studies that mapped flood vulnerability or had a flood vulnerability map as one of the outputs in the study in a developing country's context were selected. Therefore, 130 studies were considered in this scoping review paper.

The results of this review reveal that there is an increase in the number of studies that map flood vulnerability in developing countries (Figure 3.2). These studies are spread across South America, Africa and Asia. However, most of these studies were conducted in Asia (Figure 3.3).

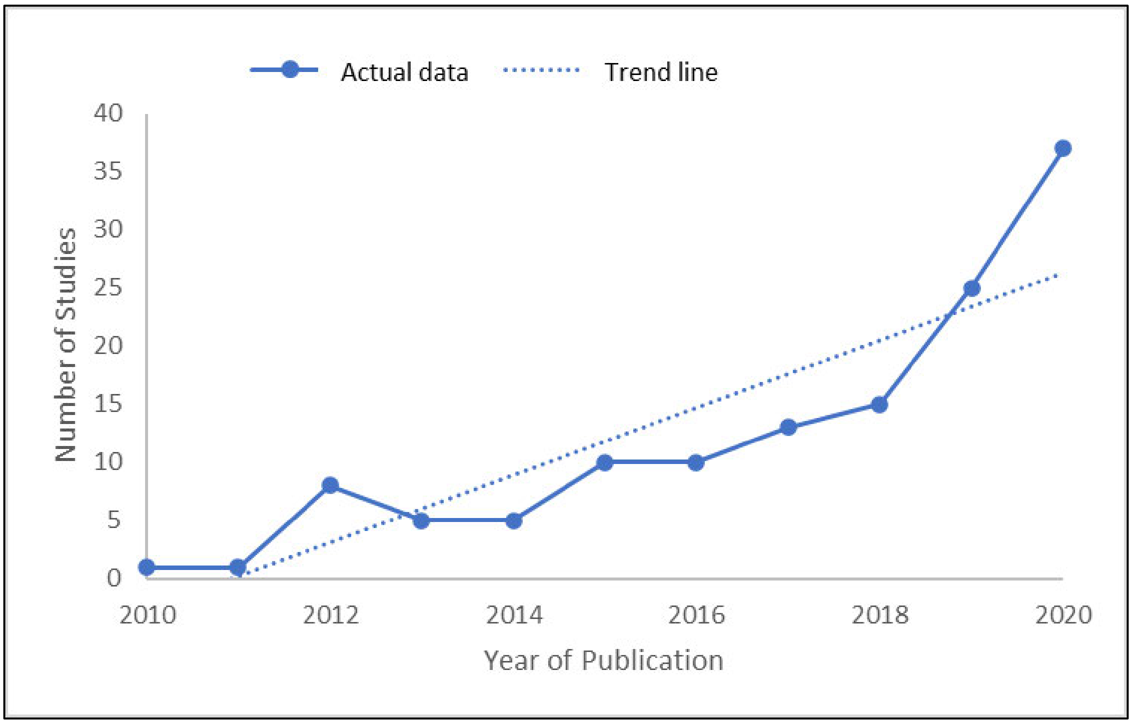

Figure 3.2 Trend of studies in mapping flood vulnerability from 2010 to 2020

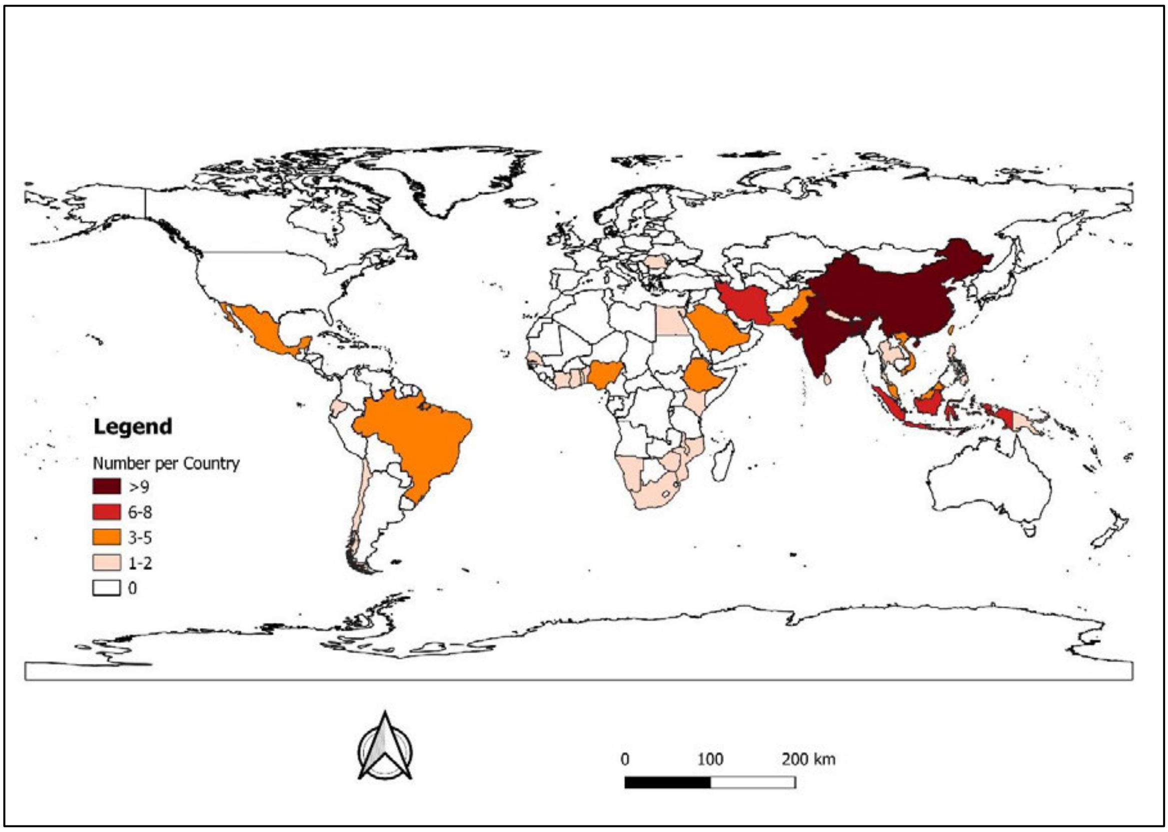

Figure 3.3 Distribution of selected research articles mapping flood vulnerability in developing countries

Table 3.1 provides a summary of the main characteristics of the 130 studies considered in this scoping review. These papers were examined for components, elements, criteria selection methods, scale and setting, data, analytical approaches, the purpose of the maps, sensitivity analysis and validation techniques used for mapping flood vulnerability in developing countries.

Table 3.1 Characteristics of studies mapping flood vulnerability synthesised in this scoping review

Author, Year of publication and Country	Components/ Factors	Elements	Criteria selection	Scale and setting	Data used	Analytical Approach/Purpose of map	Sensitivity analysis	Validation/ Accuracy Assessment
(Ochola et al., 2010) Kenya	Physical	Exposure	Literature review and Experts	Catchment-level Rural	Landsat, DEM, topographic, schools, river, drainage canals, soil type, rainfall zone, slope, the extent of the flood area, drainage density, road type, land use and density	GPS, interviews and Inverse Distance Weighted Spatial Analysis in GIS Decision making	-	-
(Muller et al., 2011) Chile	Physical, Social and Economic	Exposure & Coping/Adaptive Capacity	Literature review and Experts	Community-level Urban	DEM, Administrative units, Quick bird, land use/land cover, buildings, construction material and census data	A multi-scale approach integrating GIS, census, remote sensing, household surveys expert interviews and Local Knowledge	Yes, on weights identified as the most relevant indicators	-
(Chen & Chen, 2012) China	Physical, Social and Economic	Exposure, Sensitivity and Coping/Adaptive Capacity	Expert-based	Regional-level Urban	DEM, soils, vegetation, topographical, rainfall data, satellite images and census	AHP, correlation analysis, spatial-temporal analysis in GIS Flood risk management	-	-
(Khan & Salman, 2012) Pakistan	Physical, Social and Economic	Exposure, Susceptibility and Resilience	Expert-based	District level Rural	Administrative units, housing, population and agricultural census	GIS, correlation analysis and regression Analysis Flood risk management	-	Yes, by using independent flood recovery data
(Zou et al., 2012) China	Physical, Social and Economic	Exposure and Susceptibility	Expert-based, public participation and literature review	District level Urban	Population density, industrial output density, agricultural production density, breeding area percentage, animal density, road network density	Fuzzy AHP, Set Pair Analysis and Variable Fuzzy Sets theory and pair-wise comparison Flood risk management	-	-

(Yazdi & Neyshabouri, 2012) Iran	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Resilience	Expert-based	Sub basin-level Rural	Destroyed homes, business units affected by floods, orchards and agricultural land, people below 6 years above 65 years	Fuzzy rule-based approach, Field data collection Spatial planning	-	-
(Kienberger, 2012) Mozambique	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Coping/Adaptive Capacity	Stakeholder participation	District level Rural	Health facilities, school facilities, water points, local markets, road infrastructure, areas of conflict, accommodation centres, crop density	Geon approach with MCA and Delphi exercises & Local Knowledge Spatial planning	-	-
(Musungu et al., 2012) South Africa	Physical and Social	Exposure	Community participation and Experts	Community-level Urban	Housing units, leaking roofs, income, water level, Incidence of diseases	Participatory MCE, GIS and questionnaires Spatial planning	-	-
(Dinh et al., 2012) Vietnam	Physical, Social and Economic	Exposure, Susceptibility and Resilience	Literature review and Experts	Regional level Urban	River discharge, sea-level rise, foreshore slope, soil subsidence, coastal length, storm surge, population density, population and growth of population from census, persons with disability, shelters, cultural sites, awareness and preparedness	1D hydrodynamic model and Computed Coastal area Flood Vulnerability Index approach Flood risk management	-	-
(D. Huang et al., 2012) China	Physical, Social and Economic	Exposure	Expert-based	Regional-level Rural/Urban	Flood damage data and socioeconomic statistical data	C2R model of Data development analysis Flood risk management	-	-
(Li et al., 2013) China	Social, Economic and Environmental	Exposure and Susceptibility	Expert-based	City-level Urban	DEM, and ground cover runoff index, population density, economic density, duration of rainfall and floodwater, sediment loads, dam collapse, drainage capacity	Classic C^2R model of data envelopment analysis and time series analysis Land use planning and infrastructure layout	-	-

(Balica et al., 2013) Vietnam	Physical and Social	Exposure, Susceptibility and Resilience	Literature review and Experts	Regional-level Rural	DEM, river discharge, slope, population, percentage disable people, river network	Spatial Analyst functions in GIS Decision making	-	-
(Dewan, 2013) Bangladesh	Physical, Social, Economic and Environmental	Exposure and Susceptibility and Coping Capacity	Literature review and Experts	Community-level Urban	DEM, geology, land use/cover, distance to active channel river network, type of housing, children and the elderly population, population density and socio-economic data	SMCE-AHP, WLC and GIS Policymaking	-	-
(Roy & Blaschke, 2013) Bangladesh	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review, Experts and Community participation	Subdistrict level Rural	Administrative boundaries, rivers, roads, embankments, settlements, educational institutions, health centres, shelters, markets, Landsat 7 ETM, ASTER, IRS, Sky Med satellite image, population data from census	GIS weighted overlay and AHP Spatial planning		Yes, by using depth measurements
(Hung & Chen, 2013) Taiwan	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Stakeholder participation	Basin-level Urban	Average rainfall, elevation, proximity to rivers, populations, social dependence, income, employment, production values of industries and services	MCA, PGIS, and Local Knowledge Flood risk management	-	-
(Ouma & Tateishi, 2014) Kenya	Physical	Exposure	Expert-based	Municipal-level Urban	Rainfall, DEM, slope, drainage network and density, land-use/land-cover and soil type	Multi-parametric approach to the integration of AHP through MCDM technique in GIS using AHP Spatial planning	-	Yes, validated using depth measurements

(Lee, 2014) Taiwan	Social and Economic	Exposure and Sensitivity	Literature review	Community-level Rural	Percentage of female population, elderly population, population density, physically and mentally disabled population, low-income population, population aged 15 years or older with educational attainment	GIS, overlay functions Development planning	-	-
(Pati et al., 2014) Philippines	Social, Economic and Environmental	Exposure and Susceptibility	Expert-based	District level Rural	Demographic, socio-economic, natural resources and infrastructural data	Hydrologic Engineering Centre Hydrologic Modelling System, Hydrologic Engineering Centre's River Analysis System, survey and interviews Flood risk management	-	-
(Masuya, 2014) Bangladesh	Physical and Social	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	Community-level Urban	DEM, Landsat, Radarsat Synthetic Aperture Radar (SAR) images, distance to the river, geology, buildings, demographic and socio-economic data	SMCE-AHP, WLC Decision making	-	-
(Sowmya et al., 2014) India	Physical and Social	Exposure and Sensitivity	Literature review	City-level Urban	Income, educational qualification, frequency of flood, Height of flood experienced, awareness of flood hazards, assistance, quality of building, structure and ownership of radio/TV/telephone	MCE and GIS Spatial planning	-	-

(Akukwe & Ogbodo, 2015) Nigeria	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	City-level Urban	Monthly income, educational qualification Frequency of flood The severity of floods, Height of flood experienced, Awareness of flood hazards, assistance, Quality of building, structure ownership of radio/TV/telephone	Principal component analysis, cluster analysis, Field survey, questionnaire, and interviews, GIS Spatial planning and Emergency Planning	-	-
(Eguaroje et al., 2015) Nigeria	Physical	Exposure	Expert-based	City-level Urban	Quick bird and NigSat-1 images, topographic maps, mean annual rainfall, slope, soil types, and relief, land use, drainage order level and drainage density	MCE, WLC, remote sensing and GIS Flood risk management	-	-
(Kissi et al., 2015) Togo	Physical and Social	Exposure, susceptibility and resilience	Literature review	Sub district-level Rural	Flood frequency, flood duration, flood water level, distance to river body, altitude, no schooling, household size, female-headed, building material, community awareness, HH coping mechanisms, early warning system, household perception on flood risk, recovery capacity	GIS, interviews, personal observation and local knowledge Flood risk management	-	-
(Mwale et al., 2015) Malawi	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Coping/Adaptive Capacity	Literature review and Community participation	Community-level Rural	Home with potable water, income per capita/day, People per km, growth rate, population below the poverty line and literacy	Structured questionnaire and household Surveys Policymaking	-	-
(Nahiduzzaman et al., 2015) Saudi Arabia	Physical and Social	Exposure, Susceptibility and Coping/Adaptive Capacity	Expert-based	City-level Urban	DEM, rainfall intensity and duration, land use, income; population below 7 years and over 65 years, population density; percentage of Arabs	Watershed Modelling Systems Spatial Planning	-	-

					and Asians, and unemployment data			
(Gain et al., 2015) Bangladesh	Physical, Social and Environmental	Exposure, Susceptibility and Coping/Adaptive Capacity	Expert-based	City-level Urban	Topographic, water level, income, Literacy ratio, dependency, building age, type of building, land use, population, early warning information and age	Hydrologic model and HEC-GeoRAS Urban planning and decision making	-	-
(Sherly et al., 2015) India	Physical and Social	Exposure, Sensitivity and Adaptive Capacity	Expert-based	City-level Urban	Location of slums, literacy status, main cultivators, critical facilities like schools and hospitals, demographic and socio-economic data	Multivariate analysis, data envelopment analysis and PCA Decision making	-	-
(Masuya et al., 2015) Bangladesh	Physical and Social	Exposure and Susceptibility	Expert-based	City-level Urban	Flood depth, flood frequency, educational institutes, residential buildings, roads, and demographic data	2D multiplication-ranking matrix and spatially intersection in GIS Spatial planning and emergency management	-	-
(Hossain, 2015) Bangladesh	Physical, Social and Economic	Exposure and Susceptibility	Community participation	Household-level Rural	Level of education of household head, types of livelihoods, income and house type, house location and elevation, the distance of the house from cyclone shelter, the distance of river and road	Structured questionnaire survey, key informant interviews and field observation, GPS and GIS-based Structured Query Language query Emergency preparedness and policymaking	-	-
(Rasch, 2015) Brazil	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	District level Urban	Age, Income, health, education, Savings, access to information, civil protection, disaster preparedness, access to resources, quality and size of buildings, location of	Factor analysis Spatial planning	-	-

					dwellings, crowding and hygiene from the census			
(Behanzin et al., 2016) Benin	Physical, Social, Economic and Environmental	Exposure and Sensitivity	Literature review	Basin level Urban	DEM, administrative boundaries, road network, Landcover and hydrography data, census data	GIS-based approach Emergency and flood risk management	-	-
(Kumar et al., 2016) India	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review and Community participation	City level Urban	Temperature, precipitation, number of slums, land use, percentage of people younger than six years, liveable houses, groundwater level, area under lakes, households having housing ownership and literacy	SMCE Spatial planning	-	-
(Liu et al., 2016) China	Physical	Exposure and Sensitivity	Expert-based	City-level Urban	Geomorphological data, land use, vegetation, surface permeability, flood return periods, surface runoff, evaporation rate, interflow and groundwater drainage	Remote sensing and GIS techniques Policymaking	-	-
(Seekao & Pharino, 2016) Thailand	Physical	Exposure	Literature review	Community-level Rural	Rainfall, slope, drainage density, soil type, land use/cover, and basin size	MCA based GIS Spatial planning and policymaking	-	Yes, through actual flooding events
(Mollah, 2016) India	Physical, Social and Economic	Exposure and Sensitivity	Expert-based	Community-level Rural	Flood frequency, duration of the flood, depth of flood, percentage of flood-prone area, percentage of flood-prone area, distance to town, agriculture population demographic and socio-economic data.	Principal component analysis Flood risk management	-	-

(Tali et al., 2016) Iran	Physical, and Social	Exposure and Sensitivity	Expert-based	Sub City-level Rural/Urban	Topographic, climatic, land use and hydrometric data	Fuzzy AHP, pairwise comparison Decision making	-	-
(Wu et al., 2016) Taiwan	Physical, Social and Economic	Susceptibility, resistance and resilience	Literature review and Expert-based	Township level Urban	Demographic, socio-economic, medical, precautionary facilities and disaster data	AHP, fuzzy Delphi method and questionnaire Flood risk management	-	-
(Chang & Chen, 2016) Taiwan	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Resilience	Expert-based	Township level Rural	Land subsidence, impervious surface, population density, income, disaster experience, urbanization degree and hospital data	Geographically weighted principal component analysis Resource allocation	-	-
(Rahman et al., 2016) Saudi Arabia	Physical, Social and Economic	Exposure and Coping Capacity	Expert-based	City-level Urban	DEM, rainfall, land use, soil, population density, age, ethnicity, average household income, degree of unemployment	Gridded Surface Subsurface Hydrologic Analysis Flood risk reduction	-	-
(Islam et al., 2016) Bangladesh	Physical	Exposure	Expert-based	Regional-level Urban	DEM, Landsat imagery, geomorphology, coastal slope, shoreline change rate, rate of sea-level change, mean tide range, bathymetry and storm surge height.	Digital Shoreline Analysis System, Linear regression rate, GIS and remote sensing	-	-
(Shivaprasad et al., 2017) India	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Coping/Adaptive Capacity	Expert-based	Community-level Rural	Satellite data-sets (comprising of sensors from Radarsat-1/2, RISAT-1, Resourcesat-1/2, and IRS 1C/1DS), road network and land use, Household composition, gender poverty and unemployment derived from census data	MCA based GIS Policymaking		

(Ibrahim et al., 2017) Malaysia	Physical and Social	Exposure and Susceptibility	Expert-based	Sub basin-level Rural	Flood depth, Flood extent, DEM, River network, Vegetation cover, land use, Population density, building categories, roads, market) & public buildings	GIS overlay functions Policymaking	-	-
(Dandapat & Panda, 2017) India	Physical and Social	Exposure, Susceptibility and Coping/Adaptive Capacity	Literature review	District level Urban	SRTM dataset, LISS 3 image for land cover, river network, Geology data, demographic data from census	GIS, AHP and WLC Flood management	-	-
(Canevari-Luzardo et al., 2017) Grenada	Physical and Social	Exposure, Susceptibility and Coping/Adaptive Capacity	Community and Experts	Community-level Rural	Housing units, satellite images	PGIS methodology, fieldwork and household survey Flood risk management	-	-
(Handayani et al., 2017) Indonesia	Physical and Social	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	Urban	Built-up area, fish pond & rice field, women, children and the elderly, poor people, livelihood, house type, education level, clean water source, Sanitation, education and health facilities from Census	Ratio method and scoring method Spatial planning	-	-
(Mavhura et al., 2017) Zimbabwe	Social	Exposure and Sensitivity	Literature review and Community participation	Community-level Rural	Census data	PCA, GIS, interviews and FGD Flood risk management	-	-
(Yankson et al., 2017) Ghana	Physical and Social	Exposure, Sensitivity and Coping/Adaptive Capacity	Stakeholder participation	Community-level Urban	DEM, house materials, local drain direction, slope, distance to local drainage, distance to the sea, access to flood, early warning technology, existing household flood mitigation options, knowledge about the flood	GPS, household survey, stakeholder meetings, and interviews Policymaking and flood risk management	-	Yes, through key informants

(Sadeghi-Pouya et al., 2017) Iran	Physical, Social and Economic	Exposure, Susceptibility and Resilience	Expert-based	City-level Urban	Land use, river, building conditions, height distribution, evacuation of the riverside, training of citizens, population density and age	Scoring technique and indexing method Flood risk management	Yes, through scores of sub-criteria	Yes, through field observation
(Ge et al., 2017) China	Social	Exposure, Sensitivity and adaptive capacity	Expert-based	County-level Rural/Urban	Demographic, education, immigration and health data from a census	GIS, Getis-Ord Gi* statistic and Projection Pursuit Cluster	-	-
(Kablan et al., 2017) Ivory Coast	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Resilience	Expert-based	Sub district-level Urban	Landsat 8, literacy rate, waste collection frequency, insured people, soils, the extent of the flooded area, demographic data from the census	GIS, MOVE framework, Geographical and Household survey Decision making	-	Yes, through geographical survey
(Lian et al., 2017) China	Physical, Social and Economic	Exposure, Sensitivity and adaptive capacity	Expert-based	Catchment-level Rural	Rainfall, property data, income, road culverts, bridges and water gates, water level stations and census data	Material flow analysis, field survey and GIS Flood risk management	-	-
(Mainali & Pricope, 2017) Nepal	Physical, Social, Economic and Environmental	Exposure, Sensitivity and adaptive capacity	Literature review and Experts	National-level Rural/Urban	Climate, topography, housing, demographic, satellite and socioeconomic data	Principal Components Analysis Flood risk management	Yes, by removing different variables from the analysis	-
(Araya-Munoz et al., 2017) Chile	Social	Exposure and Sensitivity	Literature review	Regional-level Urban	Elderly and younger population, population density data	Spatial fuzzy logic modelling Decision making	Yes, based on selected indicators	-
(Mazumdar & Paul, 2018) Iran	Social	Exposure, Susceptibility and Resilience	Literature review	Community-level Urban	Illiteracy and marginalized population, primary sector and household workers, population density, Provision of basic infrastructure facilities, no assets, housing structure, communication and	Principal Component Analysis, Moran's I and Getis-Ord Gi* Policymaking and flood risk management		

					critical infrastructure from census			
(Periyasamy et al., 2018) India	Physical	Exposure and Susceptibility	Expert-based	Subdistrict level Rural	Resourcesat-2 LISS IV - 2014 data, rainfall, DEM, drainage, land use and landcover, geomorphology, lineament and zones of subsidence, soil and Geology	MCE, WOA and GIS Policymaking and flood risk management	-	-
(Schwarz et al., 2018) Senegal	Physical and Social	Exposure and Sensitivity	Expert-based	Country-level Rural/Urban	Remote sensing and census data	Cloud Computing—Google Earth Engine, PCA-based factor analysis and machine learning Decision making	-	-
(Romanescu et al., 2018) Romania	Physical	Exposure and Susceptibility	Literature review	Community-level Rural	Hydrological data, topographic maps	MCA, RRA, field visits, Interviews, FGD, GPS and indigenous knowledge Flood risk management	-	-
(Hazarika et al., 2018) India	Physical, Social and Economic	Exposure, Susceptibility and Coping/Adaptive Capacity	Community participation and Experts	District level Rural	Spatiotemporal data of satellite sensors IRS-P5 Cartosat-1, IRS-P6 LISS-3, Landsat TM, Aster DEM, and safe drinking water sources were generated from field visits, GPS, Aster DEM	MCA, RRA, field visits, Interviews, FGD, GPS & Indigenous knowledge Flood risk management	-	-

(de Brito et al., 2018) Brazil	Physical, Social and Economic	Exposure, Sensitivity and Coping/Adaptive Capacity	Expert-based	Municipal-level Urban	Persons below 12 and above 60 years, improper building material, accumulated garbage, open sewage from census, income, persons with a disability, disaster prevention institutions, evacuation drills and training, distance to shelters, health care facilities used census data	MCE using AHP and ANP, Delphi technique, interviews Spatial planning and flood risk management	-	Yes, Experts
(Harley & Samanta, 2018) Papua New Guinea	Physical	Exposure and Sensitivity	Expert-based	Catchment-level Rural	Landsat 8, distance from drainage, soil, rainfall, DEM, slope landform, land use and land cover data	MCA, WLC AHP, Remote sensing and GIS Flood mitigation and management	-	Yes, historical flood points
(Radwan et al., 2018) Saudi Arabia	Physical and Social	Exposure and Susceptibility	Expert-based	City-level Urban	Landsat 8, DEM, soil, geology, rainfall, and rainwater drainage systems data, land use/cover and population density	MCE-AHP and GIS Flood risk mitigation	-	-
(Singh & Kumar, 2018) India	Physical	Exposure	Expert-based	Basin-level Rural	DEM, IRS P6 AWiFS satellite image, drainage density, stream length, run-off volume and flow velocity	Morphometric analysis and GIS Flood mitigation	-	Yes, using satellite images and past floods damages
(Ogie et al., 2018) Indonesia	Physical and Social	Exposure, Sensitivity and Resilience	Expert-based	City-level Urban	Population density, flood gate, aerial images, population below 4 and above 70 years and waterways	Graph-based network approach, GPS, aerial image analysis and ground surveys Resource allocation	-	-

(Sianturi et al., 2018) Indonesia	Physical	Exposure	Expert-based	Regional-level Rural	MODIS imageries, flood depth and ALOS PALSAR	Vulnerability curves, GIS and GPS Water management and flood risk management	-	Yes, through fieldwork
(Indrayani et al., 2018) Indonesia	Physical, Social, Economic and Environmental	Exposure, Susceptibility and Resilience	Expert-based	Sub district-level Urban	Population density, land resource base, buildings and vegetation cover	MCA-AHP Decision making	-	-
(Caldas et al., 2018) Brazil	Physical and Environmental	Exposure and Susceptibility	Expert-based	District-level Urban	Landsat, DEM, land use, slope, and soil	MCA-AHP and pairwise comparison Decision making	-	-
(W. Yang et al., 2018) China	Physical, Social and Economic	Exposure, Sensitivity, and Adaptive Capacity	Expert-based	Regional-level Rural	Flow velocity, flooded area water depth, agricultural sensitivity, rainfall warning station density, self-restoring capacity, demographic and economic data	Fuzzy comprehensive evaluation method and coordinated development degree model Decision-making	-	-
(Weichao Yang et al., 2018) China	Physical, Social and Economic	Exposure, Sensitivity, and Adaptive Capacity	Expert-based	Regional-level Rural	Flooded area, water depth, flood velocity, agricultural sensitivity, rainfall warning station density, area of a major crop, demographic and economic data	MCDA-TOPSIS, 2D hydrodynamic model, a multi-indices system and Shannon entropy method Decision making	-	-
(Hoque et al., 2019) Bangladesh	Physical, Social and Economic	Exposure, Sensitivity and Coping/Adaptive Capacity	Expert-based	Sub district-level Urban	Landsat 8 OLI, SRTM-DEM, Precipitation, Population, Wooden house, Household with pond, and others, Household with no sanitation, and Flood shelter and health, complex and census data	MCE using AHP and ANP, household interviews Spatial planning	-	Yes, through local people, experts and policymakers

(Sarkar & Mondal, 2019) Bangladesh	Physical and Social	Exposure and Susceptibility	Literature review	Basin-level Rural	Slope, DEM, Google Earth images, Landsat 8 OLI imageries, Drainage density, rainfall, Land use/cover, roads, and topographical wetness index, Population and household data from the census	Frequency ratio model, GIS, GPS, field survey Spatial planning and flood management	-	Yes, through 100 flood points randomly divided into two groups of training and validation
(Brandt et al., 2019) Belize	Physical and Social	Exposure and Susceptibility	Community participation	Community-level Rural	Construction material, the height of a structure, Relative position of structure's first floor, Number of floors, Roof material, Occupation status, Use of structure	PGIS, sketch maps, semi-structured interviews, and building structure surveys, geostatistical hot spot analysis and local knowledge Flood risk management	-	-
(Chen et al., 2019) China	Physical and Social	Exposure and Sensitivity	Expert-based	Community-level Urban	DEM, Land use, Road, Buildings, Building Height	A local spatial dependence-based probabilistic approach Flood risk management	-	-

(Erena & Worku, 2019) Ethiopia	Physical, Social and Economic	Exposure, Susceptibility and Resilience	Literature review and Experts	Community-level Rural level	Slope, flood frequency, flood duration, flood velocity, village proximity to the river, population density, population in the flood area, emergency services, early warning, past flood experience, houses with poor materials, old people 65+, female-headed HH, female-headed HH, education level, family size, the evacuation route, insurance, cultural heritage and people access to sanitation and industries	The questionnaire-based survey, GIS and personal observation Flood management	-	-
(Ishtiaque et al., 2019) Bangladesh	Physical and Social	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	Sub district-level Rural	Hydrological data, infrastructure data, agriculture, forest and social-economic data from the census	Spatial MCDA using ANP and Key-informant interviews Flood risk management	-	-
(Adeleye & Popoola, 2019) Nigeria	Physical, Social and Environmental	Exposure and Sensitivity	Literature review	Sub district-level Urban	Quick bird image, DEM, population, building footprints, river channels and solid waste collection data	Buffer analysis in GIS, questionnaire survey and field surveys. Urban planning	-	-
(Al Baky et al., 2019) Bangladesh	Physical	Exposure	Expert-based	Sub district-level Rural/Urban	Landsat, ETM, RADARSAT image, vegetation height, water level, land use and property value	Hydraulic modelling, questionnaire survey, frequency analysis and 3D modelling Decision making	-	Yes, using the water levels

(Chakraborty & Mukhopadhyay, 2019) India	Physical, Social and Economic	Exposure, Sensitivity and Coping Capacity	Literature review and Experts	District level Rural/Urban	Landsat 8, Resourcesat-I, DEM, rivers, land cover/land use, road and rail networks, demographic and socioeconomic data	MCA, AHP and GIS Policymaking and flood risk management	-	Yes, with government reports
(Darabi et al., 2019) Iran	Physical, Social and Economic	Exposure, Sensitivity	Expert-based	City-level Urban	Depth to groundwater, rainfall, elevation, slope, distance to the river, distance to channel, curve number, quality of buildings land use, urban density, age of buildings, socio-economic conditions and population density.	Machine learning, Fuzzy AHP Flood risk reduction	-	Yes, using flooded areas
(de Brito et al., 2019) Brazil	Physical, Social and Economic	Exposure, Sensitivity and Coping/Adaptive Capacity	Expert-based	Municipal level Urban	Distance to shelters, health care facilities, evacuation drills and training, open sewage, disaster prevention institutions, accumulated garbage, building materials, income, persons under 12 years, persons over 60 years	MCA, ANP, GIS and one-at-a-time sensitivity analysis Flood risk management	Yes, through criteria weights	-
(Durga Rao et al., 2019) India	Physical	Exposure	Expert-based	National-level Rural/Urban	Rainfall, DEM, runoff, drainage density, slope, railway line, waterbody, land use/land cover and soil data	SMCE, AHP, Guiding policy development	Yes, by changing factor values	Yes, through past flood incidents
(Helmi & Basri, 2019) Indonesia	Physical	Exposure	Expert-based	Sub watershed-level Rural	Rainfall change, slope, soil, vegetation, temperature and land use	Field survey and laboratory analysis Decision-making	-	-

(Imran et al., 2019) Pakistan	Physical, Social and Economic	Exposure, Susceptibility, and resilience	Literature review	District level Rural	DEM (Aster), slope, land tenure, housing conditions, socioeconomic, risk perception, health conditions, household members, number of children, age, access to medical care, income data	Household surveys, Partial least squares structural equation model (PLS-SEM), regression analysis, GIS, GPS and remote sensing Policy formulation	-	-
(Li et al., 2019) China	Physical and Social	Exposure and Sensitivity	Expert-based	Basin-level Rural	Cultivated land, population, construction area, and the ability to handle flood disasters	GIS, Topography-based hydrological model and 1D-2D hydrodynamic model Flood risk management	Yes, by removing one or more indicators	Yes, through a comparison of calculated and field-measured maximum floodplain inundation
(Lin et al., 2019) China	Physical and Social	Exposure and Sensitivity	Expert-based	City-level Urban	Rainfall, DEM, slope, drainage distance, river distance, channel density, land use/land cover, infrastructure, Gross Domestic Product, population density and medical data	GIS-MCDM, AHP and Pairwise comparison Flood mitigation	-	Yes, using receiver operating characteristics
(Mao et al., 2019) China	Physical, Social and Economic	Exposure and Sensitivity	Expert-based	Sub City-level Urban	Landsat 8, Land use/cover, administrative boundary, historical disaster map, social and economic data from census	GIS and AHP Planning	-	-
(Nguyen & Van Nguyen, 2019) Vietnam	Physical, Social and Economic	Exposure, Susceptibility and Resilience	Literature review and Experts	Community-level Rural	Land use, infrastructure, HH in the flooded area, floodwater depth, flood frequency, rivers, villages, HH size, location of farms, number of female-headed HHs, income and HH with valuable properties	GIS, statistical equation, questionnaire survey, interviews Flood risk management	-	-

(Rey et al., 2019) Mexico	Physical	Exposure	Expert-based	Municipal-level	Elevation, land cover, bathymetric data	Sea, Lake, Overland Surges from Hurricanes model Flood risk management	-	Yes, using watermarks
(Duy et al., 2019) Vietnam	Physical	Exposure	Expert-based	City-level Urban	River network, DEM, flood depth data	Hydrological flood modelling and GIS Flood risk management	-	Yes, observation data
(Sahana & Sajjad, 2019) India	Physical and Social	Exposure, Sensitivity and Resilience	Expert-based	Community-level Rural	DEM, flood depth, Landsat, land use, slope, drainage density, proximity to drainage, demographic and socio-economic data	GIS overlay functions Policymaking	-	-
(Zhang & Chen, 2019) China	Physical and Social	Exposure and Sensitivity	Expert-based	Regional-level Rural/Urban	DEM, administrative boundaries, land use/cover, drainage, rainfall, density, slope, vegetation coverage roads, population and socio-economic data	Multi-factor analysis, AHP, GIS and comprehensive weighted evaluation. Environmental planning and disaster management	-	Yes, using old flood records
(Ali et al., 2019) India	Physical	Exposure, Sensitivity and Coping/Adaptive Capacity	Community and Experts	Regional-level Rural	Land elevation, slope angle, topographic wetness index, rainfall deviation, land use land cover, clay content in the soil, distance from rivers, GPS points, Landsat 8, SRTM DEM data, SAS Planet and Google Earth	MCDA, AHP, GIS, FR model, interviews and field observation Flood risk management	-	Yes, through flood points
(Jha & Gundimeda, 2019) India	Physical, Social, Economic and Environmental	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review	District level Rural	Flood frequency, infant mortality rate, below poverty line family, health care centre per 10,000 population, school density, road density, per capita district domestic product, female work participation rate, primary	Principal Component Analysis, GIS and Exploratory Spatial Data Analysis (ESDA) Flood risk management and policymaking	-	-

					agricultural credit society and census data			
(Xiong et al., 2019) China	Physical and Social	Exposure and Susceptibility	Expert-based	National-level Rural/Urban	Roads, buildings, flood control projects, enterprises, institutions, monitoring and warning facilities, river data, topography, soil, vegetation, hydrology, Population density, social, economic, DEM, and land use	MCDA, AHP and support vector machine model Flood risk management and policymaking	-	-
(Aksha et al., 2020) Nepal	Physical, Social and Economic	Exposure and Susceptibility	Literature review and Experts	City-level Urban	WorldView-3, ASTER-DEM, land use, slope, rainfall, Lithology, drainage networks, households that use firewood as a fuel source, demographic, social, and economic data from the census	AHP, pairwise comparison and fieldwork Flood risk management and policymaking	-	-
(Borbor-Cordova et al., 2020) Ecuador	Physical, Social and Economic	Exposure, sensitivity and adaptive capacity	Expert-based	City-level Urban	Population density, DEM, demographic, social and economic data from the census	Spatial clustering, PCA and I Moran analysis Urban planning	-	-
(Chen & Lin, 2020) Taiwan	Social and Economic	Exposure, Susceptibility and Resilience	Expert-based	City-level Urban	Population density, emergency shelters, income, minority groups, urbanization level and medical treatment	Spatial autocorrelation analysis and PCA	-	-
(Das et al., 2020) India	Physical, Social and Economic	Exposure, sensitivity and adaptive capacity	Literature review	Sub-district level Rural/Urban	Temperature, rainfall, erosion, demographic, social and economic data	PCA Emergency plans/responses	-	-

(Huq et al., 2020) Bangladesh	Economic, Social, Environmental, Structural, and Institutional	Exposure, sensitivity	Literature review and Experts	Household-level Urban	Housing type, road network demographic, social and economic data	AHP, pairwise comparison Mitigation purposes	-	-
(Kumar & Bhattacharjya, 2020a) India	Physical, Social, Economic and Environmental	Exposure, Susceptibility, and Resilience	Literature review	District level Rural	Rainfall, the proximity of villages to the river, the area affected by forest fire, urbanized area, unemployment, proximity to the river, housing conditions, demographic, social and economic data	Correlation analysis, PCA and Artificial neural network Planning and Flood risk management	-	-
(Kumar & Bhattacharjya, 2020b) India	Physical, Social, Economic and Environmental	Exposure, Susceptibility, and Resilience	Literature review and Experts	District level Rural	Flood frequency, proximity to the river, rainfall, demographic, social and economic data	Correlation analysis and GIS Policymaking	-	-
(Llorente-Marrón et al., 2020) Haiti	Social and Economic	Exposure and Susceptibility	Literature review	National-level Rural/Urban	Rainfall, health, gender roles, living conditions demographic, socio-economic data	TOPSIS, MCDM, interviews Emergency management and disaster risk management		
(Mishra & Sinha, 2020) India	Physical and Social	Exposure and Susceptibility	Expert-based	Regional-level Urban	Land use/cover, DEM, rainfall, road network, block-level boundary maps, geomorphological, hydrological, and socio-economic from census	MCDA, pairwise comparison, AHP and GIS Disaster risk management	-	Yes, inundated map and field visits
(Ofosu et al., 2020) Ghana	Physical, Social, Economic and Environmental	Exposure, sensitivity and adaptive capacity	Literature review and Experts	Basin-level	Land use land cover, type of soil, slope, drainage density, rainfall, water quality and socio-economic data	MCA-AHP, WLC and GIS Flood risk management	-	-

(Rey et al., 2020) Mexico	Physical, Social and Economic	Exposure, sensitivity and adaptive capacity	Expert-based	Municipal-level Urban	HH goods, mobility, education, communication access, water depth and type of housing from the census	CENAPRED, CENAPRED and FRI Flood risk management	-	-
(Rezende et al., 2020) Brazil	Physical, Social and Economic	Exposure, sensitivity and value	Literature review and Experts	Basin-level Urban	Income, flow velocity, water depth, land use, infrastructure and socio-economic data	MCA Decision making	-	Yes, using field data
(Sarkar et al., 2020) India	Physical	Exposure	Expert-based	Basin-level Rural	DEM, slope, rainfall, drainage frequency, high-resolution satellite image and land use data	GIS-based morphometric analysis and AHP Flood risk management	-	-
(Sutrisno et al., 2020) Indonesia	Physical	Exposure	Expert-based	City-level Urban	Rainfall, land-use/cover, slope, tidal data and geomorphological data	MCE-AHP, PCA, overlay and weighted-scored method	-	Yes, using field data
(Usman Kaoje et al., 2020) Malaysia	Physical	Exposure	Expert-based	City-level Urban	Flood depth, flood duration, flow velocity, slope, proximity to the river, Distance from the coasts, building characteristics	Questionnaire survey Planning on flood management	-	Yes, through a field survey
(Vemula et al., 2020) India	Physical	Exposure	Expert-based	City-level Urban	Landsat 7, stormwater network, DEM, rainfall, land use	Storm Water Management Model, Geophysical Fluid Dynamics Laboratory-Coupled Model 3 and Hydrological Engineering Center-River Analysis System Policy formulation and flood mitigation strategies	-	Yes, through rainfall events

(Vignesh et al., 2020) India	Physical	Exposure	Expert-based	District level Urban	Landsat 8, rainfall, slope, drainage density, Land use/cover, DEM, soil, geology, geomorphology, surface runoff	MCDM-AHP, WLC, remote sensing and GIS Planning and disaster risk reduction	-	-
(Yang et al., 2020) China	Physical	Exposure	Expert-based	City-level Urban	Land use, water depth, drainage network, aerial images, meteorological and hydrological data	Stormwater management and LISFLOOD-FP model and vulnerability curves Planning decision making	-	-
(Ziarh et al., 2020) Malaysia	Physical, Social and Economic	Exposure and sensitivity	Stakeholder participation	District level Urban	DEM, population density, percentage of vulnerable people, forest cover, demographic and socio-economic data	MCDA, catastrophe and entropy methods and questionnaire survey Flood risk management	-	-
(Huynh et al., 2020) Vietnam	Physical, Social and Economic	Exposure, Sensitivity and Adaptive capacity	Expert-based	City-level Urban	Rainfall, temperature, water flow, area of agricultural land, Livestock population, access to infrastructure, demographic and socio-economic data	Weighted-scored method Policymaking	-	-
(Kapuka & Hlásny, 2020) Namibia	Social and Economic	Exposure, Sensitivity and Adaptive capacity	Expert-based	District-level Rural/Urban	Population density, female population below 4 years and above 60 years, total unemployment rate, population with disabilities, HIV level and literacy rate	K-means clustering technique Strategic planning	-	-
(Liu et al., 2020) China	Physical, Social and Economic	Exposure, Sensitivity and Adaptive capacity	Literature review and Experts	Regional-scale Urban	GF-2 remote sensing image data, DEM, distance to water bodies, slope, land use, percentage of females, population under 15 years, education level and income data	Fine-scale coastal storm surge disaster vulnerability and risk assessment model Flood risk management	Yes, by adjusting criteria weights	-

(Morea & Samanta, 2020) Papua New Guinea	Physical	Exposure	Expert-based	Regional-scale Urban	Landsat 8, DEM, slope, soil, landform, rainfall, distance from the main river, land use/land cover, and surface runoff	GIS-based MCDA-AHP and WLC Spatial planning	-	Yes, compared with past floods
(Saber et al., 2020) Egypt	Physical	Exposure	Expert-based	City-level Urban	SENTINEL-2 satellite data, rainfall, DEM, land use	Rainfall-runoff-inundation model Spatial planning	-	-
(Wan Mohtar et al., 2020) Malaysia	Physical	Susceptibility	Expert-based	City-level Urban	Rainfall, land use and soil type	GIS overlay functions Spatial planning	-	Yes, rainfall modelling
(D'Ayala et al., 2020) Malaysia	Physical	Exposure	Literature review	Community-level Rural	3-D building dataset and 0.5m resolution, DEM, Google Street View, field survey, buildings fabric, Building condition	PARNASSUS v.3 procedure, based on a vulnerability index approach	-	-
(Ogarekpe et al., 2020) Nigeria	Physical	Exposure	Expert-based	Basin-level Rural	Land use/cover, DEM, Soil, meteorological data, Geology, flow direction, flow accumulation, slope, aspect, hill shade, stream length, stream number, stream order and stream order	Morphometric analysis, GIS & remote sensing Flood risk management	-	-
(Abdrabo et al., 2020) Egypt	Physical, Social and Economic	Exposure and Sensitivity	Expert-based	City level Urban	Total population, population density from census, and administrative boundaries, land use, building height, building conditions, building materials, spatial-temporal rainfall and runoff analysis, land value, digital elevation model and high-resolution satellite images	MCDA, AHP, GIS, remote sensing, high-quality city strategic plans and 2D rainfall-runoff-inundation simulation model Spatial planning and flood risk management	-	-

(Karunarathne & Lee, 2020) Sri Lanka	Physical, Social and Economic	Exposure, Sensitivity and Coping/Adaptive Capacity	Literature review, experts and community participation	Subdistrict level Rural/Urban	Number of under 5 children, number of people above 65 years, female-headed households, education level, family size, distance to the river, building condition, income, unemployment level, reported diseases, disabled people, and dependency ratio	Household surveys, field observations, FGDs, and informal interviews Decision-making and flood risk management	-	-
(Sarmah et al., 2020) India	Physical, Social and Economic	Exposure and Sensitivity	Community and Experts	Subdistrict level Urban	ASTER DEM, rainfall, Soil, land use, Landsat, Google Earth images, the population of the city, Road network and ward boundaries	GIS, AHP, questionnaire survey Spatial planning		
(Salazar-Briones et al., 2020) Mexico	Physical, Social and Economic	Exposure and Susceptibility	Literature review	District level Urban	Population density, population under poverty, underage and elderly population, household infrastructure, education level, employed population, from census, slope, land use, soil type, proximity to flood areas and topographic wetness index	GIS and hydrologic/hydraulic model Flood risk management	-	-
(Deepak et al., 2020) India	Physical, Social, Economic and Environmental	Exposure and Sensitivity	Expert-based	District level Peri-urban	Cartosat DEM, Resourcesat 1 image, ward map of the municipality, Google image and the Inundation map with flood levels and population data	MCDA, AHP, WLC, GIS and machine learning algorithm-Random Forest Decision making	-	-
(Fadhil et al., 2020) Indonesia	Physical	Exposure	Expert-based	Basin-level Rural/Urban	Rainfall intensity, slope, Elevation, distance from the rivers, land use and soil type	MCDM, AHP, GIS and interviews	-	Yes, through unpublished reports, physical field visits and interviews

(Adeaga et al., 2020) Nigeria	Physical	Exposure	Expert-based	City Level Urban	SRTM DEM, Administrative Map and Discharge/stage height	Cellular automation modelling in GIS Spatial planning and flood risk management	-	-
(Mohamed & Worku, 2020) Ethiopia	Physical	Exposure	Expert-based	Sub district-level Urban	SRTM DEM, Landsat 8	MCA fuzzy overlay analysis Landscaping monitoring	-	-
(Hamidi et al., 2020) Pakistan	Physical and Social	Exposure, Susceptibility and Resilience	Literature review	Sub district-level Urban	Flood experiences, injuries or death, houses in flood-prone areas, ASTER DEM, slope, Illiteracy, Dependents, Chronic illness/ disability, Employment, Income, and social network	Statistical analysis and GIS functions Policymaking	Yes, based on criteria weights	Yes, through Cronbach's alpha on indicators
(Eini et al., 2020) Iran	Social and Economic	Exposure and Sensitivity	Expert-based	City-level Urban	Elevation, slope, distance to the river, distance to channel, rainfall, curve number, land-use	Machine learning - Maximum Entropy, Genetic Algorithm Rule-Set Production, Fuzzy AHP and WLC Spatial planning and flood risk management	-	-

3.3.1 Components of flood vulnerability

The majority (60%) of the studies reviewed show that mapping flood vulnerability involved the integration of at least physical and social components. In particular, the review shows that combining physical, social and economic components was the most common (70%) way of mapping flood vulnerability in developing countries between 2010 and 2020.

3.3.2 Elements of flood vulnerability

Exposure to flood hazards was the most common (99%) element used in mapping flood vulnerability in developing countries. Most of the studies reviewed (78%), however, combined more than one element.

3.3.3 Criteria selection

The review revealed that the selection of criteria or indicators to use to map flood vulnerability in developing countries was mainly based on technical-expert knowledge and criteria existing in the literature. Very few studies (less than 10%) relied on the participation of community members. Only (Hung & Chen, 2013; Kienberger, 2012; Yankson et al., 2017; Ziarh et al., 2020) allowed the participation of other stakeholders in the identification of criteria for mapping flood vulnerability.

3.3.4 Scale and setting

The scoping review shows that mapping flood vulnerability in developing countries was done at various scales, ranging from the national to regional, sub-district, community and household levels. Increasingly, mapping flood vulnerability was being done at sub-district and community levels. However, only Hossain (2015) and Huq et al. (2020) conducted their studies at a household level. Further, most (over 52%) of the reviewed studies were conducted in urban settings.

3.3.5 Data

A variety of data was used in mapping flood vulnerability in developing countries. The data ranged from satellite images to socio-economic and demographic data. The reviewed studies in Table 3.1, show that most of the land use data used in the studies were mainly extracted from Landsat images while most of the Digital Elevation Models (DEM) for elevation and slope data were extracted from Shuttle Radar Topography Mission (STRM). The Landsat and STRM-based data were being used at all levels or scales. Census data was widely used to extract demographic and socio-economic data for use at all scales. This review also reveals that very few studies (Al Baky et al., 2019; Shivaprasad et al., 2017; Sianturi et al., 2018) used SAR data to map flood vulnerability.

3.3.6 Analytical approaches and purpose of the maps

Indicator-based Multi-Criterial Analysis (MCA) and all its variations took centre stage in mapping flood vulnerability in developing countries (Table 3.1). The MCA approaches were mainly combined with the Geographical Information System (GIS). The Analytical Hierarchical Process (AHP) was mainly used in MCA approaches. Less than 5% of the reviewed studies used Analytical Network Process (ANP), TOPSIS, fuzzy-based approaches or machine learning approaches. Information derived from field surveys and key informant interviews were also increasingly combined with MCA approaches. However, only Hazarika et al. (2018) and Romanescu et al. (2018) integrated Indigenous Knowledge in mapping flood vulnerability. This review (Table 3.1) also shows that only (Brandt et al., 2019; Canevari-Luzardo et al., 2017; Hung & Chen, 2013) used participatory GIS approaches in mapping vulnerability in developing countries.

The reviewed studies (Table 3.1) further show that flood vulnerability maps were being produced for various purposes. A considerable number of studies mapped flood vulnerability to improve spatial planning, especially in urban areas. Others were meant to inform policymakers on where the vulnerable people were located to help trigger strategic or policy interventions and flood risk management.

3.3.7 Sensitivity analysis

It can be seen from this review (Table 3.1) that sensitivity analysis was rarely conducted in mapping flood vulnerability in developing countries. Less than 10% of the studies reviewed conducted sensitivity analysis. From the few studies that conducted a sensitivity analysis, the sensitivity analysis was based on adjusting the criteria weights.

3.3.8 Validation of flood vulnerability maps

Validating the flood vulnerability maps was not very common during the review period. Only a few studies (25%) validated their final flood vulnerability maps. The validation was done through various approaches, which include technical-expert knowledge, community members, depth measurements, satellite images, actual flood events as well as flood points randomly selected in the field.

3.4 Discussion

This review shows that there has been a growing interest in mapping flood vulnerability in developing countries. Reviewed studies recognised the multidimensional and complex nature of flood vulnerability by embracing an integrated and interdisciplinary approach to mapping flood vulnerability. This was also seen in the shift from only considering exposure to flood hazards, to integrating other elements namely sensitivity or susceptibility and coping/adaptive capacity. However, the widespread use of exposure in the flood vulnerability maps could be attributed to various definitions of exposure which lead to the consideration of various variables. In some cases, only geographical and environmental variables were considered while in other cases, social or socio-economic variables were added to the geographical variable. Barroca et al. (2006, p. 554) argue that considering flood vulnerability in an interdisciplinary way has become accepted in scientific research globally because it helps to provide a comprehensive assessment of flood vulnerability at all spatial scales.

Mapping flood vulnerability at local scales is progressive in our view. This is because this scale provides the necessary detail for strategic planning, decision-making and policy intervention which helps in flood risk reduction and improving the adaptive capacity of people or the community. Most of the studies mapping flood vulnerability were conducted in urban settings. This situation suggests that vulnerability to floods in urban settings is rampant and problematic. It has been noted that people’s vulnerability to floods will increase especially due to climate change, as rainfall has been projected to increase both in frequency and intensity (Douglas et al., 2008; Kundzewicz et al., 2013). Hence, urban areas in developing countries will be the most adversely affected (Pour et al., 2020). This is due to the increased number of people living in urban areas, high population density, settlement of people in floodplains, steep slopes and wetlands, increased impervious surfaces, land-use changes, poor drainage infrastructure and indiscriminate disposal of waste which clogs drains (Drivdal, 2016; Grahn & Nyberg, 2017;

Pour et al., 2020; Zehra et al., 2019). Furthermore, most urban dwellers in developing countries have low adaptive capacities (Ajibade & McBean, 2014; Neil Adger et al., 2005).

To reduce the adverse impact of flooding on people and their property in urban areas, low-impact developments are being encouraged (Hewitt et al., 2019; Pour et al., 2020). This is because low-impact developments promote adaptation and resilience of urban areas to climate change. They also promote infiltration, and evapotranspiration, reduce runoff volumes and peak flow, extend the lag time and minimise hydrological impacts of dense urbanization (Ahiablame et al., 2012; Eckart et al., 2017; Pour et al., 2020; Seo et al., 2017).

This review further suggests a failure by many local governments in dealing with people's vulnerability to flooding. Satterthwaite et al. (2007) argue that risk reduction strategies in urban settings especially informal settlements are not given the attention they deserve because informal settlements in many developing countries are considered illegal and the data shows the severity of flood vulnerability is none existent.

The availability of more recent, reliable, disaggregated and high-resolution spatial data is a big challenge in many developing countries (Hoque et al., 2019; Kienberger, 2012; Muller et al., 2011). It is for this reason that coarse spatial resolution data was being used for mapping flood vulnerability even at the local scale or community level. In particular, Landsat images with a resolution of 30-meter resolution and SRTM data with a resolution of 90 meters and 30 meters were used for extracting land use/cover, elevation and slope data respectively at local scales. Course resolution data was used in this manner because it is freely available and accessible to many people in developing countries. Furthermore, census data was used to extract demographic data for use at all scales. However, most of the data from the census tend to be five to ten years old. Census data in most countries is usually aggregated, hence it masks critical variations in socio-economic and demographic characteristics of people at a local scale. As such the flood vulnerability maps tend not to depict the current picture and real vulnerability of people, especially at community levels. This situation reduces the usability of the flood vulnerability maps. Although household surveys are time-consuming and costly at times, they can help to provide current and detailed demographic and socio-economic information for use in flood vulnerability maps at local levels.

Satellite images that provide higher spatial resolutions are required for local-scale analysis. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery which has a resolution of 15 meters and the ALOS PALSAR which has a spatial resolution of 12.5 meters can be used to provide elevation and slope data at local levels. SAR data can also provide higher temporal and spatial resolution as well as accurate, cheaper elevation data and flood inundation information that is useful in flood risk reduction (Dewan et al., 2006; Sahana & Sajjad, 2019; Tali et al., 2016). Light Detection and Ranging (LIDAR) although not cheap can provide high-quality elevation information appropriate for mapping flood vulnerability at a local scale. Furthermore, Unmanned Aerial Vehicles (UAVs) are now available in many developing countries. These can also provide updated, reliable and high-resolution elevation information and other spatial information like buildings, rivers or roads for use at a fine scale. Sentinel 2 which has a resolution of 20 meters can also be used to extract better land use/cover data and other spatial data at no cost. Moreover, there are now many open-access data platforms that have a variety of spatial and non-spatial data that have acceptable accuracy which researchers in developing countries can utilise at no cost.

Although Indigenous Knowledge is useful in reducing disaster risk, its use in developing countries is still limited. This also explains the inadequate existence of studies using participatory methods in mapping flood vulnerability in developing countries. Kienberger (2012, p. 2014) and de Andrade and Szlafsztein (2015, p. 1492) argue that participatory approaches are important in developing countries because of the challenges of updated and reliable geospatial data. Several scholars (Hazarika et al., 2018; Hung & Chen, 2013; Kienberger, 2012) argue that flood vulnerability that takes into account different components and elements of vulnerability should ensure that there is adequate stakeholder participation.

Since indicator-based multi-criteria approaches were widely used for mapping flood vulnerability, the selection of criteria used to produce the maps is very important. This is because the criteria determine the accuracy and validity of the final flood vulnerability maps. Therefore, relying on existing literature in the selection of criteria for mapping flood vulnerability assumes that flood vulnerability is the same everywhere, yet it is context-specific (Hazarika et al., 2018; Hung & Chen, 2013; Kienberger, 2012). Furthermore, depending on technical-expert knowledge in selecting the criteria denies community members the opportunity to share their experiential knowledge of floods. As a result, the final maps may not reflect the real situation on the ground and in turn, limit their usability.

GIS was combined with MCA approaches because of its capability to integrate data from various sources as well as spatially analyse and visualise data. The AHP was widely used in MCA approaches to analyse complex decision problems. The AHP has however been criticised. Li et al. (2011) argue that while the AHP is simple to use, it does not take into account interdependent criteria. Ghorbanzadeh et al. (2018) contend that the AHP also fails to take into account many alternatives at a time. Hence, several scholars (de Brito et al., 2018; Hategekimana et al., 2018; Yazdi & Neyshabouri, 2012; Yeganeh & Sabri, 2014) recommend the use of ANP or fuzzy-based approaches as they account for interdependent criteria.

To assess the uncertainties and robustness of criteria and their weights in mapping flood vulnerability, sensitivity analysis should be done (Chen et al., 2019; de Brito et al., 2019; Ghorbanzadeh et al., 2018). Ferretti and Montibeller (2016, p. 45) state that conducting sensitivity analysis fosters transparency in mapping flood vulnerability. Validating or assessing the accuracy of the final flood vulnerability maps is also very important. de Brito et al. (2018, p. 386) argue that the failure to validate flood vulnerability maps is a recurring problem that needs to be addressed. Ouma and Tateishi (2014, p. 1542) argue that assessing the accuracy of flood vulnerability maps helps to increase their validity and usability. In our view, flood vulnerability maps were not validated partly because of a lack of reliable and easily accessible data. This could explain why some of the studies reviewed validated their maps through technical experts. However, using technical experts alone to validate flood vulnerability maps can give false accuracy levels, especially if the experts involved are not very familiar with the area for which the maps were made. SAR has been widely used for identifying flooded and non-flooded geographical areas (Dewan et al., 2006; Giustarini et al., 2015; Hao et al., 2021), we are therefore of the view that SAR can be explored and used to validate flood vulnerability maps at very minimal to no cost. The advent of Sentinel-1 provides the opportunity to acquire high temporal and spatial resolution SAR data for free.

3.5 Conclusion

Due to climate change, a lot of people and property have been projected to be vulnerable to flooding, especially in developing countries. There is therefore a need for more studies that map flood vulnerability at a finer scale such as a household level, to establish the main causes of their vulnerability to flooding as a way of preventing and mitigating flood risk. Care must be taken when selecting flood vulnerability indicators by ensuring that there is community participation. This is because community members have experiential or Indigenous Knowledge that can help to have participatory and context-specific flood vulnerability maps. Furthermore, flood vulnerability maps subjected to sensitivity analysis and validation are crucial in supporting an accurate identification of areas that need prioritization in terms of resource allocation, intervention or strengthening of people's adaptive capacity. There are now many open-source platforms that provide free data that can be utilised for mapping flood vulnerability at a local scale. Artificial intelligence, machine learning and Volunteered Geographical Information (VGI) approaches should be explored much more in mapping flood vulnerability in developing countries as they are more robust and can be used in data-scarce environments. Furthermore, SAR data can be explored in high spatial resolution elevation data as well as validating flood vulnerability maps.

There is a need to raise awareness and build capacity in low-impact development techniques especially in local authorities in developing countries to increase their implementation rate and to ensure that context-specific designs are used to promote resilience to flooding in local communities.

The main limitation of this scoping review paper is that it only examined research articles that were captured by the search criteria in Web of Science and Scopus and had a flood vulnerability map as one of the outputs of the study.

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Conflict of interest

The authors declare that there is no conflict of interest.

CHAPTER 4: USING LOCAL AND INDIGENOUS KNOWLEDGE IN SELECTING INDICATORS FOR MAPPING FLOOD VULNERABILITY IN INFORMAL SETTLEMENT CONTEXTS

This chapter is based on the following:

Membele, G. M., Naidu, M., & Mutanga, O. (2022). Using local and indigenous knowledge in selecting indicators for mapping flood vulnerability in informal settlement contexts. *International Journal of Disaster Risk Reduction*, 71(2022), 1-13.
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Abstract

Floods have been projected to increase due to climate change and informal settlements in developing countries will be the most affected. This study presents results of using Local and Indigenous Knowledge in selecting indicators for mapping the vulnerability of people to flood hazards in an informal settlement context. Using Quarry Road West informal settlement, the study employed a convergent parallel mixed-methods approach which involved a household survey (n = 359), interviews with key informants (n = 8) and a focus group discussion (n = 1). The study findings reveal that flood vulnerability in the study area is not only a result of the proximity of the houses to the Palmiet River, the M19 freeway and Quarry Road, but also a result of the nature of the soil and the type of materials people use to build their houses. Furthermore, findings reveal that using both Local and Indigenous Knowledge possessed by community members, a minimal number (sixteen) of context-specific indicators for mapping flood vulnerability in the study area were selected. The study also finds that flood vulnerability in the study area is a result of physical, socio-economic and institutional problems. Therefore, using Local and Indigenous Knowledge to select indicators for mapping flood vulnerability helps to provide a better understanding of flood vulnerability in an informal settlement and this gives decision-makers and other stakeholders a glimpse of adaptive measures that can be implemented to increase people's resilience.

Keywords: Context-specific Indicators Mapping Flood vulnerability Knowledge co-production

4.1 Introduction

The frequency and intensity of rainfall events have been projected to increase in many parts of the world due to climate change (Cardona, 2004; Myhre et al., 2019). This will lead to an increased risk of flooding in many areas around the world (Connor & Hiroki, 2005). Location, exposure of the population and infrastructure, political and institutional arrangements, and cultural and socio-economic conditions including their adaptive capacity have been identified as factors responsible for the vulnerability of people to climate risks and flood hazards. According to Adelekan (2010), many flood disasters in developing countries are due to natural hazards exacerbated by development challenges in the affected communities. Generally, factors responsible for causing flood vulnerability in a particular area help to inform the selection of indicators for mapping vulnerability to flood hazards in that specific locality (Chang et al., 2015; Cutter et al., 2003; Wisner et al., 2004; Yankson et al., 2017). Mapping flood vulnerability is valuable as it helps to spatially visualise where low or high vulnerability is, supports the production of strategic plans for reducing vulnerability and encourages the participation of community members and other stakeholders in finding sustainable solutions (Jha & Gundimeda, 2019; Scheuer et al., 2013; Wilk et al., 2018). de Brito et al. (2017) argue that promoting the participation of generally marginalized communities in flood vulnerability mapping enhances the legitimacy and reliability of the selected indicators.

The use of indicators in mapping flood vulnerability has been encouraged by many international organisations such as the United Nations International Strategy for Disaster Reduction. One of the key activities of the Hyogo framework was to develop indicators for disaster risk and vulnerability at various scales to provide decision-makers with tools to assess risks and the impact of disasters (United Nations International Strategy for Disaster Reduction, 2005). According to Mavhura et al. (2017), an indicator is defined as a qualitative or quantitative measure to simplify and communicate attributes of a situation that is complex in a particular system or community. According to Nguyen et al. (2016), one of the fundamental reasons for selecting indicators is to identify variables for the main components of flood vulnerability comprised of physical and social factors interacting with exposure, sensitivity and adaptive capacity of people in a particular locality. In this study, the emphasis is on the residents' adaptive capacity. This is because adaptive capacity is usually low for people in informal settlements who mainly live in hazardous areas, have poor living conditions and are marginalized by city authorities (Ajibade & McBean, 2014; Neil Adger et al., 2005). According to the UN-Habitat (2015), informal settlements are residential areas where the dwellers have no security of tenure, lack basic services and infrastructure, and build houses without complying with planning and building regulations. Statistics South Africa (2011) define informal settlements as unplanned settlements on unsurveyed land or located on land not designated as residential, mainly having makeshift structures. Ngie (2012) contends that a household or community's adaptive capacity modifies its vulnerability to flooding. This means that the higher the adaptive capacity of a community, the lower its vulnerability to flooding and vice versa. Furthermore, adaptive management theory advocates for collaborative and decentralised approaches to managing floods (Holley et al., 2011; Ziervogel et al., 2016). The IPCC (2012) defines adaptive capacity as the ability of a household or community to adjust or moderate potential damages by taking advantage of its strengths, resources and opportunities available to reduce the adverse impacts of hazards. Amoako (2015) argues that people's local knowledge of floods helps to improve their adaptive capacity and resilience. Hence, Chanza and De Wit (2016) argue that Indigenous Knowledge and local people's experiences of floods should not be ignored in efforts to reduce flood vulnerability in informal settlements. Other scholars (Janssen & Ostrom, 2006; Lemos et al., 2007) assert that adaptive capacity in a community can be improved by investing in information and knowledge.

Aside from the use of indicators, the curves and damage matrixes are also used in mapping flood vulnerability. The indicator-based approach is however widely used because it is considered flexible (Kappes et al., 2012). Furthermore, the use of indicators has been found to give better, transparent and trustworthy results in depicting flood vulnerability (Ciurean et al., 2013; Nasiri et al., 2016). According to Nasiri et al. (2016), mapping flood vulnerability using the indicator-based approach is preferred by decision and policymakers because it helps in raising public awareness, identifying priority measures and planning for risk response. The use of indicators has also been found to provide tools for monitoring the progress of implemented flood vulnerability reduction interventions. Balica et al. (2009) argue that the indicator-based approach is ideal for understanding the vulnerability of a system because it combines many components of flood vulnerability which make people and places susceptible to flood hazards.

The use of indicators in flood vulnerability mapping results in the development of an index whose final results are represented by a normalised or standardised number, from 0 to 1, which indicates comparatively low or high flood vulnerability. This index is mainly used to spatially map and locate hotspots of flood vulnerability in a particular geographical area. Different flood vulnerability indices have been developed at different spatial scales as a quick and consistent approach for depicting the relative vulnerability of different areas to flood hazards (Balica & Wright, 2010; Balica et al., 2009; Balica et al., 2012). Some of these indices consider flood vulnerability from a physical perspective (Ali et al., 2019; Sarmah et al., 2020; Yahaya et al., 2010) while some consider the social perspective of flood vulnerability (Cutter et al., 2003; Mavhura et al., 2017; Mazumdar & Paul, 2018). There are now many studies that consider flood vulnerability from an integrated perspective where both physical and social vulnerability are combined (Brandt et al., 2019; de Brito et al., 2018; Karunarathne & Lee, 2020).

Physical vulnerability mapping is generally not difficult to conduct because it is easy to quantify its indicators, while the integrated flood vulnerability is complex because it combines multiple aspects which include physical, social, economic and environmental factors, some of which are not easily quantifiable (Cutter et al., 2008; Khan, 2012; Nasiri et al., 2016). Physical factors can either be natural or manmade which influence the vulnerability of a place or people to floods such as infrastructure, settlement patterns, physical structures, location and topography (Balica et al., 2009; Cardona, 2004). Physical indicators include heavy rainfall, proximity to the river, level of flood water, flood return periods, inundation area, frequency of floods (Yankson et al., 2017) elevation, slope, drainage density, river discharge, flow velocity, sedimentation load, land use/cover and nature of soil (Balica & Wright, 2010; Buba et al., 2021; Hendrawan & Komori, 2021; Seekao & Pharino, 2016; Vozinaki et al., 2015; Yeganeh & Sabri, 2014). Social factors describe the context, skills, values, norms, beliefs, knowledge, behaviour of individuals or households and governance characteristics of a particular place (Balica & Wright, 2010). Mavhura et al. (2017) argue that social vulnerability is ‘deep-seated’ in the cultural and historical processes of a people in a particular locality. Social factors are however not easy to quantify. Social indicators include age (Sherman et al., 2015), housing materials, population density, land value (Abdrabo et al., 2020), educational level (Cutter et al., 2003; Y. Huang et al., 2012; Kwazu & Chang-Richards, 2021), gender (Hudson et al., 2019), persons with permanent disabilities (Fatemi et al., 2017), dependence ratio (Ullah et al., 2021), risk awareness (Rana & Routray, 2016), distance to health facilities (de Brito et al., 2017) and social ties or networks (Jones & Faas, 2017). The economic factor relates to the income and wealth of a particular area or community. The average income of households is widely used as an economic indicator for assessing flood vulnerability (Chang & Chen, 2016). According to

(Balica & Wright, 2010), the environmental factor considers damage to the environment as a result of human activity or flood events. Indicators include degraded area, forest change rate and groundwater level. Although challenging to handle, integrated flood vulnerability mapping is highly recommended (Nguyen et al., 2016). We, therefore, contend that integrating Local and Indigenous Knowledge, as an additional approach should be explored in flood vulnerability mapping, especially in informal settlements.

The use of Indigenous Knowledge has received a lot of support at the global level. The World Conference on Disaster Reduction (2005 in Hyogo, Japan), the United Nations International Strategy for Disaster Reduction (UNISDR) and the Sendai Framework for Disaster Risk Reduction 2015–2030, have called for the integration of Indigenous Knowledge in disaster risk reduction. This is because the experience and cultural insights drawn from an Indigenous Knowledge base contribute to building resilience and protection of people in high-risk areas such as informal settlements (UNDRR, 2005, 2015).

Drawing on, Local Knowledge is also important for reducing flood vulnerability at a local level because it helps in developing appropriate mitigation and coping strategies that emerge from the local community (Bernatchez et al., 2011; Brandt et al., 2019; Peters-Guarin et al., 2012; Tran et al., 2008), as it draws on and builds on embedded and intergenerational insights. Naess (2013) argues that Local Knowledge provides social capital that is crucial for dealing with hazards like floods in local communities. This is because the community and their use of Local Knowledge assist in disseminating flood early warning information at local levels (Islam et al., 2018). Local Knowledge is generally defined as knowledge acquired by people due to them living in a particular place or community for a particular period (Langill, 1999; Naess, 2013). Local Knowledge is therefore experiential and is embedded in the relationships, practices and institutions within a community (Ngwese et al., 2018). We consider Indigenous Knowledge to be a uniquely developed and dynamic knowledge system rooted in the culture of a particular geographical area or society and is transmitted from one generation to the next orally or through demonstration or repetition (Mercer et al., 2007; Michell, 2005; Ngwese et al., 2018; Sillitoe, 1998; Sillitoe, 2007). According to Ossai (2011), Indigenous Knowledge is adaptable and changes under the influence of internal experimentation and external knowledge. Fabiyi and Oloukoi (2013) argue that Indigenous Knowledge is rooted in culture and the past experiences of people in a particular geographical area. Indigenous Knowledge comprises local and situated beliefs, skills and practices that help people to have stable livelihoods and become resilient to flood hazards (Trogrlić et al., 2019; UNEP, 2008). Furthermore, several scholars (Bernatchez et al., 2011; Mavhura et al., 2013; Musungu et al., 2012; Ossai, 2011) rightly contend that Indigenous Knowledge is important because it helps to comprehend factors that cause flood vulnerability and damages caused by floods in particular geographical areas. According to Mavhura et al. (2013) Indigenous Knowledge promotes community participation and empowerment of communities affected by floods. It also promotes the implementation of adaptation interventions based on local contexts.

Within a global south geo-context, research reveals that many communities possess Indigenous Knowledge which they draw on to confront flood hazards and spatial planning problems. Literature shows a rich landscape as an example of such cases. Kasei et al. (2019) conducted a study to assess the role of Indigenous Knowledge in flood early warning in five informal settlement communities in Ghana. Dube and Munsaka (2018) examined the contribution of Indigenous Knowledge in disaster risk reduction interventions. The study was conducted in a community called Matabeleland, Tsholotsho district in Zimbabwe. In two informal settlements namely Uupindi and Oshoopala located in Northern Namibia, Hooli (2016), studied the communities' use of Indigenous Knowledge to cope with floods. Lefulebe et al. (2014), in Cape Town, South Africa, demonstrated the use of Indigenous Knowledge and stakeholders' view in the upgrading of an informal settlement called Monwabisi Park. Furthermore, Mavhura et al. (2013), examined Indigenous Knowledge-based strategies for coping with floods in two communities located in Muzarabani district, Zimbabwe. Codjoe et al. (2013) examined the experiences, perceptions and Indigenous Knowledge for dealing with excessive heat, sea-level rise, drought and floods as a result of climate change in metropolitan Accra, Ghana. In Diepsloot Township located in South Africa, Ngie (2012) integrated Indigenous Knowledge and Geographical Informal System to identify and map flood vulnerable areas.

Hence, Mercer et al. (2010) contend that Local and Indigenous Knowledge is indispensable in dealing with flood events. It is therefore our considered view that it is worth considering Local and Indigenous Knowledge in selecting indicators for mapping flood vulnerability at a Local scale. To reduce bias, we take an etic view of the community living in Quarry Road West informal settlement. This is because the etic perspective allows the researcher to observe and describe phenomena as an ‘outsider’ (Pike, 1990; Spiers, 2000). To further reduce bias, multiple methods were used to collect primary data in the study area.

According to Salvati and Carlucci (2014), the choice of indicators influences the outcome of the flood vulnerability maps. Hence, care must be taken in selecting indicators. Several scholars (Akukwe & Ogbodo, 2015; de Brito et al., 2018; Eini et al., 2020; Kumar et al., 2016; Niyongabire & Rhinane, 2019) have selected indicators for mapping flood vulnerability at city or district levels from the literature. Some scholars (Kienberger, 2012; Muller et al., 2011; Musungu et al., 2012; Yankson et al., 2017) have combined indicators from the literature with expert knowledge to map flood vulnerability at local scales or community levels. However, there are relatively few studies (Lefulebe et al., 2014; Musungu et al., 2012) that have used Local and Indigenous Knowledge to select indicators for mapping flood vulnerability at local scales and informal settlements in particular. We contend that relying on indicators generated from the literature alone is not ideal. This is because it results in having generic indicators, yet flood vulnerability is context-specific. The use of indicators generated from the literature alone also results in overgeneralised vulnerability maps which fail to accurately pinpoint where the most vulnerable people are located in a particular area. Moreover, indicators used in one location may not be appropriate in another location because factors responsible for causing flood vulnerability may be different from place to place. We also contend that relying on indicators generated from the literature and expert knowledge alone tends to be data-driven and not problem-based. Data-driven approaches tend not to reveal the actual or real situation on the ground as not easily conspicuous issues are left out because the interest was in the data and not the problem. We, however, acknowledge that informal settlements and developing countries in general, are grappling with the unavailability of updated data (Hazarika et al., 2018; Kienberger, 2012), but we believe that even in such instances locally appropriate proxies can be found. Furthermore, while it can be acceptable or appropriate to rely on expert knowledge in selecting indicators for mapping flood vulnerability, we are of the view that expert knowledge can be enhanced by integrating it with experiential and situational local knowledge transmitted from generation to generation which community members living in informal settlements affected by floods possess. In this study, experts are people from government or private institutions with extensive knowledge in analysing flood vulnerability which may have been acquired through work experience or education (de Brito et al., 2018; Krueger et al., 2012). According to Musungu et al. (2016), the challenges of infrastructure in most informal settlements have prompted informal settlement residents to use strategies of their own in dealing with floods. People living in informal settlements are not 'helpless' victims of floods, they have been actively involved in reducing flood impacts within their localities (Parsons et al., 2016). Adelekan (2010) argues that integrating expert knowledge, Local and Indigenous Knowledge possessed by communities affected by floods is crucial in achieving sustainability. Khan (2014) asserts that integrating Local and Indigenous Knowledge in flood risk reduction efforts can help to provide a broader and cost-effective understanding of the human-environment relationship which is critical for understanding and dealing with flood vulnerability at localised scales. Therefore, this study presents the results of using Local and Indigenous Knowledge in selecting indicators that can be used to map the vulnerability of people to flood hazards in an Informal settlement called Quarry Road West in Durban, South Africa. Therefore, this study seeks to address the following research questions: what factors are responsible for causing flood vulnerability in Quarry Road West informal settlement? What Local and Indigenous Knowledge-based criteria or indicators are used for mapping flood vulnerability in Quarry Road West informal settlement? To what extent can an approach that integrates Local or Indigenous Knowledge be used to select context-specific flood vulnerability indicators in the study area?

The significance of this study is firstly in that it presents an approach that integrates Local and Indigenous Knowledge in selecting locally appropriate indicators that can be used for mapping flood vulnerability in an informal settlement. Secondly, it provides a participatory approach that can be considered for selecting context-specific indicators for mapping flood vulnerability in informal settlements. This is because most of the studies that mapped flood vulnerability at different scales relied on literature and technical experts without adequately incorporating the local situation. Lastly, the study shows how the marginalized and poor people living in informal settlements are not helpless in finding solutions to their flood-related problems

4.2 Methodology

4.2.1 Study site

Quarry Road West informal settlement is located in the centre of Durban and the Palmiet River floodplain. It lies between Eastings 303250 and 303750 and between Northings 6701000 and 6701700 (Figure 4.1). According to Williams et al. (2018), the informal settlement is also located close to major transport routes and residential suburbs. The informal settlement experiences an array of economic, social and environmental challenges mainly as a result of high urbanization in Durban and climate change-induced risks. According to Mazeka et al. (2019), the settlement has around 1100 households with a population of over 2400 residents. The average household size is 3 persons per household (Williams et al., 2018). Sutherland, Mazeka, et al. (2019) state that the settlement does not have any state-subsidised low-cost housing like many informal settlements in South Africa. The houses are made by individual dwellers. Most of the residents of Quarry Road West rely on part-time and informal sector activities for survival (Williams et al., 2018). Mazeka et al. (2019) state that Quarry Road West informal settlement has high levels of unemployment, poverty, dense population and poor housing conditions. The settlement also has poor drainage and lacks basic services. Williams et al. (2018) contend that fire and flood disasters have led to the influx of people in the settlement, especially after the occurrence of the disasters and this has led to the expansion of the informal settlement. Posel and Marx (2013) state that most of the people in the settlement migrated from the Eastern Cape and other rural areas within KwaZulu-Natal Province. According to Sutherland, Roberts, et al. (2019) Quarry Road, West informal settlement was established in 1984. The residents in this informal settlement have no formal security of tenure because they illegally settled on the land. However, Williams et al. (2018) contend that the residents cannot be evicted from the land without a court order, and this gives them some kind of protection.

Williams et al. (2018) and Mazeka et al. (2019) assert that Quarry Road West informal settlement is prone to flooding which is mainly caused by the Palmiet River which passes through the settlement at an elevation of 18 m above sea level and runoff from the M19 and Quarry roads. According to Williams et al. (2018), the steep and highly modified Palmiet catchment results in a very quick discharge of water from the Palmiet River after heavy rain, which usually causes devastating effects on residents in Quarry Road West informal settlement. Mazeka et al. (2019) state that industrial, residential, nature reserves and open space characterise the land use around Quarry Road West informal settlement. Impervious surfaces have increased around the settlement due to the expansion of industrial and residential areas. This has increased runoff such that the Palmiet River peaks very quickly after rainfall (Mazeka et al., 2019; Vogel et al., 2016). According to Mazeka et al. (2019), efforts by the municipality in 2003/2004 to relocate the residents to a low-cost housing project located in the north-west of the city failed as most residents refused or returned to Quarry Road West informal settlement due to the locational advantage of the settlement which allows them to access urban opportunities and cheaply get to the city centre for jobs.

Like other settlements in Durban, Quarry Road West informal settlement experiences a humid and subtropical climate with mild, dry winters and warm, wet summers. Mean annual rainfall in Durban goes beyond 1000 mm and the total annual rainfall has been projected to increase by 500 mm, which will fall over a short period at increased intensity than was previously experienced in Durban (Williams et al., 2018). This situation will adversely affect residents of Quarry Road West informal settlement who are already vulnerable to flood hazards.

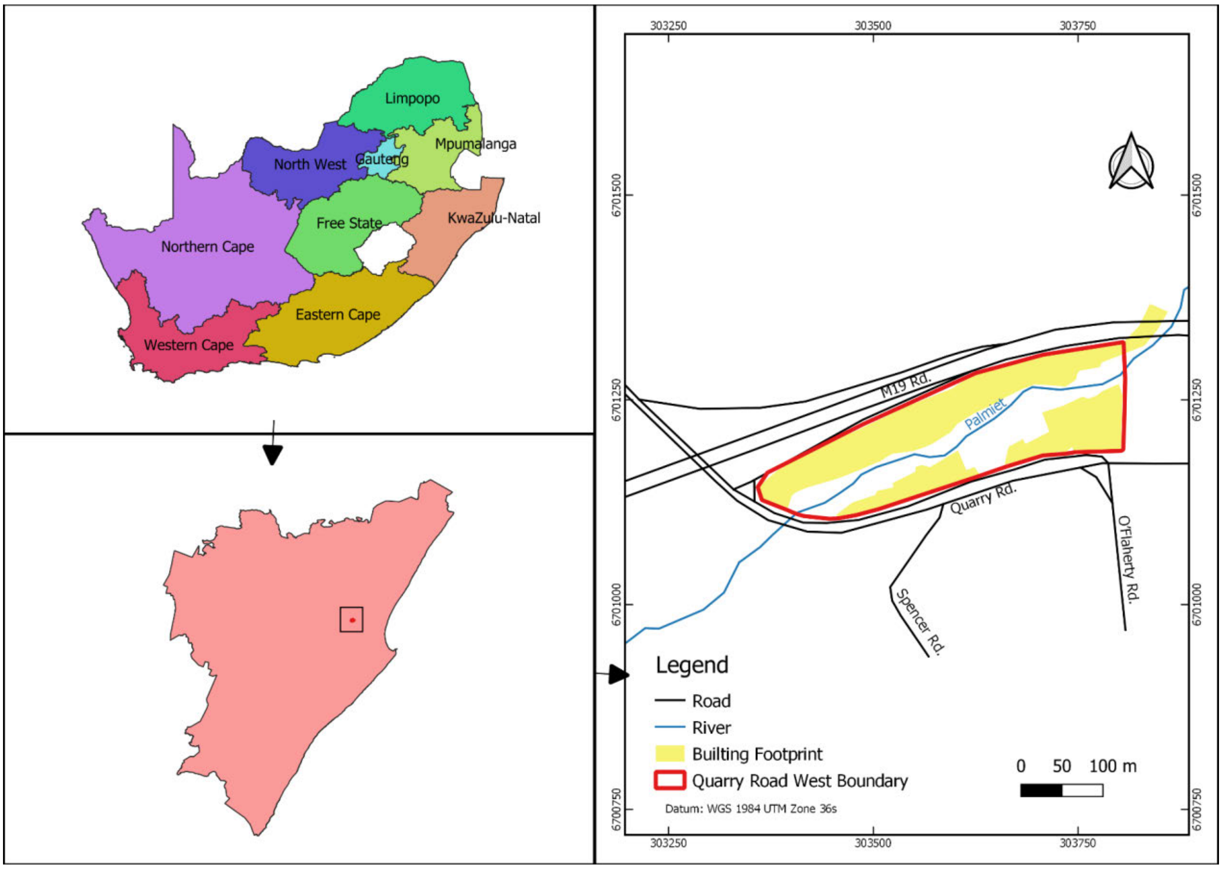

Figure 4.1 Location of Quarry Road West informal settlement

(Source: Authors)

4.2.2 Data collection and analysis

The convergent parallel mixed-methods approach was employed in this study. Therefore, quantitative and qualitative data were collected concurrently. Primary data was collected from households through a structured survey conducted from a sample of 359 households (Appendix

1). The sampled households used their Local and Indigenous Knowledge based on their experience of floods in the informal settlement. Household heads either male or female above 18 years in the sampled households were targeted because they are the ones who make decisions to deal with floods at the household level. Eight key informants purposely sampled were interviewed (Appendix 2 for the interview guide). Four key informants were officials from eThekwini municipality, from the departments of Disaster Management, Human Settlement, Environmental Planning and Climate Protection and Coastal, Stormwater and Catchment Management. One key informant was a researcher from the University of KwaZulu-Natal and three were community leaders from Quarry Road informal settlement. One focus group discussion was conducted with community members (Appendix 3 for the questions asked during the focus group discussion). Secondary data sources involved literature on indicators used for mapping flood vulnerability in different parts of the world. A combination of these data collection methods allowed for triangulation of information which helped to verify and enhance the credibility of the data (Foss & Ellefsen, 2002; Gibson, 2017). Indicators that appeared in three or more studies were considered and a list of indicators was generated (Table 4.1). The indicators generated from the literature were subjected to the key informants from the municipality and university for evaluation and selection based on what they considered as applicable indicators for the study area. Therefore, indicators selected by three or more experts (key informants from the municipality and local university) were selected and those that did not meet these criteria were left out. This resulted in the selection of twenty-one (21) indicators (Table 4.1). These indicators helped to devise questions for the household survey. Apart from the biographic information, the household heads who participated in the survey shared their experiential and situational knowledge of floods and the factors responsible for causing flood vulnerability in the informal settlement. Community members also used their Local and Indigenous Knowledge to validate the factors responsible for causing flood vulnerability in the informal settlement and selected indicators for mapping flood vulnerability in the informal settlement through a focus group discussion. It is important to note that this study does not cover what the participants understood about flood characteristics using Local or Indigenous Knowledge.

The in-depth interviews with key informants from the municipality and the university were conducted in October 2020 via the virtual zoom online platform due to restrictions on interactions through a lockdown implemented by the Government of the Republic of South

Africa to help reduce the spread of Coronavirus. The household surveys were conducted using Google Forms on mobile devices in May 2021 by four trained research assistants living within Quarry Road informal settlement. At this point, physical interactions were allowed with adherence to the Coronavirus protocols such as wearing face masks, social distancing and sanitizing regularly. A pilot survey was conducted with 36 households to ensure that the translation from English to the local language (isiZulu) was uniform and questions were asked similarly and clearly. The interviews with community leaders were conducted by the researcher with the help of a trained research assistant. These interviews were also conducted under strict adherence to all the Coronavirus prevention protocols. The research assistant provided the translation every time the community leader felt comfortable using the local language. A focus group discussion was conducted to have a consensus on the indicators for mapping flood vulnerability in the settlement. In instances where there were two or more opposing views, the views of the majority were adopted during the focus group discussion. The focus group discussion was attended by two males and five females. This was despite inviting an equal number of males and females.

The quantitative data from the household survey were analysed using descriptive and inferential statistics while qualitative data was analysed using thematic analysis. According to Kiger and Varpio (2020), thematic analysis is ideal for comprehending a set of behaviour or experiences. In this study, community members' experiences with floods were sought through the household survey and key informant interviews. The responses from the key informants and focus group discussion was transcribed, read through over and over to create sub-themes and then further synthesised into themes based on the research questions using excel. The themes included household characteristics of the respondents, factors causing flood vulnerability in the settlement and the selection of indicators for mapping flood vulnerability.

Formal ethical approval for this study was granted by the Humanities and Social Sciences Research Ethics of the University of KwaZulu-Natal, South Africa (Committee Protocol reference number: HSSREC/00001793/2020). Informed consent was also obtained from all the respondents, key informants and focus group discussants (Appendices 4-7).

4.3 Results

4.3.1 Household characteristics and flood experience

Over half (54%) of the household heads sampled were male and the rest were female. Close to 60% of the respondents were single, 25% were cohabiting and the rest were either married or separated, divorced, widowed or widowers. More than three-quarters (75%) of the respondents were below 40 years and the rest were between 41 and 60 years. Less than 5% of the respondents had college or university education, 41% had secondary education, 46% has basic education and the rest (9%) had no formal education.

Most of the respondents (67%) had been living in Quarry Road informal settlement for more than four years and the rest (33%) had been living in the settlement for less than three years. Most respondents living in the settlement were South African (69%) and the rest (31%) were from other African countries mainly from Malawi, Mozambique and Lesotho respectively. Many of these foreigners have been in the settlement since the early 1980s when the settlement was established. A bigger proportion (61%) of the respondents owned the houses they were living in, while some (36%) were renting and a very small proportion (3%) were living in houses belonging to a relative.

The survey showed that a very big proportion (91%) of the sampled households were affected by floods every rainy season and only a few (9%) were not. The majority (52%) of respondents had children under the age of five years, but most (68%) of them did not live with their children under five years in the same households. These children were mainly living with their grandparents and other relatives in their rural homes. Furthermore, more than three-quarters (77%) of the respondents did not live with their children below the age of twelve years in the same household. Almost all (98%) sampled households did not have elderly people above 60 years living in their households. The household survey results also show that a very big proportion (96%) of the respondents did not live with persons with a permanent disability in the same household.

The survey results also show that most (70%) of the respondents were in employment and those not employed (30%) were generally involved in some form of informal business (46%) and the same proportion (46%) were not working or were reliant on social grants from the government.

The rest (8%) were engaged in temporal jobs for survival. The average income of the sampled households was grouped into five categories (Figure 3.2). The results show that the majority (60%) of the sampled households earned an average income below R2,500 per month.

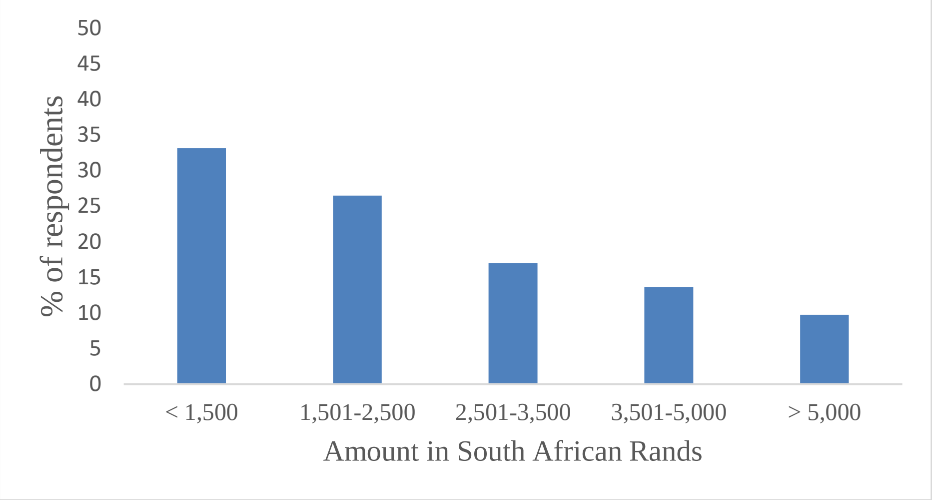

Figure 4.2 Average income of sampled households

The results also show that a little over half (51%) of the sampled households did not receive flood early warning information from the WhatsApp group or any other means while a considerable proportion (49%) received the information. Those who received the information mainly (60%) accessed it through traditional media namely television and radio (Figure 3.3). To establish if there is a significant difference between households that receive early flood warning information and those that did not receive the information, a two proportional z test was conducted. The result ($z = 0.54$, $p > 0.05$) shows that there is no significant difference between households that received flood early warning information and those that did not receive the information.

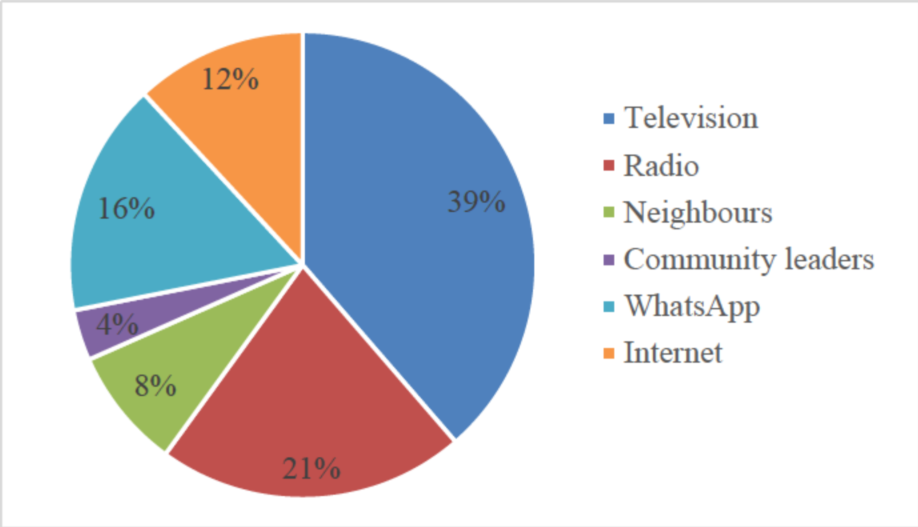

Figure 4.3 Media used to access flood early warning information

4.3.2 Factors causing flood vulnerability in the settlement

The results from the household survey show that the proximity of houses to the Palmiet River, nature of the soil, proximity of houses to the M19 and Quarry Roads and the type of materials people use to build houses are the main factors responsible for causing flood vulnerability in Quarry Road West informal settlement (Figure 3.4).

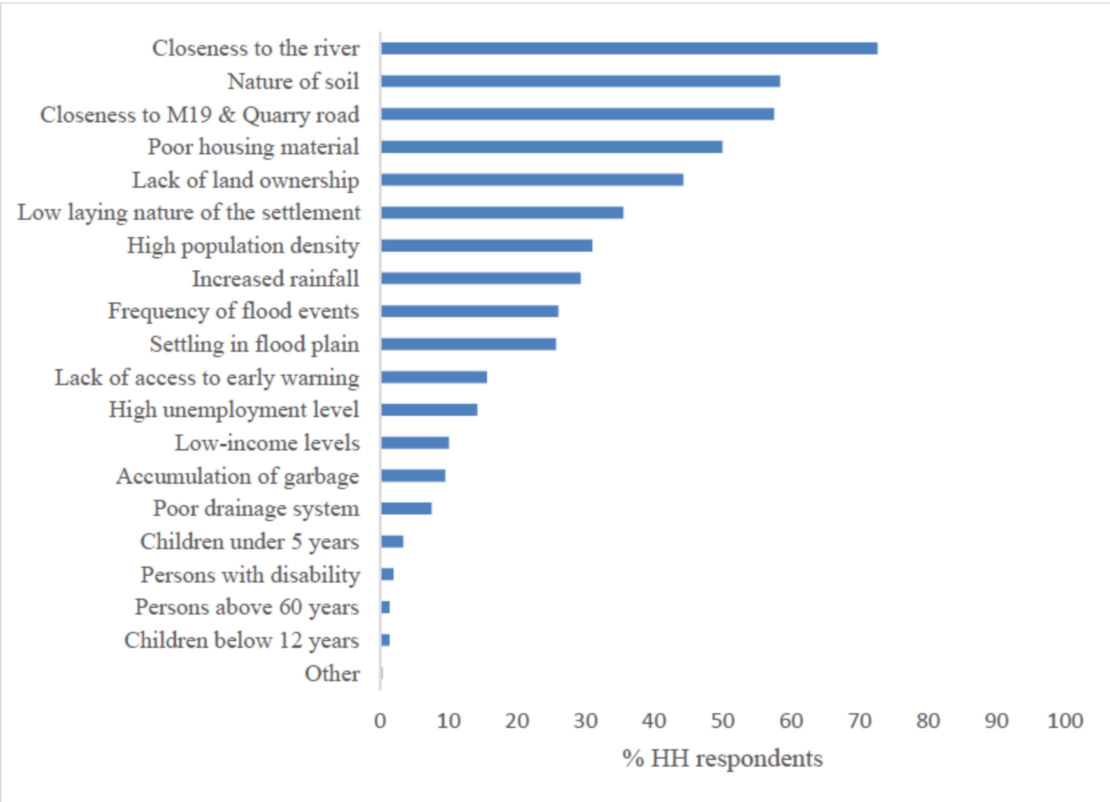

Figure 4.4 Causes of flood vulnerability in Quarry Road informal settlement

4.3.3 Selection of indicators for mapping flood vulnerability

After evaluating the factors responsible for causing flood vulnerability in the settlement from the household survey, the focus group discussants generated indicators that could be used for mapping flood vulnerability in Quarry Road West informal settlement. The final selection of these indicators was done during a focus group discussion. Two indicators not captured from the household survey were added to the list of indicators by the focus group discussants. These indicators are flow velocity and social ties. In emphasising the significance of the flow velocity of water in the river, one focus group discussant (FGD1) stated that: 'the water in the river nowadays comes with some much pressure and hits the river banks with force' and another discussant (FGD2) commented on social ties stated: 'every time people on the banks cry for help, a lot of people open their doors to receive their valuable items and provide them a place to sleep.' Furthermore, the results show that out of the 33 indicators generated from the literature, the 'experts' selected twenty-one (21) indicators as ideal for mapping flood vulnerability in the study area. Twelve (12) indicators selected by the community overlapped with those generated from the literature and selected by the 'experts'. However, four (4) were not selected by the 'experts' nor were they used in the literature for mapping flood vulnerability. Hence a total of sixteen (16) indicators were selected by the focus group discussants for mapping flood vulnerability in Quarry Road West informal settlement (Table 3.1).

Table 4.1 Indicators selected by experts and community members for mapping flood vulnerability in Quarry Road West informal settlement

Factor/Element	**Indicators from the literature**	**Expert selection**	**Community members' selection**
	Amount of rainfall	×	×
	Flood frequency	×	
	Proximity to river	×	×
	Flood water level		
	Drainage density		
	Flow velocity	×	×
	Slope	×	×
Physical	Elevation	×	
	Nature of Soil	×	×

	Land cover	×	
	Type of building material	×	×
	Critical infrastructure e.g., bridges		
	Drainage system*		×
	Distance to health facilities	×	
	Proximity to main roads*		×
Economic	Average income	×	×
	Level of Unemployment	×	×
	Persons with permanent disabilities		
	Persons under 5 years	×	
	Persons under 12 years	×	
	Persons over 60 years		
	Population density	×	×
	Literacy rate	×	
	Access to early warning information	×	×
Social	Female-headed households	×	
	Evacuation drills		
	Level of Education	×	×
	Social ties	×	×
	Access to media/awareness	×	
	Health insurance		
	Dependence ratio		
	Land ownership*		×
	Accumulated waste*		×

Note: * not selected from the literature.

4.4 Discussion

The indicators selected by the community members for mapping flood vulnerability in Quarry Road West informal settlement are locally appropriate and context-specific as they are based on the informal settlement dwellers' experiential and local situational knowledge.

It is interesting to note that while most of the sampled households in the study area had children, they generally did not live with them in their households, nor did they live with people above 60 years and those with a permanent disability. This could imply that most residents in the informal settlement were aware of the flood risks and hazards that were in the settlement and that living with their children under twelve years increased their level of vulnerability to flooding. It also could explain why most people in informal settlements in South Africa have a strong link with their rural homes (Marx & Charlton, 2003; Mazeka et al., 2019). The awareness of risks by most residents in Quarry Road West informal settlement can be attributed to the positive influence that the Palmiet River Rehabilitation Project (PRRP) has had on the settlement and the Palmiet River catchment as a whole. The PRRP has been working in the Palmiet river catchment to promote shared governance on climate change and has also been implementing adaptation-oriented interventions (Martel & Sutherland, 2019). Under this project, the community in Quarry Road West informal settlement successfully developed a risk map for the settlement (Mazeka et al., 2019). Therefore, the widely used indicators in the literature such as children under five, below twelve, elderly above 60 years and persons with permanent disability were left out of the indicators selected for mapping flood vulnerability as they were not applicable for the study area.

Several factors were identified to be responsible for causing flood vulnerability in the informal settlement, but only a minimal number were considered to be the more influential. The most influential factors were used to select indicators for mapping flood vulnerability in Quarry Road West informal settlement. For instance, although the frequency of floods and the settling of people in the floodplain were found to be among the factors responsible for causing flood vulnerability in the study area, the focus group discussants felt that these factors were less influential hence they could not be considered as indicators for mapping flood vulnerability in the study area. It was argued that despite them settling in the floodplain, not everyone was adversely affected by floods. During a focus group discussion, the discussants however argued that the amount of rainfall they were experiencing in the settlement was above normal. Hence increased rainfall was selected as an indicator for mapping flood vulnerability in the settlement and not the frequency of floods or settling in the flood plain. This goes to show that Local and Indigenous based Knowledge supports the reality of climate change and its effects. The increase in rainfall disasters has been identified as one of the effects of climate change in Durban and many countries (Dintwa et al., 2019; Munyai et al., 2019; Williams et al., 2018).

Increased rainfall has partly contributed to increased runoff hence the flow velocity of the water in the Palmiet river is very high, especially since Quarry Road West informal settlement is located downstream of the Palmiet river catchment that is generally characterised by steep slopes, hence water is quickly discharged downstream where the study area is located (Vogel et al., 2016). The residents recollect that in April 2019, they witnessed one of the worst floods which resulted in floodwater washing away close to 300 houses. The high flow velocity of the water in the river has resulted in the river widening thereby exposing more households to floods. Hence together with flow velocity, the proximity of houses to the river was selected as an indicator for mapping flood vulnerability in Quarry Road West informal settlement. Some houses in the settlement are now located less than 2 m from the banks of the Palmiet River. Houses close to the river are generally vulnerable to flood hazards (Balica & Wright, 2010; Yankson et al., 2017). With the Palmiet river, widening, and more rainfall expected, these houses will be very vulnerable to floods. Vozinaki et al. (2015) and Hendrawan and Komori (2021) argue that flow velocity is an important indicator for mapping flood vulnerability when an area of interest is within a river catchment characterised by steep slopes. This is because the increased velocity of the water especially during a flash flood increases the level of damage experienced in an area.

The nature of the soil was selected as an important indicator for mapping flood vulnerability in the settlement. This is because the soil in the settlement was said to be highly erodable. The washing away of the topsoil in the settlement exposed most houses to floods, especially since most houses in the settlement were not built on strong foundations and the material used to construct the houses was of poor quality. Interestingly, studies that have considered the nature of the soil for mapping flood vulnerability in the literature mainly considered the soil permeability and texture and not its erodibility (Buba et al., 2021; Seekao & Pharino, 2016; Yeganeh & Sabri, 2014). This shows the significance of local knowledge in understanding flood risks.

Based on the community members' Local and Indigenous Knowledge four (4) indicators were found to be specific to the study area. These are proximity to main roads (M19 and Quarry roads), accumulated waste, drainage system and land ownership. These indicators were unique to the study area and have not been previously used in the literature to map flood vulnerability except for accumulated garbage which de Brito et al. (2017) considered for mapping flood vulnerability in Brazil albeit it was at a municipal scale and not at the local level or informal settlement level.

The waste deposited in the Palmiet River upstream accumulates and clogs the calvets under the Quarry Road bridge and as a result, water usually changes direction to the calvet which may be less clogged thereby discharging the water with a lot of pressure or force. Therefore, the accumulation of waste particularly under the Quarry Road bridge also contributes to the high flow velocity of the water in the Palmiet River which adversely affects residents in the study area. This was because the high flow velocity widens the river banks and washes away the topsoil thereby exposing people's houses to flooding. The selection of accumulated waste as one of the indicators for mapping flood vulnerability in the settlement reveals institutional or governance weaknesses in the settlement and the Palmiet River Catchment as a whole. This is because the findings show that the municipality and the residents in the city particularly those living within the Palmiet River Catchment have failed to adequately deal with the problem of solid waste. Several scholars (Mazeka et al., 2019; Vogel et al., 2016; Williams et al., 2018) found that there is poor solid waste management in the Palmiet River Catchment and Quarry West informal settlement in particular.

Proximity to the main roads was identified as an indicator for mapping flood vulnerability in the settlement. Firstly, there are no storm drains between the M19 road and the informal settlement and the road is slightly tilted towards the river hence all the runoff from the road which is supposed to find its way to the river ends up in the settlement. The land between the M19 road and the river is generally flat, hence the water which accumulates in the settlement stays there for a long time. Secondly, Quarry Road receives a lot of runoff water from two roads Spencer and O'Flaherty which are on higher elevations. With increased rainfall, the storm drains in Quarry Road fail to handle the volume of water hence the water finds its water in the informal settlement. The blockage of storm drains due to indiscriminate disposal of solid waste within the settlement has also compounded the situation. A non-profit organisation called Green Corridor usually provides refuse bags to households in the study area to enable people to dispose of their waste from designated points from which the municipality collects it. However, their efforts were limited as they sometimes failed to provide the refuse bags on time. As a result, waste was disposed of indiscriminately within the settlement, some of which finds its way into the river and storm drains. The contribution of the M19 and Quarry roads to causing flooding in the settlement has also been reported by Williams et al. (2019) and Mazeka et al. (2019).

The slope was selected as one of the indicators for mapping flood vulnerability in the settlement because the settlement was flat. There is reduced runoff when the land in the settlement is flat hence water stays in the settlement for a longer time (Seekao & Pharino, 2016). According to Yeganeh and Sabri (2014), the extended time the water stays causes increased damages in a settlement. Müller et al. (2020) argue that most informal settlements are generally located in flat areas. This is made worse by the lack of drainage infrastructure in the settlement to remove the water, hence most people are vulnerable to floods as some of the water finds its way into their houses. The drainage system was, therefore, selected as another indicator for mapping flood vulnerability in the study area. The lack of a drainage system is a big problem in most informal settlements especially in developing countries because most municipalities claim to have no mandate to provide such infrastructure in informal settlements (Drivdal, 2016; Grahn & Nyberg, 2017; Williams et al., 2019; Zehra et al., 2019).

The lack of land ownership also made the residents vulnerable to floods. This is because they were not allowed to build permanent structures as they were considered illegal settlers. People who own the land they live on or those with guaranteed security of tenure, tend to invest in better housing (Nyametso, 2012; Reale & Handmer, 2011; Sarmiento et al., 2020). Furthermore, the lack of land ownership makes most households in Quarry Road West informal settlement vulnerable to floods because even when floods were imminent, people delayed leaving their houses for fear of losing their land to other people who would build a new house immediately after the flood. Hence Sarmiento et al. (2020) argue that secured land ownership in informal settlements leads to increased resilience of the community to natural hazards. The lack of land ownership by people in Quarry Road West informal settlement has resulted in landlords (landowners) becoming tenants after a flood event. According to Williams et al. (2018) hazards like floods have led to the expansion of the Quarry Road West informal settlement.

Most houses (over 95%) in Quarry Road West informal settlement were built using poor quality materials, hence most households were vulnerable to floods. Several people whose houses were washed away by the April 2019 floods rebuilt their houses in the open spaces that were still available in the settlement. Noteworthy was the open space that was used for community meetings and upon which shelters for flood victims would be erected. This space no longer exists anymore and in the likely event that another flood hit, the flood victims would have to be evacuated and sheltered at another locality distant from the settlement which would itself increase their vulnerability (de Brito et al., 2017).

Over 95% of the houses in Quarry Road informal settlement were built using low-grade corrugated iron sheets while some were built using wood. The poor-quality materials used to build the houses coupled with their weak foundations made them fail to withstand the high-velocity floodwaters, especially those houses close to the river. The materials used to build the houses were also prone to leakages. This situation does not only destroy their property, it also exposes people to more vulnerability and causes health problems (Shah et al., 2020).

With a high number of people living within a small piece of land (approximately 50,733 sq. km) and very close to each other, hence most households were vulnerable to floods. Most houses generally share a wall with their neighbours and if one house was hit by the floodwater and collapsed, more households were affected because once one collapsed, it pulled or pushed a neighbouring house, which in turn, affected other houses. Hence, the population density was selected as another indicator for mapping flood vulnerability in the settlement. High population density increases the exposure of people to the impacts of floods in a particular area (Abdrabo et al., 2020; Kablan et al., 2017).

Although the majority (70%) of the sampled household heads indicated that they were in employment, a detailed analysis of the 'kind' of employment most of them were engaged in showed that many were working as domestic workers in the nearby residential neighbourhood called Reservoir Hills (a predominantly Indian community) or as salespersons where they were not paid a lot of money. Low-level education was also related to the income individual earned. Residents with a low income had little to no ability to reduce risks or implement meaningful mitigation or adaptation measures at the household level (Cutter et al., 2003). Furthermore, most residents' ability to find better jobs was hampered by their 'low' level of education hence unemployment was also selected as one of the indicators of flood vulnerability in the settlement. Low levels of education adversely hinder people's uptake and use of information on flood preparedness (Kwazu & Chang-Richards, 2021). The problem of unemployment in the study area has also been reported by other researchers (Mazeka et al., 2019; Williams et al., 2019).

Social ties were not identified as one of the factors responsible for causing flood vulnerability in the settlement but social ties were selected by community members during the focus group discussion as an important indicator for mapping flood vulnerability in the settlement. This was because the community in Quarry Road West informal settlement had very strong social ties such that most people in the settlement were willing to help one another whenever there was a disaster in the settlement. Moreover, it was the residents' strong ties that made it possible for people in the informal settlement to spread the flood early warning information received. Generally, strong social ties decrease the vulnerability of people to flood hazards (Jones & Faas, 2017). Households in Quarry Road West informal settlement received flood early warning information in various ways. During the interviews with some community members, it was stated that early flood warning information specific to the study area was received via WhatsApp by a small group of community members and leaders and then shared with friends and neighbours who also shared the information with others by word of mouth. This agrees with Martel and Sutherland (2019) who stated that the establishment of a WhatsApp group helped people in Quarry Road West to access flood early information. The information shared on the WhatsApp group was received from the municipality's Forecast Early Warning System (FEWS). But the results from this study suggest that the flood early warning information shared on the WhatsApp group did not reach everyone in the settlement. This could be because there were only a few people on the WhatsApp group or some people could not afford to have internet bundles to regularly access the flood early warning information via WhatsApp. It could also be because the flood early warning information from the WhatsApp group was in English and not in the local language, hence the information could not be read by many people. Mustafa (2010) argues that the language in which the flood early warning information is communicated to the community can be a barrier to effective communication of flood risks. People's access to flood early warning information through television and radio was however not unique to Quarry Road West informal settlement alone, (Bajracharya et al., 2021) found similar results in the Koshi Basin, Nepal. In our view, information received from traditional media on early flood warnings tends to be generic and often lacks actionable instructions relevant to a particular locality. This situation made most residents of Quarry Road West informal settlement vulnerable to floods. Utilising the residents' Local and Indigenous Knowledge in selecting indicators for mapping flood vulnerability in Quarry Road West informal settlement is crucial because it raises awareness among community members and promotes community participation in finding solutions to the flood vulnerability problem in the community (Holley et al., 2011; Ziervogel et al., 2016). According to (Parsons et al., 2016) adaptive capacity allows the community to make positive changes through learning. This underpins the significance of Local and Indigenous Knowledge in disaster risk reduction initiatives

4.5 Conclusion

The objective of this study was to present results of using Local and Indigenous Knowledge in selecting indicators that could be used to map the vulnerability of people to flood hazards in an informal setting. The selection of indicators using Local and Indigenous Knowledge was conducted in Quarry Road West Informal settlement located in Durban, South Africa.

The results of this study have shown that the main factors responsible for causing flood vulnerability in the settlement are not only the proximity of houses to the Palmiet River and M19 or Quarry Roads. The nature of the soil and the type of materials people use to build their houses were also mainly responsible for causing flood vulnerability in the settlement. Utilising the community member's Local and Indigenous Knowledge made it possible to have an in-depth analysis of the local situation and generation of locally appropriate and context-specific indicators for mapping flood vulnerability in Quarry West informal settlement. Furthermore, only a minimal number of twelve indicators were selected from the twenty-one indicators that were initially selected by experts from the municipality and a local university. Four indicators were unique to the study area and had not been used to map flood vulnerability at a local scale or informal settlement level in the literature. These indicators are proximity to main roads, drainage system, accumulated garbage and land ownership. This study, therefore, demonstrates the significance of using the community members' Local and Indigenous Knowledge in selecting locally based and appropriate indicators that can be used for mapping flood vulnerability at a specific local scale which the literature or experts may not consider. It also provides a participatory approach that could be considered for selecting context-specific indicators for mapping flood vulnerability in informal settlements. Furthermore, this study shows how marginalized and poor people living in informal settlements were not helpless in finding solutions to their flood-related problems.

A major limitation of this study is that the selected indicators had not yet been operationalised in mapping flood vulnerability in the study area, hence it is difficult to assess their practicality.

These indicators will however be applied or tested as the study continues. To increase the usability of the selected indicators in mapping flood vulnerability in the study area weighting of the indicators with the participation of community members is needed. It is therefore our considered view that the use of Local and Indigenous Knowledge-based indicators is important because it helps to have a better understanding of the flood risk. It also gives decision-makers and other stakeholders an insight into adaptive measures that can be implemented to increase people's resilience in a particular area. Therefore, more effort and collaborative programmes aimed at improving the adaptive capacity of the residents in Quarry Road West informal settlement are needed to help them become more resilient to flood hazards.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CHAPTER 5: APPLICATION OF ANALYTIC NETWORK PROCESS (ANP), LOCAL AND INDIGENOUS KNOWLEDGE IN MAPPING FLOOD VULNERABILITY IN AN INFORMAL SETTLEMENT

This chapter is based on the following:

Membele, G. M., Naidu, M., & Mutanga, O. (In review). Using local and indigenous knowledge in selecting indicators for mapping flood vulnerability in informal settlement contexts. International Journal of Disaster Risk Reduction. *Environmental Science and Policy*

Abstract

In developing countries, informal settlements are mainly located in floodplains and wetlands, hence, they are frequently affected by floods. The objective of this study is to demonstrate a methodological approach that integrates the community members' Local and Indigenous Knowledge and GIS-based Multi-Criterial Decision Making using the Analytic Network Process (ANP) in mapping flood vulnerability in an informal settlement. The study was conducted in Quarry Road West informal settlement located in Durban, South Africa. A mixed-method approach that involved a household survey (n=359), interviews with key informants (n=10) and focus group discussions (n=2) were used in this study. The results of this study showed that households along the Palmiet River were highly vulnerable to flooding. The results also showed that a section of the settlement called Mcondo 1 was highly vulnerable to flooding while maMsuthu had low flood vulnerability. The sensitivity analysis results showed that changing the indicator weights, correspondingly, affected the output of the flood vulnerability map. Therefore, this study can serve as a guide or tool for decision-makers on how to comprehensively integrate ANP, Local and Indigenous Knowledge in mapping flood vulnerability which can help to have context-specific and sustainable solutions.

Keywords: Participatory modelling, Analytic Network Process, Super Decision Software, Multi-criteria analysis.

5.1 Introduction

A growing number of countries across the world have been affected by floods due to dense population, inappropriate land use planning and climate change (Cardona, 2004; Gandini et al., 2020; Lin et al., 2019; Myhre et al., 2019). Developing countries however are the most affected. This is due to their poor socio-economic conditions, inadequate financial resources, increased imperviousness, inadequate drainages, poor solid waste management and the construction of houses in flood plains and wetlands (Adelekan, 2010; Asiedu, 2020; Peters-Guarin et al., 2012). In developing countries, most informal settlements are located in sensitive and fragile environments, which makes them susceptible and vulnerable to flood hazards (Abunyewah et al., 2018; Mahabir et al., 2016). According to Roy et al. (2018, p. 283), close to 60% of the informal settlement dwellers in developing countries live in Sub-Saharan Africa and the UN-Habitat (2010) estimates that by 2050, the number of people living in informal settlements will increase to 3 billion. The UN-Habitat (2015) defines an informal settlement as housing areas where people build houses without complying with planning and building regulations, lack basic services and infrastructures and have no security of tenure. There is, therefore, a need to have a critical interest in reducing flood vulnerability in informal settlements, particularly in developing countries because informal settlements accommodate most of the urban dwellers (Duijsens, 2010; Flores et al., 2020; Zerbo et al., 2020).

A review of literature conducted by Membele et al. (2022a) shows that there has been a shift in the way flood vulnerability is considered in developing countries. Flood vulnerability is widely considered to be integrated because it combines both physical and social vulnerability (Cutter et al., 2003; Paul & Routray, 2010). Integrated flood vulnerability is important because it takes a holistic and interdisciplinary approach crucial in facilitating a complete assessment of flood vulnerability (Barroca et al., 2006). Flood vulnerability is therefore considered as an interrelationship of exposure, sensitivity or susceptibility and adaptive capacity (Akukwe & Ogbodo, 2015; Chen et al., 2021; Roy & Blaschke, 2013; Yuan et al., 2016). Exposure is defined as the predisposition of a system, community or physical items to impacts of floods due to location (Balica et al., 2012; Hung & Chen, 2013; Sadeghi-Pouya et al., 2017), while sensitivity is defined as the fragility or capacity of a system, individual or community to withstand the impact of flood hazards (Jha & Gundimeda, 2019; Roy & Blaschke, 2013; Yankson et al., 2017). Adaptive capacity is the ability of an individual, system or community to adjust, respond or recover from an adverse impact of floods (Borbor-Cordova et al., 2020; Kienberger, 2012; Roy & Blaschke, 2013). In our view considering flood vulnerability from an integrated perspective facilitates strategic policy formulation and implementation, which are important for sustainable disaster management.

According to Mazumdar and Paul (2018) locating vulnerable people in a community and identifying the reasons for their vulnerability has been a huge challenge for decision and policymakers. Mapping flood vulnerability especially at a local level is crucial because it helps to precisely locate where highly vulnerable people or households are, thereby helping in designing appropriate emergency alternatives and mitigation strategies (Hoque et al., 2019; Mazumdar & Paul, 2018; Romanescu et al., 2018).

Therefore, this study was anchored on the ‘place-based’ approach to mapping flood vulnerability (Cutter, 1996; Cutter et al., 2008; Dintwa et al., 2019). According to Dintwa et al. (2019), the feedback mechanism embedded in place-based approaches where an increase or decrease in risk, leads to enhanced or decreased vulnerability, allows it to inform policy and mitigation interventions. Hung and Chen (2013) contend that mapping flood vulnerability is important because it helps to guide decision-makers on how they can prepare and deal with climate change impacts. Furthermore, mapping flood vulnerability enhances the participation of community members (Membele et al., 2022b; Scheuer et al., 2013; Wilk et al., 2018). Membele et al. (2022b) argue that Local and Indigenous Knowledge help to foster community participation and the implementation of context-specific adaptation measures.

According to Langill (1999), local knowledge is knowledge acquired or possessed by people because of living in a particular community or locality for a considerable period. Indigenous Knowledge is a body of knowledge embedded in people’s way of thinking, skills, technology, culture and social practices passed on from one generation to the next (Fabiyi & Oloukoi, 2013; Sillitoe, 2007; UNEP, 2008). However, the use of Local and Indigenous Knowledge in mapping flood vulnerability especially in informal settlements remains underutilised (Dube & Munsaka, 2018; Membele et al., 2021, 2022a), mainly because some practitioners argue that Local and Indigenous Knowledge cannot be scientifically validated. Chanza and De Wit (2016) contend that community members' situational and experiential knowledge is crucial in mapping flood vulnerability at a local level. Hung and Chen (2013) further argue that the incorporation of Local and Indigenous Knowledge in mapping flood vulnerability especially in developing countries has been a challenge. However, Local and Indigenous Knowledge has been identified to be crucial in dealing with hazards like floods at local levels (Holley et al., 2011; Mavhura et al., 2013; Membele et al., 2021, 2022b; Ziervogel et al., 2016). In particular, the use of Indigenous Knowledge in helping to protect communities in high-risk areas to build resilience has also been underscored by the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015).

Many strategies have been used to map flood vulnerability in developing countries. The indicator-based Multi-Criterial Decision Making (MCDM) using Analytic Hierarchical Process (AHP) and Geographical Information Systems (GIS) have been widely used in mapping flood vulnerability in developing countries (Abdullah et al., 2021; de Brito & Evers, 2016; Membele et al., 2022a). The indicator-based approach is common in mapping flood vulnerability because of its flexibility, trustworthiness, transparency and ability to combine many elements that contribute to making people and places vulnerable to hazards like floods (Balica et al., 2009; Ciurean et al., 2013; Kappes et al., 2012; Nasiri et al., 2016). GIS-based MCDM approaches have been helpful in vulnerability mapping because they have an explicit, rational, spatial and efficient process that leads to justifiable and explainable choices, thus helping to enhance quality decision making (Abdrabo et al., 2020; Ferretti & Pomarico, 2013; Morea & Samanta, 2020).

The AHP developed by Saaty (2007) has been widely used for mapping flood vulnerability in developing countries, because it is simple, flexible and has the ability to structure the decision problem in a hierarchy (de Brito et al., 2018; Li et al., 2011; Roy & Blaschke, 2013). However, Aminu et al. (2014) argue that the AHP considers flood vulnerability elements as separate elements. It is our view that the 'separateness of elements' seldom happens in real life because flood vulnerability elements namely exposure, sensitivity and adaptive capacity are interwoven (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Roy & Blaschke, 2013; Yuan et al., 2016). Ghorbanzadeh et al. (2018) further contend that the AHP does not consider multiple alternatives at a time.

One of the MCDM approaches that take into account interdependent elements is the Analytic Network Process (de Brito et al., 2018; Ekmekcioğlu et al., 2022; Esfandi et al., 2022; Ghorbanzadeh et al., 2018; Ghosh et al., 2021). However, studies that used ANP in mapping flood vulnerability, particularly in developing countries and informal settlements in particular are rare (Membele et al., 2022a). A few studies (de Brito et al., 2018; Ishtiaque et al., 2019) that used ANP to map flood vulnerability in developing countries, mapped flood vulnerability at a municipal level and sub-district level respectively, but not at a local and fine scale such as informal settlement. Furthermore, a few studies (de Brito et al., 2018; Ishtiaque et al., 2019) that have used the ANP to map flood vulnerability in a developing country context, used experts or decision-makers and not community members. Hoque et al. (2019) contend that mapping flood vulnerability at a local scale such as an informal settlement by using a multi-criteria analysis approach was crucial in providing detailed and accurate flood vulnerability information needed for decision-making. However, it has been argued that many MCDM studies especially in developing countries suffer from a lack of updated spatial data. To overcome this challenge, collecting accurate spatial data using field surveys were gaining traction in data-scarce environments like developing countries (Akukwe & Ogbodo, 2015; Huq et al., 2020; Lian et al., 2017; Muller et al., 2011; Sarkar & Mondal, 2019; Usman Kaoje et al., 2020).

Therefore, this study demonstrates the integration of community members' Local and Indigenous Knowledge with a GIS-based MCDM using ANP to map flood vulnerability in an informal settlement. In particular, the study was conducted in an informal settlement called Quarry Road West located in Durban, South Africa. The study endeavours to answer the following questions: To what extent can an approach that integrates Local, Indigenous Knowledge and GIS-based MCDM using ANP be used to map flood vulnerability in Quarry Road West informal settlement? How well does the ANP present flood vulnerability in the study area? What areas in the study experience low, moderate and high flood vulnerability? The novelty of this particular study lies in the operationalisation of indicators selected using community members' Local and Indigenous Knowledge in mapping flood vulnerability in an informal settlement (Membele et al., 2022b). This study is also significant because it represents one of the first experiments that used the ANP to map flood vulnerability through the participation of community members living in an informal settlement

5.2 Methodology

5.2.1 Description of the study area

Quarry Road West informal settlement is located close to the Durban city centre. The informal settlement is about 31,250.84 m^2 in size. The informal settlement is positioned within the Palmiet River Catchment and the Palmiet River cuts across the settlement (Figure 5.1). Furthermore, the settlement is located between the M19 freeway and Quarry Road about 2.7 km from the uMngeni river (Sutherland, 2019). Quarry Road West informal settlement was established 36 years ago when the first occupants settled in a section called maMsuthu (Sutherland, Roberts, et al., 2019). In the early 2000s, the settlement expanded to the other three sections across the flood plain (Mazeka et al., 2019). Most of the people in the settlement were from rural parts of South Africa, mainly from the Eastern Cape and KwaZulu Natal Provinces (Williams et al., 2018). Sutherland, Mazeka, et al. (2019) contend that the people in Quarry Road West informal settlement were politically organised with strong social ties and identity. Like many other informal settlements in developing countries, the number of households in the informal settlement keeps on increasing.

According to Williams et al. (2018), Quarry Road West informal settlement had 931 households in 2017 and in 2019, the number increased to 1100 with over 2400 people (Mazeka et al., 2019). Using an aerial photograph, it can be seen that the number of households (building footprints) increased to over 1200 in 2020. Rapid urbanization in Durban and the effects of climate change have caused economic, social and environmental challenges in Quarry Road West informal settlement (Le Quéré et al., 2020; Williams et al., 2019). Flooding is one of the biggest challenges the informal settlement dwellers were grappling with (Le Quéré et al., 2020; Mazeka et al., 2019; Williams et al., 2018). Increased impervious surfaces due to a high number of residential and industrial areas as well as the steep slopes in the Palmiet River Catchment exacerbate flooding in the informal settlement (Mazeka et al., 2019; Williams et al., 2018).

According to Williams et al. (2018), Quarry Road informal settlement (like the whole of Durban) experiences a subtropical and humid climate characterised by mild, dry winters and warm as well as wet summers. Mean annual rainfall is over 1000 mm but experts project it to go up by 500 mm.

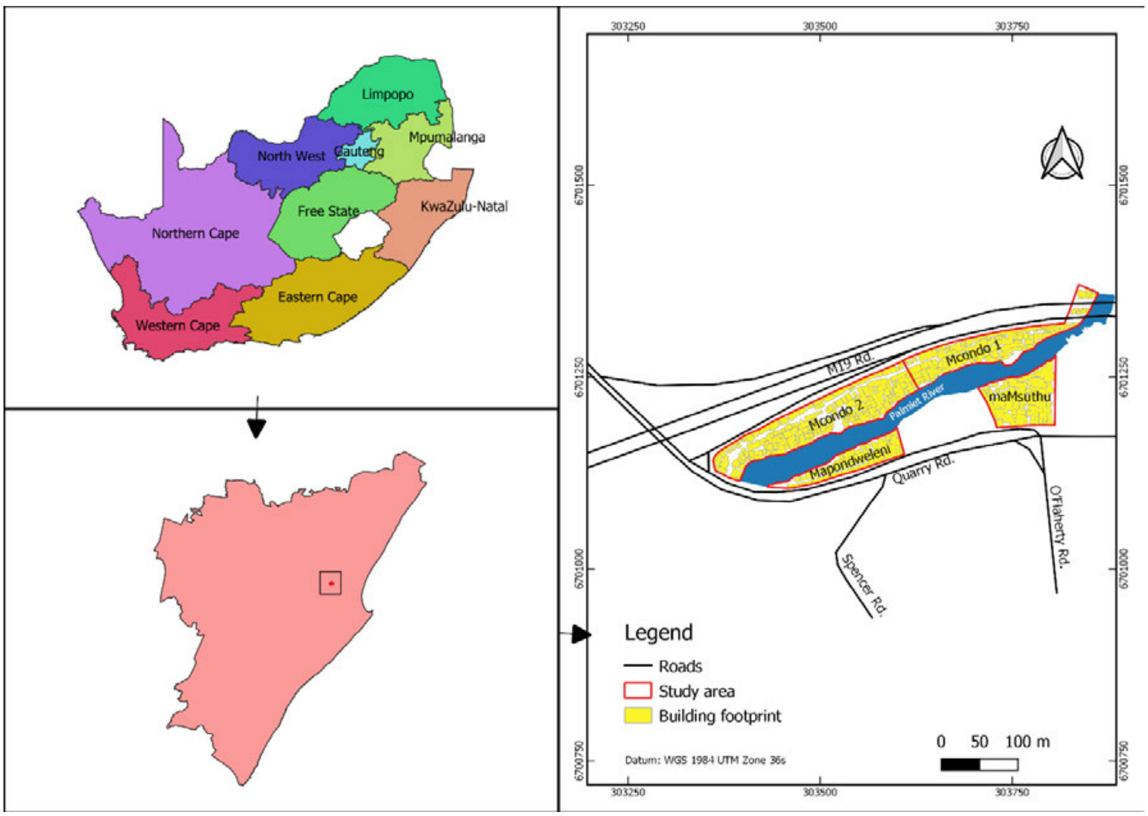

Figure 5.1 Quarry Road West informal and the three sections

(Source: Authors)

5.2.2 Data collection and analysis

The data collection for this study started in October 2020 with key informant interviews. The virtual zoom online platform was used to conduct in-depth interviews with the key informants from the municipality (four) and local university (one). These key informants were selected purposefully based on their knowledge of managing floods in the study area. The zoom platform was used to conduct the interviews due to the Covid-19 restrictions which were implemented by the government in South Africa to reduce physical or human interactions.

In May 2021, physical interactions were allowed by the government hence, household surveys (359), face-to-face interviews and focus group discussions were conducted. Four trained research assistants living in the study area conducted the household survey using Google Forms loaded on mobile devices. The household surveys (359) were preceded by a pilot survey with 36 households. This was done to ensure that there were no distortions during translation from English to isiZulu (local language). The in-depth interviews with community leaders (three) and focus group discussions (two) were conducted face-to-face by the researcher in May 2021, and a trained research assistant translated words that were said in the local language. The focus group discussions were attended by seven community members composed of five females and two males. Although an equal number of males and females were invited in both cases, only two men attended the focus group discussions. This could be because most males were away looking for part-time and only came back home late in the evening. The interview with community members (two) to validate the flood vulnerability map was conducted in March 2022. The household survey, interviews and focus group discussions were conducted with strict adherence to all Covid-19 prevention protocols which included social distancing, sanitizing and wearing of a face mask.

Informed consent was granted by all the participants and the Humanities and Social Sciences Research Ethics of the University of KwaZulu-Natal, South Africa (Committee Protocol reference number: HSSREC/00001793/2020) granted Ethical approval for this study.

This study used mixed methods and the methodological approach applied eight steps. These steps included the identification of stakeholders, structuring of the problem, selection of flood vulnerability indicators, clustering and weighting of indicators, standardization of indicators, aggregation and mapping of flood vulnerability, sensitivity analysis and validation of the flood vulnerability map (Figure 5.3). These steps are explained as follows:

5.2.3 *Identification of stakeholders*

This step involved the identification of key stakeholders in mapping flood vulnerability in Quarry Road West informal settlement. Four of these key informants were from the eThekwini municipality. These were from the departments of Environmental Planning and Climate Protection, Coastal Stormwater and Catchment Management, Human Settlement and Disaster Management. Three key informants were leaders in Quarry Road West informal settlement and two were community members and one key informant was a researcher from the called University of KwaZulu-Natal. Community members from Quarry Road West informal settlement were also identified as crucial stakeholders in mapping flood vulnerability. This was because they were the ones who experienced the floods hence, they needed to be involved in the flood vulnerability mapping process. The next step involved identifying the causes of flood vulnerability in the study area.

5.2.4 *Structuring of the problem*

Designing the decision problem is one of the first and fundamental steps in any decision-making process (Durga Rao et al., 2019). Therefore, with the goal of mapping flood vulnerability in Quarry Road West informal settlement using community members' Local and Indigenous Knowledge, key informants particularly from the eThekwini municipality and the local university selected some indicators they considered locally appropriate from the list of indicators that were generated from the literature. These indicators were then used for designing questions for the household survey. The household survey helped to generate the main factors responsible for causing flood vulnerability in Quarry Road West informal settlement. It is worth noting that this study is a continuation of the study conducted by Membele et al. (2022b) in which causes of flood vulnerability and indicators for mapping flood vulnerability were identified using community members' Local and Indigenous Knowledge.

5.2.5 *Selection of flood vulnerability indicators*

The final set of indicators used for mapping flood vulnerability in Quarry Road West informal settlement was selected using a focus group discussion. Therefore, sixteen context-specific indicators were selected (Membele et al., 2022b). The selected indicators had to be clustered and weighted to establish the significance of each indicator in mapping flood vulnerability in the study area (Table 5.1).

5.2.6 Clustering and weighting of indicators

Another focus group discussion was conducted to group the selected indicators into three clusters namely exposure, sensitivity and adaptive capacity. The discussants also presented how the indicators were related to each other. This process led to the development of a structure to use for mapping flood vulnerability in Quarry Road West informal settlement (Figure 5.2). The links in the developed structure represented both positive and negative interactions. The interdependence of relationships between the indicators was shown by the direction of the arrows. Arrows with double directions showed mutual influence between clusters or indicators while a single arrow showed the dominance of one indicator over another. The loops in the structure indicated inner dependences among the indicators.

The community members during the focus group discussion further generated the influence of each indicator in causing flood vulnerability in the settlement. This was done by ranking or assigning percentages to each indicator (Table 5.1). These percentages were later aligned to the ratio of 1-9 developed by Saaty (2007) for use during the pairwise comparison according to the Analytic Network Process. For instance, when comparing an indicator with 12% influence with another indicator with 2%, the number 9 (based on Saaty (2007)'s scale) was assigned to the indicator with 12%. This was because there was evidence that the indicator which had a rank of 12% was extremely important than the indicator which had a 2% influence. Furthermore, when comparing the indicator with 12% influence with another one with 9% influence, the indicator with 12% was assigned a number 3. This was because the indicator with 12% influence was much more important than the indicator with 9% influence. Equal importance was assigned to indicators that had the same percentages. For instance, when comparing proximity to roads and accumulated waste, the number 1 was assigned during the comparison. This was because both indicators had an 8% influence. Therefore, the two indicators contributed equally to the goal.

The ANP in Super Decision Software version 2.10.0 was used for weighting the indicators because it uses a network of feedback and interrelations (Saaty, 2007; Saaty, 2013). Flood vulnerability is also said to be an interrelationship of exposure, sensitivity and adaptive capacity (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Roy & Blaschke, 2013; Yuan et al., 2016). Chang et al. (2015) argue that the ANP provides better results for assigning weights to criteria or indicators because it captures the interdependence of criteria. With the ANP, each cluster was compared against another cluster and each indicator was compared against the related indicator to ascertain the significance of each cluster and indicator over the other (Figure 5.2). Using the weights generated through the pairwise comparison, the unweighted supermatrix, weighted supermatrix, cluster supermatrix and the limit supermatrix were computed automatically in the Super Decision Software. At this stage, a sanity check was conducted in the Super Decision Software to make sure that there were no errors. This study had an average Consistency Ratio of 0.0427. Therefore, the matrix was acceptable because the Consistency Ratio of 0.0427 was less than the standard threshold of 0.1 (Chen et al., 2010; Ghorbanzadeh et al., 2018). The limit supermatrix was then normalized and priorities or weights for each indicator were generated (Table 5.1). The cluster for exposure had a normalised weight of 0.61, a sensitivity of 0.27 and an adaptive capacity of 0.12. Because the indicators had different units, standardizing or normalizing them was required.

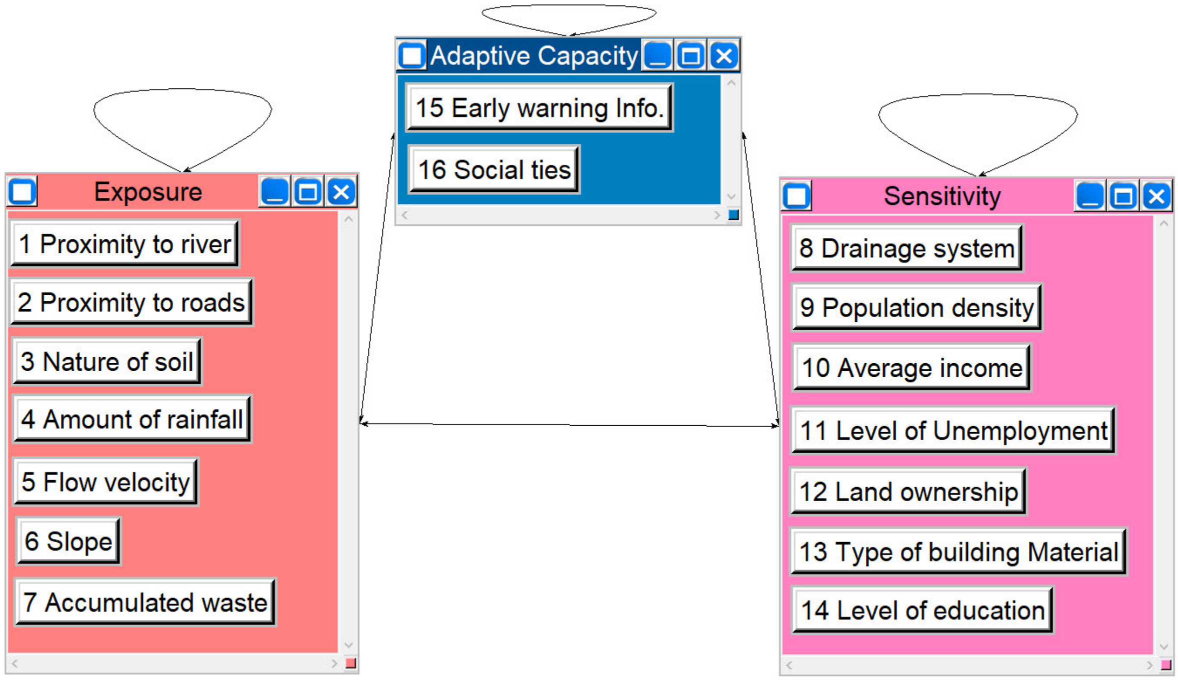

Figure 5.2 ANP structure used to map flood vulnerability in this study

Table 5.1 Community members' indicator weights and weights generated using ANP

Cluster	Indicator	Community members weighting	Weight using Pairwise comparison (ANP)
Exposure	Proximity to river	12%	0.2207
	Nature of soil	12%	0.0372
	Amount of rainfall	9%	0.1854
	Flow velocity	9%	0.1814
	Proximity to roads	8%	0.0457
	Accumulated waste	8%	0.0390
	Slope	5%	0
Sensitivity	Type of building material	9%	0.1629
	Average income	5%	0.0093

	Level of education	4%	0.0034
	Land ownership	3%	0.0003
	Drainage system	2%	0.0481
	Population density	2%	0.0050
	Level of unemployment	2%	0.0004
Adaptive Capacity	Social ties	5%	0.0186
	Early warning information	5%	0.0426

5.2.7 Standardization of indicators

Standardizing the indicators is very important because it transforms the indicators with different measurement scales into common units thereby making the analysis meaningful (Shrestha et al., 2016).

Most of the spatial data used in this study were captured from the sampled households using a Global Positioning System (GPS) during fieldwork conducted in May 2021. The sampled households were spread across the four sections of Quarry Road West informal settlement. This was to ensure that updated and accurate data were captured for mapping flood vulnerability in the study area. This was also done to overcome the unavailability of high-resolution spatial data at a community level.

A Spatial Join in ArcGIS Pro 2.6 was used to join the attributes from the GPS to the building footprints which were digitized from a very high resolution (0.01m x 0.01m) aerial photograph. Then the joined building footprints were spatially joined with a 1m x 1m fishnet which covered the whole study area. Then spatial queries were used to create vector layers for each indicator. The aerial photograph, soils and elevation data were provided by the eThekwini municipality while the rainfall data was provided by the South African Weather Services. The data from the municipality and the South African Weather Services were converted into one projection system (WGS 84 UTM Zone 36s) to have better results during the overlay analysis. The clip function in GIS was used to extract data for the study area.

The indicators were then analysed using various GIS operations. The spatial buffer was used for indicators like proximity to the river, proximity to main roads and drainage system. Flow velocity was generated by calculating flow accumulation from a Digital Elevation Model (DEM) and the reclass function was used to estimate the hydraulic radius. Then Manning's N was generated from a land cover dataset with a resolution of 10 x 10m raster pan-sharpened from the Sentinel 2 imagery (Kaplan, 2018). The Manning' N equation was then used to calculate the flow velocity of the study area (equation 1).

$$V = \left(\frac{R_h^{\frac{2}{3}} * \sqrt{S}}{N} \right) \tag{1}$$

Where V is the Flow velocity, R_h is the Hydraulic radius, S is the slope in per cent and N is Manning's constant (Murwira et al., 2015).

Since each indicator or data layer had different attribute classifications, units and values, they had to be converted into a common scale. Value functions in ArcGIS Pro 2.6 of 0 to 1 were used to reclassify all the spatial data layers into a common scale. The low flood vulnerability was represented by 0 and the high flood vulnerability was represented by 1. The assignment of value functions to the attributes was done during a focus group discussion with community members. An explanation was given to the discussants on the meaning of every attribute and how it increased or decreased flood vulnerability. The standardized vector layers were then converted to 1m x 1m raster files for subsequent aggregation and mapping of flood vulnerability.

5.2.8 Aggregation and mapping of flood vulnerability

This stage involved combining the 15 indicators to create a composite flood vulnerability map for the study area. The weighted sum in ArcGIS Pro 2.6 was used to combine the indicators based on their assigned weights (Table 5.2). The weighted sum was used because it allows assigning of negative and positive weights to indicators (Abdelkader & Delali, 2012). In this study, two indicators namely early warning information and social ties were given negative values during the aggregation process because the adaptive capacity (early warning information and social ties) reduces flood vulnerability, while exposure and sensitivity increase flood vulnerability hence, they were given positive values. Therefore, the more adaptive capacity, the lower the level of flood vulnerability in that area (Kissi et al., 2015; Yankson et al., 2017). The final flood vulnerability map had values ranging from 0 to 1, where the low value represented low flood vulnerability and higher values corresponded to high flood vulnerability (Figure 5.4).

5.2.9 Sensitivity analysis

To ascertain the robustness of the flood vulnerability map, a sensitivity analysis was conducted. This was done by altering the weight of the indicators and then assessing the output of the flood vulnerability map. In particular, sensitivity analysis was conducted by assigning equal weight to all the indicators (Figure 5b). Another sensitivity analysis was conducted by assigning positive values to adaptive capacity indicators which were initially assigned negative values (Figure 5.5c).

5.2.10 Validation

This study used quantitative and qualitative methods to validate the final flood vulnerability map. The quantitative method involved overlaying the flood vulnerability map with the affected households on the 1:100 years flood line. The 1: 100 years flood line was provided by the eThekwini municipality. The qualitative method involved two community members who had lived in the informal settlement for more than ten years. These community members were independently availed with the final flood vulnerability map overlaid on the aerial photography. This was done to help the community members to have proper orientation of the study area. Then an explanation was given of the meaning of the colours on the map. The community members were separately asked if the map represented the flood vulnerability situation of the informal settlement.

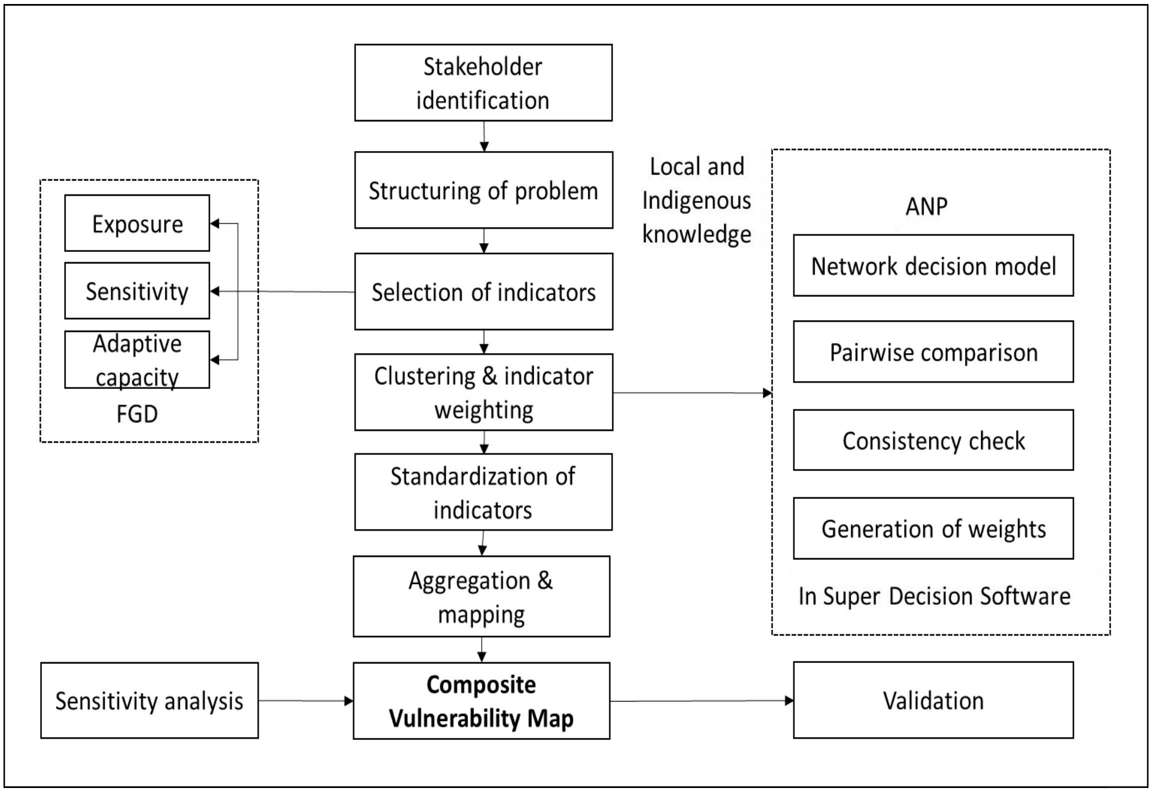

Figure 5.3 Schematic representation of the methodological approach applied

5.3 Results

The spatial distribution of flood vulnerability in the study area showed that the area or households close to the Palmiet River were highly vulnerable to flood hazards (Figure 5.4). Using community members' Local and Indigenous Knowledge in the weighting of indicators for mapping flood vulnerability in the study area revealed that the most influential or important indicators for mapping flood vulnerability in the informal settlement were proximity to river (22% of importance), amount of rainfall (19% of importance), flow velocity (18% of importance) and type of building material (17% of importance) (Table 5.1). The results also showed that the effect of proximity to main roads, nature of soil and drainage system had a low to moderate influence on flood vulnerability in the settlement.

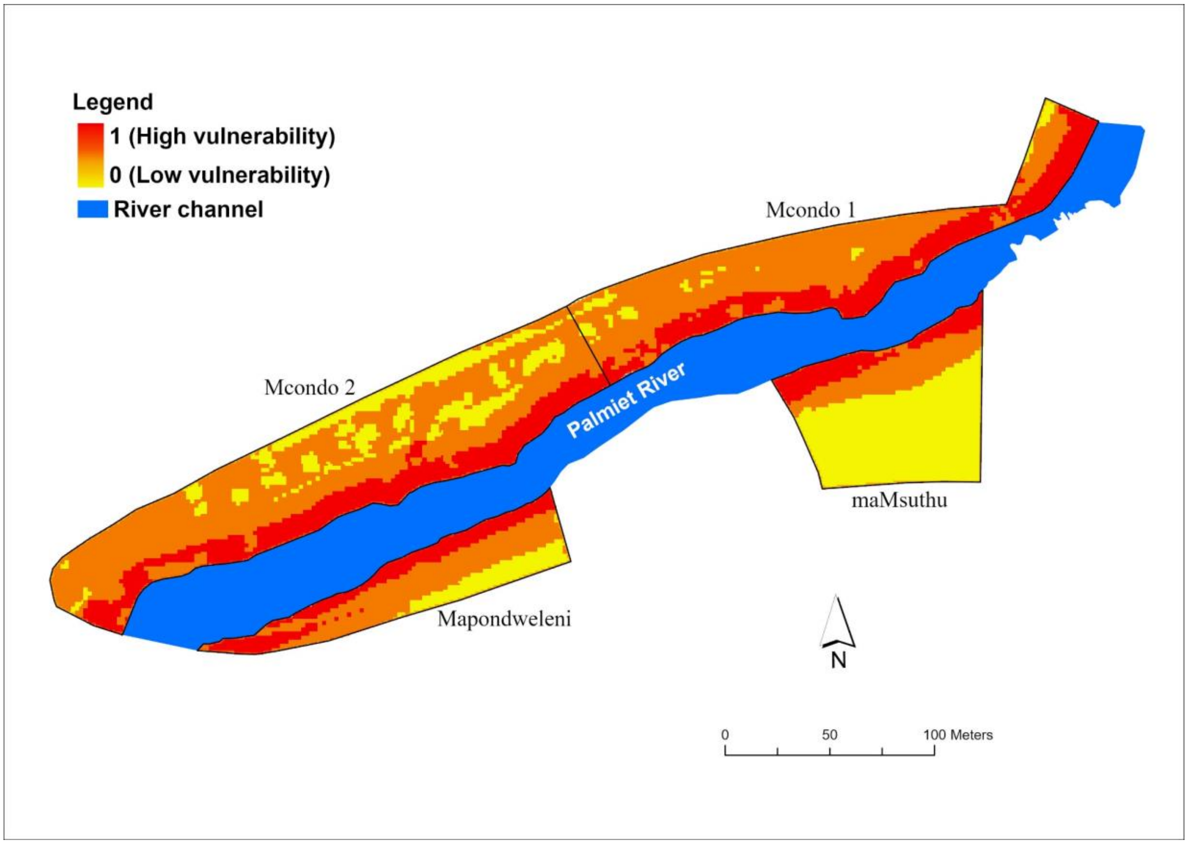

Figure 5.4 Final flood vulnerability map

(Source: Author)

Table 5.2 Household levels of flood vulnerability in the four sections of Quarry Road West informal settlement

Section name	Low vulnerability	Moderately vulnerable	Highly vulnerable
Mcondo 1	35	207	119
Mcondo 2	135	253	80
maMsuthu	176	70	45
Mapondweleni	42	54	47
Total	**388**	**584**	**291**

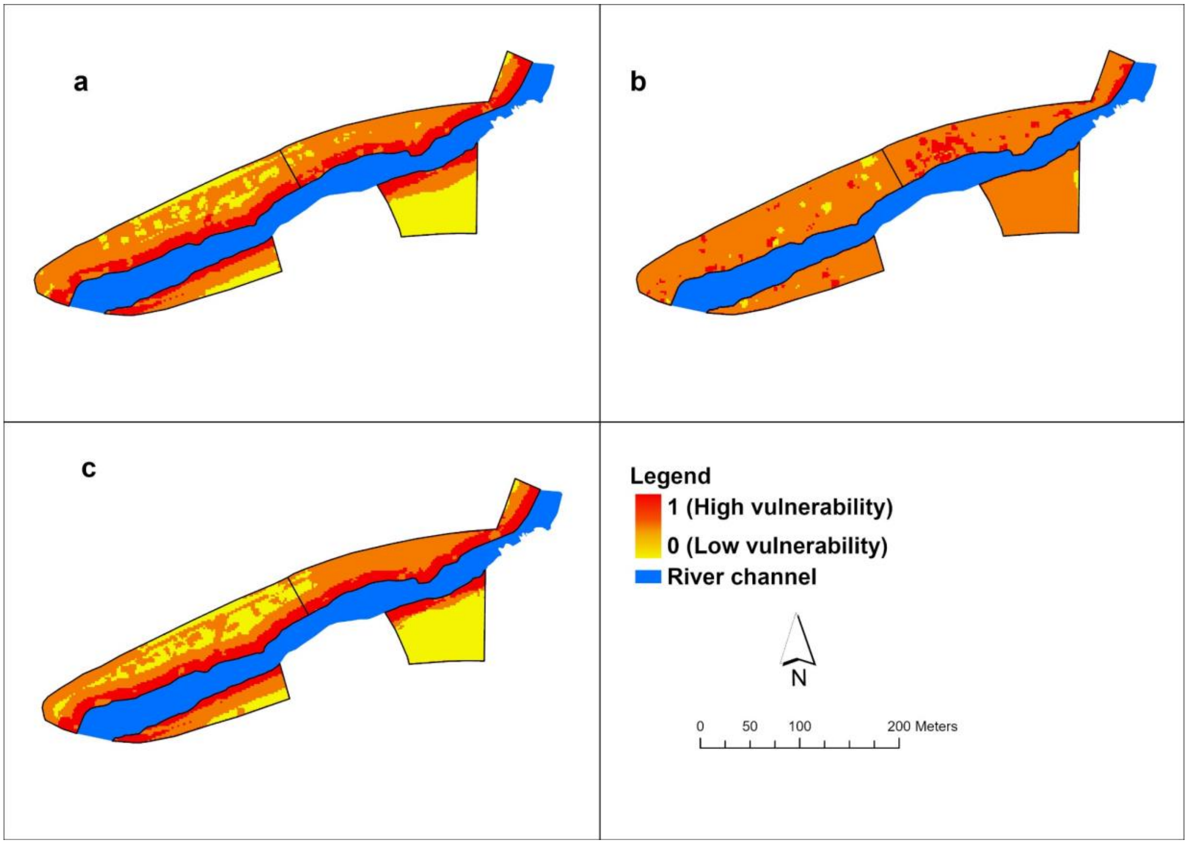

Figure 5.5 Sensitivity analysis of the flood vulnerability map.

(Figure 5.5a. Final flood vulnerability map with adaptive capacity indicators based on negative values for adaptive capacity. Figure 5.5b Flood vulnerability map based on equal weights and Figure 5.5c. Flood vulnerability is based on using positives values for all indicators)

(Source: Authors)

Zonal Statistics conducted in Arc Pro 2.6, from the composite or final flood vulnerability map showed that a section of the settlement called Mcondo 1 had the highest number of households highly vulnerable to flooding. Mcondo 2 had the highest number of households moderately vulnerable to flooding, while maMsuthu had the highest number of households with low flood vulnerability (Table 5.2). The results also show that close to 50% of households in Quarry Road West informal settlement were moderately vulnerable to flood hazards and 31 % of households had low flood vulnerability.

The results of the final flood vulnerability map (Figure 5.4 and Figure 5.5a) were compared with results obtained from altering indicator weights during the sensitivity analysis. The results of assigning equal weight to indicators showed a huge increase in the number of households moderately vulnerable to floods. It also showed a decrease in the number of households with high and low flood vulnerability (Figure 5.5b). Assigning positive values to adaptive capacity indicators (social ties and early warning information) showed an increase in the number of households with low flood vulnerability (Figure 5.5c). The results also showed a decrease in the number of households moderately vulnerable to flooding. The results of the three flood vulnerability maps were therefore different.

The final flood vulnerability map was validated in two ways. The results validating the flood vulnerability map and the affected households on the 1:100 years flood line showed that 134 households in Quarry Road West informal settlement were outside the flood line. Of these, the majority (70%) of the households had low flood vulnerability and were mainly located in maMsuthu. The two community members who also validated the flood vulnerability expressed satisfaction with the output of the flood vulnerability map. They stated that Mcondo 1 indeed had the highest number of households highly vulnerable to floods and that maMsuthu had a low number of venerable households in Quarry Road informal settlement. They also stated that the map rightly showed that the main entrance to the settlement was regularly flooded and therefore the households around that area were also highly vulnerable to floods.

4.0 Discussion

The study has demonstrated how a methodological approach that integrates the participation of community members by using their Local and Indigenous Knowledge with the GIS-based MCDM Analytic Network Process approach mapped flood vulnerability in Quarry Road West informal settlement with a higher degree of reliability and accuracy. The ANP approach was found to be very effective in modelling complex interrelationships of elements used for mapping flood vulnerability in Quarry Road West informal settlement. The feedback and dependences inherent in the ANP allow it to handle complex and multi-dimensional problems (Esfandi et al., 2022; Feyzi et al., 2019; Ghaemi Rad et al., 2018; Wu et al., 2018). Several scholars (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Membele et al., 2021; Roy & Blaschke, 2013; Yuan et al., 2016) argue that flood vulnerability is multi-dimensional and is based on an interrelationship of exposure, sensitivity and adaptive capacity. Therefore, using the ANP approach provides a better opportunity to mimic what takes place in the real world (Anand & Kodali, 2009), which in turn, provides better and more reliable results for mapping flood vulnerability in the study area. This could explain why de Brito et al. (2018) recommended the use of the ANP in mapping complex problems like flood vulnerability. However, Ghorbanzadeh et al. (2018) criticise the ANP for its high uncertainty and ability to marginalize community members due to its reliance on expert opinions. We are of the view that this weakness was overcome in this study by using community members' Local and Indigenous Knowledge in the flood vulnerability mapping process. Ferretti and Pomarico (2012) argue that using the ANP facilitates having reliable results because stakeholders involved in using ANP tend to have a cautious reflection of the problem and priority of the mapping process.

Furthermore, this methodological approach successfully displayed the levels and spatial extent of flood vulnerability in the study area. This is crucial for monitoring the level of flood vulnerability over time and for implementing strategic decisions. According to Hung and Chen (2013), interventions aimed at reducing flood vulnerability should be focused on areas that have the highest vulnerability or areas clustered spatially. Yankson et al. (2017) further argue that the lack of information on the levels of flood vulnerability in an area adversely affects the implementation of local adaptation plans. In this study, flood vulnerability reduction efforts should start with areas along the Palmiet River and the M19 bridge in Mcondo 1 as these are areas were highly vulnerable to floods. This study, therefore, enhances the understanding of areas that need immediate intervention in terms of reducing flood vulnerability in the study area.

The methodological approach used in this study also provides a participatory and comprehensive approach for mapping flood vulnerability in an informal settlement context by integrating community members' Local and Indigenous Knowledge. de Brito and Evers (2016) argue that the participation of different stakeholders in mapping flood vulnerability especially in developing countries was fragmented. In South Africa, a literature review conducted by Membele et al. (2021) found that community participation in mapping flood vulnerability in informal settlement contexts was fragmented and mainly ended with community members responding to questions asked to them during interviews and questionnaires administered to them. Therefore, this study has demonstrated how community members could adequately participate in mapping flood vulnerability. In this study, community members participated in identifying factors that were responsible for making people vulnerable to flood hazards, selected locally appropriate indicators, assigned weights to indicators and validated the flood vulnerability map. The participation of informal settlement dwellers who have for a long time been marginalized in mapping flood vulnerability in informal settlements, particularly in developing countries is crucial in promoting ownership, resilience and sustainable disaster risk reduction in informal settlements (Botha & van Niekerk, 2013; Hedelin et al., 2017; Membele et al., 2021; Scheuer et al., 2011; Wilk et al., 2018; Williams et al., 2018). Furthermore, reducing flood vulnerability in informal settlements is crucial because it contributes to achieving Sustainable Development Goals (SDGs), particularly number 11 which relates to making cities and human settlements safer, resilient and sustainable (United Nations Development Programme, 2022). It is our considered view that community participation in mapping flood vulnerability was enhanced by using the informal settlement dwellers' Local and Indigenous Knowledge. However, in urban studies and informal settlements, in particular, Indigenous Knowledge has been underutilised in mapping flood vulnerability (Dube & Munsaka, 2018; Kasei et al., 2019). Furthermore, a review of literature conducted by Membele et al. (2022a) found that there was limited use of Indigenous Knowledge in mapping flood vulnerability in developing countries, yet the Sendai Framework for Disaster Risk Reduction 2015–2030 and the World Conference on Disaster Reduction held in Hyogo, Japan and have repeatedly called for the use of Indigenous Knowledge in disaster risk reduction (UNDRR, 2005, 2015). According to Bernatchez et al. (2011), Local and Indigenous Knowledge provides an in-depth understanding of factors that influence flood vulnerability in a particular area, which helps decision-makers know what to do to improve people's adaptive capacity and resilience.

Furthermore, unlike Ngie (2012) who independently analysed and compared the community's Indigenous Knowledge on floods and a flood vulnerability map produced using GIS in Diepsloot, Johannesburg, this study has demonstrated how the special attributes of Local and Indigenous Knowledge could be combined with a GIS-based MCDM approach at once to map vulnerability in Quarry Road West informal settlement. Furthermore, to the best of our knowledge, this study is one of the first to comprehensively integrate Local and Indigenous Knowledge in mapping flood vulnerability in an informal settlement context using the MCDM ANP approach.

The study revealed that Quarry Road West informal settlement was highly exposed and sensitive to flood hazards and that the adaptive capacity of the people in the community was low albeit significant in helping people to reduce their flood vulnerability. This study also found that proximity to the river, amount of rainfall, flow velocity and type of building material significantly influenced the level of flood vulnerability in the informal settlement. In most studies, exposure is considered a major contributor to the vulnerability of people to flood hazards in many areas (Hung & Chen, 2013; Sadeghi-Pouya et al., 2017). Ochola et al. (2010) also found that proximity to the river, amount of rainfall, flow velocity, soil type, elevation and type of building materials were influential in causing flood vulnerability in Kenya's Nyando River catchment. The study conducted by Ochola et al. (2010) differs from this study in that soil type and elevation were not considered to be highly influencing flood vulnerability in Quarry Road West informal settlement. This further speaks to the ability of the ANP to allow stakeholders to have a careful reflection and understanding of the decision problem, thereby selecting and assigning weights appropriately (Ferretti & Pomarico, 2012). de Brito et al. (2018) in Brazil found that households with improper building materials followed by the number of evacuation drills and training were the most important indicators for mapping flood vulnerability. Similar to this study, Aksha et al. (2020) conducted a study in Nepal that found that areas along the Sardu and Seuti Rivers had the highest level of flood vulnerability. This was because households and areas close to the river tend to be prone to increased flow velocity and erosion of the river banks, which caused the floodwater to enter the houses and in many cases made dwellings collapse (Membele et al., 2022b). Since many people in informal settlements, especially in developing countries live in fragile environments such as flood plains and wetlands (Adelekan, 2010; Asiedu, 2020; Peters-Guarin et al., 2012), the projected increase in the frequency and intensity of rainfall due to climate change (Cardona, 2004; Myhre et al., 2019) will make more informal settlements dwellers highly vulnerable to flood hazards. In Quarry Road West informal settlement, in particular, moderately vulnerable households will become highly vulnerable to flood hazards, particularly if nothing is done to increase the community's adaptive capacity. Therefore, in an event that many people in the settlement became highly vulnerable to flooding, very few people in Quarry Road West informal settlement will be in a position to help their friends or neighbours during a flood. This situation will, in turn, weaken the strong social ties that the residents have for a long time used to deal with floods.

The results of this study showed that a section called maMsuthu had a low number of households vulnerable to flood hazards. This is because, unlike the other three sections, maMsuthu is located on a mound that was not within the 1:100-year flood line (Mazeka et al., 2019). This explains why the first occupants of Quarry Road West informal settlement did not settle anywhere else in the settlement but they settled in maMsuthu. The results of this study also showed that there were some pockets or areas in the informal settlement with low flood vulnerability (Figure 5.4). Notwithstanding the locational advantage of Quarry Road West to economic opportunities for the residents (Mazeka et al., 2019), this situation (pockets of low flood vulnerability) could explain why some residents went back to the informal settlement despite having been relocated to an area called Parkgate which had better housing. Furthermore, one of the main reasons why Mcondo 1 was highly vulnerable to flooding is that the section is close to the M19 bridge, and when the calvets under the bridge got blocked due to the accumulation of waste, the water easily found its way to Mcondo 1 (Membele et al., 2022b). Poor solid waste management has been identified as one of the major causes of flooding not only in Quarry Road West informal settlements but also in other informal settlements in many developing countries (Asiedu, 2020; Mazeka et al., 2019; Williams et al., 2018).

Updated and accurate spatial data in most developing countries is a challenge. Therefore, most of the spatial data used in this study were captured with a GIS while administering the household survey. This was to ensure that updated and accurate data were captured. Capturing spatial data this way could be expensive especially if the area was big, it is, however, one of the best ways for generating updated, accurate and fine resolution data (de Andrade & Szlafsztein, 2015; Kienberger, 2012).

Sensitivity analysis helps to check whether or not a change in criteria weights affects the output (Chen et al., 2010; Crosetto et al., 2000; de Brito et al., 2019). According to Ferretti and Montibeller (2016) conducting a sensitivity analysis in mapping, flood vulnerability increase the transparency of the results. However, sensitivity analysis is lacking in most studies that mapped flood vulnerability in developing countries (Membele et al., 2021, 2022a). After conducting a sensitivity analysis, this study found that assigning positive values to adaptive capacity indicators (initially assigned negative values) and assigning equal weights to all indicators changed the output of the flood vulnerability maps. This showed that the flood vulnerability map was robust, reliable and accurate for informing decision-making (Ferretti & Montibeller, 2016; Thabane et al., 2013).

The lack of accurate and updated spatial data has also been identified to negatively affect the validation of flood vulnerability maps in developing countries (Membele et al., 2022a). In this study, the 1:100 years flood line and two community members validated the final flood vulnerability map. Rincón et al. (2018) contend that validating flood vulnerability maps helped to enhance the legitimacy and usability of the maps. Membele et al. (2022a) contend that validating flood vulnerability maps was crucial if the maps were to inform decision-making. However, Fekete (2009) argues that independent datasets to use to validate flood vulnerability maps were scarce in many areas, hence many studies did not validate their maps. A few studies that validated their maps used various approaches. Roy and Blaschke (2013) used depth measurements to validate their flood vulnerability map, while Seekao and Pharino (2016) used actual flood events, de Brito et al. (2018) used expert knowledge and Hoque et al. (2019) used community members and other stakeholders. Hoque et al. (2019) contend that qualitative validation of flood vulnerability maps by community members was also acceptable, especially in developing countries where high temporal and spatial resolution data was a challenge.

5.4 Conclusion

This study has demonstrated a novel and comprehensive methodological approach that integrates community members' Local and Indigenous knowledge with the GIS-based MCDM ANP approach in mapping flood vulnerability in an informal settlement in Durban South Africa. This approach jointly used the beneficial and inherent attributes of Local, Indigenous Knowledge and the GIS-based MCDM approach to map flood vulnerability in the study area. The ANP approach was found to be effective in modelling the complex interrelationships of elements and indicators for mapping flood vulnerability. This led to the mapping of flood vulnerability reliably and transparently. It is, therefore, our considered view that the identification of households or areas vulnerable to flood hazards in Quarry Road West informal settlement should not be an end in itself, but rather it should enable decision-makers from the municipality and other stakeholders to work hand in hand with the community members in finding ways to improve people's adaptive capacity and resilience to flooding in the informal settlement. Failure to come out with any intervention will adversely affect many people as moderately vulnerable households will become highly vulnerable to flooding, especially due to the expected increase in the frequency and intensity of rainfall as a result of climate change.

The methodological approach demonstrated in this study can be utilized in similar environments or adapted by selecting context-specific indicators and weights. Although used on flood vulnerability, this approach can be used for another type of hazard. Furthermore, this approach can be used as a tool for monitoring flood vulnerability, emergency preparation and spatial planning as well as flood risk management.

CHAPTER 6: SUMMARY AND SYNTHESIS OF THE THESIS

This chapter provides a summary of the findings and a synthesis of the research. It also provides a conclusion and recommendations for future work.

6.1 Introduction

Informal settlements, especially in developing countries will be in existence for a long time. This is mainly due to the rapid population growth and rural-urban migration most cities are experiencing (United Nations, 2019; Zerbo et al., 2020). Furthermore, most municipalities in developing countries are unable to meet the demand for cheaper and decent accommodation for the ever-increasing number of poor people living in the cities. The informal settlements where most of the poor people in urban areas live are prone to many hazards such as floods. These informal settlements are also characterised by, poor drainage systems, high population density, inadequate solid waste management and poor socio-economic conditions (Dintwa et al., 2019; Maheu, 2016). Dwellers of informal settlements are not involved in planning or devising flood risk reduction initiatives because most municipalities consider them to be illegal (Satterthwaite et al., 2007; Williams et al., 2018). Therefore, reducing flood vulnerability in informal settlements requires a deeper understanding of the economic, economic, social, cultural, physical and environmental, characteristics of the community (Dintwa et al., 2019). Local and Indigenous Knowledge has been identified to be crucial in understanding the local context and promoting resilience (Dekens, 2007; UNDRR, 2015). However, the pace at which Local and Indigenous knowledge is being utilised in helping to reduce flood vulnerability in urban areas and informal settlements, in particular, has been slow (Dube & Munsaka, 2018; Kasei et al., 2019). Therefore, this study supports the relatively limited research (Lefulebe et al., 2014; Musungu et al., 2012) that argues that integrating Local, Indigenous Knowledge and GIS in mapping flood vulnerability, helps in having a thorough understanding of flood vulnerability in a particular geographical area.

Mapping flood vulnerability helps to identify the location of vulnerable households as well as the factors that make them vulnerable (Hoque et al., 2019; Jha & Gundimeda, 2019). Therefore, mapping flood vulnerability makes it easier to formulate and implement policies and strategies to reduce flood vulnerability in a particular geographical area. Mapping flood vulnerability in an informal settlement provides the required detail for reducing risks and improving the adaptive capacity and resilience of the local people. Ngie (2012) and Abunyewah et al. (2018) argue that when a community has a higher adaptive capacity to floods, its level of flood vulnerability correspondingly reduces.

In this study, we emphasise that Local Knowledge and Indigenous Knowledge are different. Local Knowledge is defined as the knowledge acquired by people as a result of them residing or being familiar with a particular area (Langill, 1999; Naess, 2013), while Indigenous Knowledge is rooted in culture and includes skills, practices, values, beliefs and norms passed on from one generation to the other generation (Alexander et al., 2019; Ngwese et al., 2018; Sillitoe, 2007; UNEP, 2008).

This study was anchored on the adaptive management and 'place-based' theories. The adaptive management theory supports a bottom-up, participatory, locally based and holistic mechanism for managing flood hazards (Holley et al., 2011; Ziervogel et al., 2016). The 'place-based theory' argues that a decrease in risk leads to a decrease in vulnerability in a particular locality. This in turn supports the formulation of appropriate policies and interventions (Cutter, 1996; Cutter & Finch, 2008; Dintwa et al., 2019).

The objectives of the study were to:

1. Provide a detailed overview of approaches and the state of knowledge in the literature on the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in developing countries
2. Investigate the main factors that influenced people's vulnerability to flooding in Quarry Road West informal settlement
3. Determine local context-specific indicators using Community member's Local and Indigenous Knowledge for mapping flood vulnerability in Quarry Road West informal settlement
4. Develop a methodological approach that comprehensively integrates local and Indigenous Knowledge and GIS in mapping flood vulnerability in an informal settlement

6.2 Approaches and state of the knowledge in integrating IK and GIS

A review of the literature and scholarship on the integration of Indigenous Knowledge and GIS in mapping flood vulnerability in South Africa provided evidence that showed that approaches used for integrating Indigenous Knowledge and GIS were fragmented (Chapter 2). This is because the studies did not jointly combine Indigenous Knowledge but separately analysed results using Indigenous Knowledge and GIS and then compared results at the end. The review also shows that the use of Indigenous Knowledge and adequate community participation in mapping flood vulnerability in South Africa is limited. Furthermore, sensitivity analysis and accuracy assessments of the flood vulnerability maps were lacking in the reviewed studies. This limited the reliability and usability of the flood vulnerability maps by decision-makers (Ouma & Tateishi, 2014). The review showed a shift from concentrating on biophysical or social vulnerability to integrated flood vulnerability. This integrated approach combined factors that exposed and made people sensitive to flood hazards including their income, level of education, population structure and access to flood early warning information. This shift also suggests that flood vulnerability is complex, hence it required a comprehensive approach to understand and reduce it. The review also showed that integrating Indigenous Knowledge and GIS was crucial in finding solutions to the flood vulnerability problem in informal settlements. This is because Indigenous Knowledge and GIS provided a comprehensive, culturally appropriate, cost-effective, context-specific and participatory understanding of the human-environment linkages of flooding in particular areas (Khan, 2014; UNDRR, 2005; Wisner et al., 2004). Therefore, this review highlighted a need for a holistic, participatory and reliable approach to integrate Indigenous Knowledge and GIS to map flood vulnerability in informal settlements in South Africa.

Another review of literature whose objective was to establish methodological approaches that were used for mapping flood vulnerability in developing countries between 2010 and 2020 was conducted in Chapter 3. This review showed that indicator-based Multi-Criterial Analysis using the Analytical Hierarchical Process (AHP) approach was mainly combined with GIS in mapping flood vulnerability in developing countries notwithstanding the challenges associated with the AHP, for instance, its failure to consider interdependent criteria (de Brito & Evers, 2017; Li et al., 2011). The review also found that existing literature and expert knowledge were mainly used for selecting indicators at all spatial scales. This situation robbed community members of the opportunity to find cost-effective, locally appropriate and sustainable solutions for dealing with floods in their locality. Furthermore, course data from Landsat, Shuttle Radar Topography Mission (STRM) and census were used to extract data for mapping food vulnerability even at fine scales like informal settlements. This situation adversely affected the quality of the flood vulnerability maps. The use of Local and Indigenous Knowledge in mapping flood vulnerability in developing countries was also limited. This situation helps to explain why community participation in mapping flood vulnerability in developing countries was correspondingly limited. Like in the South African context, sensitivity analysis and validation of flood vulnerability maps were also lacking in many developing countries. This was mainly due to the unavailability of updated and high-resolution data at fine scales. This situation did not only adversely affect the production of flood vulnerability maps in informal settlements, but negatively impacted the reliability and usefulness of the flood maps for decision-making.

6.3 Factors responsible for causing people's vulnerability

Residents of Quarry Road West informal settlement identified several factors causing their vulnerability to floods (Chapter 4). Chief among these factors is their closeness to the Palmiet River. The study found that some of the houses in Quarry Road West informal settlement were less than 2 m from the river banks. What worsened the situation was that the banks were widening due to increased rainfall and the velocity of the water in the rainy season. As a result, several houses were at risk of being washed away. Furthermore, the soil was also found to be very prone to erosion. This was a big challenge because it exposed people's houses to falling at the slight increase of runoff, especially since the houses were made from very weak foundations. The M19 freeway on the north and north-western side of the settlement and the Quarry Road on the south-eastern side of the settlement also increased people's vulnerability to flooding in the informal settlement. This is because the M19 freeway did not have storm drains, hence the water collected from that road found its well in the informal settlement. The water remained in the settlement for a considerable period because the land is flat. The storm drains on Quarry Road can no longer handle the increased amount of rain and poor solid waste management in the settlement has worsened the situation as the waste clogged the drains thereby making the water find its way to the settlement. The other factor that increased the resident's flood vulnerability was the type of materials they were using to build their houses. The study found that most people in the study areas used corrugated iron sheets of low grade and a few people used wood. As a result, the houses were prone to being washed away. Their houses were also prone to water leakages which further exposed them to health-related problems (Shah et al., 2020).

Since the informal settlement was located on land belonging to a private landowner and the state (Sim et al., 2019; Wiltgen Georgi et al., 2021), the residents of Quarry Road West informal settlement were not allowed to build permanent houses. Therefore, the residents were vulnerable to flooding as most of them delayed seeking refuge elsewhere even when a flood was eminent for fear of losing their land to someone else since they did not own the land. The factors that were responsible for causing flood vulnerability in Quarry Road West informal settlement enabled the community members to select indicators for mapping flood vulnerability in the informal settlement.

6.4 Context-specific indicators for mapping flood vulnerability

Studies that mapped flood vulnerability at various spatial scales used indicators that were generated using expert knowledge and existing literature (Chen et al., 2019; de Brito et al., 2018; Eini et al., 2020; Muller et al., 2011; Musungu et al., 2012). This situation suggests that flood vulnerability is generalised and not specific to a particular geographical area. Using overgeneralised indicators makes it difficult to accurately locate the most vulnerable people or households living in a particular locality. Furthermore, community participation was limited and this gave an impression that local communities did not understand what needed to be done to map or reduce flood vulnerability in their communities. Therefore, this study sought to present the results of using Local and Indigenous Knowledge in selecting indicators for mapping the vulnerability of people to flood hazards in an informal settlement context. The study was conducted in Quarry Road West informal settlement, located in Durban, South Africa (Chapter 4).

This study showed that the Local and Indigenous Knowledge that community members living in an informal settlement possess was crucial in identifying context-specific indicators for mapping flood vulnerability. This study revealed that while local ‘technical experts’ identified twenty-one indicators for mapping flood vulnerability in Quarry Road West informal settlement, community members using their Local and Indigenous Knowledge identified a minimal number of sixteen locally appropriate indicators (Table 6.1). This revealed that while it was necessary to use indicators from the literature and expert knowledge in mapping flood vulnerability, these could be enhanced by integrating Local and Indigenous Knowledge possessed by community members living in a particular informal settlement. This is because the indicators selected by the local people were context-specific and more nuanced. Furthermore, of the indicators that the community members selected, proximity to main roads, land ownership, drainage system and accumulated waste were found to be unique to the study area as they had not been used before in the literature for mapping flood vulnerability. This signifies the importance of Local and Indigenous Knowledge in helping to find solutions to problems faced by local communities. The study also highlights the need to involve community members in identifying solutions to their challenges, thereby augmenting the idea that marginalized informal settlement dwellers were not ‘helpless’ victims of floods.

Furthermore, this study pointed out the need for the flood early warning information shared to the community via WhatsApp in English to also be shared in the local language to increase the effectiveness of the information as well as to increase the number of community members getting the warning unequivocally considering the low levels of education in the settlement.

This study underscores the significance of using the indicator-based approach which the United Nations International Strategy for Disaster Reduction (2005) has been encouraging in mapping flood vulnerability. The indicator-based approach supports a more holistic approach to mapping flood vulnerability because it considers social and biophysical factors of flood vulnerability.

Table 6.1 Indicators selected by community members for mapping flood vulnerability in Quarry Road West informal settlement

Factor/Element	Indicators from the literature	Community members' selection
	Amount of rainfall	×
	Flood frequency	
	Proximity to river	×
	Flood water level	
	Drainage density	
	Flow velocity	×
	Slope	×
Physical	Elevation	
	Nature of Soil	×
	Land cover	
	Type of building material	×
	Critical infrastructure e.g., bridges	
	Drainage system*	×
	Distance to health facilities	
	Proximity to main roads*	×
Economic	Average income	×
	Level of Unemployment	×
	Persons with permanent disabilities	
	Persons under 5 years	
	Persons under 12 years	
	Persons over 60 years	
	Population density	×
	Literacy rate	
	Access to early warning information	×
Social	Female-headed households	
	Evacuation drills	
	Level of Education	×
	Social ties	×
	Access to media/awareness	
	Health insurance	
	Dependence ratio	

Land ownership*	×
Accumulated waste*	×

Note: * indicators not selected from the literature

6.5 Mapping flood vulnerability in informal settlements

This study demonstrated the practicality of using indicators generated by community members' Local and Indigenous Knowledge for mapping flood vulnerability in an informal settlement context (Chapter 5). In this study, a novel, participatory and comprehensive methodological approach that integrated the community members' Local and Indigenous Knowledge and GIS-based Multi-Criterial Decision Making using the Analytic Network Process was used in mapping flood vulnerability in Quarry Road West informal settlement (Chapter 5). This approach involved the participation of community members not only in identifying factors responsible for causing flood vulnerability or selecting indicators, but it fostered the participation of community members in weighing indicators, standardizing, aggregating and validating flood vulnerability maps. It can therefore be argued that the approach used in this thesis helped to raise public awareness of flood vulnerability among Quarry Road West informal settlement dwellers. This study has also shown that the critique that has been levelled against GIS as being too 'technical expert' oriented in mapping processes (Manap et al., 2013), can be minimised by adequately involving the participation of community members in the stages of the flood vulnerability mapping process (Brandt et al., 2019; Canevari-Luzardo et al., 2017). It also utilized the strengths that Local, Indigenous Knowledge and GIS inherently possess.

Furthermore, the Analytic Network Process was found to help handle the complex nature of flood vulnerability as biophysical and social factors of flood vulnerability as well as exposure, sensitivity and adaptive capacity components were considered. The Analytic Network Process manipulated the interrelated nature of factors that caused flood vulnerability in the study area.

Updated and high-resolution data generated in Quarry Road West informal settlement were used to map flood vulnerability. Mapping the intensity of flood vulnerability for instance as high, moderate and low vulnerability was vital in helping to locate venerable areas or households in the study area. Households or areas close to the Palmiet River were found to be highly vulnerable to flooding in the informal settlement. Areas or households in the central parts of Quarry Road West informal settlement mainly had moderate flood vulnerability while areas on the elevated parts of the settlement especially in maMsuthu had low flood vulnerability. The generated flood vulnerability map was subjected to sensitivity analysis and validation. The result of the sensitivity analysis showed that the flood vulnerability map was robust and the validation showed that the mapping process was reliable. This, therefore, provides the potential of using the generated map for decision-making by planners, disaster risk managers and other stakeholders in efforts to deal with floods in Quarry Road West informal settlement.

6.6 Conclusion

The overall aim of this study was to establish a methodological approach for integrating Local, Indigenous Knowledge and GIS in mapping flood vulnerability in Quarry Road West informal settlement in Durban, South Africa. Despite the calls by the United Nations Office for Disaster Risk Reduction (UNISDR) and the World Conference on Disaster Reduction at the international level, the Disaster Management Act No. 57 of 2002 and the National Disaster Management Framework of 2005 at the national level in South Africa, acknowledging the need to consider Indigenous Knowledge in disaster risk reduction, very little has been done on the ground. Therefore, this study has demonstrated the importance of using the community members' Local and Indigenous Knowledge in selecting context-specific and locally appropriate indicators for mapping flood vulnerability at a local scale which the literature or experts may not consider. This, therefore, highlights the significance of Local and Indigenous Knowledge in reducing flood risks in informal settlements. It can therefore be argued that the community members’ Local and Indigenous Knowledge should be at the centre of all interventions in Quarry Road West and other informal settlement to increase’s people resilience to flooding and other hazards. The failure of most municipalities to integrate local and Indigenous Knowledge in disaster management continues to marginalize and disempower people living in informal settlements from participating in finding solutions to flood problems that continue to adversely affect them. Local and

Indigenous Knowledge enables people at local scales to cope and adapt to floods as it helps to raise awareness at a local level. It also helps to have a more nuanced understanding of flood vulnerability which in turn could guide what has to be done to reduce people's vulnerability to floods in a particular geographical area. Therefore, municipalities and other stakeholders must take a keen interest in reducing flood risk and vulnerability in informal settlements. Failure to do this has far-reaching consequences for the poorest in the cities who mainly live in informal settlements and the city as a whole. This is because having a flood in an informal settlement requires money and human resources to help flood victims. This situation may lead to the diversion of resources meant for service provision in the city to deal with the flood disaster which may have occurred in an informal settlement.

This study has shown that flood vulnerability in the settlement is spatially differentiated and that it is not the entire settlement that is very vulnerable to flooding. Therefore, interventions aimed at reducing flood risks in the settlement should target particular areas more than others.

Local authorities, decision-makers and other stakeholders should strive to help people living in informal settlements reduce their vulnerability to flooding. This is particularly important because climate change will cause an increase in floods in many areas. The latest floods experienced in Durban on the 12th of April 2022 destroyed over 60 houses in Quarry Road West informal settlement. This situation shows the need for an urgent intervention to deal with floods in the informal settlement before more houses and lives are lost.

Since many people in informal settlements in developing countries and South Africa, in particular, are located in hazardous areas such as flood plains, there is a need for local authorities or municipalities to conduct routine maintenance of riverine systems. Doing this will help to reduce the siltation of rivers and the widening of river banks. It will also help to improve the flow of water in the rivers.

Furthermore, improving the governance system in local authorities, particularly in disaster management is crucial in increasing the adoption of bottom-up approaches and the use of community members' Local and Indigenous Knowledge in informal settlements as giving a voice and increasing the participation of local people in disaster management increases their resilience.

Collaborative in-situ upgrading of the informal settlement that involves adequate community participation is therefore recommended in Quarry Road West informal settlement, especially since the relocation programme that was undertaken in the settlement failed. Collaborative in-situ upgrading will ensure that the upgrading utilizes the rich experiential and situational knowledge of the local people to manage flood risks. It will also ensure that challenges of poor drainages, housing conditions, waste collection, land ownership and building very close to the river or main roads are addressed. Quarry Road West informal settlement does not only have a comparative advantage of being close to the Durban CBD or easy access to different urban social amenities, but residents of Quarry Road West informal settlement also have a 'sense of place' and have a special attachment to that place. Relocating people who have lived in an area for 3 decades and have developed strong social ties is not easy.

The study has shown that the Analytical Network Process helps comprehensively integrate Local, Indigenous Knowledge and GIS in a participatory manner by jointly and genuinely utilizing the inherent characteristics that each of them possesses to map flood vulnerability in an informal settlement. The challenges associated with the indicator-based approach in mapping flood vulnerability were managed in this study by having community members participate in the weighting, standardization and aggregation processes. However, there is still a need to explore additional studies or approaches for integrating community members' Local and Indigenous Knowledge in mapping flood vulnerability in informal settlements.

6.7 Recommendations for further research

Future research should therefore endeavour to explore how to integrate community members' Local and Indigenous Knowledge with machine learning, artificial intelligence, volunteered geographical information and TOPSIS approaches in mapping flood vulnerability in informal settlements.

Furthermore, low impact developments are useful in promoting the resilience of urban areas to climate changes in that they reduce runoff volumes, reduce hydrological impacts of dense urbanization and promote infiltration (Hewitt et al., 2019; Pour et al., 2020). However, locally appropriate local impact developments for use in informal settlements have not yet been established. Therefore, more studies are needed to firstly investigate the extent to which low impact development techniques can be used to reduce flooding in informal settlements and secondly, there is a need to establish context-specific designs for informal settlements, especially in developing countries.

In more open or less densified urban areas Synthetic Aperture Radar (SAR) data should be explored in validating flood vulnerability maps.

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APPENDICES

Appendix 1 Digital structured survey administered in Quarry Road West informal settlement

Section 1 of 2

Flood Vulnerability mapping in Quarry Road West

Greetings, a student from UKZN is carrying out a research on the integration of indigenous knowledge in mapping flood vulnerability in Quarry Road West Informal Settlement. I will appreciate if you can spare about 20 minutes of your time to respond to a few questions. All the information will be only be used for research purposes and will remain confidential.

Untitled section

Enumerator Code

The eCode is the unique identify for a research assistant.

eCode *

Your answer

A. Demographic characteristics
Please answer questions below

1. What is your gender? *

- ◯ Male
- ◯ Female

2. What is your marital status? *

- ◯ Married
- ◯ Divorced
- ◯ Separated
- ◯ Widowed
- ◯ Cohabiting
- ◯ Single
- ◯ Other: ____________________

3. What is your age? *

- ◯ 20 years and below
- ◯ Between 21 and 30 years
- ◯ Between 31 and 40 years
- ◯ Between 41 and 50 years
- ◯ Between 51 and 60 years
- ◯ Between 61 and 70 years
- ◯ 70 years and above

4. What is your highest level of education? *

- ◯ None
- ◯ Grade 1 to 7
- ◯ Grade 8 to 9
- ◯ Grade 10 to 12
- ◯ College or University

5. Do you have children? *

- ◯ Yes
- ◯ No

6. How many children or dependents live within your house? *

- None
- 1 to 2
- 3 to 4
- 5 to 6
- 7 and above

7. How many people in your household are below 5 years? *

- None
- 1 to 2
- 3 to 4
- 5 to 6
- 7 and above

8. How many people in your household are below 12 years *

- None
- 1 to 2
- 3 to 4
- 5 to 6
- 7 and above

9. How many people in your household are above 60 years? *

- ◯ None
- ◯ 1 to 2
- ◯ 3 to 4
- ◯ 5 to 6
- ◯ 7 and above

10. Is there any person (s) with a permanent disability in your household? *

- ◯ Yes
- ◯ No

11. For how long have you been living in this settlement? *

- ◯ Less than 1 year
- ◯ 2 to 3 years
- ◯ 4 to 6 years
- ◯ 7 to 9 years
- ◯ 10 years and above

12. What is your country of origin? *

- ◯ South Africa
- ◯ Malawi
- ◯ Lesotho
- ◯ Eswatini
- ◯ Mozambique
- ◯ Zambia
- ◯ Congo
- ◯ Rwanda
- ◯ Burundi
- ◯ Tanzania
- ◯ Other: ______

B. Livelihood and living conditions

13. Are you in employment? *

- ◯ Yes
- ◯ No

14. If No, what do you do for a living?

Your answer ______

15. How many people in your household earn an income? *

- ◯ None
- ◯ 1 to 2
- ◯ 3 to 4
- ◯ 5 to 6
- ◯ 7 and above

16. What is your average household income per month (in Rands)? *

- ◯ 1,500 and below
- ◯ 1,501 to 2,500
- ◯ 2,501 to 3,500
- ◯ 3,501 5,000
- ◯ Above 5,000

17. Do you receive any social welfare grant from the government? *

- ◯ Yes
- ◯ No

18. If Yes, to question 17, what type of a social welfare grant do you receive?

- ◯ Child Support Grant
- ◯ Grant-in-Aid
- ◯ Care Dependency Grant
- ◯ Foster Child Grant
- ◯ Social Relief of Distress Grant
- ◯ Disability Grant
- ◯ War Veteran's Grant
- ◯ Other: ____________________

19. Who owns the house you live in? *

- ◯ Myself
- ◯ The landlord
- ◯ A relative
- ◯ Other: ____________________

E. Flood early warning information

20. Do you receive any flood early warning information from the WhatsApp group or any other means? *

- ◯ Yes
- ◯ No

21. If yes to question 20, how helpful is the flood warning information?

- ◯ Not helpful
- ◯ Helpful
- ◯ Very helpful
- ◯ Extremely helpful

22. How do you receive the flood early warning information? (Tick all applicable responses)

- ☐ Television
- ☐ Radio
- ☐ WhatsApp
- ☐ Cell phone SMS
- ☐ Internet
- ☐ Neighbours
- ☐ Community leaders
- ☐ Other: ______

E. Exposure and sensitivity of the settlement to flood hazards

23. Does your household get affected by floods every rainy season? *

- ◯ Yes
- ◯ No

24. Does garbage (solid waste) contribute to flooding in this settlement? *

- ◯ Yes
- ◯ No

25. Does water from the roof of the neighbour's house contribute to flooding in this settlement? *

- ◯ Yes
- ◯ No

26. How do you rate your household's vulnerability to floods? *

- ◯ Less vulnerability
- ◯ Medium vulnerability
- ◯ High vulnerability
- ◯ Very high vulnerability

27. If given the chance, can you agree to be relocated to another place? *

- ◯ Yes
- ◯ No
- ◯ Other: ____________

28. What makes your household exposed to flood impacts? (Tick all applicable responses) *

- ☐ Closeness of the house to the river
- ☐ Closeness of the house M19 road
- ☐ Increased rainfall
- ☐ Increased runoff from higher land
- ☐ Accumulated garbage (Solid waste)
- ☐ Lack of proper drainage system
- ☐ Other: ____________

29. What makes your household have little defense against flood impacts? (Tick all applicable responses)

- [ ] Lack of land ownership
- [ ] Low income
- [ ] Unemployment
- [ ] Lack of critical infrastructure (e.g. schools, hospitals, bridges)
- [ ] Materials used to construct the house
- [ ] Lack of access to flood early warning information
- [ ] Other: ____________________

30. What characteristics of the settlement makes it more exposed to flood impacts? (Tick all applicable responses) *

- [ ] Low laying nature of the settlement
- [ ] Soil type
- [ ] Closeness of settlement to the river
- [ ] Closeness of settlement to the M19 Road
- [ ] Poor drainage system
- [ ] Frequency of floods
- [ ] Other: ____________________

31. What characteristics of the people in the settlement make them defenseless against to flood impacts? (Tick all applicable responses) *

- [ ] Lack of land ownership
- [ ] High population density
- [ ] Low-income levels
- [ ] High unemployment
- [ ] Lack of access to flood early warning information
- [ ] Too many female headed households
- [ ] Materials used to construct houses
- [ ] Accumulation of garbage (solid waste)
- [ ] Other: ____________________

F. Indigenous knowledge and adaptive capacity

32. Is there any cultural or experiential based strategy which helps you to know that there will have a flood in your settlement? *

- ◯ Yes
- ◯ No

33. If Yes to question 31, what is that strategy

Your answer

34. What cultural or experiential based strategies do you use to prepare for floods? (Tick all applicable responses)

- ☐ Putting cement on the sides of the house
- ☐ Putting sand bags on the sides of the house
- ☐ Putting house foundation on tyres
- ☐ Heaping sand on the sides of the house
- ☐ Putting stones on the sides of the house
- ☐ Raising the entrance to the house
- ☐ Putting a plastic on top of the roof
- ☐ Building trenches
- ☐ Taking my valuable items somewhere else
- ☐ Raise my bed slightly higher
- ☐ Other: ____

35. What do you do when your house is flooded? *

- ◯ Temporarily vacate the house
- ◯ Stay in the house
- ◯ Other: ____________

36. If you temporarily vacate the house, where do you normally go to?

- ☐ A friend's house within the settlement
- ☐ A neighbour's house within the settlement
- ☐ A central location organised by the municipality (Disaster management)
- ☐ A relative's house outside the settlement
- ☐ Other: ____________

37. If you stay in the house, what do you usually do to deal with the floods?

- ☐ Raise my bed slightly higher
- ☐ Put important things on higher platforms
- ☐ Remove the water with a bucket
- ☐ Other: ____________

38. When the flood is over, what cultural or experiential based strategies do you use to recover from the impact of floods?

Your answer ____________

39. Which of the following factors do you think should be taken into account when mapping flood vulnerability in the settlement? *

- [ ] Low laying nature of the settlement
- [ ] Closeness to the M19 and Quarry road
- [ ] Closeness to the river
- [ ] Frequency of flood events
- [ ] Soil type (nature of soil)
- [ ] Increased rainfall
- [ ] Accumulation of garbage
- [ ] Low Income levels
- [ ] High unemployment level
- [ ] High Population density
- [ ] Household with children under 5 years
- [ ] Households with persons below 12 years
- [ ] Households with persons above 60 years
- [ ] Households with persons with a disability
- [ ] Lack of flood early warning information
- [ ] Lack of land ownership
- [ ] Housing material
- [ ] Settling in flood plain
- [ ] Poor drainage system
- [ ] Other: ____________

40. What do you think should be done to reduce negative effects of floods in this settlement?

Your answer ____________

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Appendix 2 Researcher's Interview Schedule for interviewing key informants

The objective of this interview is to elicit information on the factors that underlie exposure and sensitivity to flood vulnerability of Quarry Road West residents and to find out their indigenous knowledge of dealing with floods. This study also seeks to find out indigenous-based criteria/indicators for mapping flood vulnerability in the settlement. The individual information collected will be confidential and only used for academic purposes.

1. What physical factors expose residents of Quarry Road West informal settlement to flood events?

2. What general factors make the residents of Quarry Road West susceptible to flood vulnerability?

3. What is the major cause of flood vulnerability in Quarry Road West?

4. Are there any flood early warning systems available for people in Quarry Road West?

5. People living in Quarry Road West have experienced flood disasters for many years. What are experiential-based practices employed by the residents to predict an imminent flood event?

6. What experiential-based practices do residents of Quarry Road West employ to reduce the adverse impact of flood during a flood event?

7. What cultural practices do residents in Quarry Road West use to deal with life after a flood event?

8. What factors hinder the residents' capacity to deal with floods in the settlement?

9. What should be done to reduce flood vulnerability in Quarry Road West informal settlement?

10. What policy recommendation can you suggest to help improve people's coping or adaptive capacity in the settlement?

11. Which of the following criteria/indicators (see Table 1 below) are locally appropriate for mapping flood vulnerability in Quarry Road West informal settlement?

List of some criteria used for mapping flood vulnerability (based on a literature review)

S/N	Criteria/Indicator	Tick (or use green colour)		S/N	Criteria/Indicator	Tick (or use green colour)
1	Flood frequency			2	Monthly household per capita income	
3	Flood extent			4	Unemployment rate	
5	Elevation			6	Households with improper building material	
7	Soil type (nature of soil)			8	Population density	
9	Flood depth			10	Unsafe drinking water	
11	Drainage density			12	Female-headed household	
13	Gender			14	Evacuation drills and training/Evacuation procedure	
15	Distance to river			16	Early warning	
17	Slope			18	Distance to shelters	
19	Land use /cover			20	Health care facilities	
21	Precipitation/Rainfall			22	Health insurance	
23	Critical infrastructure (water and sewage treatment plants, power plants, hospitals, roads, bridges)			24	Literacy rate	
25	Households with accumulated garbage/waste			26	Educational level	
27	Persons with permanent disabilities			28	Cultural heritage	
29	Persons under 5 years			30	Social networks	
31	Persons under 10 or 12 or 14 or 15 years			32	Emergency management committee/Flood management measures	
33	Persons over 60 years			34	Risk Awareness /Access to media	
35	Social hotspots (hospitals, schools, day-care centres, retirement homes)			36	Dependence ratio/ Dependence on welfare grants	

12. Which criteria/indicators are missing from Table 1, but are important for mapping flood vulnerability in Quarry Road West informal settlement?
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
………………………………………………………………………

- **Thank you very much**

Appendix 3 Question for the Focus Group Discussion

The objective of this focus group discussion is to elicit information on the issues that cause flood vulnerability in Quarry Road West informal settlement and then generate a list of indicators for mapping flood vulnerability in the informal settlement. The individual information collected will be confidential and only used for academic purposes.

Date: …………………….

Time: ……………………

Number of Male ………… and number of females ……………..

Questions:

1. What do contribute to flooding vulnerability in this informal settlement?

2. From the table presented before you, what factors should be considered for mapping flood vulnerability in the settlement?

3. What indicators do you think are important for mapping flood vulnerability but are missing from the provided table?

4. Which indicators fall under exposure, sensitivity and adaptive capacity?

5. How do the indicators were related to each other?

6. How does each indicator influence flood vulnerability in the settlement (use percentages?

Appendix 4 Template for Informed Consent Document (IsiZulu)

Sawubona mhlanganyeli,
Igama lami ngingu Garikai Martin Membele. Ngenza I PhD ngiyenza e University ya KwaZulu-Natal, kwi khampasi yase Pietermaritzburg. Isihloko socwaningo lwami sithi: Ukuhlanganisa ulwazi lwabomdabukanye ne GIS ekuvezeni ubungozi bezikhukhula e mixhasweni yase Quarry Road West e Thekwini, KwaZulu-Natal. Inhloso yalolu cwaningo ukuthola izindlela zokuhlanganisa ulwazi lwendabuko kanye ne GIS ekuvezeni ubungozi bezikhukhula emixhasweni yase Quarry Road West e Thekwini eNingizimu Afrikha. Nginentshisekelo yokuxoxisana nawe ukuze sabelane ngomuzwa wakho kuloludaba.

Ngicela uqaphele lokhu:

- Ulwazi onikezela ngalo kule ngxoxo luzosetshenziselwa ukwenza lolucwaningo kuphela.
- Ukubamba iqhaza kwakho kungokokuzithandela.
- Unelungelo loku bamba iqhaza noma ukungabambi iqhaza noma uyeke ukubamba iqhaza kulolu cwaningo . Ngeke ujeziswe ngokungalibambi iqhaza kulolu cwaningo.
- Imibono yakho kulolucwaningo izosetshenziswa ngokufihlilwe.Imininingwane yakho noma igama lakho lizogodlwa kulesisifundo.
- Lengxoxo ngeke idlule kwi hora elilodwa.
- Ama rekhodi Kanye nezinye izinto eziphathelene nalolucwaningo kuzogcinwa endaweni ephephile ekhiwa nge phasiwedi engakwazi ukuthi itholwe yimi Kanye no mpathi wami kuphela. Emva kweminyaka emihlanu sihambisana nemithetho ye Nyuvesi lemininingwane izaku cishwa.
- Uma uvuma ukuhlanganyela nathi sicela u sayine lesimemezelo esinanyathiselwe kulesi statimende.

Ngiyatholakala: School of Social Sciences, University of KwaZulu-Natal, Pietermaritzburg Campus, Email: garikaimembele@yahoo.com Cell: 068 560 0696

Umphathi wami u Professor Maheshvari Naidu, Osebenzela e School of Social Sciences, Howard College Campus, Durban of the University of KwaZulu-Natal. Utholakala ku: email: naiduu@ukzn.ac.za Phone number: +27312607657

Okwesibili wami u Professor Onisimo Mutanga, Osebenzela e School of Agriculture, Earth and environmental sciences, Pietermaritzburg Campus, University of KwaZulu-Natal.

Contact details: email: mutangao@ukzn.ac.za Phone number: +27718548022

The Humanities Kanye ne Sayensi Yezenhlalo icubungula izimilo zokuziphatha Batholakala lapha: HSSREC Ethics Office, Email: hssrec@ukzn.ac.za Telephone: 031 260 8350/4557/3587

Ngiyabonga ukuhlanganyela nawe kulolucwaningo.

Appendix 5 Informed consent declaration form (isiZulu)

ISIMEMEZELO

Mina…………………………………………………………………………… *(Ungakhetha noma ufakeamagama afi ngqiwe*) Lapha ngiyaqinisekisa ukuthi ngiyakuqonda okuqukethwe ile ncwadi Kanye nohlobo lwesihloko salolu cwaningo**: Ukuhlanganisa ulwazi lwabomdabukanye ne GIS ekuvezeni ubungozi bezikhukhula e mixhasweni yase Quarry Road e Thekwini, KwaZulu-Natal.** Ngiyavuma ukubamba iqhaza kulolu cwaningo.

Ngiyaqonda ukuthi nginelungelo loku ngahlanganyeli kulolu cwaningo uma ngizizwa ngingasathandi.Ngiyavuma ukubamba iqhaza kulolucwaningo:

Ngizobamba iqhaza kulolu cwaningo kwi: (Khetha kokufanele)

a. Kwi ngxoxo
b. Ingxoxo yeqembu ekugxilwe kulo

Ngiyavuma / Angivumi ukuba lengxoxo iqoshwe (Uma kukhona)

Isiginesha yomhlanganyeli: **Usuku:**

……………………………………. ……………………………….

Appendix 6 Template for Informed Consent Document (English)

Dear Participant,
My name is Garikai Martin Membele. I am a PhD candidate studying at the University of KwaZulu-Natal, Pietermaritzburg Campus. The title of my research is **Integrating Local and Indigenous Knowledge and Geographical Information Systems in Mapping Flood Vulnerability at Quarry Road West Informal Settlement in Durban, KwaZulu-Natal.** The aim of the study is to establish a methodological approach for integrating indigenous knowledge and GIS to map flood vulnerability in Quarry Road West informal settlement in Durban, South Africa. I am interested in interviewing you so that you share your experiences on the subject matter.

Please note that:

- The information that you provide will be used for scholarly research only.
- Your participation is entirely voluntary. You have a choice to participate, not to participate or stop participating in the research. You will not be penalized for taking such an action.
- Your views in this interview will be presented anonymously. Neither your name nor identity will be disclosed in any form in the study.
- The interview will not exceed an hour.
- The record as well as other items associated with the interview will be held in a password-protected file accessible only by my supervisors and myself. After a period of 5 years, in line with the rules of the university, the information will be deleted.
- If you agree to participate please sign the declaration attached to this statement

I can be contacted at: School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg Campus, Email: garikaimembele@yahoo.com
Cell: 068 560 0696

My main supervisor is Professor Maheshvari Naidu, who is located at the School of Social Sciences, Howard College Campus, Durban of the University of KwaZulu-Natal.
Contact details: email: naiduu@ukzn.ac.za Phone number: +27312607657

My second supervisor is Professor Onisimo Mutanga, who is located at the School of

Agriculture, Earth and environmental sciences, Pietermaritzburg Campus, University of KwaZulu-Natal.
Contact details: email: mutangao@ukzn.ac.za Phone number: +27718548022

The Humanities and Social Sciences Research Ethics Committee contact details are as follows: HSSREC Ethics Office, Email: hssrec@ukzn.ac.za Telephone: 031 260 8350/4557/3587

Thank you for your contribution to this research.

Appendix 7 Informed consent declaration form (English)

DECLARATION

I………………………………………………………………………… *(Name is optional and may be replaced by initials*) hereby confirm that I understand the contents of this document and the nature of the research title**: Integrating Indigenous Knowledge and GIS in Mapping Flood Vulnerability in Quarry Road West Informal Settlement in Durban, KwaZulu-Natal.** I consent to participating in the research project.

I understand that I am at liberty to withdraw from the project at any time, should I so desire. I also understand the intention of the research. I hereby agree to participate in the:

I will participate in the research through: (tick the appropriate response)

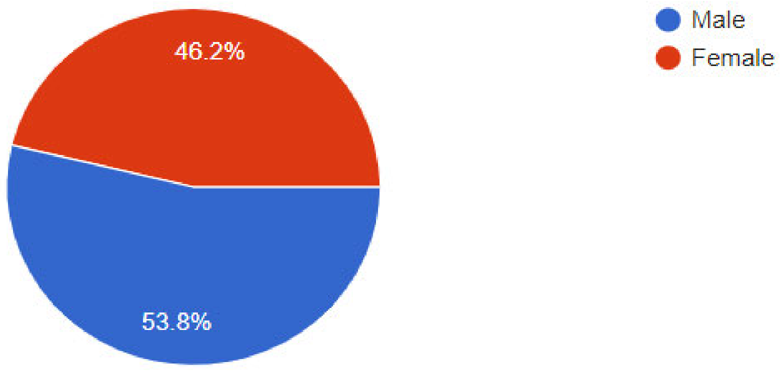
c. An Interview
d. A Focus Group Discussion

I consent / do not consent to have this interview recorded (if applicable)

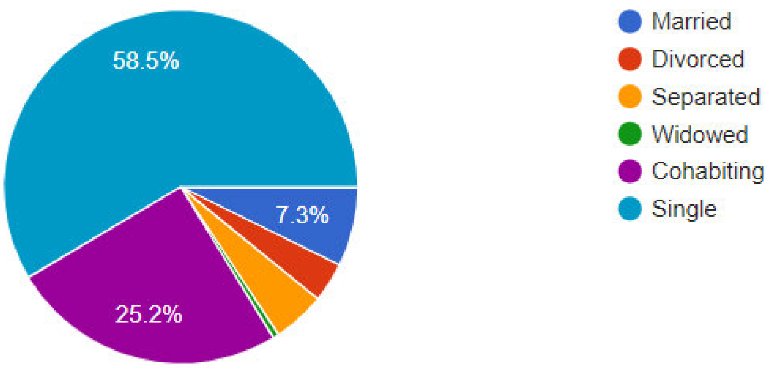
Signature of participant: **Date:**

…………………………… ………………………

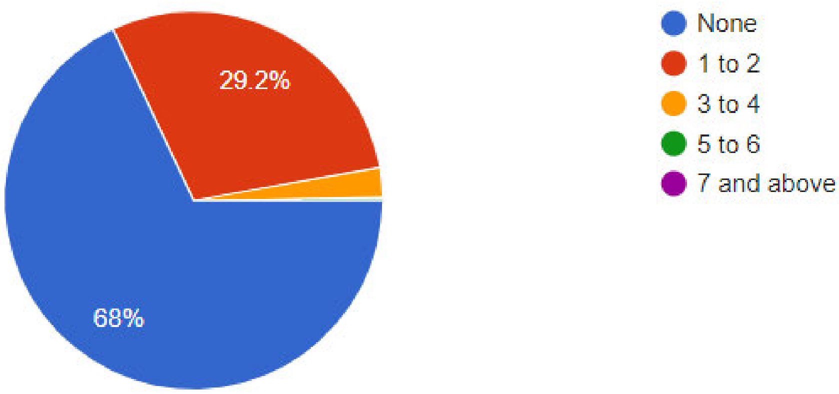
Appendix 8 Gender of the household heads surveyed



Appendix 9 Martial status of the respondents



Appendix 10 Sampled households with children below 5 years



Appendix 11 House ownership among the sample households