ASSESSMENT OF PHYSICAL VULNERABILITY OF BUILDINGS TO FLOODING IN LILONGWE CITY, MALAWI

MSc THESIS (GEOGRAPHIC INFORMATION SYSTEMS)

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Assessment of Physical Vulnerability of Buildings to Flooding in Lilongwe City, Malawi

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A THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF BUILT ENVIRONMENT IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE (MSc) IN GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

The research on flood vulnerability in Malawi has focused on social, economic and human vulnerability; hence, there is limited data on the physical vulnerability of buildings that could assist in flood risk reduction. The study investigated the physical vulnerability of buildings to flooding in low-income settlements of Biwi and Kawale1 in Lilongwe City. The GIS OLS regression tool and SPSS 20 were used to correlate the exposure factors and physical vulnerability of buildings. The study established that the buildings made of burnt bricks with cement mortar walls and cement floors had a low vulnerability, while buildings with burnt bricks in mud mortar walls and cement floors had a high vulnerability. The GIS's OLS regression revealed that the physical vulnerability of buildings was significantly influenced by building typologies and floodwater depth with Sig. value .001($p<.001$) and Sig. value .004($p<.005$) respectively. The study established that there was variation in how the exposure factors influenced the physical vulnerability of building Types. The study concludes that building typology and floodwater depth greatly influenced the physical vulnerability of buildings. It also concludes that there was variation in how the proximity of buildings to the river, floodwater depth and floodwater duration contributed to the physical vulnerability of building Types. The study recommends that buildings should be constructed with flood-resistant materials and raised foundations in flood-prone areas to reduce flood risk. It also recommends that flood vulnerability studies should be conducted in other flood-prone areas to support effective citywide urban planning and management.

Key concepts: Physical vulnerability, Flooding, Exposure

DEDICATION

I dedicate this thesis to my late father, Bernard Emmanuel Mathambo and my mother Silvia Lloyd Mathambo. I wish my late father were around to see the fruits of his mentorship.

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I thank God Almighty for His supplies and provisions which facilitated the payment of the cost of this study and also for keeping me in good health throughout my study, without which I could not have managed to undertake this programme.

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DECLARATION BY CANDIDATE

I, CHRESCEUNTIA MATAMBO, hereby declare that this thesis titled, "**Assessment of the physical vulnerability of buildings to flooding in Lilongwe City, Malawi",** is my own work; that it has not been submitted before for any degree or examination at any other university, and that all the sources I have used or quoted have been duly cited in the text and acknowledged as complete references.

Parts of the materials presented in this thesis have been submitted for publication to UCLPRESS (UCL Open:Environment) and has been posted as preprint at doi.org/10.14324/ucloepreprints.279.v1. It appears as "Physical Vulnerability of Buildings to Flooding in Lilongwe City, Malawi."

________________________ ____________________

Student's name/signature Date

CERTIFICATE OF APPROVAL

I, the undersigned, have examined the final electronic copy of this thesis for form and content and certify that this thesis is a result of the author's work and that to the best of my knowledge, it has not been submitted for any other academic qualification within Mzuzu University or elsewhere. I can confirm that the thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on 30 *November 2023.*

______________________________ _______________________

Major Supervisor: Date

Dr. Mtafu Zeleza Manda

______________________________ _______________________

Second Supervisor: Date

Dr. Denis Mavuto Tembo

ACRONYMS

DoDMA	Department of Disaster Management Affairs
DTM	Digital Terrain Model
EaR	Elements at Risk
ESRI	Environmental Systems Research Institute
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GoM	Government of Malawi
HH	Household
IPCC	Inter-governmental Panel on Climate Change
MASDAP	Malawi Spatial Data Portal
MGDS III	Malawi Growth Development Strategies III
MZUNIREC	Mzuzu University Research Ethics Committee
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OLS	Ordinary Least Squares
PDNA	Post Disaster Needs Assessment
SDGs	Sustainable Development Goals
SPSS	Statistics Package for Social Scientists
SQL	Structured Query Language
STRM	Shuttle Radar Mission
TS	Technical Summary
UN	United Nations
UNISDR	United Nations International Strategy for Disaster Reduction
WHE	World Housing Encyclopaedia

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CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter presents the background of the study, research problem, objectives, justification of the research, and ethical considerations.

1.2. Study background

Cities in Sub-Saharan Africa have been experiencing more recurring threats of flooding in recent years (Ramiaramanana & Teller 2021). It has been reported that "the flooding has a direct impact on the population, buildings, livestock, crops, and goods, as well as an indirect impact on human, economic, social, financial, political, and institutional terms" (Tiepolo 2014 p. 25) in urban areas in the South of the Sahara. The increase in urban population has exacerbated the exposure of the urban population to flooding due to the high housing demand, which has forced low-income people to settle in flood-prone zones (Ramiaramanana & Teller 2021). Douglas et al. (2008) posit that many low-income people face problems associated with severe flooding in Africa. Most low-income people are attracted to settling in flood-prone areas by cheap housing and accessibility to jobs (Erman & Kerle 2022) though in some cases wealthier people also construct buildings in these areas (Wisner et al. 2003). Despite this, both the poor and richer people tend to be affected by flood events, and poor people are likely to be impacted more (Yang et al. 2018). Sagala (2006) affirms that most of the people who settle in risky areas are low-income people since land in river reserve areas is cheaper than in the upland. Besides, low-income people live in poor-quality buildings that are constructed from low-quality materials that cannot withstand flooding, hence making them vulnerable (De Risi et al. 2013). Masozera, Bailey & Kerchner (2006) emphasise that the poor are more likely to die, suffer from injuries, have proportionately higher material losses, more psychological trauma; and face more obstacles during the phases of response, recovery, and reconstruction.

Urban areas in Malawi have also experienced increasing climate change-related extreme weather events in recent years, like floods, among others (Ngwira 2016). The types of floods that affect these urban areas are flash floods and river flooding, also called fluvial flooding (Salamiet al 2017). Fluvial flooding is triggered by excessive rainfall over some hours, resulting in the overflow of rivers (Salami et al 2017). Flash floods are rapid surface water triggered by intense rain thunderstorms or a sudden discharge of water from a reservoir, which results in short high flow velocities of water causing considerable damage (Hong et al. 2012 cited in Karagiorgos et al. 2016). The flood occurrences in Malawi have caused physical damage to assets such as buildings, infrastructure, industrial plants, standing crops, grain stores, livestock, and social infrastructure, as well as the loss of human life and injury (Akol et al. 2015). Floods have also led to indirect damages like the disruption of livelihoods and transportation (communication) in the affected areas and causing sickness and diseases like cholera and malaria. DoDMA (2015) estimated flood damage at MK 124.5 billion (US$ 286.3 million) while losses amounted to MK21 billion (US$48.4 million) with the housing sector suffering the highest damage calculated at MK59.3 million. Hammond et al. (2014) assert that flooding can cause major disruptions in cities and lead to significant impacts on people, the economy, and the environment. For example, the flood events of 2015 in Malawi affected over one million people, displacing 336,000 and killing 104 people (Kita 2017). The 2015 flood events also resulted in damage and losses estimated at US$ 335 million, which is estimated to be equivalent to around 0.5% of GDP (World

Bank 2016 cited in Gama 2017). Malawi was also hit by flood events in 2019, 2022 and 2023 (DoDMA 2019; DoDMA 2022; DoDMA 2023). The country witnessed the most devastating flood events in 2023 induced by Tropical Cyclone Freddy. Tropical Cyclone Freddy caused heavy rains accompanied by strong winds, flash flooding, mudslides and landslides over the southern region of Malawi (DoDMA 2023). Tropical Cyclone Freddy induced flood events and landslides had devastating effects on households causing 679 deaths, 537 people missing, 2178 people injured, and 882,989 people had their houses damaged. The floods also destroyed crops, livestock and lifeline infrastructure (ibid.). River flooding has become a common occurrence in Lilongwe City in recent years. Lilongwe City Council reported that the City has been experiencing river flooding in the years 2012, 2015, 2017, 2018, 2019 and 2020. Some of the major contributors to flooding are human activities such as unregulated urban growth and unplanned settlements on river reserve areas, disregard for waste management, and poor maintenance of drainage (Salami et al 2017). The construction of buildings in river reserves and the dumping of solid waste are a common sight in most of the rivers in urban areas and these exacerbate flooding since the river flow channel becomes narrow, thereby reducing its discharge capacity and hence, increasing flood during heavy and prolonged rains (Oluwasegun 2017).

Some of the areas that experience recurring river flooding in Lilongwe City are Biwi, Kawale, Mchesi, Chipasula, Area 22, Kaliyeka, Ngomani, Mgona, Mtandire, Area 49, 18 and 47 (Medecins Sans Frontiers 2017). Davies (2017) reports that the Mchesi River flooded on 16 December 2017 and caused six (6) deaths, two (2) injuries, displacement of 1000 people (200 households) and damages to residential buildings and their contents in low-income settlements of Kaliyeka, Chipasula, Area 22, Biwi, Kawale and Mchesi. According to the Regional Office for Southern Africa (ROSA) (2012) and Lilongwe City Assembly ((LCA) 2012), low-income settlements of Biwi, Kawale and Mchesi in Lilongwe City experienced floods caused by the Mchesi River on 17 February 2012. It was reported that Kawale1 had one (1) loss of life, seven (7) buildings collapsed rendering 28 people homeless, and loss and damage of household property. In addition, there was a disruption in social-economic activities (schools, churches and clinics) and loss of the source of livelihood to house owners due to the collapse and damage to buildings (some developed large cracks posing danger to their inhabitants), outside property like pit latrines and bathrooms were also destroyed. Biwi reported that four (4) houses collapsed which left eleven (11) people injured and homeless. In addition, two (2) hawkers and their contents were destroyed, food items were destroyed, shallow water wells and building surroundings were contaminated with mud and solid waste, and loss of livelihood by house owners due to the collapse of buildings (that were rented out) and disruption on socio-economic activities; for example, small businesses and school activities were suspended.

1.3. Problem Statement

The households in the low-income settlements of Biwi and Kawale1 have been experiencing recurring river flooding in recent years, causing loss of lives, damage to lifeline infrastructure (roads and bridges) and buildings, and disruption of social-economic activities. For instance, the most devastating flood event of 16 December 2017 caused 4 deaths, the collapse of 29 houses, and the displacement of 300 households (Lilongwe City Council 2017). Although there are reports on damages and collapse of buildings caused by flooding of the Mchisi River, the physical vulnerability of buildings has not been assessed in the study area to assist in developing flood risk reduction measures (Müller et al 2011). Additionally, the studies on flood vulnerability in Malawi have focused on social-economic and human vulnerability, therefore, this study aimed to contribute to filling the knowledge gap on the physical vulnerability of buildings to flooding in low-income settlements of Biwi and Kawale 1.

1.4. Study Objectives

1.4.1 Main objective

The main objective of this study was to assess the physical vulnerability of buildings to flooding in the low-income settlements of Biwi and Kawale 1 in Lilongwe City.

1.4.2. Specific Objectives

The specific objectives are:

i. to characterise key elements at risk of floods for physical vulnerability assessment.
ii. to analyse the exposure of buildings to flood hazards
iii. to assess the physical vulnerability of buildings to flood hazards
iv. to assess the effectiveness of flood protection measures applied to the buildings

1.4.3 Research Questions

To achieve the specific objectives, the following research questions corresponding with specific objectives were responded to:

i. What are the key elements at risk of flooding for physical vulnerability assessment in low-income settlements of Kawale1 and Biwi in Lilongwe City?
ii. What proportion of buildings is exposed to flood hazards?
iii. How vulnerable are different types of buildings to flood events?
iv. How effective are building protective measures in reducing the physical vulnerability of buildings?

1.5. Justification of the study

This study is in line with both policy frameworks and development agendas.

On national agenda and policy frameworks, the study resonates with the Malawi 2063 Vision Pillar 4 and Enabler 7, which aspires for a safe, secure, and sustainable environment by among others reducing the impacts of natural disasters and climate diversities. The study is also aligned with Malawi Growth Development Strategies III (MGDS III) Development Area 7.2, which promotes the reduction of vulnerability and enhanced resilience of the population to disasters and socio-economic shocks (GoM 2017). Further, the study is in line with the Malawi National Disaster Risk Management Policy, policy statement 2 of Priority Area 5 (Reduction of underlying risks) which aims at improving building safety and the protection of critical lifeline infrastructures as part of the reduction of risk factors (GoM 2015). On the international scene, the study is in line with the United Nations (UN) 2030 Agenda on Sustainable Development Goals (SDGs) Goal 11 which encourages governments to make cities and human settlements inclusive, safe, resilient, and sustainable (UN 2015).

1.6 Thesis Structure

Chapter 1 is the introduction, which gives the background of the study, problem statement, objectives of the study, justification of the study, ethical considerations, and structure of the thesis.

Chapter 2 presents a review of relevant literature. It also provides theoretical and conceptual frameworks. The theoretical framework contains two framings of vulnerability: Social and Physical vulnerability. The conceptual framework contains a definition of key terminologies relevant to the study. The Chapter further presents the different methods used in the physical vulnerability of buildings assessments.

Chapter 3 describes the study area, research design, sampling frameworks and techniques and presents the methodology of data collection, processing and analysis.

Chapter 4 presents the results of the study focusing on the demographic information of the participants, key elements at risk (buildings), exposure of buildings to flooding, information on building protection measures, and physical vulnerability of buildings.

Chapter 5 provides a discussion of the results of the study.

Chapter 6 provides the conclusion, and recommendations for further action and future study. Figure 1 shows the structure of the thesis.

1.7 Conclusion

This introductory Chapter presented the study background, problem statement, study objectives, research questions, justification of the study, and outlined the structure of the thesis. The next Chapter presents the relevant literature review for the study.

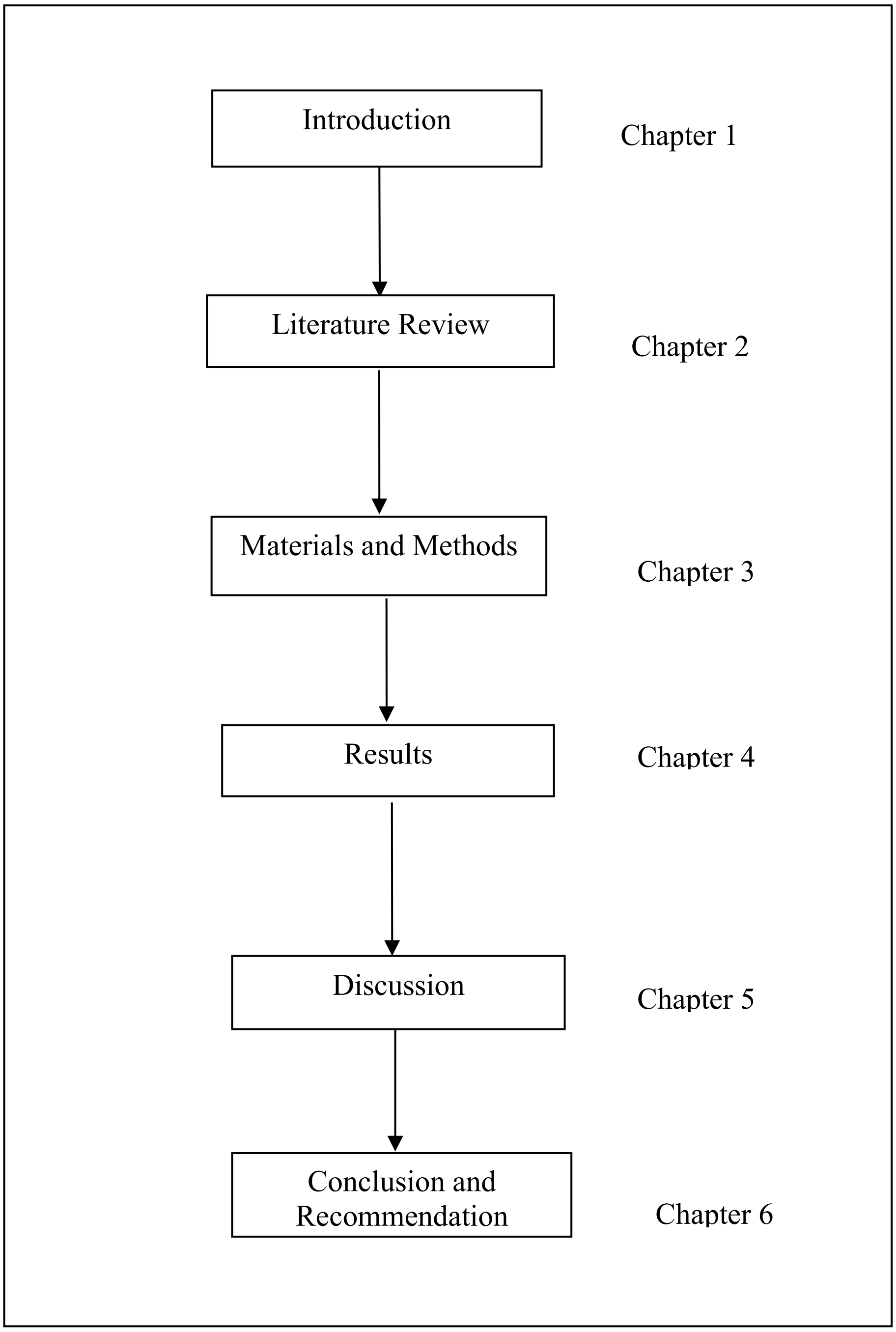

Figure 1: Structure of the Thesis

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents the theoretical and conceptual frameworks for the study and discusses the relevant literature on physical vulnerability assessment studies and methods for the assessment of physical vulnerability.

2.2 Theoretical Framework

This thesis was informed by vulnerability framing from natural hazard science, which follows the hazard, and impact approach that has been discussed in Brooks (2003). The hazard and impact approach views vulnerability in terms of the extent of loss or damage that the human system suffers because of the system's susceptibility and exposure to a hazard event (Brooks 2003). In other words, vulnerability is determined by the nature of the hazard (such as intensity, frequency, and duration), exposure (for example, proximity to the river, surroundings, or terrain characteristics), and susceptibility or sensitivity (like building materials, age of the building, foundation height) (Linkao & Quin 2011). Brooks (2003) observed that the approach of determining vulnerability in terms of hazard impact or damage resulting from exposure and susceptibility or sensitivity of the system to the hazardous event is in line with the definition of vulnerability in the IPCC Third Assessment Report (TAR) (IPCC 2001a). Brooks (2003) termed the hazard and impact approach "physical vulnerability," since it reflects and highlights physical impacts on the exposed and susceptible system

Brooks (2003) and several authors like O'Brien, et al. (2011), Brooks et al. (2004), Kelly & Adger (2000), and Füssel (2006) agree that vulnerability is rooted in two different discourses and two different underlying interpretations. The two vulnerability framings have been given different terms by different authors though they refer to the same vulnerability lineage. For example, Füssel (2006) frames vulnerability as "external" and "internal," O'Brien et al. (2007) perceive vulnerability as "Outcome" and "Contextual," Linkao & Qin (2011) interpreted vulnerability as (Urban) impact and (urban) inherent vulnerability and Brooks (2003) identifies two approaches of vulnerability traditions and termed them physical and social vulnerability. Though the above-cited authors give different terms for the two categories of vulnerability interpretations, the characteristics of the factors discussed for the two lineages by the cited authors are the same, what differentiates them is the language they have used (Müller, Reiter, & Weiland 2011). For instance, "external", "outcome" and "impact" vulnerability (Füssel 2006; O'Brien et al. 2011; Linkao & Qin 2011) mean "physical vulnerability" (Brooks 2003).

2.2.1 Social context of vulnerability

Social vulnerability is perceived as an inherent property of a system arising from its internal characteristics (Kelly & Adger 2000). The internal characteristics exist before the system encounters a hazardous event (Brooks 2003) and they determine the level of vulnerability (Kelly & Adger 2000). Some factors that determine the vulnerability of individuals or communities are hazard-specific (such as closeness to flooded areas) (Cardona et al. 2012) while others are generic factors that determine vulnerability to different ranges of hazards, for, example, poverty, inequality, health, access to resources, ethnicity or social class, lack of social networks and social support mechanisms among others (ibid). Similarly, Kelly & Adger (2000) framed social vulnerability following the "entitlements theory" which was developed by Sen (1983). The entitlement theory focuses on the inequality in the communities in terms of resource allocation, social class, and ethnicity among others, which affect the communities' coping capacity to hazard impacts. Kelly & Adger (2000) argue that poverty is directly related to access to resources and the marginalisation of communities. The marginalised community may be poor due to the lack of diversification of income sources, which can affect their choices in implementing coping strategies hence increasing their vulnerability (Kelly & Adger 2000).

Other researchers suggest that some characteristics of built and social environment influence the vulnerability of communities and that it is advisable to identify the built and social environment characteristics from the historical data of hazard impacts of elements at risk (Linkao & Quin 2011; Papathoma-Kȍhle et al. 2007). The studies that follow this route assess both the physical and social vulnerability of communities.

2.2.2 Physical context of vulnerability

Physical vulnerability originated from the hazard and impact approach from climate change-related studies (Brooks 2003). In this approach, physical vulnerability is perceived as a function of hazard, exposure, and sensitivity (ibid). According to Van Westen (2014, pp. 5-4), "physical vulnerability means the potential for physical impacts on the physical environment (which can be expressed as elements-at-risk), resulting from the occurrence of a natural phenomenon of a given magnitude and is "expressed on a scale from 0 (no damage) to 1 (total damage)". Papathoma-Kȍhle et al. (2012) observed that in most studies concerning physical vulnerability, vulnerability is perceived as "the degree of loss to a given element, or set of elements within the area affected by the hazard." In this perception, the emphasis is on the role of hazard and their physical impact (Ciurean et al. 2013, p.14) on the exposed susceptible systems.

Physical vulnerability is determined by exposure to hazards, the sensitivity of infrastructures, populations, or activities, and the resulting or potential impacts (Lankao & Quin 2011). More so, physical vulnerability is a functional relationship between process magnitude, the impacts on the structural element at risk, and exposed values (Füchs 2009; Guillard-Gonçalves 2016). For example, the physical vulnerability of the built environment is related to the fragility of physical structures and is defined as the expected degree of loss or damage resulting from the impact of a certain hazard event on the elements at risk (Guillard-Gonçalves 2016). The impact on physical structures can only happen to structures that are present at the location where hazard events (such as floods) can occur (Huq & Hossain 2015). Messner & Meyer (2005, p.150) note that "an element at risk of being harmed is the more vulnerable, the more it is exposed to a hazard and the more it is susceptible to its forces and impacts". They further suggest that any (flood) vulnerability analysis needs information concerning factors that are specified as elements of at-risk indicators, exposure indicators, and susceptibility indicators.

Given the foregoing, the current study focused on the physical vulnerability of buildings to floods; therefore, it adopted the hazard and impact approach (Brooks 2003). The researcher agrees with the view that the damage or loss of buildings is a result of the interaction of hazards and buildings that are susceptible and exposed to hazardous events. For this reason, the physical vulnerability of buildings can be determined by relating the magnitude of hazard impacts with exposure, and susceptibility of buildings (Füchs 2009).

2.3 Conceptual framework

This section presents the definition of key terms used in the conceptual framework shown in Figure 2. The conceptual framework shown in Figure 2 illustrates the hazard and impact approach of vulnerability discussed in Brooks (2003). Figure 2 shows the physical vulnerability lineage, where vulnerability is determined by the physical impacts caused by the hazards on the exposed human systems (Brooks 2003). The factors that determine physical vulnerability are *hazard* (characteristics), *exposure* (location of human system and its environment characteristics) and *susceptibility* (characteristics of the human system that make them weak to resist the hostile environment). The existence of coping capacity may reduce the physical impacts, hence reducing physical vulnerability. Figure 2 shows the three variables (susceptibility, exposure to hazard and coping measures/strategies) that influence the physical vulnerability of a human system. Figure 3 illustrates the interactions of flood hazard, exposure, and vulnerability which produce floods physical impacts (physical vulnerability).

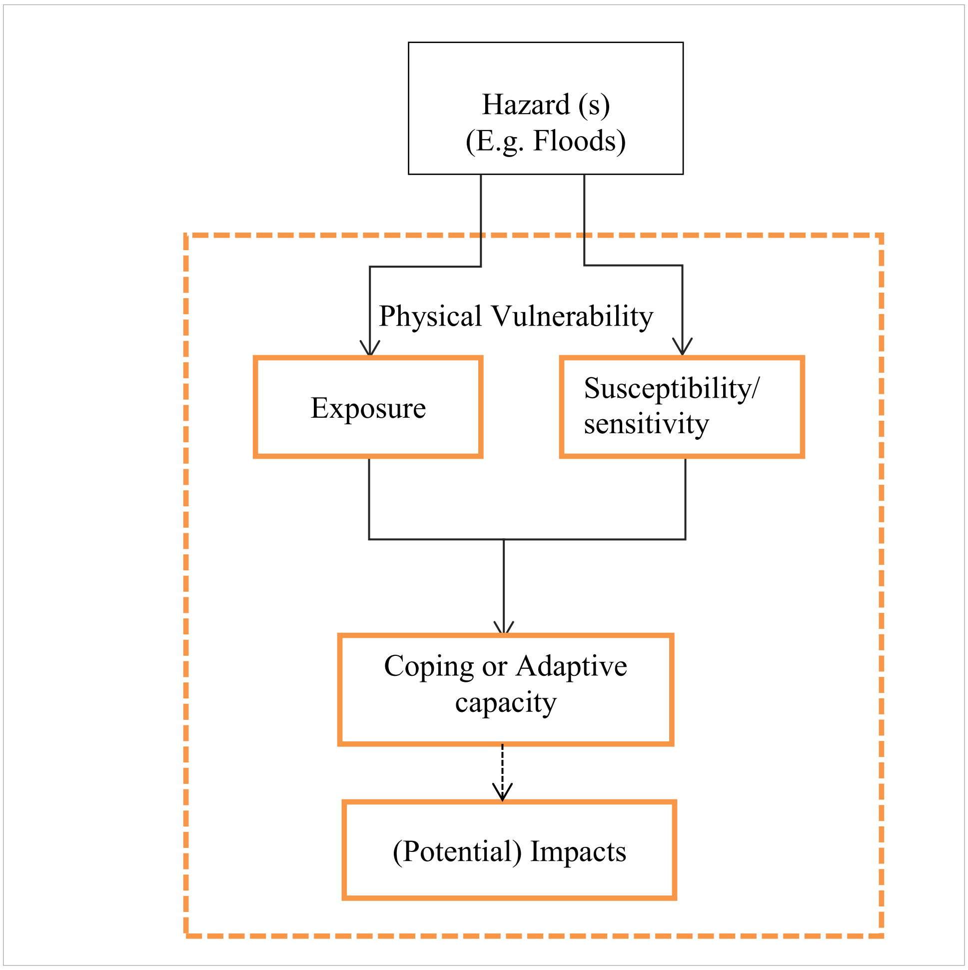

Figure 2: Conceptual Framework for Physical Vulnerability

Source: Modified from Lankao & Qin, 2011; Turner et al. (2003)

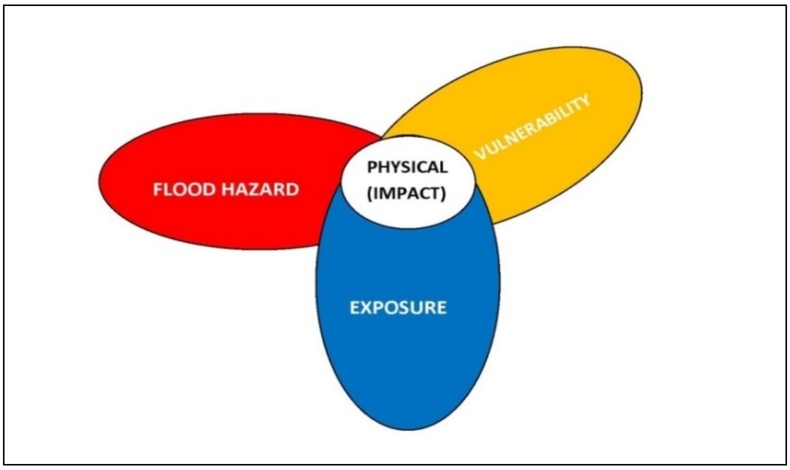

Figure 3: Hazard and Impact Physical Vulnerability Tradition

Source: Modified UN Spider (Disaster Risk Management)

2.3.1 Definitions of Key Terms

Definitions of key terminologies related to hazard and impact vulnerability are defined as follows:

"*Exposure* is when people, property, systems or other elements are present in hazard zones that are thereby subject to potential losses" (UNISDR 2009, p.21). Balica (2007) describes exposure as "the values that are present in the areas potentially threatened by hazard (such as floods)." In these definitions, exposure has a spatial connotation, it means to be found in a hazardous area or place where there is a danger of suffering damage or loss. The Glossary of Environment Statistics (United Nations 1996, p.32) defines exposure as "a condition of being unprotected in an environment containing harm-producing substances or factors, it is measured in terms of level and duration." In this definition, exposure means the condition of being powerlessness and unprotectedness of elements at risk such as communities, buildings, lifeline infrastructures, and crop fields among others that are located in hazardous areas (ibid.). The meaning of exposure in the definition has double facets, suggesting that both the condition or susceptibility of elements at risk (as unprotected) and the condition of the environment (containing harm-producing substances or factors) are exposure factors.

A *hazard* is defined as a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation (UNISDR 2004 cited in UNISDR 2015). According to IPCC Technical Summary (TS, p. 39) (Field et al. 2014), a hazard is defined as "the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources" (Field et al. 2014, p. 39). Hazards are classified based on their causative origins, such as natural, anthropogenic, or socio-natural in origin (UNISDR 2017).

Susceptibility is the extent to which the system or an element of a system will suffer loss due to a perturbation or stress (UNISDR 2009). Susceptibility is also defined as the degree to which a system is adversely or beneficially affected by climate-related stimuli (Van der Geest & Schindler 2017). Susceptibility is understood, in the case of buildings, as their propensity to experience harm and is determined by their structural design, intrinsic properties, and the material used (Samuels et al. 2009; Naumann et al. 2010 cited in Blanco-Vogt & Schanze 2013). Susceptibility is often calculated by the damage ratio varying between no damage (0%) and destruction (100%) (Popat 2017).

Impact represents the overall effects of a hazardous event, including negative and possibly positive ones (UNISDR 2015). Negative impacts are those that cause losses, for example, loss of business due to the disruption of economic activities after the displacement of households resulting from the flood event. Positive effects of impacts are outcomes that result in economic gains, for example, an increase in sales of building materials during the reconstruction period after a flood event. Impacts refer to effects on lives, livelihoods, health, ecosystems, economies, societies, services, and infrastructure due to interaction with hazardous events (Field et al. 2014).

Coping capacity is the ability of people, organisations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters (UNISDR 2009). Coping strategies are actions undertaken during a hazardous event to counter the impacts of sudden or unusual events. In other words, it is the ability to deal with the situation at hand, which depends on the strength attribute, and resources.

2.3.2 The concept of vulnerability

Vulnerability is a broad concept with several meanings depending on the perspective of various disciplines (Uwakwe 2015). Haq & Hossain (2015) argue that vulnerability varies according to the field, purpose, and interest. Some disciplines define vulnerability as a pre-existing condition of a system, suggesting that the condition exists before the occurrence of a hazardous event as in Adger (2000), while others define vulnerability as a condition that manifests due to susceptibility and exposure of the system that has encountered a hazardous event. For example, Turner II et al. (2003, p.8074) define vulnerability as "the degree to which a system, or subsystem or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stressor." Ciurean et al. (2013) define vulnerability as the potential for loss to the elements at risk caused by the occurrence of a hazard and depends on multiple aspects arising from physical, social, economic, and environmental factors. The Intergovernmental Panel on Climate Change defines vulnerability as the degree to which a system is susceptible to and is unable to cope with the adverse effects (of climate change) (McCarthy et al., 2001a cited in Adger, 2006). In this definition, vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2001, p.995 in Hug & Hossain 2015). The vulnerability can be considered as a function of risk, danger levels, level of exposure, or adaptive responses available (Winograd 2016). The diverse definitions of vulnerability confirm that vulnerability has different facets.

"Vulnerability is also understood to be "multi-dimensional and differential, scale-dependent, and dynamic" (Huq & Hossain 2015, p.55). Vulnerability is said to be multi-dimensional since it varies within the same area, among, and within social groups. Papathoma-Köhle et al. (2007, p.767) assert that "not everything and everyone located within the risk zone is equally vulnerable." Vulnerability also varies in terms of the scale of the analysis whether in temporal or spatial scales or both. For example, some vulnerability studies focus on future (prediction) vulnerability, which is assessed at a regional or national spatial scale, while other vulnerability analyses concentrate on the current households, communities, or subnational scales of vulnerabilities after the occurrence of a hazard event. Vulnerability analysis for future (predictions) at a regional or national scale uses generalised indicators (such as national population census data) or variables that result in a lot of uncertainties and generalised outcomes, as opposed to results of vulnerability analysis at the household or community level, are more detailed and accurate. Furthermore, vulnerability is regarded to be dynamic since the characteristics and driving forces of vulnerability change over time (Müller, Reiter, & Weiland 2011). The different definitions of vulnerability are a manifestation of the different pathways of how the vulnerability is assessed using different vulnerability factors (Papathoma-Köhle et al. 2011). For instance, natural hazard scientists and engineers look at vulnerability as the potential for loss of the elements at risk caused by the occurrence of a hazard (Ciurean et al. 2013) and focus on the reaction of individual buildings to the impact of a natural process (Papathoma-Köhle et al. 2011). Whereas social scientists perceive vulnerability in terms of a lack of coping capacity due to poverty or differences in resource allocation (entitlements).

The current study adopts the definition by Turner II et al. (2003, p. 8074) where vulnerability is perceived as "the degree to which a system, or subsystem or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stressor." This definition is similar to the vulnerability definition of Ciurean et al. (2013). The current study has focused on the physical vulnerability of buildings and their contents.

Physical vulnerability means the potential of physical impact on elements–at-risk (EaR) or the degree of loss to a given element at risk or set of EaR resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage) (Van Westen & Kingma, 2009). Sagala (2006) defines physical vulnerability as how EaR or built environment is adversely affected by the occurrence of natural hazards. The physical vulnerability of property addresses the effects of interaction between the damaging agent and the physical environment, (Winograd 2016) or it indicates the physical impact because of directly encountering a hazard (Zhang 2013). Physical vulnerability relates to factors of exposure and susceptibility to the built environment in terms of material and design, the remoteness of the place, closeness to the hazardous area, and the magnitude of the damaging phenomena (Adeloye et al. 2015).

2.4 Review of Studies on Physical Vulnerability

This section presents literature on the physical vulnerability studies in Malawi, flood physical vulnerability studies from other countries, the application of GIS in flood vulnerability studies, types of approaches to physical vulnerability assessment, coping strategies, and protection measures for buildings.

2.4.1 Physical Vulnerability Studies in Malawi

Studies on the assessment of physical vulnerability to natural hazards have been conducted more in developed countries and rarely done in developing countries (Sagala 2006) like Malawi. There are limited studies in the literature on the assessment of the physical vulnerability of buildings to natural hazards (such as flooding) in Malawi.

Goda et al. (2016) conducted a risk assessment of urban and rural settlements around Lake Malawi (in Karonga, Mzuzu, Mangochi, Zomba, and Lilongwe). The study aimed to assess the seismic risk of Malawian communities quantitatively and identify data and models for exposure, hazard, and vulnerability modules that are suitable for Malawi. Buildings were classified based on the World Housing Encyclopaedia (2002) where building classes similar to buildings in Malawi were retrieved and assigned their vulnerability classes and the percentage of buildings in each vulnerability class was calculated. Hazard, Exposure, and vulnerability indicators were used in the models for risk and seismic vulnerability analysis. Vulnerability indicators consisted of building materials and their ratings on seismic vulnerability by the World Housing Encyclopaedia (WHE), and the percentages of buildings in each vulnerability class. Global vulnerability functions were used to assess the seismic vulnerability of buildings based on expert judgement (since damage data was not available). Three models were used to predict the collapse of buildings due to different magnitudes of earthquakes (ground shaking and motion). The 2009 Karonga seismic damage data was used to validate the findings. However, the results from building collapse curves for three types of buildings were not reported since the results were identical and it was attributed to the 15% of buildings that had unclassified vulnerability class. The findings on the prediction of earthquake impact on the population showed that Lilongwe had a greater earthquake impact on the population than other sites. The results of the seismic risk assessment showed that the hazard level was influenced by proximity to fault systems and rapture characteristics.

Ngoma et al. (2019) conducted a study whose main aim was to investigate the characteristics of current building stocks in Malawi and to develop a building classification scheme that is consistent with the structural engineering perspective and define their seismic vulnerability. The data for buildings were collected from urban and rural areas in Central and Southern Malawi. The buildings were classified based on the PAGER system as mud walls with horizontal wood elements and mud walls without horizontal wood (M1 and M2 respectively); Adobe blocks were subdivided into adobe blocks, mud mortar, wood roof, and floors (A1), and adobe block, mud mortar, straw and thatched roof (A2); unreinforced fired brick masonry was subdivided into unreinforced fire brick masonry with mud mortar (UFB1) and unreinforced fire brick masonry with cement mortar (UFB4). The proportion (percentages) of the number of buildings per class was calculated, and the building classes were assigned seismic vulnerability rates. The seismic fragility curves for collapsed buildings were modelled and predicted using Modified Mercalli intensity (MMI). The results from seismic fragility curves showed that mud walls without horizontal wood (M2), adobe block, mud mortar, wood roof and floors (A1), adobe block, mud mortar, straw, and thatched roof (A2), and unreinforced fired brick masonry with mud mortar (UFB1) are more vulnerable to seismic hazards. The unreinforced fired brick masonry with cement mortar

(UFB4) has the lowest vulnerability. The results of the fragility of buildings were not validated with the real damage data due to a lack of empirical data.

Banda (2015) carried out research whose aim was to investigate the role of contextual factors in flood impact vulnerability in the context of climate change. Flood impact on residential buildings and their contents were assessed in South Lunzu and Ndirande using physical exposure measures that were categorised as impact and resistance parameters. Impact parameters also known as exposure factors used were: inundation depth, inundation duration, and proximity of buildings to the river while resistance parameters were the characteristics of elements at risk of flood. Damages to walls, external toilets, protective trees, and windows were used as building resistance parameters for specific house structure damage. Damage to the window was used as a pointer to the extent of damage caused to the building. The extent of damage to the house structure was rated and coded from 0-3 (where 0 denoted no damage, 1 represented slight damage, 2 represented more damage and 3 represented severe damage (destroyed)). Floodwater coverage was used as an indicator of the extent of damage to both the buildings and contents. The damage to assets was also rated depending on water coverage on the floor and the resulting extent of the damage. Where there was no water coverage, it meant no asset was damaged. The overall impact was achieved by listing building damage and content classes in a matrix and then comparing the ratings and combining the rates. The role of exposure and contextual factors on household impacts were assessed using statistical methods (the Chi-square association test). The results showed that two exposure measures (inundation duration and proximity to the river) did not influence overall household impact. Inundation depth had an insignificant influence on the overall flood impacts. However, the study found that there was a significant relationship between the number of stressors per household and the household impact.

The above studies assessed building vulnerability either directly as in Ngoma et al. (2019) or indirectly as in Banda (2015) where flood impact on buildings was assessed. In the study of Goda et al. (2016), the focus was on the risk assessment of the population to seismic hazards; however, the risk of the population cannot be assessed without looking at the hazard and vulnerability of buildings. The Goda et al. (2016) study was conducted at a large spatial scale and the buildings were classified using a global database that contributed to variations in the building fragility to seismic hazards. Moreover, there were uncertainties in the models, hence the accuracy of the predictions was compromised. Ngoma et al.'s (2019) study was also done at the subnational spatial level; however, the typology of the buildings was localised, therefore, making the modelled earthquake fragility functions for the buildings closer to reality although there was still some uncertainty due to the model errors. Furthermore, there was no historic damage data for buildings to validate the results of the predictions from the models.

It has been noted in the literature that vulnerability is dependent on a hazard, spatial and temporal scale, and site-specific (Papathoma-Köhle et al. 2012). For instance, the findings of the fragility of buildings to the seismic hazard cannot be applied to buildings' sensitivity to flood hazards, since buildings respond differently to different hazards. The other point to note is that models have the disadvantage of predictions that have many uncertainties resulting in compromised accuracy.

The current study assessed the physical vulnerability of buildings to flood hazards and the damage data was collected at the household level, which fills the knowledge gap.

2.4.2 Physical vulnerability assessment studies from other countries

Uwakwe (2015) conducted a flood physical vulnerability assessment of four building types using the empirical approach at Castries old Central Business District and Dennery Village in Saint Lucia. Buildings were classified based on building materials for walls, floors, and roofs. The depth-damage vulnerability curves and indicator-based methods were used to relate damage to four types of buildings with different levels of floodwater. The study found that the structures made of wood walls, wood floors, and galvanized iron sheet roofs were the most vulnerable while the structure types made of concrete walls, ceramic tiles floors, and roofs were the least vulnerable to flood hazards.

Sagala (2006) assessed the physical vulnerability of six types of buildings, building contents, and outside property to flood hazards. The buildings were classified based on walls and roof materials. The physical vulnerability of buildings and assets to the flood was assessed by depth-damage curves. The study found that the structure types made of plywood walls and wooden floors were more vulnerable, while buildings made of hollow blocks and concrete floors were least vulnerable. The vulnerability of building contents was determined by the number of floors of the buildings, and damage to outside properties was not found as the property was shifted to safe areas.

Fatemi et al. (2020) conducted a study on the physical vulnerability to flooding in the peri-urban areas of Dhaka, Bangladesh. The study examined the physical vulnerability of residential buildings, flood damages, and local physical response to floods. The variables that were used were building materials, the position of the buildings with the street plinth height, the age of the buildings, and the availability of building protection measures. The buildings' typology was classified based on the roof, walls, and floor materials. The physical vulnerability was measured using flood damage as the variable. SPSS Cramer's V correlation test was used to determine the degree of influence of each variable on flood damage. The results showed that buildings constructed from durable materials experienced low damage while those constructed with temporary and natural materials suffered high damage. On the age of the buildings, it was revealed that the buildings that were five years or less, experienced a low damage rate while those with more than 20 years had the highest damage rate. The relationship between the heights of the building to the plinth level showed that buildings with high heights to the plinth level had low flood damage and those with low heights suffered great damage.

Blanco-Vogt & Schanze (2013) conducted a study where the physical susceptibility of buildings to flood impacts was assessed on a large scale and a methodological framework was developed. The methodological framework comprises three modules: a method for setting building taxonomy for settlements; a method for assessing the physical susceptibility of the building; and, a method for technological integration of the two modules. Buildings were digitized from very high-resolution (VHR) satellite images, aerial photos, and digital surface model data and later were verified in the field to improve the accuracy of the interpretation of buildings that suffered occlusion by trees and the presence of corrosion in the roof materials. The building characteristics were identified during the field verification exercise where the buildings were visually compared with the pictures (of buildings). Each characteristic of building materials was given a code as an identifier and assigned a class. Expert judgement was used to assign susceptibility ratios (values) to building classes based on their construction materials and resistance to flood damage. Synthetic depth-damage functions were generated for each type of building to relate floodwater depth and the corresponding damage caused to the structure.

Papathoma-Köhle et al. (2007) conducted a physical vulnerability assessment of elements at risk of landslide using the vulnerability indicators method with the "elements at risk database" framework for Lichtenstein, Germany. Data for buildings were extracted from remote sensing images and characteristics that influence their vulnerability to landslides like the number of floors, the existence of large windows, material, and the age of the buildings were codified, assigned standardized weights, and populated in GIS. All the weighted codes were summed up to produce an individual building's vulnerability index and a vulnerability map was produced. The vulnerability level of six types of buildings and their contents were correlated with floodwater depth inside the buildings using depth-damage vulnerability curves. The Multi-Criteria Evaluation Method was used for vulnerability assessment.

From the studies above, flood physical vulnerability of buildings was conducted by relating damage magnitude and floodwater depth or level inside the buildings. The building structure characteristics, which were used to typify them, were slightly different due reason that people from different places use different construction materials and designs.

2.4.3 Application of GIS in flood vulnerability studies

A GIS facilitates the input, storage, management, analysis, integration, and output of spatial data that can aid with real-time decision-making and strategic planning for effective risk management and hazard preparedness (Oluwasegun 2017). However, there is limited literature on GIS-based physical vulnerability to flooding assessment studies, most studies use GIS for creating "elements at risk database" (Papathoma-Köhle et al. 2007), spatial data collection using mobile GIS gadgets (Sagala 2006), producing vulnerability maps (Papathoma-Köhle et al. 2007) and spatial data analysis (Hoque et al. 2011; Kaur et al. 2018; Rimba et al. 2016; Mohammad & Schanze 2019; Udo & Eyoh 2017; Ghajari et al. 2017 among others). Some studies used spatial statistics regression analysis to relate the dependent and explanatory variables in flood vulnerability assessment (Ebert & Kerle 2008; Jeong & Yoon 2018).

The discussion below focuses on the flood vulnerability studies that used GIS extensively in their analysis.

Hoque et al. (2011) assessed spatial flood vulnerability at Kalapara Upazila in Bangladesh. The study used 16 relevant characteristics under three vulnerability components: physical vulnerability, social vulnerability, and coping capacity. The physical and social vulnerability and coping capacity characteristics were converted into spatial layers, weighted, and standardised to support the analytic hierarchy process in ArcGIS software. Individual vulnerability map components of physical and social vulnerability and coping capacity were converted to raster format and were weighted (based on expert judgement) using the raster overlay technique. The physical and social vulnerability maps were merged by multiplication (physical x social vulnerability values) and the product was subtracted by coping capacity map values by the use of the arithmetic operator in the raster overlay tool in GIS, the outcome map from the raster overlay operations was the final overall vulnerability map of the area. The map was classified using the Natural Breaks statistical classification method in ArcGIS software and the different levels of vulnerability in the area were identified from the produced maps.

Akukwe & Ogbodo (2015) conducted a study on vulnerability to flooding using spatial analysis in Port Harcourt Metropolis, Nigeria. Exposure, sensitivity, and adaptive capacity indicators were used to assess vulnerability. Vulnerability indicators were calculated according to the equation provided by Deressa et al. (2008) and weighted using Madu's (2011) equations. Principal Component Analysis (PCA) was performed to produce the scores for indicators that were used as weights during the calculation of indices for zones. Cluster analysis was conducted to differentiate the levels of vulnerability in the zones and to group zones of similar vulnerability levels. A map was produced to show the spatial distribution of flood vulnerability in the study area. Levels of vulnerability to flooding were compared across the 13 zones of the study area.

Vaghani (2005) used GIS in a flood impact analysis study for the demarcation of flood-prone areas and conducted a flood impact analysis on land use, roads, soil, river, and vegetation of Lake Roxen and Lake Glan in Sweden. The output map products showed flood impacts on the environment and primary risk areas.

Oluwasegun (2017) conducted a GIS-based analysis of flood-vulnerable areas in the Benin - Owena River Basin, in Nigeria. The study aimed to explore the potentials of GIS in data capture, processing, and analysis in identifying flood-prone areas with high-risk levels and the vulnerability of residents to plan disaster mitigation and preparedness. Spatial data for rivers were used to generate buffer zones for flood-risk areas. GIS overlay analysis was used to determine the level of risk of settlements to flooding by intersecting the settlements layer and flood risk areas (river buffer areas) layer. The study identified settlements that were at high risk of flooding, which needed to be prioritised in the application of mitigation measures.

Sarma (2013) assessed flood risk and riverbank erosion in the rural society of Majuli in India using field surveys and remote sensing methods. Remote Sensing and GIS were used to map flood inundation and identify areas facing river flooding and riverbank erosion by intersecting the 5km by 5km grid data of erosion with flood inundation maps. The study revealed that most of the areas in the central and south-western parts of Majuli were flooded in 2004 and GIS analysis validated that six villages were continuously facing severe river-bank erosion.

Sagala (2006) used Mobile GIS devices to collect building characteristics, building damage, flood water depth (inside buildings), and the interviewees' location data in GIS Shapefile format. GIS was used to interpolate flood depth data using a Triangulated Irregular Network (TIN), which was used to generate flood depth-damage vulnerability functions for each of the elements at risk using regression analysis.

Müller, Reiter, & Weiland (2011) empirically investigated urban flood vulnerability at household and municipality spatial levels in Santiago de Chile. The location of buildings to the street level and distance to the waterway, construction materials of buildings and availability of private protection measures were used as parameters. GIS data, census data, and the classification results of the remote sensing image data were used to derive information for indicators. Expert judgement scores were used for weighing indicators. GIS was used to assign weights to indicators through a tool that was created in Model Builder. A GIS flood vulnerability map was generated from the indicators.

Jeong & Yoon (2018) conducted a study in South Korea, whose aim was to examine the relationship between vulnerability factors related to social, economic, and environmental aspects of the community and the economic losses from the disaster. Ordinary Least Square (OLS) regression was used to model the relationships and the results showed that disaster damage was more severe in communities where annual precipitation was high and natural disasters happened frequently. The OLS regression model results showed that open space had a negative correlation with disasters, in other words, it contributed significantly to reducing disaster damage, and the community living in buildings older than 60 years had a positive relationship with disaster damage but had a statistically insignificant influence on disaster damage. The housing density had a statistically significant influence on disaster damage though had a negative relationship with disaster damage.

Ebert & Kerle (2008) conducted a social vulnerability study based on building characteristics at the household level in Tegucigalpa, Honduras. Remote sensing and

GIS data were used to delineate proxy variables that were used to analyse social vulnerability indicators. 47 proxy variables (explanatory variables) and social vulnerability variables (gender, literacy, wall and roof materials of buildings water availability, etc.) were used as dependent variables of a stepwise regression model. The results showed that a high proportion of built-up areas and buildings on medium slopes had a high social vulnerability, a high amount of infrastructure had high social vulnerability though of low significance and there was an insignificant relationship between the number of buildings at risk of floods and distance to lifelines.

In the above-cited studies, GIS was used to delineate flood hazard zones (risk areas) and flood impact analysis (Vaghani 2005), examine flood vulnerability of settlements and people (Oluwasegun 2017), determine flood characteristics, like flood depths and terrain characteristics such as rate of change of coastal shores, slopes (topography) and vulnerability of the population (Jana & Hedge 2016). Two of these studies used GIS regression models to relate the dependent and the explanatory variables. These studies were conducted on different spatial scales, some at the macro (regional) or meso (national) scale, and the results are mostly generalized, as they do not pinpoint the physical vulnerability of individual buildings. Except for Sagala (2006), who conducted the physical vulnerability of residential buildings using depth-damage curves at the household level.

In the present study, GIS Spatial Statistics (Ordinary Least Square (OLS)) regression tool and Spatial Analysis tools were used to model spatial relationships between the physical vulnerability of buildings (as dependent variable) to exposure characteristics (building typology, water level inside the buildings, proximity of buildings to the river, and duration of floodwater in the buildings) as explanatory or independent variables. Spatial statistics OLS regression analysis performs global ordinary least squares linear regression to generate predictions or to model a dependent variable in terms of its relationships to a set of exploratory variables (ESRI 1995-2019). The estimated linear relationships are either positive or negative and are depicted by the explanatory variable's coefficient value and the scatterplots. For instance, a negative coefficient value denotes a negative correlation between the dependent and explanatory variables.

2.5 Physical vulnerability to floods assessment

Flood affects people, buildings, and infrastructure located within inundated areas as well as those outside those areas (Guarin 2003) differently. Physical vulnerability to flood assessment deals with ascertaining the level of damage or loss to a set of elements at risk in a specified location (Olesen et al. 2017). The damage or losses can be either direct or indirect (Uwakwe 2015). Direct damages are a result of physical contact with floodwater onto people, property, lifeline infrastructure, crops, or any object (ibid). Likewise, indirect damage or losses are a consequence of direct impact but occur outside the event spatially and temporally (Fhang 2013) such as disruption of socio-economic activities, like disturbance of academic calendars due to closure of schools after the occurrence of floods, loss of business caused by the interruption of traffic (due to damaged roads and bridges), public services and any other disturbance. However, most studies on physical vulnerability assess structural damage or collapse of buildings and non-structural damage (damage to contents or assets) (Van Westen 2014).

2.5.1 Approaches to assessment of the flood physical vulnerability of buildings

Ciurean et al (2013, pg.15) identified two approaches to flood vulnerability assessment: the first approach "quantifies the expected or actual damages to a structure expressed in monetary terms or through an evaluation of the percentage of the expected loss;" and the second approach "deals with the physical vulnerability of individual structures" and estimates the probability of physical damage occurrence or collapse of a single element such as a building (ibid). There are two methods of flood physical vulnerability assessment stemming from the second approach and the methods are empirical and analytical (Van Westen & Kingma 2011). The empirical approach is based on observed flood damage data collected through questionnaires, interviews, and field mapping (Ciurean et al. 2013). The advantage of the empirical approach is that real damage is used and the disadvantage is that it depends on the availability of damage data and the respondents' risk perception. Whereas in the analytical approach, different flood characteristics (flood depth, duration, and velocity) and buildings' physical characteristics are used in the laboratory experiments (models) to simulate the fragility of the structure. The outcome of structure reactions in the laboratory experiment is quantified and the reliability and probability of structural failure are estimated (Ciurean et al. 2013). There are three main methods commonly used in the empirical approach to physical vulnerability assessments and each method requires different parameters for expressing it (Uwakwe 2015). The methods are depth-damage functions (vulnerability curves), vulnerability indicators, and damage matrices. Below is a discussion of physical vulnerability assessment methods:

i. The stage-damage functions (vulnerability curves) method

This method uses actual damage surveys or synthetic data to measure the vulnerability of elements at risk under study (Sagala 2006). The damage is considered in monetary (cost of repair or replacement) form and is regarded as a function of the inundation depth (Olesen et al. 2017). This method requires extensive information on damaged buildings (Uwakwe 2015). The slow-moving flood water is used in the depth-damage curves since it determines the intensity of the flood and the magnitude of damage easily (Sagala 2006). The applicability of depth-damage curves is limited to slow-rising, low-silt, and low-flow floods (NZIER 2004 cited in Papathoma-Kòhle 2010).

Several physical vulnerability assessment studies have used stage-damage functions, depth-damage functions, or vulnerability functions (Papathoma-Kòhle et al. 2011; Pistrika et al. 2014; Sagala 2006; Uwakwe 2015; Guarin 2003; Mazzorana et al. 2014) among others. Most of these studies were done at the macro (national) and meso (municipal) spatial scales as opposed to the household level due to data availability limitations. The studies done at national or regional scales are mostly based on expert opinion on the vulnerability of structures, existing data on building structure types and population of areas are obtained from the national census. Data on the value of buildings is acquired from insurance firms. Most of the results of assessments are generalised vulnerability outcomes with some uncertainties about the vulnerability functions. Papathoma-Kòhle et al. (2019) noted that curves are associated with a large number of uncertainties deriving from the fact that the construction and design characteristics of buildings are not often considered, instead empirical relationships between hazard magnitude and observed loss are used.

ii. The second method uses vulnerability indicators.

The vulnerability indicator method is preferred by policymakers since it gives a clear image of the vulnerability of places suitable for disaster risk mitigation and management planning (Nasiri et al. 2016). In this method, damage assessment is conducted by taking into consideration all the factors that influence the physical vulnerability of a building (Uwakwe 2015). The selection of indicators is based on two theory-based approaches - data-based also known as inductive and deductive (Füssel 2010). In the inductive approach, indicators are selected from observed vulnerability outcomes, while in the deductive approach, indicators are selected using hypothetical construction. In some physical vulnerability indicator-based assessment methods, damage assessments are conducted based on all factors that influence the physical vulnerability of buildings (Uwakwe 2015). The choice of indicators is based on the objectives of the study, the type of hazard, and the site-specific (Uwakwe 2015). For instance, Papathoma-Kòhle et al. (2007) used construction materials and the age of buildings, the existence of surrounding walls and large windows on the mountain slope, and the number of floors as factors for increased vulnerability of buildings to landslides. Müller et al (2011) used the location of buildings to the street level (plinth) and distance to the waterway, construction materials of buildings, and availability of private protection measures. Uwakwe (2015) applied wall materials, the height of buildings above the ground, the number of floors, maintenance, and age as factors or indicators of buildings' physical vulnerability to floods.

iii. The damage matrices

This method uses actual damage or historical data of flood events. The relationship between hazard intensity and the degree of damage is presented in a vulnerability table or matrix, especially when the hazard intensity has no intermediate values (Guillard-Gonçalves 2016). Damage data is tabulated with each magnitude of damage categories assigned to physical vulnerability value or scale. The disadvantage of this method is that it depends on the availability of flood damage data.

The present study followed the empirical approach and the damage grades of buildings were used as vulnerability indicators. The indicators were selected from observed and questionnaire data from vulnerability outcomes. The flood (hazard) characteristics (flood inundation level and duration) and building susceptibility characteristics that contribute to the structure's vulnerability were used. GIS Spatial Analysis, Spatial Statistics Analysis Regression tools (OLS), and SPSS were used to relate physical vulnerability scales with exposure factors. Table 1 shows some relevant variables used for flood physical vulnerability assessment according to Müller, Reiter, & Weiland (2011). The variables presented are construction materials of buildings, location of the building to the river or inundation areas, and availability of protection factors.

Table 1: Relevant variables for flood vulnerability assessment

Variable	Relevance
The main construction material for the roof, walls, and floor	- to determine the physical fragility of flood events and indicate the resistance to damage and the social status - Some types of construction material allow humidity to remain in the walls or floor after flood events, which can lead to health problems and sometimes structural failure.
Position of buildings to the river	to determine the likelihood of buildings' suffering damage in case of a flood event
Availability of protection measures	protection infrastructure e.g. wall fences, terraces, storm drains

Source: Adopted from Muller et al. (2011)

2.5.2 Protective strategies and preventative measures for buildings

It is common knowledge that effective protective strategies reduce flood impact and the absence of the same aggravates flood impacts (Fatemi et al. 2020). Some studies on physical vulnerability assessment to flood (Müller et al 2011; Banda 2015; Malgwi et al 2019; Fatemi et al. 2020) have included coping strategies applied to the buildings or building protection and prevention measures to enhance their resistance or reduce their susceptibility to damage. Müller et al. (2011, p.2108) noted that "people and buildings are only exposed if they do not have sufficient structural and private measures to flooding."

The study conducted by Müller et al (2011) focused on investigating the reasons for vulnerable conditions in Santiago and evaluated the effectiveness of building prevention and protection measures in reducing urban vulnerability to flooding. The study found that permanent protection measures (which required big financial investment) were undertaken after a building or household had suffered flood damage, while preventative protection measures were done before and during flood events to inhibit the damage of structure materials by floodwater. The statistical correlation analysis results showed that the protection and preventive measures had an insignificant influence on the vulnerability of the buildings or households, which suggests that the protection and preventive measures that were applied were not effective in reducing the vulnerability of buildings.

The study conducted by Banda (2015) assessed coping strategies applied by households or buildings to mitigate flood damage. The building protection and preventative measures were categorised under technological coping strategies and these were divided into land management, building materials, and construction methods. Land management strategy involved managing the surroundings of the buildings to slow down rainwater runoff, digging drains as outlets for excess rainwater, and planting trees, grass, and bamboo along the streams or rivers to stabilise the river banks. Building materials and construction methods strategies included modification of buildings after suffering from flood damage such as reinforcing walls, putting heavy items (like stones, and sandbags) on roofs, elevating part of the building, constructing embankments, fences, and terraces along the river to shield the buildings from floodwater. The study investigated the influence of coping strategies on flood impacts, and the results showed that the buildings that had protection and preventative measures in Ndirande experienced low flood impacts while buildings with protection and preventive measures in South Lunzu experienced high flood impacts and only 9% of buildings with protection and preventative measures had less flood impacts.

The study conducted by Malgwi et al (2019) developed a generic physical model for the assessment of exposed buildings to flood to be used in data-scarce regions. The flood impact and resistance parameters were used in building a susceptibility index. The impact parameters comprised flood hazard characteristics (frequency and magnitude) while resistance parameters were related to the susceptibility of buildings (construction materials and surroundings of buildings) and local protection measures. Local protection measures consisted of structures attached to the building (like raised veranda or doors) and those located in the surroundings of buildings such as stone or brick fences. The impact and resistance parameters were used to develop a building predisposition index (BPI) which was used to predict the extent of damage a building would experience due to flood impact.

Fatemi et al. (2020) conducted a study on physical vulnerability and local response to flood damage in the peri-urban areas of Dhaka. The response strategies by the exposed population to floods that were identified were: (i) modification of buildings by installing rain gutters, strengthening the plinth, and building walls by using flood-resistant materials. (ii) modification of the surroundings of buildings by digging water drains, and laying sandbags among others (iii) improvements at the neighbourhood level, like cleaning drains and canals, and building retaining walls as barriers to floodwater. The statistical correlation analysis was conducted to examine if the modification of buildings had any influence on the damage of buildings to flooding, and the results revealed that there was a significant modest association with Cramer’s $V=0.425$, $p<.001$.

CHAPTER 3: MATERIALS AND METHODS

This chapter presents information on the study site, materials, and methods for data collection and analysis.

3.1. Introduction

This chapter describes the study site and explains the materials and methods used for data collection and analysis.

3.2 Study area

The study was conducted in Lilongwe City, which has a population of 989,318 (NSO 2019). The population has grown from 674,448 to 989,318 within 10 years, with a growth rate of 3.8% per annum (ibid.). The pressures on land resources result in the high acquisition value of serviced plots hence forcing low-income people to settle in flood-prone areas where the value of the land acquisition is affordable (Masozeraet al 2006; Sagala 2006).

The study was conducted in two settlements of Biwi and Kawale1 within a 50-metre buffer zone area along the Mchesi river, between Chidzanja and Kawale bridges (Figure 4). Mchesi river acts as a physical boundary between Kawale and Biwi Townships.
It has been observed that there has been an increase in the number of people settling on river banks and other reversed areas since the coming of the multi-party dispensation in 1994, as Manda (2005, p.15) observed that "people in Lilongwe City invaded all road reserves, stream reserves and open spaces claiming they needed land for housing."

The study site was selected because the two settlements have been experiencing recurring flood events; the worst floods were experienced in December 2017 and January 2019 hence the availability of flood damage to buildings and flood characteristics data. The other reason for the choice of the site was that there were different types of buildings (constructed using local construction materials), which provided a variety of building materials for physical vulnerability assessment. The data for the flood event of 2017 was used in this study due to the availability of flood damage, magnitude of damage to buildings and flood characteristics data.

Figure 4 shows a map of Biwi and Kawale settlements showing the study area (buffer zone area along Mchesi river in purple colour) highlighted with the red boundary. Figure 5 is a map of Lilongwe City with an inset of an image map of Biwi and Kawale1 50 metre buffer area highlighted in the red boundary.

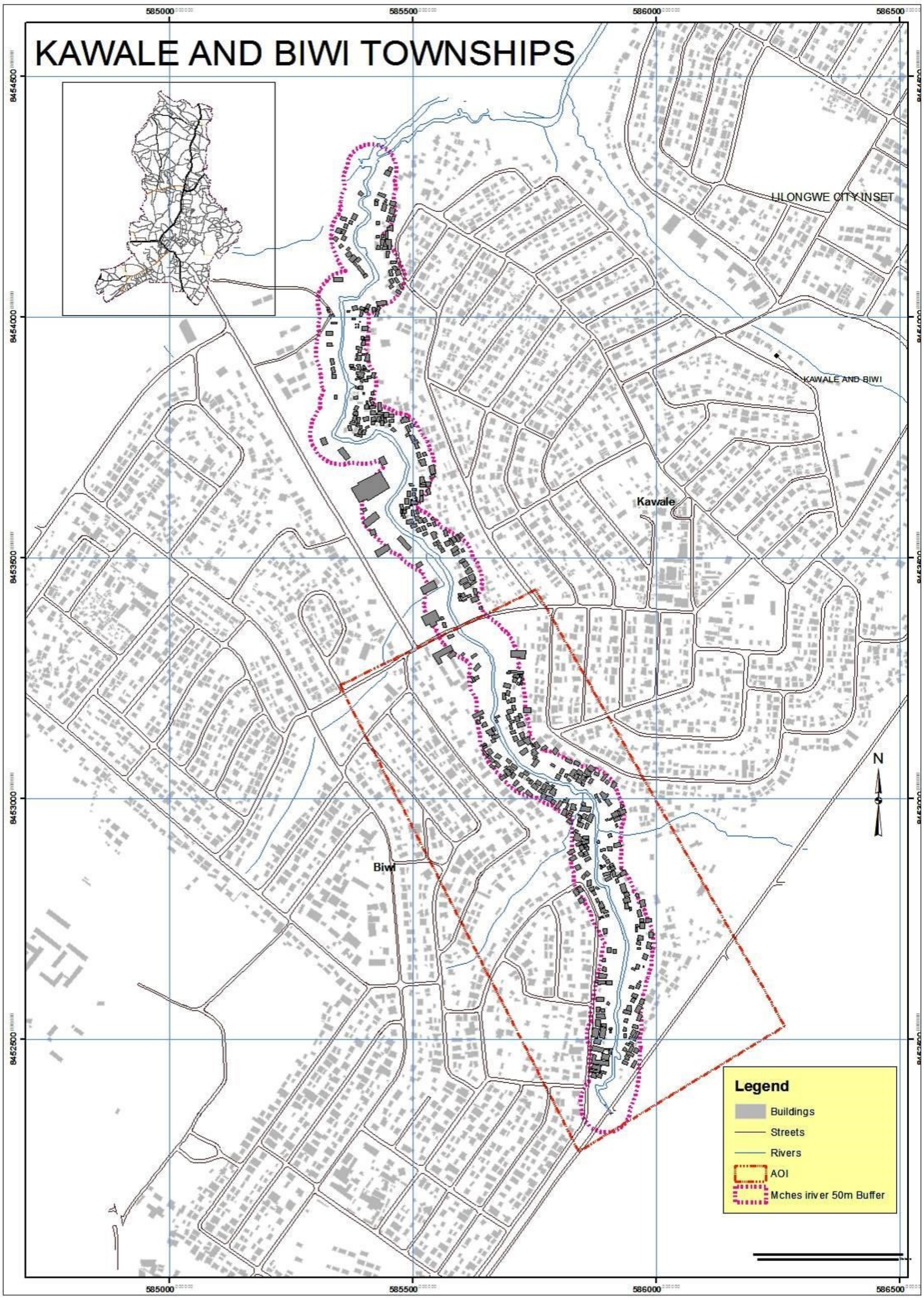

Figure 4: Map of Biwi and Kawale

Source: Researcher (2019): GIS layers from the Department of Surveys

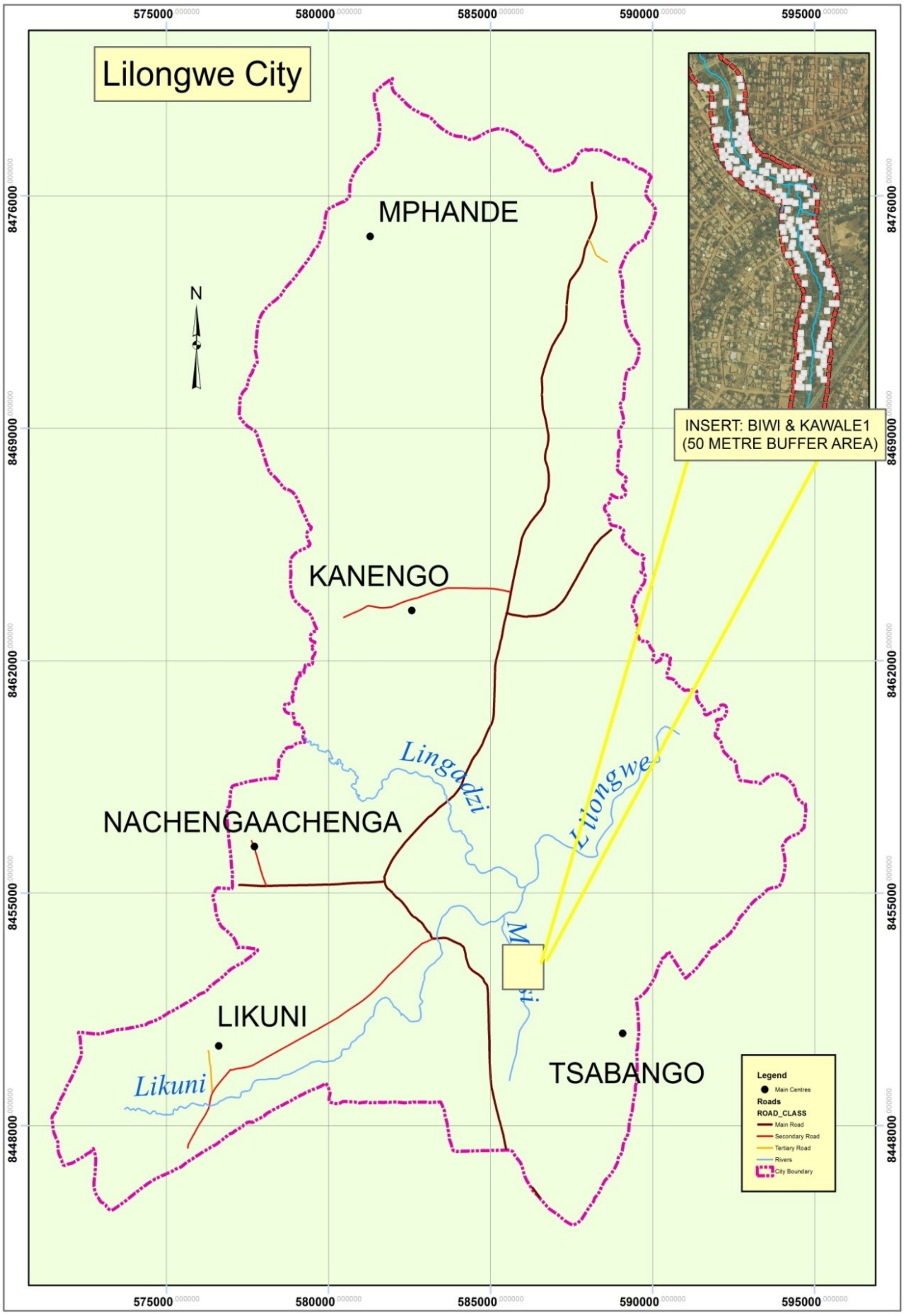

Figure 5: Map of Lilongwe City with Inset of Biwi and Kawale1

Source: Researcher (2018) and GIS layers from Surveys Department

3.3. Research Design

The study adopted a mixed methods design where both quantitative and qualitative approaches were used. Quantitative data was collected using questionnaires, interviews, remote sensing data (satellite image and STRM digital terrain model), and field measurements were used to collect quantitative data. Qualitative data was collected through interviews and field observations. Quantitative data included the age of the head of households, the monthly income of households, the depth and duration of flood water inside buildings, the magnitude of damage or loss, the location of buildings (coordinates), the height of the foundation of buildings and households flood inundation experience (frequency). Qualitative data included the gender of heads of households, the maintenance status of buildings, building use (land use), and construction materials for walls, windows, doors, roofs and floors and types of protection measures of buildings.

3.4. Sampling Framework and Methods.

3.4.1 Population and Sample Size

There was no available data for the total number (population) of buildings in the study area, therefore a high resolution (0.60m resolution) Quick bird satellite image of 2016 was used to extract (digitise) buildings and a total of 200 buildings were digitised. Therefore, 200 buildings were used to calculate the sample size for building inventory. The household interviews concentrated on the upper part of the buffer zone area (from Chidzanja to Kawale bridge) where it was reported that 29 buildings had collapsed and 300 households displaced during the 2017 flood event. 130 buildings were identified from digitised buildings for the area and they were used for computing the sample size for household interviews. The population for building inventory (200) and household interviews (130) were finite; therefore, the computed sample sizes were adjusted for finite population sample sizes to increase the power of statistical tests by Hoyle's (2018) formula. The sample size for both building inventory and household interviews was first computed based on infinite population using Israel's (2012) formula for calculating infinite population size (Equation 5): $n = \frac{N}{1+N(e)^2}$ (where: n is the sample size, N is the population size; E is the level of precision set at 5% or 0.05).

Sample size (infinite) for building inventory = $n = \frac{N}{1+N(e)^2} = 200/(1+200(0.05)^2)$= 133

Sample size (infinite) for household interviews= $n = \frac{N}{1+N(e)^2} = 130/(1+130(0.05)^2)$=98

Therefore, the adjusted (finite) Sample size for building inventory (Hoyle 2018 Equation 5): $na = \frac{n}{1+\frac{n-1}{N}} = 133/(1+(133-1)/200)$ = 80 (where: na is the adjusted sample size, n is the sample size for an infinite population and N is the population size) and the adjusted sample size for household interviews is:

$na = \frac{n}{1+\frac{n-1}{N}} = 98/(1+(98-1)/130)$ = 56. Hereafter, the sample sizes for building inventory and household interviews were 80 and 56 respectively.

3.4.2 Sampling Methods

The systematic random sampling technique was used for both building inventory and household interviews since the settlement pattern was linear either following the Mchesi river or roads. According to Parveen & Showkat (2017), systematic random sampling is a probability sampling technique that gives each element an equal chance of being selected to be in a sample. The selection criteria for the sample elements were based on Glen (2015) where the K^{th} element was computed by dividing the population by sample size (N/n); 200/80=2.5 rounded to 3 as the determined sample interval for building inventory. The sample interval for household interviews was computed: N/n= 130/56=2.3 and was rounded to 3.

Purposive sampling was used in selecting key informants, 2 civil protection committee members, 2 Block leaders, 1 official from Lilongwe City Council, 1 official from DoDMA, and 1 Malawi Red Cross official. The key informants were chosen based on the assumed knowledge and experience in occurrences of the flood events in the study area due to their official positions (Clifford et al., 2010 cited by Ngwira, 2016).

3.5. Data Collection, materials, and Sources

In this study, both primary and secondary data sources were used. This was done to ensure the accuracy and reliability of the data. Primary data was verified by secondary data and vice versa. For instance, the data on flood history from online sources were verified by household interview data. Primary data was the main source of data for this study. The primary data was collected through building inventory (field observations, and measurements), household interviews (questionnaires), and key informants' interviews.

3.5.1 Building inventory

Building inventory is the process of collecting information to be used for characterising the key elements at risk (Sagala 2006). Field reconnaissance was conducted before the building inventory task to acquaint the researcher with the study area. A Building Survey/Inventory form (Appendix D) and a buffer zone map (Figure 6) was used to guide data collection. The tasks involved visiting buildings, making observations and measurements (Sagala 2006) and collecting data about the construction materials of buildings (walls, floors, roofs, and windows), foundation heights of buildings (above the ground), geographic location (Coordinates) of buildings, building function/use, maintenance status, and proximity of buildings from the river.

3.5.2 Household interviews

This was the main source of data for the study. The questionnaire was prepared in English and later translated into Chichewa for easy communication with the respondents. Testing of the questionnaire was done on two buildings by two groups of research assistants (4 research assistants). Some parts of the questionnaire were found redundant and were removed. The questionnaires were taking 25-30 minutes per household on average. The questionnaire had four parts: demographic information of households, location of the building, additional building information, flood damage history, number of flood events experienced, and coping measures (Appendix D). Questionnaires were administered to households that were selected based on systematic random sampling. Every 3rd building was selected randomly from the first, following a linear settlement pattern and a total of 52 households were interviewed.

The activities undertaken as part of data collection were: measuring the flood water level inside the buildings for the 2019 flood event and flood marks on the walls for the 2017 flood event, taking the location (coordinates) information of buildings, observing damages occasioned to buildings by floods, recording damages for contents and outside property, and observation of buildings protection measures (coping strategies). Damage and flood characteristics data were collected for the 2017 and 2019 flood events. It was not possible to administer more questionnaires on 11th and 12th January 2019 due to the flood event of 10th January, hence most households were busy draining floodwater from houses, cleaning mud and sediments, while other households were repairing collapsed parts of houses. The respondents had to specify the part of the building structure that was damaged and the level of floodwater at which the damage occurred. The damage was rated from: Nothing happened (NH), Half collapsed (HC), and Collapsed (C). Most of the respondents gave one level of water for all damages, as opposed to the level of floodwater against each degree of damage. The reason given was that they did not capture the levels of floodwater at which each degree of damage occurred.

3.5.3 Key Informant Interviews

A checklist was provided to key informants to get their perception of flood damage and causes and to validate data collected from household interviews (Appendix D).

3.5.4 Equipment and materials used

The Handheld GPS receivers, Measuring Tape, and a Still Camera were used for data collection. The Handheld GPS receivers were used to collect data about the locations (coordinates) of buildings during building inventory and household interviews. Measuring tapes were used to measure the heights of the foundations from the ground, and the depth of floodwater inside the buildings. The Still Camera was used to take pictures of different types of buildings, protection measures, and damaged buildings and contents.

3.5.5 Secondary Data Collection

Secondary data were comprised of internet or online sources (such as Needs Assessment Reports, Newspapers, and online resources) and remote sensing and GIS data (Shapefiles) from the Department of Surveys and MASDAP web portal. Table 2 shows secondary data (GIS and remote sensing) and source.

Table 2: Secondary data and their sources

Data Layer	Description	Sources
City Boundary	This layer contains the Lilongwe City boundary	Dept. of Surveys
Rivers Shapefile	This layer contains all rivers in Lilongwe City	Dept. of Surveys
Roads Shapefile	This layer contains all roads in Lilongwe City	Dept. of Surveys
Township boundary	This layer contains the boundary of Townships	Lilongwe City
2016 Satellite image	Quick Bird satellite image of Lilongwe City	Dept. of Surveys
STRM	A digital terrain model of 30-metre resolution	MASDAP

Source: Fieldwork (2018)

3.6. Ethical consideration

To adhere to ethical standards for the conduct of research, the following steps and procedures were taken into consideration: Firstly, this research was approved by the Mzuzu University Research Ethics Committee (MZUNIREC) Appendix A). Secondly, permission to conduct the study in Kawale and Biwi was granted by the Lilongwe City Council (Appendix E) and within the study areas, the Block Leaders granted permission to carry out data collection. Thirdly, the privacy and confidentiality of the research participants were assured by ensuring that each participant signed an informed consent form (Appendix B) before the interviews started. The consent form outlined the purpose of the study, the right for them to withdraw and how the collected data would be treated with confidentiality through anonymity. Fourthly, the private information provided by the research subjects was handled in a highly confidential manner by concealing their identity and the data in the questionnaires were kept under the researcher's custody to ensure privacy and make sure that the names of research subjects should not appear in the report /thesis. Lastly, participants were informed that the results of the research will be used for academic purposes.

Figure 6: Buildings in the 50m buffer area

Source: Surveys Department (Satellite image) analysis

3.7. Data Analysis

Data preparation and processing were done before data analysis. Building inventory and household questionnaire data was tabulated in Microsoft Excel and SPSS 20 software and, thereafter, was analysed in both SPSS 20 and ArcGIS 10.7.1 software.

3.7.1 Database creation of elements at risk

Data from building inventory and household questionnaires were linked with the coordinates of buildings to create a database of buildings in a GIS environment (Figure 7).

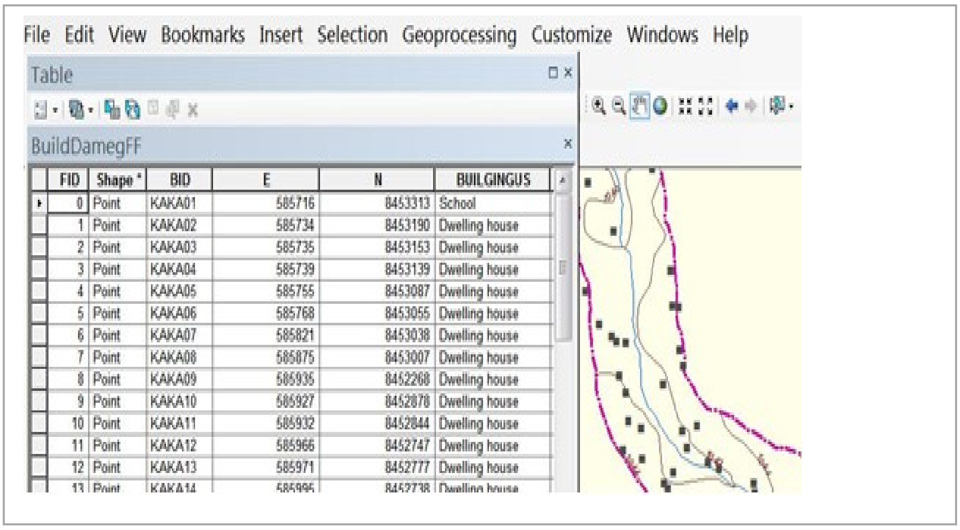

Figure 7: GIS Database for buildings
Source: Fieldwork (2018) Biwi and Kawale1 GIS database

3.7.2 Data Processing Methods

The characteristics of buildings that make them resistant to natural hazards are different from one type of hazard to another. For example, the criteria for the classification of buildings for physical vulnerability to seismic hazards assessment is different from the construction materials considered in physical vulnerability to flood hazards assessments. Ngoma et al. (2019) noted that the classification of buildings for seismic vulnerability assessment is based on engineering perspectives, such as building external and internal dimensions, sizes of piers and openings, mortar material type, type of brick bonding, the thickness of joints, and support conditions among others. Building characteristics relevant to assessing flood vulnerability are the main construction material for roofs, walls, and floors (Sagala, 2006; Collins et al., 2009; Müller, Reiter, & Weiland 2011 and Uwakwe 2015). However, the Malawi National Statistics Office (NSO 2019) classified dwelling houses as (a) permanent structures (roof made of iron sheets, tiles, concrete or asbestos, and walls made of burnt bricks, concrete or stones); (b) semi-permanent structure (built of non-permanent walls such as sun-dried bricks or non-permanent roofing materials such as thatch); and (c) traditional structure (built of non-permanent walls such as sun-dried bricks or non-permanent roofing materials such as thatch). This type of classification could not fit with the building materials for walls, roofs and floors used in the study area; therefore, the NSO (2019) building classification has been improved with reference to available literature to inform this study. Therefore, the building typology was based on the classification method used in flood physical vulnerability of buildings studies from the literature (Fatemi et al. 2020; Uwakwe 2015; Blanco-Vogt & Schanze 2013; Müller et al 2011; Sagala 2006; Cutter et al. 2003). To characterise buildings, ArcGIS 10.7.1 software's spatial analysis tool (Query (SQL)) was used to segregate buildings based on construction materials for walls and floors in the database and assign the typology. An example of one of the queries was *"*SELECT* FROM *Buildings* WHERE *"Wall material type = Burnt bricks with cement mortar and Floor material type = cement,"* this query retrieved all buildings that met the query condition and were assigned the appropriate building classes. The buildings were classified by their construction materials since construction materials determine the resistance or fragility of the structures to natural hazards (Fatemi et al. 2020).

Literature on the physical vulnerability of buildings to flooding provides exposure factors used in the analysis (Fatemi et al. 2020; Banda 2015; Singh et al. 2019 among others) as locational characteristics of the surroundings of buildings and the extent of flooding. The locational characteristics of the buildings are the geographic location (coordinates) of buildings, the elevation of the surrounding terrain of buildings and the proximity of buildings to the river. The creation of the buffer zone of the study was based on Land Use Development Management Guidelines and Standards (GoM 2014 p.71) which stipulates that "an area of 15 to 30 metres of any river bank is protected." Therefore, the building locations were classified as less than 30 metres (representing protected areas) and 31 to 50 metres (presumed as safe areas). The 50-metre buffer zone of Mchesi river was generated around the river to show the extent of the study area. The flood characteristics used in this study are the level of floodwater in the buildings, duration of inundation of buildings (inside) and frequency of flooding. The data for locational characteristics (elevation of the surroundings of the buildings and distance to the river) were processed in Microsoft Excel, ArcGIS and SPSS software. The proximity of buildings to the river was determined by segregating the buildings that were at a distance of less than 30 metres and those located between 31 to 50 metres from the river. The flood characteristics' exposure factors were processed in ArcGIS. The floodwater level inside the buildings was interpolated and classified in ArcGIS 10.7.1 software. The floodwater levels outside the buildings were computed using the GIS Field Calculator tool by adding the foundation height of buildings to the floodwater level inside the individual buildings (*Floodwater level outside =floodwater levels inside + foundation heights*), thereafter classification was done.

The working definition of physical vulnerability for the current study is "the degree of loss to a given element or set of elements within the area affected by the hazard" (Papathoma Kòhle et al. 2012), therefore damage data for buildings, contents and outside property were processed in ArcGIS and SPSS software. The damage to buildings was described as Nothing happened (NH), Half collapsed (HC), and Collapsed (C) in the questionnaire (Sagala 2006). Table 3 presents the descriptions of damage to the buildings' structures derived from questionnaires.

Table 3: Descriptions of damage to building types

Serial No.	Damage type	Description
1.	Nothing happened (NH)	If material types of floor, wall, window, and door were not damaged due to a certain level of flood depth
2.	Half collapse (HC)	If material types of floor, wall, window, and door got damaged from a certain level of floodwater depth and there is a need for repair
3.	Collapse (C)	If the material type of floor, wall, window, and door got completely damaged from a certain level of flood depth and needs to be replaced

Source: Adopted from Sagala (2006)

The data on the damage to the building contents included the quantities (number) of damaged contents, the cost of repair or replacement, and the type of household assets (like Electric appliances, Food items, Clothes and bedding, furniture, and kitchen utensils). The magnitude of damage was recorded by households as *Nothing happened*, *Half or 50% damage*, and *Completely damaged*.

The damages defined in Table 3 were further processed and assigned damage ratios based on the magnitude of damage to parts of the building structures presented in Table 4.

Table 4: Building structure damage classification and scales

Category	Damage combinations	Damage scales assigned
1	Nothing or no damage happened to the floor, wall, window, and door from floodwater.	0
2	One part of the structure had half-collapsed due to floodwater	0.125 (rounded up to 0.13)
3	One structure material type had *Collapsed*	0.25
4	One material type *Collapsed* and another *Half Collapsed*	0.375 (rounded to 0.38)
5	Two structure material types *Collapsed*	0.5
6	Four material types had *Half Collapsed*	
7	Two structure material types *Collapsed* and one *Half Collapsed*	0.625 (rounded to 0.63)
8	Three structure material types *Collapsed*	0.75
9	Three structure material types *Collapsed* and one *structure Half-Collapsed*	0.88
10	All four-structure material types Collapsed	1

Source: Modified from Uwakwe, 2015.

The classification of damage ratios of contents was based on the number of groups of contents that were damaged, for instance, if half of the electrical appliances were damaged while all other categories of contents were not damaged then a vulnerability scale of 0.1 was assigned. Table 5 shows the matrix of damage and vulnerability scales.

Table 5: Matrix of contents damage and vulnerability scales.

Category	Description	Vulnerability Scale
1	No damage occurred to all contents in the building	0
2	Half damage occurred to one content group only while the other categories were not damaged	0.1
3	One contents group got completely damaged while the others were not damaged	0.2
4	One contents group got completely damaged and another group had half of the contents damaged while the remaining ones were not damaged	0.3
5	Two content groups were completely damaged	0.4
6	Two contents groups got completely damaged and one contents group is half damaged while the remainder is not.	0.5
7	Three content groups were completely damaged while the remaining groups were not impacted	0.6
8	Three contents groups were completely damaged and one contents group was half damaged while the rest were not	0.7
9	Four contents groups were completely damaged while the remaining ones were not impacted	0.8
10	Four contents groups got completely damaged and one group was half damaged	0.9
11	All household contents group or groups got damaged	1

Source: Modified from Uwakwe (2015); Sagala (2006)

3.7.3 Data Analysis

The data analysis was conducted using ArcGIS 10.7.1 and SPSS 20 software. The ArcGIS spatial analysis, proximity and spatial statistics tools and SPSS (descriptive frequency statistics, Cross-tabulation analysis and Chi-square test) were used.

3.7.4 Conclusion

This chapter discussed the study design, tools, and methods for data collection, processing, and analysis methods that were used in this study. Primary data about building inventory, building and contents damage, and flood characteristics were collected during the field survey, measurements and observation, and household interviews. Handheld GPS gadgets were used to collect the location (coordinates) of buildings. Measuring tapes were used to measure floodwater depths inside buildings (markings on walls), the distance of buildings to the river (where possible), and the height of the foundation above the ground. Digital still cameras and phone cameras were used to take pictures. Data were prepared, processed, and analysed in Microsoft Excel, ArcGIS software, and SPSS as presented in Figure 8.

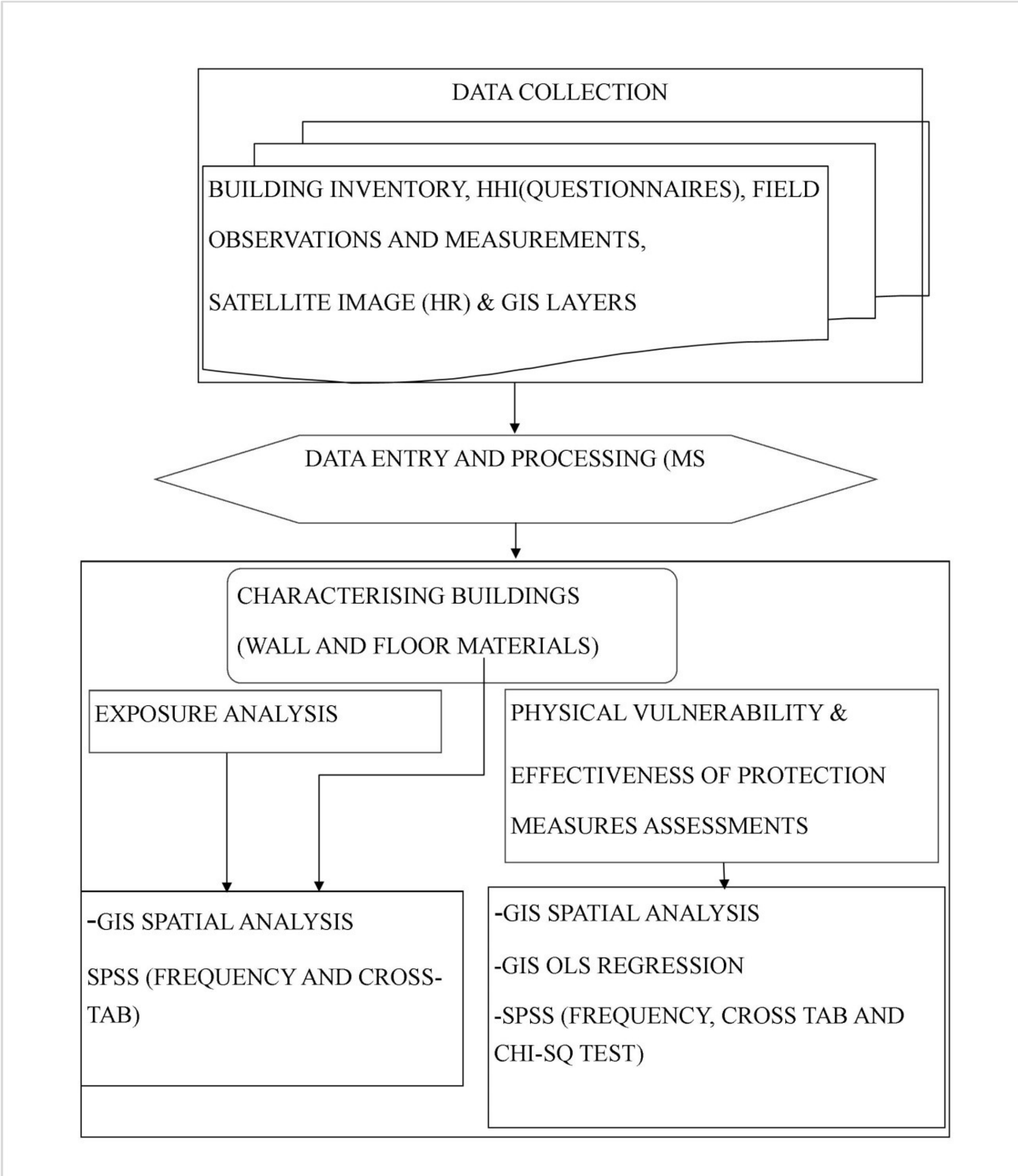

Figure 8: Data Collection and Analysis Methods
Source: Researcher (2018)

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results of the study. Firstly, the demographic information of the households is presented followed by the characteristics of buildings and contents, the exposure factors, physical vulnerability assessment, and analysis of the effectiveness of building protection measures.

4.2 Demographic information of households

The demographic information about households was analysed in SPSS 20 software where summary tables, graphs, and pie charts were produced to present the results.

4.2.1 Designation of respondents in households and public buildings

The descriptive statistics frequency analysis results show that most (71%) of the respondents were heads of households. Table 6 presents the results of the analysis.

Table 6: Designation of respondents

Designation	No. of people	Per cent
School guards	2	2.4
Church members	2	2.4
House servants	5	6.0
Household heads	60	71.3
Neighbours	5	6.0
Sons and daughters	6	7.2
No data	3	3.6

Source: Fieldwork (2018)

4.2.2 Distribution of Ages of Heads of Households

The ages of the heads of households ranged from 19 to 79 years. The predominant ages of heads of households were between 31 to 64 years (81%). Figure 9 shows the distribution of age ranges of heads of households.

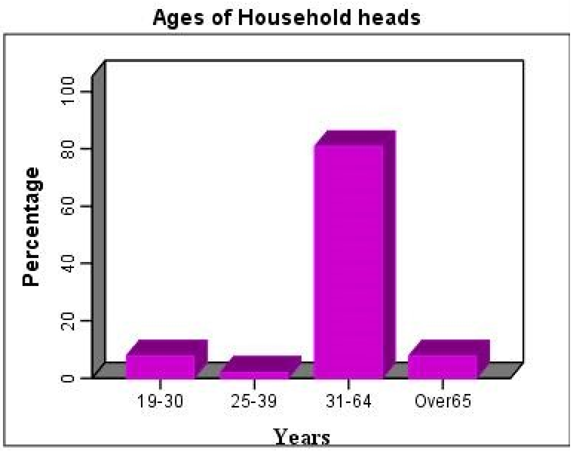

Figure 9: Age of Heads of Households

Source: Fieldwork (2018)

4.2.3 Gender of Heads of Households

It was found that there were more male-headed than female-headed households. The results in Figure 10 show that 69% of the heads of households were male, while 31% were female.

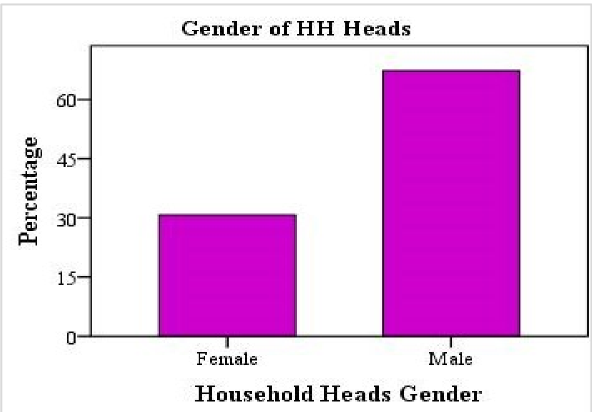

Figure 10: Households Heads Gender

Source: Fieldwork (2018)

4.2.4 Literacy level of the heads of households

The level of education strongly relates to employment status, income level, and social status (Subasinghe & Kawasaki 2021). Literacy level has also a bearing on access to information on the early warning of flood hazards and choices of risk reduction measures. The results of the analysis show that more household heads had formal education ranging from primary to tertiary level. Only 4% of the household heads had no formal education. Figure 11 presents the results of the analysis.

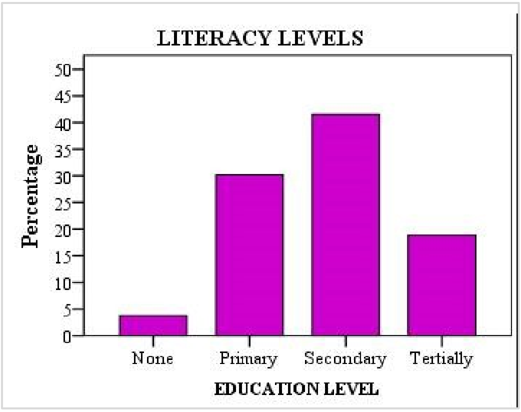

Figure 11: Households Heads Literacy
Source: Fieldwork (2018)

4.2.5 Households Monthly Income

The income of the households indicates their economic status and determines the households' ability to save money for developing coping measures and reconstruction after the flood event (Sagala 2006). The households in the study area are low-income earners and this is evident from the results of the analysis which show that 81% of households' monthly income was less than K100, 000. Figure12 shows the results of the analysis.

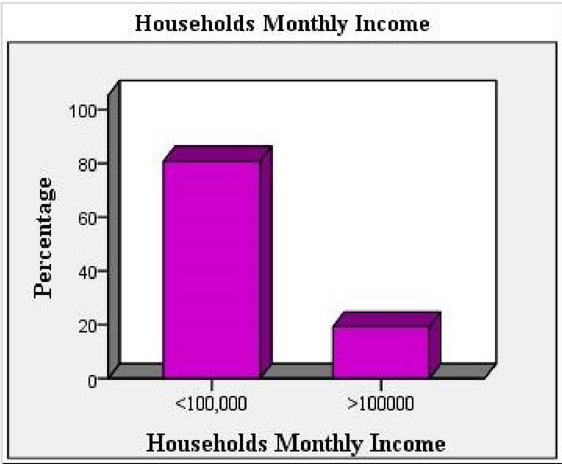

Figure 12: Households Monthly income
Source: Fieldwork (2018)

4.3 Characterisation of elements at risk

To characterise key elements at risk of flooding for physical vulnerability assessment in the study area, the physical characteristics of buildings were analysed. The results of the analysis are presented in the subsequent sections.

4.3.1 Descriptions of buildings from inventory

Building characteristics relevant to assessing flood vulnerability are the main construction material for roofs, walls, and floors (Collins et al. 2009; Müller, Reiter, & Weiland 2011). In addition, the study also considered the maintenance status, age of buildings, and foundation of the buildings. The following sections present the results of the analysis.

i. Building materials

The wall materials that were identified from the building inventory data were burnt bricks with cement mortar, burnt bricks with mud mortar, and sun-dried bricks with mud mortar. Table 7 shows that 61.4% of buildings had burnt bricks and cement mortar, 18.1% of buildings had walls made of burnt bricks and mud mortar, and 20.5% of the buildings had sun-dried bricks and mud mortar.

Table 7: Common construction materials

Part of building	Type of material	No. of buildings	Percentage
1. Wall	Burnt bricks and cement mortar	51	61.4
	Burnt bricks and mud mortar	15	18.1
	Sun-dried bricks and mud mortar	17	20.5
2. Floor	Cement	73	88
	Earth	10	12
3. Roof	Corrugated iron sheets	83	100
4. Window	Glass	70	84.3
	The mixture of metal and glass	1	1.2
	Plastic paper	1	1.2
	Wood	8	9.6
	None	3	3.6

Source: Fieldwork (2018)

The study found two types of floor materials that were commonly used; these were cement and Earth or mud. The results of the analysis show that most (88%) of buildings had their floors made of cement or concrete materials. Table 7 shows the results of the analysis. It was also found that all the buildings in the study area were roofed with one type of roofing material and it was corrugated iron sheets.

The analysis results also revealed that there were four types of materials for windows and the most common materials for windows were glass. The results of the analysis in Table 7 show that 84.3% of buildings used glass, 9.6% of buildings had wood, and 1.2% of buildings had plastic papers and a mixture of metals and glass as window materials. Figure 13 shows a building with a mixture of window materials.

Figure 13: Some of window materials
Source: Fieldwork (2018)

ii. Buildings' Maintenance status

The status of maintenance of buildings has a bearing on the resistance of the buildings to flood impacts. The results of the analysis show that there was variation in the maintenance of buildings. Figure 14 shows the results of the analysis that 21% of the buildings were in good condition, 23% of buildings were moderately maintained, 10% of buildings were poorly maintained and 2% of the buildings were in a dilapidated state.

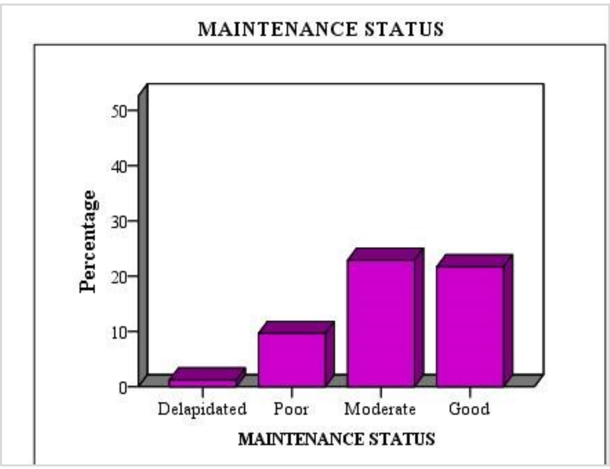

Figure 14: Buildings Maintenance
Source: Fieldwork (2018)

iii. Ages of buildings

The age of a building can be one of the contributing factors to its vulnerability especially when the building is poorly maintained and has been in contact with flood water many times; its fragility can be weakened (Uwakwe 2015). The results of the analysis show that the ages of buildings were between 0 to 25 years old and a higher percentage of buildings were ages between 11 to 20 years old. Table 8 presents the results of the analysis.

Table 8: Ages of buildings

Building ages (years)	Frequency	Percentage
0-5	14	16.9
6-10	16	19.3
11-15	17	20.5
16-20	17	20.5
21-25	12	14.5
No data	7	8.4
Total	83	100.0

Source: Fieldwork (2018)

iv. Building foundation height

The height of the foundation of buildings from the ground surface can lessen the entry of floodwater into the buildings (Sagala 2006). It was observed during the fieldwork which took place after the 10 January 2019 flood event that floodwater had an easy entry into buildings with the low foundation heights resulting in damage to household property. The results of the analysis show that close to half (48%) of the buildings had low-height foundations. Figure 15 presents the results of the analysis.

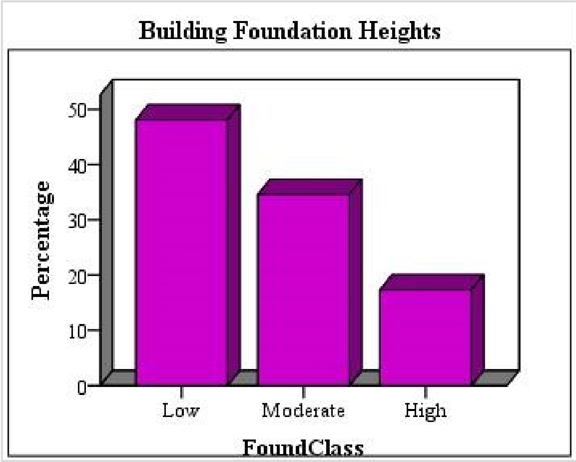

Figure 15: Building foundation heights
Source: Fieldwork (2018)

4.3.2 Buildings descriptions from household interviews

Additional information on buildings from household interviews was analysed and the results are presented in the subsequent subsections.

i. Number of households per building

It was observed that all the buildings had one floor; however, some were extending horizontally as blocks. The building blocks were accommodating more than one household. This practice can have a negative implication in terms of the number of households that can be impacted per building; this suggests that the more the number of households per building, the more the number of people to be impacted by floods. The results of the analysis in Table 9 show that more than half of the buildings (50%) were occupied by one household per building, and 36.5% of the buildings were semi-detached buildings (housing two households).

Table 9: Number of Households per building

No. of HH	Frequency	Percentage
Single	26	50
Double	19	36.5
Multi	7	13.5
Total	52	100

Source: Fieldwork (2018)

ii. Nature of land use (Building functions)

Land use is one of the proxies used in physical vulnerability studies (Uwakwe 2015). Different types of land use suffer different physical and economic losses due to flood impacts, for instance, commercial buildings can suffer more content losses than residential buildings (Sagala 2006). The study identified two types of building functions (land uses) from household interview data. Table 10 presents the results of the analysis and shows that 96.2% of buildings were residential and 3.8% were schools.

Table 10: Distribution of Buildings' Function/use

Building function/use	No. of buildings	Percentage
Dwelling house	50	96.2
School	2	3.8
Total	52	100.0

Source: Fieldwork (2018)

4.3.3. Typologies of buildings from inventory and household interview

Building construction materials are some of the factors that influence susceptibility to structure failure (Guarin 2003). The results of the analysis are discussed in the subsequent sub-sections.

i. Buildings typology from inventory

The analysis results in Table 11 show that six types of buildings were common in the study area, namely: Type1- burnt bricks with cement mortar walls and cement floor, Type 2- burnt bricks with cement mortar walls and earth floors, Type 3- burnt bricks with mud mortar walls and cement floors, Type 4- burnt bricks with mud mortar walls and earth floors, Type 5 - sun-dried bricks with mud mortar walls and cement floors, and Type 6 -sun-dried bricks with mud mortar walls and earth floors. It was found that more than half (57.8%) of the buildings were constructed with burnt bricks in cement mortar walls and cement floors and the less common building type was built of sun-dried bricks with mud mortar walls and earth floors.

Table 11: Building structure classification

	Floor Type		
Wall Material Type	Cement	Earth	Total
Burnt/ fired bricks with cement mortar	57.8 % (48)	2.4% (2)	50
Burnt/ fired bricks with mud/earth mortar	15.7 % (13)	3.6% (3)	16
Sun-dried bricks with mud/earth mortar	15.7% (13)	4.8% (4)	17

Source: Fieldwork (2018)

ii. Building typologies from household interviews

Building typologies from household interviews were used in the physical vulnerability assessment. The results of the GIS analysis in Table 12 show that there were five classes of buildings from household interviews. These were: Type 1- Burnt bricks with cement mortar walls and cement floors, Type 2- Burnt bricks with earth mortar walls and cement floors, Type3 - Burnt bricks with earth mortar walls and mud floors, Type 4 – Sun-dried bricks with earth mortar walls and cement floors and, Type 5 – Sun-dried bricks with earth mortar walls and mud floors. The results of the analysis show that 50% of buildings were classified as structure Type 1. Table 12 presents the results of the building types.

Table 12: Building Types from interviewed households

Building Type class	No. of buildings	Percentage
Structure Type 1	26	50.0
Structure Type 2	8	15.4
Structure Type 3	7	13. 5
Structure Type 4	8	15.4
Structure Type 5	3	5.7
Total	52	100.0

Source: Fieldwork (2018)

Figure 16 shows some of the buildings with different construction materials in the study area.

Figure 16: Some of the buildings in the study area
Source: Fieldwork 2018

4.4 Analysis of exposure of buildings to floods

The second specific objective of the study was to determine the exposure of buildings to flooding. Since exposure describes the extent of the flood (Pati and Cruz 2017), and also the buildings that are in contact with floodwater are considered exposed (Leal et al., 2021). To this effect, the characteristics of the location of buildings (proximity to the river, and terrain elevation of the surroundings of buildings) and the characteristics of floods the floodwater level (depth), flood history (experience), and duration of flood inundation were used to determine the exposure of buildings to flood impacts.

4.4.1 Characteristics of the location of buildings

The proximity of buildings to the river and the terrain elevation of the surroundings of the buildings were related to the number of flood events experienced to determine the exposure of buildings to floods.

i. The proximity of buildings to the river

The analysis results for the proximity of buildings to the river show that both buildings that were located at a distance of less than 30 metres and those located beyond 30 metres from the river were exposed to either one to two flood events. Table 13 shows the results of the analysis.

Table 13: Exposure factors and frequency of flood inundation

Locational characteristics	Description	Flood inundation frequency		
		None	≤2 times	>2 times
Proxy to river	<30m	0% (0)	93.5% (29)	6.5% (2)
	31-50m	4.8% (1)	90.5% (19)	4.8% (1)
Elevation type	Flat	0% (0)	100% (14)	0% (0)
	Gentle slope	2.7% (1)	91.9% (34)	5.4% (2)

Source: Fieldwork (2018)

iii. Elevation of the terrain in the surroundings of the buildings

The results for terrain elevation of the surroundings of buildings in Table 13 show that most of the buildings that were on both flat and gently sloping terrain experienced one to two flood inundations. Figure 20 shows a raster map showing terrain elevation.

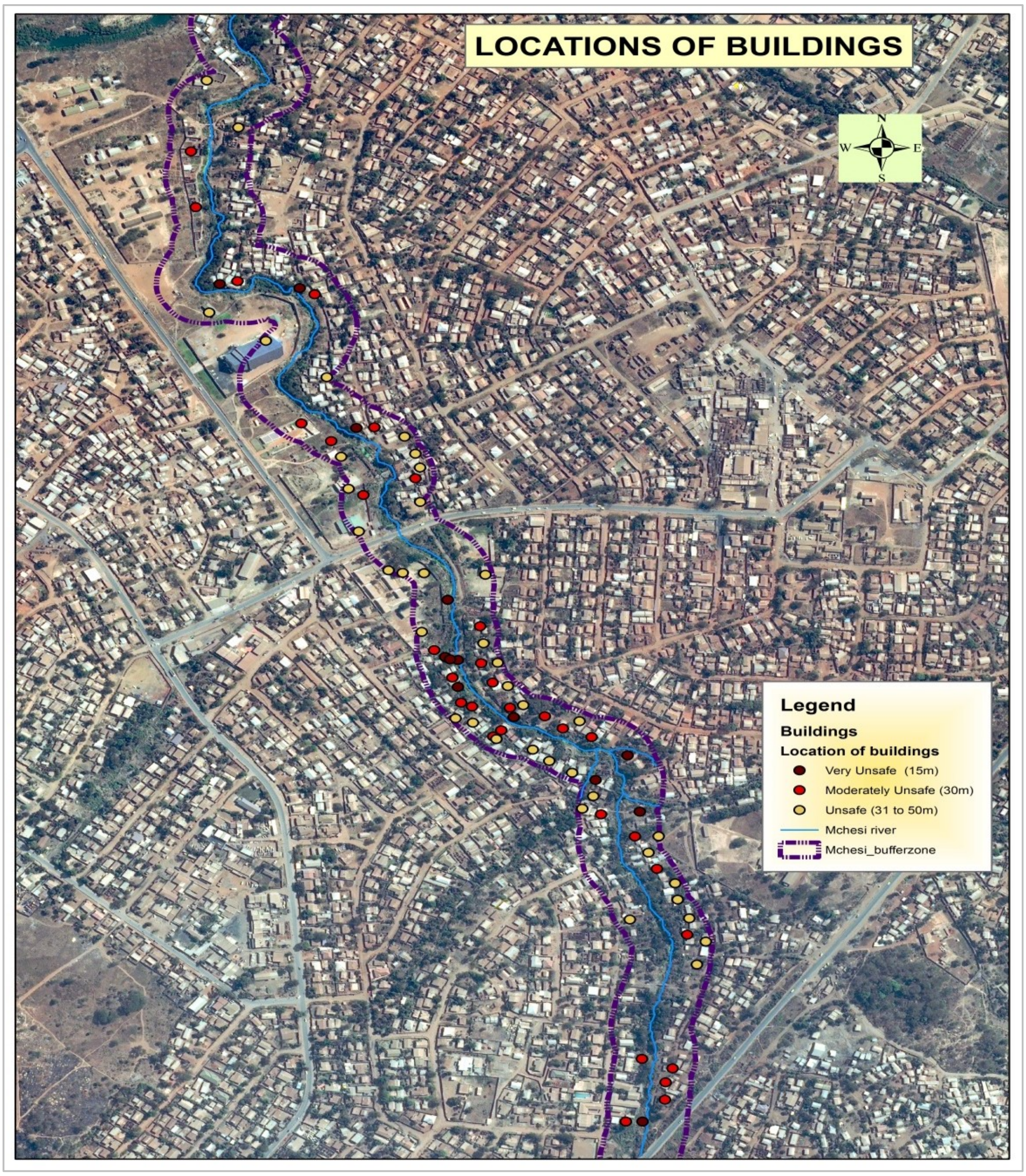

Figure 17: Proximity of buildings to the river

Source: Fieldwork (2019) and Satellite image from Dept. of Surveys

Figure 17 shows buildings with locations categorised as not more than 15 metres from the river as “very unsafe,” located between 15 to 30 metres as “moderately unsafe”, and located between 31 to 50 metres from the river as “unsafe.”

Figure 18 shows a building close to the river and Figure 19 shows different terrain characteristics.

Figure 18: Buildings close to the river
Source: Fieldwork (2019)

Figure 19: Terrain elevation of surroundings of buildings

Source: Fieldwork (2019)

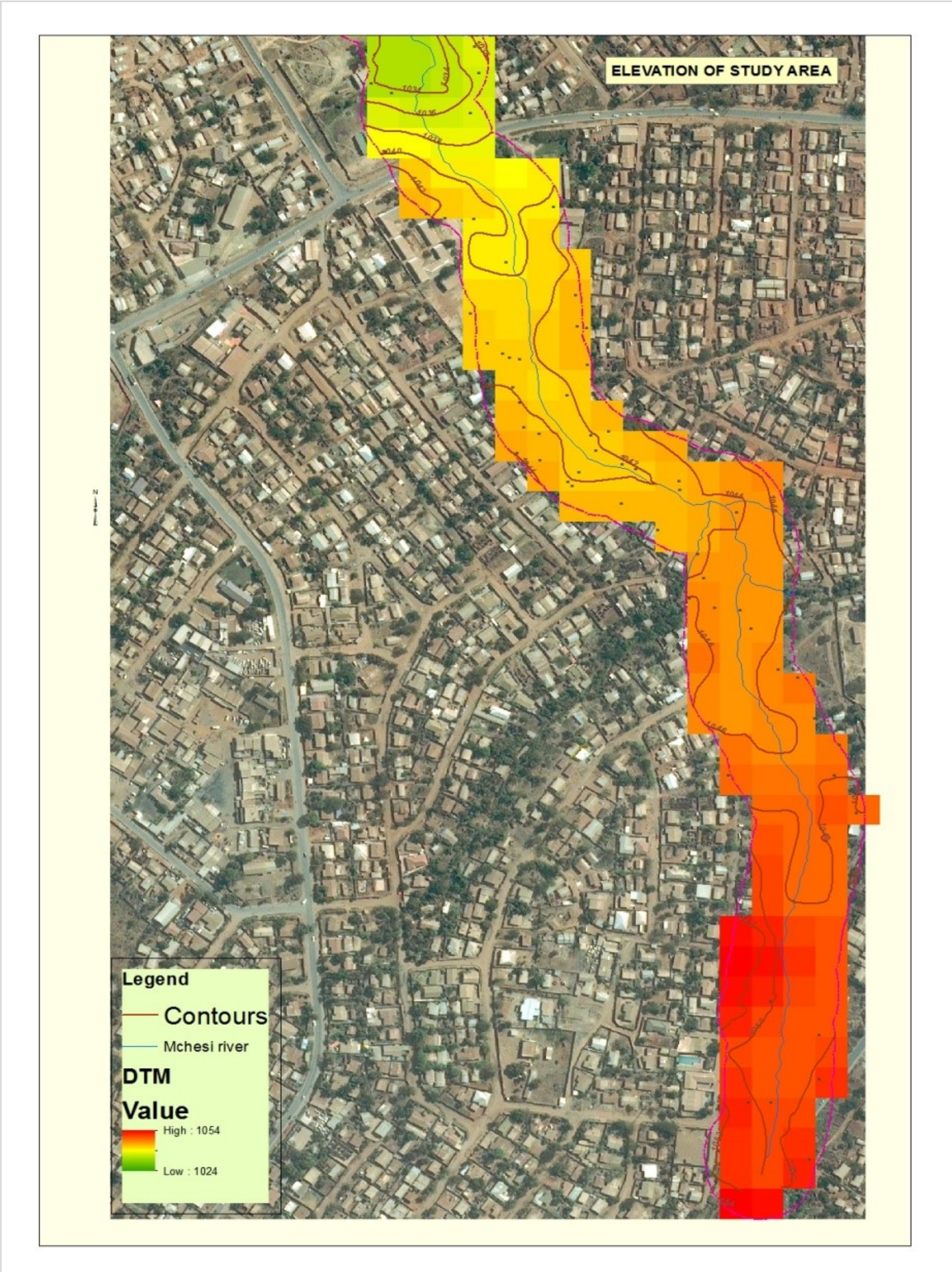

Figure 20: Terrain elevation of the area
Source: Fieldwork (2018) and Satellite image and STRM DTM from Surveys Department

4.4.2 Flood extent and flood damages

The results of the analysis for flood characteristics are presented in the subsequent subsections.

4.4.2.1 Flood extent

i. The flood water level inside the buildings

The results of the analysis in Table 14 show that more buildings were inundated by floodwater with over half (54%) of the buildings flooded with high (more than 60 centimetres) levels of floodwater.

Table 14: Floodwater depth inside buildings

Floodwater Depth	Buildings Frequency	Percentage
Low (<30 cm)	11	21
Moderate (31-60cm)	13	25
High (>60 cm)	28	54
Total cases	52	100

Source: Fieldwork (2018)

The white dashed lines in Figure 21 show the floodwater levels of the 10 January 2019 flood event, (a) inside and (b) outside some of the buildings.

Figure 21: Floodwater level inside buildings
Source: Fieldwork (2019)

Figure 22 shows a map of floodwater levels outside the buildings in the study area. The floodwater levels outside the buildings were categorised in the map as *Shallow* (21.6 to 49 centimetres), *Moderate* (49 to 85.6 centimetres), *High* (85.6 to 122 centimetres), and *Extremely high* (158.7 to 297.9 centimetres).

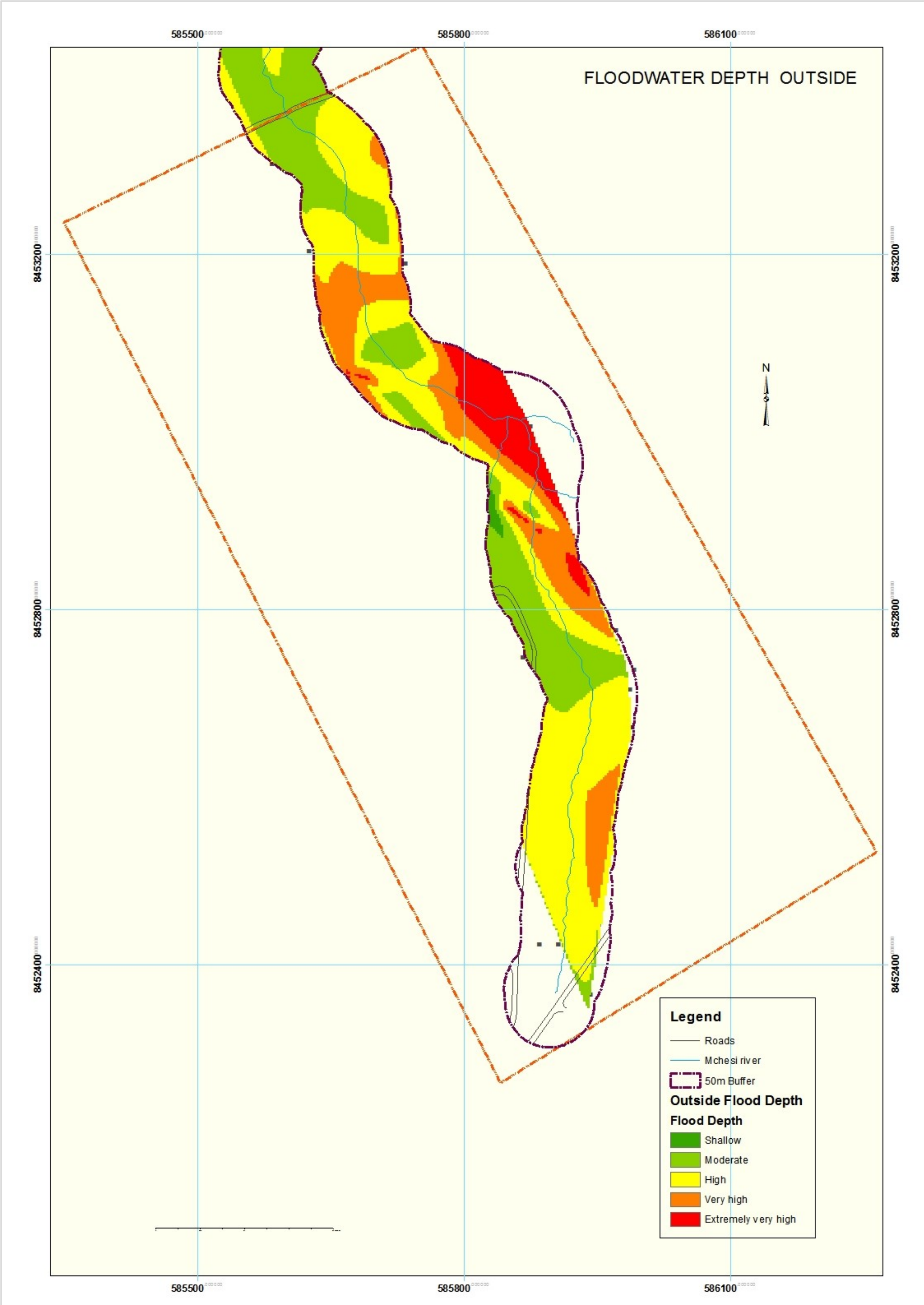

Figure 22: Floodwater level outside the buildings

Source*:* Fieldwork (2018)

ii. Duration of floodwater in the buildings

The results of the analysis show that relatively a high percentage of the buildings were inundated for more than 1 hour, with 15% of the buildings inundated for more than 6 hours. This may be due to high floodwater depth inside the buildings which may take more time to subside or leave the building. Table 15 presents the results.

Table 15: Floodwater duration inside the buildings

Floodwater duration	No. of buildings
None (0)	21% (11)
1-3hrs	38% (20)
4-6hrs	25% (13)
>6hrs	15% (8)

Source: Fieldwork (2018)

4.4.2.2 Flood damages on buildings and exposure factors

The results of the cross-tabulation analysis between exposure factors and flood damages show that there was some variability in how exposure factors influenced the degree of damage to buildings. The results of the analysis are presented in the subsequent subsections.

i. Elevation of surroundings of buildings and flood damages

The results in Table 16 show that buildings on both flat and gently sloping terrain registered a considerably high percentage of buildings with low damage (57% and 63% of buildings respectively). The buildings that were on flat terrain had a relatively higher percentage of buildings with high damage (29%) as compared to buildings on gentle slopes (15%).

ii. The proximity of buildings and flood damage

The results show that a relatively high percentage of buildings that were located both at distances of less than 30 metres and between 31 to 50 metres (61% and 62% of buildings respectively) from the river had low flood damage. Table 16 presents the results of the analysis.

Table 16: Exposure Factors and Building Damage Relationships

		Buildings damage class		
Exposure factors	Description	Low	Moderate	High
Elevation	Flat	57% (8)	14% (2)	29% (4)
	Gentle slope	63% (24)	21% (8)	15% (6)
Proximity to river	<30m	61% (19)	19% (6)	19% (6)
	31-50	62% (13)	19% (4)	19% (4)
Floodwater Depth	Low (<30 cm)	91% (10)	0% (0)	9% (1)
	Moderate (31-59 cm)	77% (10)	15% (2)	8% (1)
	High (over 60 cm)	44% (12)	29% (8)	29% (8)
Floodwater Duration	Less than 1hr	55% (6)	18% (2)	27% (3)
	2 to 4hrs	66% (19)	21% (6)	14% (4)
	More than 4hrs	58% (7)	17% (2)	25% (3)

Source: Fieldwork (2018)

iii. The floodwater depth inside the buildings and flood damage to buildings

The floodwater depth is one of the main flood characteristics used in most physical vulnerability analysis studies that use depth–damage or fragility curves (Sagala 2006; Uwakwe 2015; Van Westen 2013). The results in Table 16 show that 44% of the buildings that were inundated with high floodwater levels (over 60 cm) registered low damages and the buildings that were inundated with low floodwater depth had more (91%) buildings with low damages.

iv. Floodwater duration and damage to buildings

The floodwater duration and the degree of damage to buildings cross-tab analysis results show that 66% of the buildings that were inundated for more than two (2) hours had low damage. Table 16 presents the results of the analysis.

4.5 Assessment of Physical Vulnerability of Buildings and Contents

The Physical vulnerability assessment of buildings to flood relates to the degree of damage to the physical structure of buildings and the intensity of the floods (Van Westen 2013). The results of the analysis on the magnitude of damage to buildings and their contents and the relationship between physical vulnerability and exposure measures are presented in the following subsections.

4.5.1 Flood damage to buildings, contents, and outside property

Since different construction materials of buildings are impacted differently by floodwater (Banda 2015; Leal et al. 2020), the results of the analysis of damage to building types, contents, and outside property are presented in the ensuing subsections.

i. Damage to building typologies

The results of the analysis in Table 17 show that building Type 2 registered relatively high damages (38% of the buildings). However, the other building types had a low percentage of flood damage. Figure 23 shows a collapsed building due to flood impacts. Figure 24 shows a map of different magnitudes of damage of buildings, deep red dot represents buildings that registered high damage while light red dots show buildings with low damage.

Figure 23: Collapsed building
Source: Fieldwork (2018)

Table 17: Building typology and flood damages

Building typology	Buildings damage classes		
	Low	Moderate	High
1	69.2% (18)	15.4% (4)	15.4% (4)
2	50% (4)	12% (1)	38% (3)
3	57.1% (4)	28.6% (2)	14.3% (1)
4	63% (5)	25% (2)	12% (1)
5	33.3% (1)	33.3% (1)	33.3% (1)
Total Number of buildings =52			

Source: Fieldwork (2018)

ii. Flood damage to Contents

The results of the analysis in Table 18 show that all households living in different types of buildings suffered varying degrees of damage to building contents with households dwelling in building Type 4 having the highest percentage (63%) of damage or loss of contents.

Table 18: Building types and contents damage

Building typology	Contents damage classes		
	None	Low	High
1	8% (2)	50% (13)	42% (11)
2	0% (0)	50% (4)	50% (4)
3	0% (0)	43% (3)	57% (4)
4	0% (0)	38% (3)	63% (5)
5	33% (1)	33% (1)	33% (1)
	Total Number of buildings =52		

Source: Fieldwork (2018)

iii. Damage to outside property

The outside property that suffered flood damage was mostly kitchen utensils that were left outside during the flooding events and were swept away by floodwater. The other damage that occurred was on pit latrines and brick wall fences. The overall situation was that about 73.5% of the households did not lose or suffer damage to any outside property. Table 19 shows the results of the analysis of the damage to outside property that was damaged and the percentages of affected households.

Table 19: Loss of outside property

Outside Property Damaged /Loss	No. of Households
Livestock	2.4 % (2)
Fence	1.9% (1)
Kitchen utensils	8.4% (7)
Pit latrines	4.8% (4)
No property damage	73.5% (61)
No data	8.4% (7)

Source: Fieldwork (2018)

4.5.2 Analysis of damages and exposure factors

The damage scales of buildings in Table 5 were classified into five (5) classes and assigned damage ratios in Table 20. Damage classes (Table 20) were reduced (reclassified) to four classes and assigned vulnerability classes and ratios in Table 21. Figure 27 is a map showing the spatial distribution of the magnitude of damages on buildings (from “No damage to Collapsed” buildings) produced from Table 20.

Table 20: Building damage ratios

Damage classes	Damage ratios
No damage	0
Slight damages	0.13-0.25
Moderate damage	0.38-0.5
Severe damage	0.6- 0.8
Collapse	0.88-1.0

Source: modified from Reese & Ramsy 2010

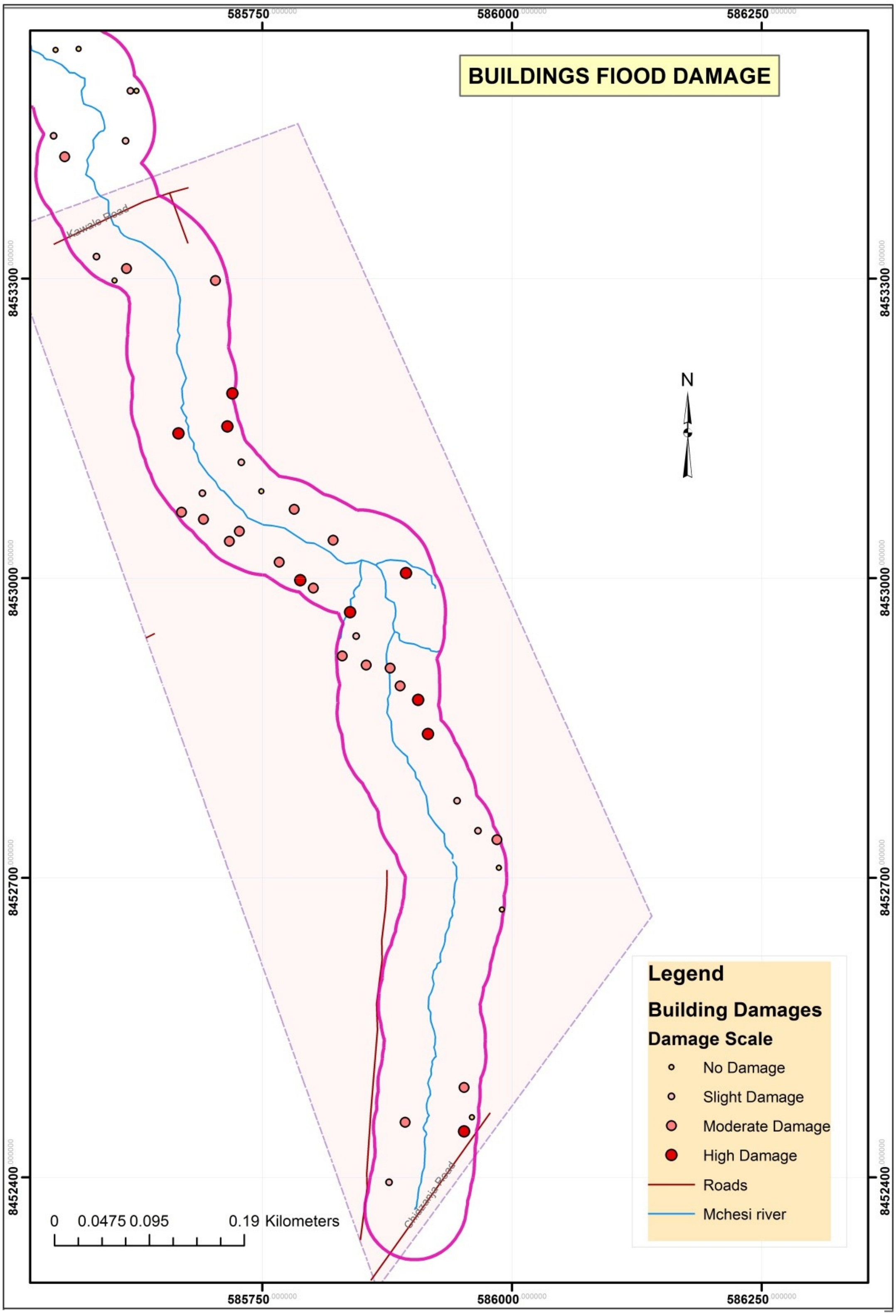

Figure 24: Damages of buildings

Source: Fieldwork (2018)

Table 22 is an extract of vulnerability classes and ratios from Table 21, and it was used in the analysis of the physical vulnerability of buildings.

Table 21: Flood damages and Physical vulnerability scales

Damage descriptions	Vulnerability class	Value of Vulnerability
No damage	No Vulnerability	0
Slight damage	Low Vulnerability	0.01– 0.31
Moderate	Moderate Vulnerability	0.4 - 0.71
Severe and Collapse	High Vulnerability	0.8- 1

Source: Fieldwork (2018)

Table 22: Physical vulnerability of building classes

Vulnerability class	Value of Vulnerability
No Vulnerability	0
Low Vulnerability	0.01– 0.31
Moderate Vulnerability	0.4 - 0.71
High Vulnerability	0.8- 1

Source: Fieldwork (2018)

4.5.2.1 Building typologies and physical vulnerability relationship

The results of the OLS spatial correlation between building typologies (as an explanatory variable) and physical vulnerability (as a dependent variable) in Table 23 show that there was a positive relationship between the physical vulnerability of buildings and building typologies with a statistically significant positive Coefficient value of 0.063399($p<.05$). The positive Coefficient value suggests that physical vulnerability was increasing relative to the order of increasing building typology number. For instance, building Type 1 had low vulnerability while building Type 5 had a high vulnerability. The Variance Inflation Factor (VIF) value was 1.061345 indicating that there was no redundancy among explanatory variables in the model (large VIF values >7.5 indicate redundancy among explanatory variables (ESRI, 1995-2019)). The Chi-square test results in Table 23 show that the building typologies had a strong influence on the vulnerability of buildings to floods, with Chi-square Pearson's Value- 91.4 ($p<.001$) and Crammer's V value was.602 which is close to 1 (Field, 2013). Dependent variable: Physical vulnerability of buildings.

Table 23: Buildings' physical vulnerability and exposure factors

Explanatory Variables	Coefficient	Probability [b]	Robust_Pr[b]	VIF
Building Typology	0.0634	0.0342 ($p<.05$)	0.0344	1.0613
Floodwater depth	0.0041	0.0002 ($p<.001$)	0.0000	1.0532
Floodwater duration	0.0022	0.6437	0.4816	1.0554
Proximity to river	-0.0775	0.1803	0.1393	1.0644

Independent Variables	Chi-square Value	df. value	Sig. Value	Crammer's V value
Building types	91.4	.15	.001 ($p<.001$)	.6
Floodwater depth	15	4	.004 ($p<.05$)	.3
Proximity to river	5.41	2	.763	.4
Flood duration	1.7	2	.421	.2

Source: Fieldwork (2018)

i. Building Type 1- Burnt bricks with cement walls and cement floors

There were 24 buildings in this class recorded from household interview data.

The results of the analysis show that building Type 1 was the least vulnerable. Table 24 shows that 44% of the buildings were not vulnerable to floods, 28% of the buildings had a low vulnerability, 16% of the buildings had a moderate vulnerability and 16% had a high vulnerability.

ii. Building Type 2- Burnt bricks in the earth (mud) mortar walls and cement floors

There were 8 buildings in this category from the household interview data. The Cross-tabulation analysis results show that a relatively higher percentage (38%) of buildings had high vulnerability. Table 24 shows the results of the analysis. The walls of this building type have weak resistance to floodwater due to the weak bond between burnt bricks and mud mortar (Malgwi et al., 2020).

iii. Building Type 3- Burnt bricks with mud/earth mortar walls and mud floors.

The analysis results show that 43% of the buildings were not vulnerable to floods; this could suggest that there were other factors at play since the wall materials for this building type are similar to the walls of the building Type 2. The results of the analysis are presented in Table 24.

iv. Building Type 4- Sun-dried bricks with mud or earth mortar walls and cement floors.

This category of buildings is less common and according to what was observed during buildings inventory, most of these buildings were on plots that were allocated by the City Council and hence over 30m from the river. The results show that 50% of the buildings had a low vulnerability, this can be attributed to some other factors. The results of the analysis are presented in Table 24.

v. Building Structure Type 5 – Sun-dried bricks in mud or earth mortar walls and earth floor.

This building type is uncommon among the building typologies and is perceived as having low resistance to floodwater hence expected to be of high vulnerability. Contrary to that, the Cross-tabulation analysis results presented in Table 24 show that there was an equal distribution of buildings in three categories of physical vulnerability (low, moderate and high). The results revealed that 33.3% of the buildings had a low vulnerability, 33.3% of the buildings had a moderate vulnerability and 33.3% of the buildings had high vulnerability classes. This can be attributed to less representative data of this building type, hence not giving a true reflection of their vulnerability status.

Table 24: Physical vulnerability and building types

Building typologies / Vulnerability Classes	Building Type 1	Building Type 2	Building Type 3	Building Type 4	Building Type 5
No vulnerability	42% (11)	25% (2)	42.8% (3)	13% (1)	0 (0%)
Low vulnerability	27 % (7)	25% (2)	14.2% (1)	50% (4)	33% (1)
Medium vulnerability	15% (4)	12% (1)	28.6% (2)	25% (2)	33% (1)
High vulnerability	15% (4)	38% (3)	14.2% (1)	13% (1)	33% (1)

Source: Fieldwork (2018)

4.5.2.2 Buildings' Physical Vulnerability and proximity to the river relationship

The Physical Planning guidelines stipulate that "an area of 15 to 30 metres from the river is protected" (GoM, 2014). It means that no development or construction of buildings is allowed within 15 to 30 metres distance from any river. The spatial statistics Ordinary Least Square (OLS) regression analysis results in Table 23 show that the relationship between the variables was statistically insignificant with a negative

Coefficient value -0.077483(p>.05), and a Probability [b] value of 0.180293. This implies that buildings' proximity to the river insignificantly contributed to the physical vulnerability of buildings. The negative Coefficient value indicates that there was a negative spatial relationship between the variables and it implies that the closer the buildings are to the river the more vulnerable it becomes. This was also evident in the gradient of the scatterplot, which was almost a zero gradient (horizontal line). The Chi-square association test results in Table 26 show that the proximity of buildings to the river had a weak influence on the buildings' physical vulnerability with Pearson's Chi-square Value of .541(p>.05) (agreeing with the spatial statistics (OLS) regression analysis outcome). The Cross-tabulation analysis results in Table 25 show that 32.3% of buildings that were located at a distance of less than 30 metres from the river were not vulnerable to flood impacts while 33.3% of buildings that were located at a distance of more than 30 metres from the river had a low vulnerability. In addition, 19.4% of buildings located at distances of less than 30 metres and more than 30 metres from the river had a high vulnerability to flood impacts.

Table 25: Proximity to the river and buildings' physical vulnerability

	Buildings per vulnerability class				
Proximity	None	Low	Moderate	High	Total
<30m	32.3% (10)	29% (9)	19.4% (6)	19.4% (6)	60% (31)
>30m	33.3% (7)	33.3% (7)	14.2% (3)	19% (4)	40% (21)

Source: Fieldwork (2018)

The results from Chi-square correlation test between physical vulnerability of buildings and individual building types presented in Table 26 show that the physical vulnerability of building Type 4 (with walls made of sun-dried bricks in mud mortar and cement floor) was significantly influenced by the proximity of the buildings to the river, with Pearson's Chi-Square value of 9.6 *(P<.05)*. Crammer's V test value was .73, which shows that the building types association between the two variables was strong as the value was closer to 1 (Field, 2013). The results of the correlations between the physical vulnerability of the other four building types and their proximity to the river (Table 26) revealed that the proximity of buildings to the river had an insignificant influence on their physical vulnerability.

Table 26: Building typologies and proximity to the river

Building typologies	Pearson's Chi-Square value	Degree of freedom (df.) value	Sig. value
1	1.7	4	.773
2	2.8	2	.240
3	5.3	2	.070
4	9.6	4	0.048 (p<.05)
5	3.0	2	.223

Source: Fieldwork (2018)

4.5.2.3 Relationship between Physical vulnerability of Buildings and floodwater depth (level) inside the buildings

The results of the OLS regression analysis in Table 27 show that the floodwater depth (inside the buildings) had a great influence on the physical vulnerability of buildings with a positive Coefficient value was 0.004088 (p<.01). The positive coefficient value indicates that there was a positive relationship between the variables, which means that the vulnerability of buildings increases as the floodwater level increases. The residual scatter plot indicated that the residuals were normally distributed and were not spatially auto-correlated (as shown by the spatial autocorrelation test). The results show that the model had a Variance Inflation Factor (VIF) value of 1.168978, which was not greater than 7.5; this indicates that there was no redundancy among explanatory variables (ESRI, 1995-2019). The scatter plot (Figure 25) had a positive steep slanting diagonal indicating a strong positive spatial correlation. The Chi-Square test results in Table 27 (which acted as a check to the OLS spatial correlation results), show that there was a statistically significant relationship with Pearson's Chi-Square value of 15 ($P<.01$) and Crammer's V association test result was .3 which shows that the relationship was moderate since the value is closer to half of 1 (Field 2013).

The relationship between the physical vulnerability of individual building types and floodwater levels results are in Table 27. The results revealed that floodwater level had a great influence on the vulnerability of building Type 1 (building with burnt bricks in cement mortar and cement floor) and building structure Type 4 (sun-dried bricks with mud mortar walls and mud/earth floor) with Chi-square values 9($p<.05$) and 10($p<.05$) respectively.

Table 27: Vulnerability of Building Types and Floodwater Depth

Building Types	Pearson's Chi-Square Value	Degree of freedom Value	Sig. value
1	9	4	.050 (p<.05)
2	17.5	20	.620
3	11.3	8	.184
4	10	4	.048 (p<.05)
5	.750	1	.386

Source: Fieldwork (2018)

4.5.2.4 Building types' physical vulnerability and floodwater duration

Spatial statistics OLS regression analysis between the building typologies (dependent variable) and floodwater duration (explanatory variable) results in Table 23 show that the relationship was statistically insignificant with a coefficient value of 0.000958 (p>.05) and Probability [b] value of 0.760. The VIF value was 1.055433 (not greater than 7.5) which indicates that there was redundancy among explanatory variables of the OLS model. The SPSS Chi-square test results in Table 23 show that the floodwater duration inside the buildings had an insignificant influence on the vulnerability of the buildings with Pearson's Chi-Square value 1.7 (p>.05), agreeing with the OLS statistical relationship results. The Chi-square test results for individual building Types in Table 28 revealed that floodwater duration had a significant influence on the physical vulnerability of building Type 1 and building Type 2. The results for the physical vulnerability of building Type 1 and floodwater duration were statistically significant with Pearson's Chi-Square value 47.8 (p<.05), and the correlation results for the physical vulnerability of building Type 2 and flood duration show that the relationship was also statistically significant with Pearson's Chi-Square value of 10 *(p<.01).* The Crammer's V test results for building Type 1 were Crammer's V Value of .499, while the vulnerability of building Type 2 and floodwater duration Crammer's V Value was 1. Both Crammers' V tests results indicate that there was a very strong relationship between the variables, which implies that the floodwater duration greatly influenced the vulnerability of the two types of buildings. The floodwater duration had an insignificant contribution to the vulnerability of building Type 3 and building Type 4 while the Chi-square test for the vulnerability of building Type5 and floodwater duration returned void due to constant floodwater duration.

Table 28: Floodwater duration and physical vulnerability of buildings

Building Types	Pearson's Chi-Square value	Degree of freedom (df.) value	Sig. value	Crammer's V value
1	47.8	28	.011 (p<.05)	.499
2	10	2	.007 (p<.01)	1
3	17.04	20	.650	.320
4	12.37	12	.416	-
5	-	-	-	

Source: Fieldwork (2018)

4.5.3. Building contents physical vulnerability assessment

The vulnerability scales of building contents in Table 5 were weighted with foundation heights and the possible weighted content vulnerability scales are presented in Table 29. The matrix of the weighted contents vulnerability scales (Table 29) was assigned vulnerability ratios presented in Table 30 that were used in the physical vulnerability assessment of contents.

Table 29: Weighted Content vulnerability by Foundation height

	Vulnerability Condition description	Weighted ratio
1	If Vulnerability content=0, and Foundation Class =High;	Vulnerability =0
2	If Vulnerability content=0 and Foundation Class = Moderate	Vulnerability =0.005
3	If Vulnerability content=0 and Foundation Class= Low	Vulnerability =0.01
4	If Vulnerability content= 0.1 and Foundation Class =High	Vulnerability =0.01
5	If Vulnerability content= 0.1 and Foundation Class =Moderate	Vulnerability =0.105
6	If Vulnerability content= 0.1 and Foundation Class = Low	Vulnerability =0.115
7	If Vulnerability content=0.2 and Foundation Class =High;	Vulnerability =0.2
8	If Vulnerability content=0.2 and Foundation Class = Moderate	Vulnerability =0.205
9	If Vulnerability content=0.2 and Foundation Class = Low	Vulnerability =0.215
10	If Vulnerability content=0.3 and Foundation Class = High	Vulnerability =0.3
11	If Vulnerability content=0.3 and Foundation Class = Moderate	Vulnerability =0.305
12	If Vulnerability content=0.3 and Foundation Class = Low	Vulnerability =0.31
13	If Vulnerability content=0.4 and Foundation Class =High	Vulnerability =0.4
14	If Vulnerability content=0.4 and Foundation Class =Moderate	Vulnerability =0.405
15	If Vulnerability content=0.4 and Foundation Class = Low	Vulnerability =0.41
16	If Vulnerability content=0.5 and Foundation Class = High	Vulnerability =0.5
17	If Vulnerability content=0.5 and Foundation Class = Moderate	Vulnerability =0.505
15	If Vulnerability content=0.5 and Foundation Class =Low	Vulnerability =0.51
16	If Vulnerability content=0.6 and Foundation Class = High	Vulnerability =0.6
17	If Vulnerability content=0.6 and Foundation Class = Moderate	Vulnerability =0.605
18	If Vulnerability content=0.6 and Foundation Class = Low	Vulnerability =0.61
19	If Vulnerability content=0.7 and Foundation Class = High	Vulnerability =0.7
20	If Vulnerability content=0.7 and Foundation Class = Moderate	Vulnerability =0.705
21	If Vulnerability content=0.7 and Foundation Class = Low	Vulnerability =0.71
22	If Vulnerability content=0.8 and Foundation Class = High	Vulnerability =0.8
23	If Vulnerability content=0.8 and Foundation Class = Moderate	Vulnerability =0.805
24	If Vulnerability content=0.8 and Foundation Class = Low	Vulnerability =0.81
25	If Vulnerability content=0.9 and Foundation Class = High	Vulnerability =0.9
26	If Vulnerability content=0.9 and Foundation Class = Moderate	Vulnerability =0.905
27	If Vulnerability content=0.9 and Foundation Class = Low	Vulnerability =1
28	If Vulnerability content=1 and Foundation Class = High	Vulnerability =1
29	If Vulnerability content =1 and Foundation Class = Moderate or Low	Vulnerability =1

Source: Fieldwork (2018)

Table 30: Building contents physical vulnerability ratios

Vulnerability class	Value of Vulnerability
No Vulnerability	0
Low Vulnerability	0.005 – 0.31
Moderate Vulnerability	0.4 - 0.71
High Vulnerability	0.8 – 1.0

Source: Fieldwork (2018)

4.5.3.1 Building types and physical vulnerability of building contents

The contents vulnerability ratios in Table 30 were correlated with building types, the proximity of buildings to the river, floodwater depth and duration and the results are in Table 31. The results show that there was a statistically insignificant relationship between the physical vulnerability of building contents and building typologies with the Chi-square Value was 5.6(p>.05). The results translate that the buildings' typologies insignificantly influenced the physical vulnerability of contents

Table 31: Contents Vulnerability and Exposure factors

Exposure factors	Pearson Chi-Sq. Value	df.	Sig. Value
Building typology	5.6	8	.689
Floodwater duration	8.018	2	. 018(p<.05)
Floodwater depth	10.154	4	.049 (p<.05)
Proximity to river	.634	2	.728

Source: Fieldwork (2018)

The results in Table 32 show that there was a proportionally small variation in the physical vulnerability of contents for all building Types. Building Type 4 (sun-dried bricks with mud mortar walls and cement floors) had the highest percentage (63%) of buildings with high vulnerability of contents to floods, 57% of building Type 3, 50% of building Type 2, 42% of building Type 1 and 33% of buildings in building Type 5 had high vulnerability of contents to floods. Figure 25 shows some of the building contents that were damaged by floods on 10 January 2019 flood event.

Table 32: Contents vulnerability per building types

Building Types	Contents vulnerability	
	Low	High
1	58%(15)	42%(11)
2	50%(4)	50%(4)
3	43%(3)	57%(4)
4	38%(3)	63%(5)
5	67% (2)	33% (1)
Total number of cases =52		

Source: Fieldwork (2018)

Figure 25: Some of the building contents damaged by floodwater
Source: Fieldwork (2019) January flood event

4.5.3. 2 Building contents vulnerability and floodwater duration inside the building

The floodwater duration initial classes (<1hr, 1 to 3hrs, 4 to 10hrs, and >10hrs) were reduced to two categories as l"<1hr" (less than 1 hour) and ">1hr" (more than 1 hour), the reasoning for reclassification was to reduce the number of cells with 0 values during Chi-square test. The results of the Chi-square test are in Table 33 and show that there was a significant relationship between the physical vulnerability of contents and floodwater duration. Pearson's Chi-Square value was 8.018 *(p<.05).* Crammer's V test was conducted to examine the strength of the relationship between the variables and the outcome was Crammer's V value was .393 which indicates that the relationship was moderate since .393 is closer to half of 1 (Field, 2013). The results suggest that the vulnerability of contents was influenced significantly by the duration of floodwater inside the buildings. The cross-tabulation analysis results between building contents vulnerability and floodwater duration inside buildings are in Table 32 and show that 55% of buildings that had contents inundated for more than 1 hour had a high vulnerability, 25% and 20% of buildings that were flooded for more than 1hrs had moderate and low vulnerability of contents respectively. The buildings that were inundated for less than 1 hour registered 58% and 42% of buildings with low and high vulnerability of contents respectively.

Table 33: Exposure factors and contents vulnerability correlation

Exposure factors	Chi-square Value	df. Value	Sig, Value	Crammer's V
Floodwater duration	8.018	2	0.018 (p<.05)	.393
Floodwater depth	10.154	4	0.038 (p<.05)	.312
Proximity to river	0.634	2	0.728	.110

Sources: Fieldwork (2018)

Table 34: Exposure Factors and Contents Vulnerability Distribution

Exposure factors		Contents Vulnerability Low	Moderate	High
Floodwater duration	Low (<1hr)	58% (7)	0% (0)	42% (5)
	High (>1hr)	20% (8)	25% (10)	55% (13)
Floodwater depth	Low (<10cm)	55% (6)	9% (1)	36% (4)
	Moderate (10 to 49cm)	31% (4)	39% (5)	31% (4)
	High (>50cm)	18% (5)	14% (4)	68% (19)
Proximity to river	<30metres	29% (9)	23% (7)	48% (15)
	30 to 50 metres	29% (6)	14% (3)	57% (12)

Sources: Fieldwork (2018)

4.5.3.3 Contents Vulnerability and the floodwater depth

The Floodwater depth scales (classes) were reclassified from the initial categories (<10cm as “Shallow”, 10 to 49cm as “Moderate”, 50 to 99cm as “High” and >100cm as “Very high”) to Low (less than 10cm), Moderate (10cm to 49cm) and High (more than 50cm) to <10 centimetres as *“Low”*, 10 to 49 centimetres as *“Moderate”* and >50centimetres as *“High”*. The reclassification was done to reduce the number of cells with no values during the Chi-square test. The results of the Chi-square association test between the contents vulnerability and floodwater depths in Table 33 show that there was a significant relationship with Pearson’s Chi-Square value of 10.154 *(p<.05)* and the Crammer’s V test had a value of .312 which indicates that the relationship was moderate since .312 is closer to half of 1 (Field, 2013). This suggests that the floodwater depth significantly influenced the vulnerability of building contents. The Cross-tabulation results in Table 34 show that 55% of buildings that had low floodwater levels had low vulnerability of their contents, 31% of buildings that were inundated with moderate floodwater levels had low vulnerability of their contents and 18% of buildings that had high levels of flood-water had low vulnerability of their assets. Figure 26 shows the map of building contents vulnerability with most of the building contents having high to moderate vulnerability (deep red dots on the map).

4.5.3.4 Contents vulnerability and proximity of buildings to the river

The results presented in Table 33 of the Chi-square analysis show that the relationship between the contents' vulnerability and the proximity of buildings to the river was statistically insignificant. Pearson's Chi-Square value was .634, df. Value 2, and Sig. value .728 ($p>.05$). This shows that there was a weak association between the vulnerability of building contents and the proximity of buildings to the river. The Cross-tabulation results in Table 34 show that 48% of buildings located at a distance of less than 30 metres from the river had high vulnerability of contents and also that 57% of buildings that were located between 31 to 50 metres had high vulnerability of their contents, this implies that the contents were vulnerable to flooding irrespective of the distance of buildings from the river. This could be attributed to a high percentage of buildings with low foundation heights of buildings in the study area (Figure 15).

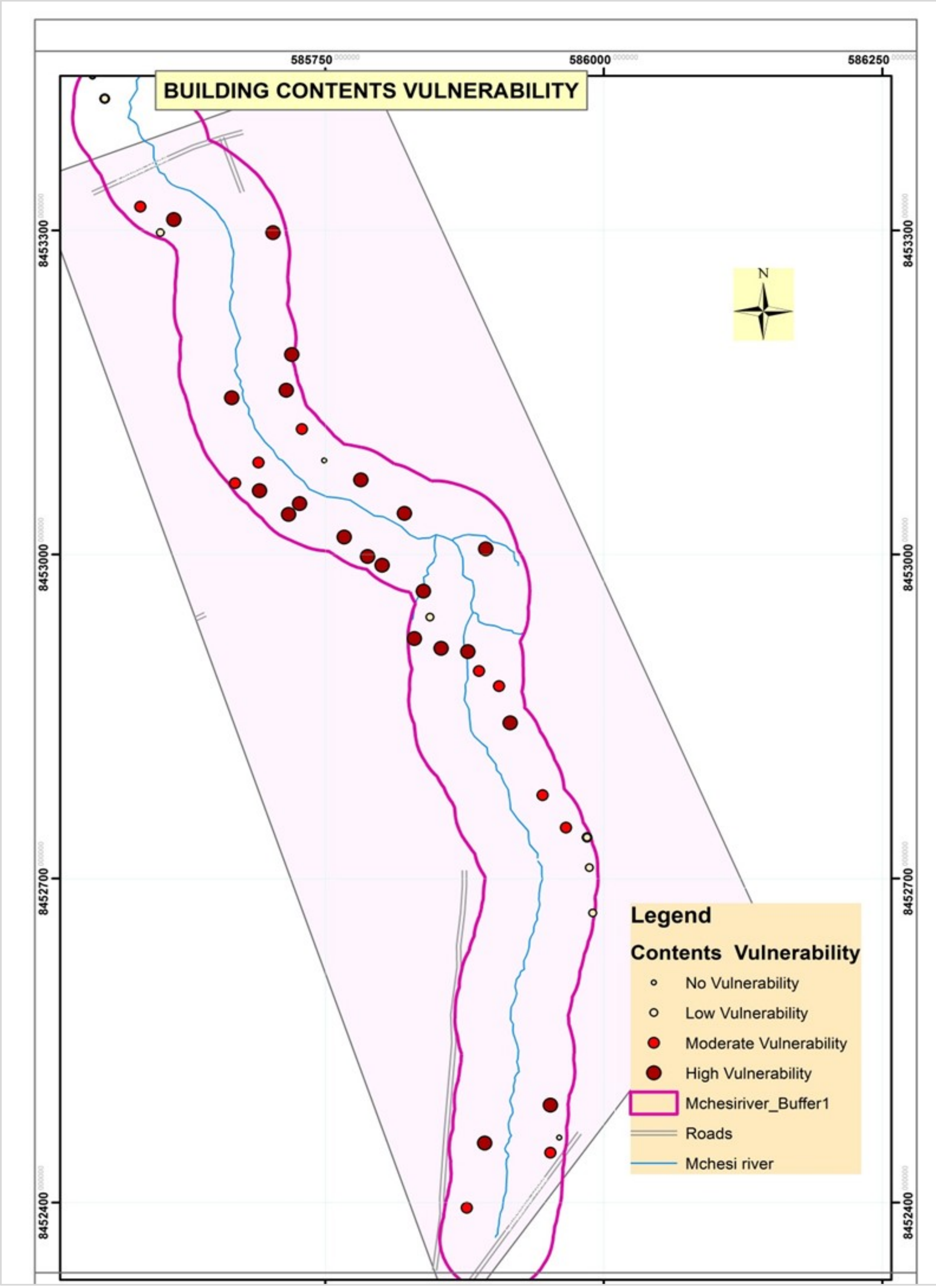

Figure 26: Contents vulnerability
Source: Fieldwork (2018)

4.5.4 Overall vulnerability of buildings

The overall physical vulnerability of buildings was a result of an aggregation of the physical vulnerability of buildings and contents (Table 22 and Table 30). The results of the analysis in Table 35 show that there was a variation in the overall physical vulnerability of buildings to floods with building Type 2 (burnt bricks and mud mortar walls and cement floors) having the highest percentage (38%) of buildings with high overall physical vulnerability. The results also reveal that 50% of building Type 1 (burnt bricks with cement mortar walls and cement floors) had low. The other interesting scenario is that of building Type 4 which had 63% of its buildings with moderate overall physical vulnerability and building Type 5 had 33% of its buildings with high, moderate, and low overall physical vulnerability.

Table 35: Physical Vulnerability of Buildings

Building Types	Overall Vulnerability		
	Low	Moderate	High
1	50% (13)	35% (9)	15% (8)
2	50% (4)	13% (1)	38% (3)
3	43% (3)	43% (3)	14% (1)
4	25% (2)	63% (5)	13% (1)
5	33% (1)	33% (1)	33% (1)

Source: Fieldwork (2018)

4.6 Assessment of the effectiveness of flood protection measures for buildings

The fourth specific objective of the study was to assess the effectiveness of flood protection measures and strategies applied to the buildings. This section discusses the results of the assessment of the effectiveness of building protection measures, analysis of household economic resources that aid in reconstruction and recovery activities (as coping capacity), and prevention measures for building contents from flood damage and loss.

4.6.1 Building structure protection measures

The study identified building protection and prevention measures presented in Table 36. The building protection measures were classified as structure, non-structural and reforestation of the river reserves measures (Van Westen 2016). In addition, economic resources from households that facilitate the development of building protection measures were also analysed. Blanco-Vogt & Schanze (2013) underline the requirement for analysing the economic resources for recovery or reconstruction activities for the coping capacity of buildings.

i. Structural measures

Structural protection measures also known as flood barricading (Plessis & Viljoen 1999) are measures employed to protect buildings from flood damage. The measures are the choice of building construction materials and foundation elevation (Van Westen 2016). It was observed that some buildings had more elevated foundations (Figure 17) than others and other buildings were constructed using durable construction materials. On the choice of flood-resistant building materials as a structural protection measure, it was found that 61% of buildings had walls constructed with burnt bricks and cement mortar (Table 7). The results of the analysis are presented in Table 35 and show that 29% of the buildings that had low damage were constructed with burnt bricks and cement mortar walls, 14% of buildings with low damage were constructed with burnt bricks and mud mortar walls, and 19% of buildings that had low damage were constructed with sun-dried bricks with mud mortar walls. The results on foundation heights (Table 36) show that 78% of the buildings with high foundation elevation (> 70 centimetres) had low flood damage and none of the buildings suffered high damage. The results also show that 33% of buildings with moderate foundation height (39 to 69 centimetres) and 16% of buildings with low foundation heights (< 39 centimetres) suffered high damage.

Table 36: Building Protection measures and building flood damages

Building protection measures		Building damage grades		
Structural	Description	High	Moderate	Low
Wall material Types	Burnt bricks and cement mortar/ durable wall materials	12% (6)	15% (8)	29% (15)
	Burnt bricks and mud mortar	6% (3)	2% (1)	14% (7)
	Sun-dried bricks and mud mortar	2% (1)	2% (1)	19% (10)
Foundation height	High (>70cm)	0% (0)	22% (2)	78% (7)
	Moderate (39-69cm)	33% (6)	17% (3)	50% (9)
	Low (<39cm)	16% (4)	20% (5)	64% (16)
Non-structural and Structural	Protecting building surrounding/area and durable wall materials	10% (5)	10% (5)	25% (13)
Non-structural	Protecting buildings surrounding areas	6% (3)	4% (2)	19% (10)
Re-afforestation of flood plain or river reserve	Planting trees in the river reserve to reduce run-off, stabilise river reserves and modify the behaviour of the floods	12% (6)	12% (6)	15% (8)

Source: Fieldwork (2018)

ii. Non-structural measures

The non-structural measures are applied to protect the building site/area through the blocking of floodwaters, such as drainage improvement or building water retention zones (CHARIM 2016). The non-structural measures were constructing barriers such as brick fences, and terraces along the riverside, digging storm drains around the buildings, and laying sand and stone bags along the riverside to keep floodwater from entering the houses (Van Westen 2016). It was also observed that most of the buildings had multiple protection measures and some employed re-afforestation on the river reserve. Therefore, it was not possible to evaluate the effectiveness of individual non-structural measures in isolation from others. The results of the cross-tabulation analysis (Table 36) show that the buildings that employed more than one building protection measures registered a low damage percentage. Table 36 shows that 25% of the buildings that had both structural and non-structural protection measures experienced low damage, 19% of buildings that had non-structural building protection measures only registered low damage on buildings, 4% of buildings that had structural protection measures only recorded low damage and 14%of buildings that did not have any protection measure suffered low damage. Re-afforestation on flood plains or riverbanks modifies the behaviour of floods (Van Westen 2016). The cross-tabulation analysis results for the effectiveness of re-afforestation in reducing flood damage show that 15% of buildings that had re-afforested the riverbanks suffered low damage, 12% of buildings had high damage and 12% of buildings had moderate damage. Figure 27 shows some of the building protection measures that were employed. The figure shows (a) Terraces, brick fences, and grass (b) Sandbags, trees, and bamboo (c) vegetation, storm drain, and brick wall fence (d) storm drain, bamboo and trees along the riverside.

Table 37: Buildings' protection measures

Source of data	Type of protection and measures	Actions applied	Rationale for choice	Literature
Building inventory, field observation, and household interviews.	-Structural measures (Measures to modify flood behaviour).	Re-afforestation to reduce surface run-off and stabilise river banks.	Measures to modify the behaviour of floodwater (to reduce rainwater run-off and stabilise the river banks or flood plains).	The Geneva Association (2020); Van Westen (2016); Fatemi et al.(2020); Cordero et al.(2017); Mirarajkar(2021)
	-Buildings structural and non-structural measures or coping mechanisms of structural type of buildings (modifying the buildings and the surroundings).	-Structural protection measures: raising foundation and construction using flood-resistant materials, applying cement plaster on walls of the buildings with cement, and enhancing the foundation of buildings. -Non-structural measures: elevating surroundings of buildings (e.g. verandas), digging storm drains to direct floodwater away from the buildings, constructing a barrier between the structure and the source of flooding (e.g. brick fences), heaping sandbags, using flood-proof materials (e.g. covering walls of the buildings with plastic sheets).	Ensure structural integrity is maintained (measures to modify the building's resistance to flooding and actions undertaken on the surroundings of the buildings to keep floodwaters out.	Van Westen(2016), Sagala (2006):Fatemi et al.(2020); Cordero et al.(2017);
Data from Key Informants: (DoDMA, Malawi Red Cross, Civil Protection Committee members)	• Buildings' structural and non-structural measures (modifying the buildings and the surroundings).	Structural measures: Rebuilding or repairing buildings with flood-resistant building materials; Raising the foundation of buildings during reconstruction (modification of building structure).	Ensure structural integrity is maintained.	Sagala (2006);Fatemi et al.(2020); Cordero et al.(2017); Mirajkar (2021)
	Coping strategies or temporary flood proof measures.	Non-structural measures: Piling sandbags, digging storm drains, covering walls of buildings with plastic sheets, and cleaning storm drains.	Keeping out the floodwater from buildings and lessening damages.	Sagala (2006):Fatemi et al.(2020); Cordero et al.(2017); Mirajkar (2021)

Source: Fieldwork (2018)

Figure 27: Some of the building protection measures
Source: Fieldwork (2018)

4.6.2 Coping Capacity of Buildings

The socioeconomic status of the inhabitants of the buildings has implications on the choice of building protection and prevention measures (Blanco-Vogt & Schanze 2013). For instance, the choice of flood resistance and durable construction materials and modification of buildings requires many resources (Sagala 2006). On the other hand, the use of construction materials that can easily be damaged by floods not only increases the vulnerability of inhabitants of buildings but also increases their economic burden by repairing and reconstructing buildings and replacing assets (ibid.). Since the physical vulnerability of buildings and contents is one of the determinants of the vulnerability of the inhabitants (Fatemi et al. 2020), "it is important to analyse the economic resources for the recovery or reconstruction of buildings activities" (Blanco-Vogt & Schanze 2013, p. 21077). To investigate the effectiveness of the building protection measures in reducing the physical vulnerability of buildings, the monthly income of households (economic resources) was correlated with the building protection measures employed. The correlation results in Table 38 show that there was a statistically significant association between the monthly income of households and building protection measures with Sig. Value .001(p<.001). The Cross-tabulation analysis results in Table 38 show that 57% of households whose monthly income was between MK30,000 to MK60,000 were housed in the buildings that had all three building protection measures, 29% of households with monthly income between MK61,000 to MK100,000 resided in buildings that had all building protection measures, and 14% of households with monthly income over MK100,000 lived in buildings applied with all three types of building protection measures. This may suggest that most of the least monthly income households had experienced more flooding in the area or were aware of the flood risk hence employing the protection measures.

Table 38: Household Income and the Building Protection Measures

	HH income per month (MK)			
Protection measures	30000 -60000	61000-100000	>100,000	No data
All measures	57% (4)	29% (2)	14% (1)	0% (0)
Reforestation and non-structural	50% (1)	0% (0)	0% (0)	50% (1)
Structural and Non-structural	63% (22)	17% (6)	20% (7)	0% (0)

Pearson's Chi-square value	df. Value	Significant value
22.361	6	.001(p<.001)

Source: Fieldwork (2018)

4.6.3 Protection Measures for Building Contents

The household interview data revealed that some households sought refuge from relatives and neighbours and took with them their valuable assets for safety while some households reported that they remained in their houses but had placed their valuable assets on raised or high places like on top of tables. Cross-tabulation analysis results in Table 39 show that 42% of households that placed their contents in high places suffered low damage, 50% of households that moved their contents to neighbours or relatives had low damage while 50% of households that sought refuge to neighbours and relatives had suffered high damage. This may suggest that the households did not move all their assets to either high places or neighbours and hence still recorded damages.

Table 39: Flood Prevention Measures and Contents Damage

	Contents damage classes			Total buildings
Prevention measures	Low	High	None	
Placed on a higher place	42% (10)	46% (11)	13% (3)	24
Moved to neighbours	50% (14)	50% (14)	0% (0)	28

Source: Fieldwork (2018)

4.7 Assessment of overall physical vulnerability and protection measures

The section presents the results of the Cross-tabulation analysis between building protection, coping capacity measures, and overall physical vulnerability of buildings.

4.7.1 Buildings' protection measures and overall physical vulnerability

The results of the cross-tabulation analysis show that more buildings with both structural and non-structural protection measures had a low overall physical vulnerability. Table 40 presents the results and shows that 78% of the buildings that had low overall physical vulnerability were applied with both structural and non-structural protection measures and 22% of buildings with low overall physical vulnerability had all three protection measures (structural, reforestation, and non-structural). The findings imply that the choice of durable building materials coupled with the actions undertaken on the surroundings of the buildings greatly reduced the vulnerability of buildings. However, the Chi-square test results show that there was a weak correlation between overall physical vulnerability and building protection measures with Pearson's Chi-square value of 5.005, df. value 4, and Sig. value .287 (p>.05), this suggests that the protection measures were not effective.

Table 40: Overall vulnerability and Protection measures

Protection measures	Buildings' Overall Vulnerability		
	Low	Moderate	High
All measures	22% (4)	6% (1)	20% (2)
Reforestation and non-structural	0% (0)	13% (2)	0% (0)
Structural and Non-structural	78% (14)	81% (13)	80% (8)
Total Cases=52			

Source: Fieldwork (2018)

4.7.2 Coping capacity and overall physical vulnerability of buildings

The type of the building or house one lives in is an economic indicator of the household (Subasinghe & Kawasaki 2021) and the socioeconomic status of the inhabitants of the buildings has implications on the choice of building protection and prevention measures (Blanco-Vogt & Schanze 2013). Chi-square correlation test results show that the association between households' monthly income had a statistically insignificant influence on the overall physical vulnerability of buildings with Pearson's Chi-square Value 10.089, df. Value 6 and Sig. Value .121(p>.05). The Cross-tabulation analysis results presented in Table 41 show that all buildings (100%) with high overall physical vulnerability belonged to households with monthly income between MK30,000 to MK 60,000 and 30% of buildings that had low overall vulnerability were inhabited by households whose monthly income was more than MK100,000.

Table 41: Overall physical vulnerability and Monthly Income

Overall Vulnerability	Household monthly income (MK)			
	30000-60000	61000-100000	>100000	No data
Low	48% (11)	17% (4)	30% (7)	4% (1)
Moderate	53% (10)	26% (5)	16% (3)	5% (1)
High	100% (10)	0% (0)	0% (0)	0% (0)

Source: Fieldwork (2018)

4.8 Conclusion

This chapter has discussed the results of the analyses. The results on the characterisation of key elements at risk show that the buildings constructed of burnt bricks in cement mortar and cement floors were common in the study area. The exposure analysis revealed that buildings were exposed to floods in different magnitudes regardless of their proximity to flood-prone zones and the elevation of the surroundings of buildings influenced the degree of exposure of buildings to floods. The assessment of the physical vulnerability of buildings revealed that building types and floodwater depth greatly influenced the physical vulnerability of buildings. The building protection measures were fairly effective mostly for the buildings that had all three - structural, non-structural and reforestation as protection measures.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter discusses the findings of the study in relation to the findings in the relevant literature that was reviewed.

5.2 To characterise key elements at risk of flooding

It was established that five types of residential buildings and their contents were key elements at risk and the most common building type was Type 1 (constructed with burnt bricks and cement mortar walls and cement floors). The findings may suggest that the inhabitants of the study area are aware of the flood risk hence the choice of construction materials that are durable and permanent. The findings agree with the study of Ngoma et al. (2019, p.65), which found that "the use of fired bricks and cement mortars is increasing in the urban areas." Ngoma et al. (2019) also found six building typologies for seismic vulnerability in Malawi.

5.3 To analyse the exposure of buildings to flood hazards

"Exposure is when people, property, systems or other elements are present in hazard zones that are thereby subject to potential losses" (UNISDR, 2009: pg. 21). The study established that more buildings (more than 90%) were inundated with one or two flood events irrespective of their locational characteristics (terrain elevation and proximity to river). However, it was also found that a high percentage of buildings on flat terrain suffered more damage than those on gentle slopes, this may imply that the buildings on the flat terrain were highly impacted since floodwater flows with less resistance on flat land than flowing upland on gentle terrain. It may also suggest that other factors may have contributed to the damage of buildings on flat terrain, for example, floodwater velocity and pressure (which were not used in the present study due to the nonavailability of data) as Kreibich et al. (2009) noted that the damage to buildings structure is always the consequence of both water depth and flow velocity**.** The findings agree with the study of Leal et al. (2021) which found that the exposed buildings have different intensities of physical impact due to their location in flood-prone areas. Regarding exposure of buildings based on their proximity to the river, it was revealed that buildings that were close (less than 30 metres) and far (31 to 50 metres) from the river were indiscriminately inundated by either one to two flood events. The findings did not agree with the Land Use Planning and Development Management Guidelines and Standards (GoM 2014) which set areas between 15 to 30 metres from the river (river reserves) as safe for development. Additionally, more buildings that were located both at a distance of less than 30 metres and between 31 to 50 metres from the river had low damage, this may imply that the distance stipulated in the Land Use Planning and Development Management Guidelines and Standards (GoM 2014) as safe for development are not. The findings agree with the findings of the study by Banda (2015) which found that the proximity of buildings had an insignificant influence on the damage to buildings due to floods. The findings may also suggest that there might be other factors at play, like the use of flood-resistant building materials, the use of multiple building protection measures and that the buildings were on raised ground, among others. Going to flood characteristics, it was established that more than half (54%) of the buildings were inundated with high floodwater depth (over 60 centimetres). Furthermore, the buildings that were inundated with low floodwater levels had low damages while those flooded with high levels had relatively high damages. The findings agree with the study of Papathoma-Köhle et al. (2007) which found that the degree of damage or loss was dependent on process intensity, for example, low flood depth would result in low flood damage and vice versa.

5.4 To assess the physical vulnerability of buildings and contents

Buildings are affected by flood hazards due to their poor quality, vulnerable physical location, flood hazard intensity, and ineffective protection measures (Fatemi et al. 2020).

The study established that the building typology and floodwater depth had a statistically significant correlation with the physical vulnerability of buildings, this implies that the two variables greatly contributed to the physical vulnerability of buildings. The results are in line with the studies of Sagala (2006), Uwakwe (2015), Fatemi et al. (2020), and Leal et al. (2021) which found that the quality of building materials determines the resistance of buildings to flood physical vulnerability and that the intensity of damaging agent (floodwater) increases the flood impact on buildings (Malgwi et al. 2020). Further, the correlation between the physical vulnerability of buildings and the proximity of buildings had a weak relationship, which suggests that the physical vulnerability of buildings was not influenced by their proximity to inundation areas, this contradicts the Land Use Planning and Development Management Guidelines and Standards (GoM 2014). Going to individual building types, it was established that the relationship between floodwater depth inside buildings and the physical vulnerability of building Type 1 (made of burnt bricks with cement mortar walls and cement floors) and building Type 4 (constructed with sun-dried bricks and mud mortar walls and cement floors) were statistically significant, suggesting that the floodwater level greatly contributed to the physical vulnerability of the two building types. This agrees with the study of Leal et al. (2021) which found that high floodwater depth increases hydrostatic pressure on the exposed durable buildings resulting in high vulnerability. This however, contradicts the findings of Fatemi et al. (2020), and Sagala (2015) that the vulnerability of a building type is mainly determined by the construction materials used. The building Type 1(made of burnt bricks with cement mortar walls and cement floors) is considered a permanent building (Ngoma et al. 2019) or durable building structure, so for its physical vulnerability to be influenced by floodwater depth, may suggest that there were other contributing factors which can be, for instance, low building foundations, age of the buildings and other flood characteristics like flow velocity, and debris among others which were not used in the analysis. The findings of the correlation of proximity of buildings to the river and their physical vulnerability revealed that the physical vulnerability of building Type 4 (constructed with sun-dried bricks and mud mortar walls) was statistically significant, this suggests that the physical vulnerability of the building Type4 was greatly influenced by their proximity to the inundation area. It was further established that the physical vulnerability of building type1 (burnt bricks with cement mortar walls and cement floors) and building Type2 (burnt bricks with mud mortar and cement floors) was influenced by floodwater duration. This suggests that the longer the floodwater stayed in these building Types, the more they were vulnerable to damage due to floods. This could be more prominent with building Type2 whose mortar is mud which tends to absorb more flood water when exposed to floodwater for a long time compromising the building's resistance in the process. This agrees with the findings of a study of Uwakwe (2015) which established that some exposed buildings were weakened or distorted in shape due to long periods of inundation of walls and floors by floodwater and also by the impacts of hydrodynamic forces that come with floodwater while other buildings withstood the pressures.

The damage to contents is linked to floodwater entry and level into the buildings (Rees and Ramsy, 2010). The spatial analysis results revealed that the foundation of buildings had a great influence on the physical vulnerability of contents, the findings suggest that building contents from a raised high foundation of the building were not impacted by floodwater conversely, contents from buildings with low foundation were vulnerable to flood damage. The findings are in line with the studies of Sagala (2006) and Rees and Ramsy (2010) which found that building contents from buildings with one-storey and low foundations had high vulnerability, unlike contents in buildings with raised foundations or two-storey buildings. It was established that there was a statistically weak association between the physical vulnerability of contents and building Types, this may suggest that the exposed buildings could be resistant to flood impacts while they had low foundation heights causing floodwater to enter and inundate the contents. The other explanation could be that the inhabitants of the exposed buildings developed protection measures after experiencing flood events, consequently, the contents of the building had low damage (Komolafeet al 2019). Going to flood characteristics, it was revealed that floodwater depth and duration had a statistically strong correlation with contents vulnerability, this suggests that the contents vulnerability was greatly influenced by the two variables. The other factor could be that most of the building's foundation heights were low making the floodwater have easy entry into the buildings. The contents that were in the buildings with high foundations were safe since high foundation heights deter floodwater entry into the house hence reducing the physical impact of contents.

5.5 To assess the effectiveness of building protection measures

The study established that most of the buildings had multiple building protection measures such as local structural, reforestation, and non-structural measures since households were aware of flood risk (had been experiencing flooding). It was revealed that the buildings that had all three protection measures (structural, reforestation, and non-structural measures) and those that had applied structural and non-structural protection measures had a low overall physical vulnerability, while buildings with non-structural and reforestation as protection measures had a moderate overall vulnerability. This may suggest that structural measures (including choice of flood-resistant building materials, and raising the foundation of buildings among others) were key in reducing the flood impacts, this agrees with the study of Sagala (2006) which found that houses which had modified walls, foundations and floors with flood resistant materials had low damages. On the correlation between building protection measures and the overall vulnerability of buildings, it was established that there was a weak correlation which means that the measures were not effective. This suggests that the building protection measures could not reduce the overall vulnerability of buildings. This was evident during the 10 January 2019 flood event where some brick fences that were erected to protect the buildings and their inhabitants had collapsed, even trees, bamboo and grass could not withstand the pressure of floodwater. The findings agree with the study of Mülleret al (2011) which found that protection measures were not effective in reducing the physical vulnerability of buildings to floods. Additionally, the relationship between the household monthly income and overall physical vulnerability of buildings revealed that all households with the least monthly income were dwelling in buildings that had a high overall physical vulnerability. This is a true reflection of the study area which is a low-income area, since the richer people can construct buildings that can withstand floodwater while low-income earners use inexpensive, locally found construction materials that cannot resist the pressure of floodwater and can be damaged, and collapse (Fatemi et al. 2020; Leal et al. 2021) after being inundated by floods. The findings agree with the findings of Yang et al. (2018) and Sagala (2006) that households with low monthly income suffer more losses and damages because they have low adaptive capacity. Wisner et al. (2003, p.9) noted that “the poor live in flimsier houses than the rich and they are more vulnerable.”

5.6 Conclusion

This chapter has discussed the findings of this research based on the research objectives. The results of the characteristics of buildings and contents, the extent of flood impact on buildings and their contents, their physical vulnerability, and the effectiveness of protection measures for buildings. The next chapter presents the conclusion and recommendations of the findings of the study.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations of the study.

6.1 Conclusion

The study aimed to assess the physical vulnerability of buildings to floods in the low-income settlements of Biwi and Kawale1 in Lilongwe City. To achieve the main objective of the study, four research questions were answered and are discussed in the following subsection.

The first question was, *What are the key elements at risk of flooding for physical vulnerability assessment in low-income settlements of Kawale and Biwi in Lilongwe City*, to respond to this question, detailed data was collected from randomly selected 83 participants during building inventory and 52 participants during household interviews. The data was used to identify key elements at risk. The study identified residential buildings and contents as key elements at risk. Buildings were further characterised based on construction materials for walls and floors to typify them for physical vulnerability assessment, consequently, five building Types were found from household interviews. It is, therefore, concluded that the key elements at risk were five types of residential buildings and their contents.

The second question was *what proportion of buildings is exposed to flood hazards?* The study revealed that over 90% of buildings were exposed to flooding irrespective of their locational characteristics, and most (91%) households reported having experienced one to two flood events with over half of the buildings being inundated with high floodwater levels (more than 60 centimetres). It was concluded that all buildings in the study area were exposed to flooding of different intensities irrespective of their locations.

The third question was *how vulnerable are different types of buildings to flood events.* To respond to this question, the physical vulnerability ratios of buildings were correlated with building typology and exposure factors (proximity of buildings to the river, floodwater depth and duration). The study revealed that the typology of buildings significantly influenced their vulnerability, with building Type2 (burnt bricks with mud mortar walls and cement floor) having high vulnerability and building Type1 (burnt bricks with cement mortar and cement floor) having low vulnerability. The correlation between exposure factors and the physical vulnerability of buildings revealed that there was variation in how the exposure factors contributed to the physical vulnerability of buildings. Therefore, it was concluded that building Type1 and type2 had a low and high physical vulnerability to flooding respectively. Besides that, there was variation in how exposure factors influenced the physical vulnerability of building Types.

The fourth research question was *how effective are the building protective measures in reducing the physical vulnerability of buildings?* To answer this question, the building protection measures employed in the study area were categorised into structural (choice of construction materials and building modifications), non-structural (measures applied to protect the building site/area through the blocking of floodwaters) and reforestation of the riverbanks as a way of reducing run-off, stabilising the riverbanks and controlling the flood velocity. It was established that the relationship between the overall physical vulnerability of buildings and building protection measures was statistically insignificant. It is concluded that building protection measures were not effective in reducing the overall physical vulnerability of buildings and that the financial resources of the households (monthly income) had a bearing on the overall physical vulnerability of buildings.

The overall conclusion of the study is that the building materials greatly influenced the physical vulnerability of buildings as evidenced by the correlation analysis. However, all the buildings in the study area were exposed to floods regardless of the locational and flood characteristics, this may suggest that other flood characteristics like flood velocity and volume of sediments in floodwater played a role in the physical vulnerability of buildings, more so considering that the two bridges at Chidzanja and Kawale roads act as bottlenecks to the flow of floodwater. The approach of the assessment of the physical vulnerability of the buildings was consistent with advocates of inclusion of physical vulnerability of buildings and coping or protection strategies assessments in the vulnerability assessments. Additionally, the assessment of the physical vulnerability of buildings is a catalyst for flood risk reduction.

6.2 Recommendations

This section discusses the recommendation of the study based on the conclusion of the findings.

The first task was to characterise elements at risk in the study area. To this effect, the study established that most of the buildings in the study area were constructed with burnt bricks with cement mortar and roofed with corrugated iron sheets. These types of buildings are classified as permanent buildings and are regarded as relatively durable and strong. The study, therefore, recommends that all buildings should be constructed with durable and flood-resistant materials in areas that are beyond 30 metres from the river to reduce the loss of lives and household property.

The exposure analysis revealed that all buildings in the study area are exposed to flooding regardless of the locational Table 42: Buildings Protection and prevention measures from flood hazards of the surroundings of the buildings and flood intensity, the study recommends that buildings that are in recommended locations (beyond 30 metres from the river) should have raised foundations to deter floodwater from entering the homesteads.

The study established that the variation in the physical vulnerability of buildings could not be better explained based on the exposure factors used in this study alone, it is recommended, therefore, that further research should be conducted on the physical vulnerability of buildings in flood-prone areas in the whole City of Lilongwe with enough data about flood characteristics and building materials that can support citywide land-use planning and flood risk prevention and mitigation

In addition, the study recommends that local structural and non-structural building protection measures should be enhanced to increase their effectiveness in protecting the buildings and the inhabitants from flood impacts.

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APPENDIX

APPENDIX A: ETHICAL APPROVAL

MZUZU UNIVERSITY

DIRECTORATE OF RESEARCH

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
MALAWI
TEL: 01 320 722
FAX: 01 320 648

MZUZU UNIVERSITY RESEARCH ETHICS COMMITTEE (MZUNIREC)

Ref No: MZUNIREC/DOR/23/40 **12/04/2023.**

Chresceuntia Matambo,
Mzuzu University,
P/Bag 201,
Luwinga,
Mzuzu 2.

cmsasa@mubas.ac.mw

Dear Chresceuntia Matambo,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL REF NO: MZUNIREC/DOR/23/40: ASSESSMENT OF PHYSICAL VULNERABILITY OF BUILDINGS TO FLOODING IN LOW-INCOME AREAS OF LILONGWE CITY: CASE OF KAWALE1 AND BIWI

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the Mzuzu University Research Ethics Committee (MZUNIREC) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee with a final report of the study. The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Committee Address:
Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2; E-mail address: mzunirec@mzuni.ac.mw

Wishing you a successful implementation of your study.

Yours Sincerely,

Gift Mbwele
SENIOR RESEARCH ETHICS ADMINISTRATOR
For: CHAIRMAN OF MZUNIREC

Committee Address:
Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2; E-mail address: mzunirec@mzuni.ac.mw

APPENDIX B: INFORMED CONSENT

Informed Consent Form

Mzuzu University Research Ethics Committee (MZUNIREC)

Informed Consent Form for Research in Assessment of Physical Vulnerability of buildings to flooding in low-income areas: Case of Kawale1 and Biwi in Lilongwe City.

Introduction

I am **Chresceuntia Matambo-Msasa** from the Department of Built Environment, Faculty of Environmental Sciences. I am doing research on the **Assessment of the Physical Vulnerability of buildings to flooding in low-income settlements of Kawale1 and Biwi in Lilongwe City.** This consent form may contain words that you do not understand. Please ask me to stop as we go through the information and I will take time to explain. If you have questions later, you can ask them to me or another researcher.

Purpose of the research

This research aims to assess the physical vulnerability of buildings to flooding in low-income areas of Kawale1 and Biwi in Lilongwe City.

Type of Research Intervention

This research will involve your participation in an individual/ household interview.

Participant Selection

You are being invited to take part in this research because you are a resident of this area and may have experienced Mchesi river flood events and their impacts.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. If you choose not to participate nothing will change. You may skip any question and move on to the next question.

Duration

The research takes place for **2 years**.

Risks

You do not have to answer any questions or take part in the interviews if you feel the question(s) are too personal or if talking about them makes you uncomfortable.

Reimbursements

You will not be provided with any incentive to take part in the research.

Sharing the Results

The knowledge that I will get from this research will be used for academic purposes and will be shared with universities with similar programmes (like Geographic Information

Systems, Urban Planning, and /or Disaster-related programmes). Following, the results will be reported as a thesis for academic purposes.

Who to Contact

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact: Ms. Chresceuntia Matambo Msasa, Mzuzu University, P/B 201, Luwinga, Mzuzu. Cell: +265(0)999 248 895 or Associate Prof. Mtafu Manda, Mzuzu University, P/B 201, Luwinga, Mzuzu 2. Cell: +265(0) 991 457 272.

APPENDIX C: DATA COLLECTION TOOLS

i. BUILDING SURVEY/INVENTORY

INVENTORY FORM

AREA/TOWNSHIP...

BLOCK LEADER NAME... DATE...............................

Building ID	UTM Coordinates		Wall type	Floor material type	Height above ground (m)	Building use/function	Distance to the river	Ownership status	Maintenance status

i. HOUSEHOLD INTERVIEWS

QUESTIONNAIRE

Research Title: Assessment of Physical Vulnerability of Households to Flood in Informal Settlements, Case studies: ***Kawale1 and Biwi Townships in Lilongwe City*****.**

Researcher: Chresceuntia Matambo-Msasa

Contact: cmsasa@poly.ac.mw

This information will only be used for scientific research. We thank you for your help and cooperation.

Questionnaire number ……………………………	Date ………………………………
Area & Block Leader name………………………	UTM Coordinates: X……...........… Y…............……..

1. General Information

1.1 Respondent's profile

Respondent's name :……………………………………………………………..……

Gender: Male……….............……... Female…………….….. Age:...............................

Designation (household/official):............................ Length of stay in the area:........(yrs).

1.2. Building Information

Building age	0-5 years	5-10years	10-15Years	15-20years	>20years
Building size	≤ 50m²	51m²-75m²	75m² -100m²		
Ownership	1) Owner	2) Rented	3) Other		

2. Elements at Risk (adopted from Uwakwe, 2015)

2.1 Building characteristics (*Please specify*)

Building function	1). House	2). School	3). Church/Mosque	4). Shop/Hawker	5). Clinic
Floor material	1). Concrete/Cement	2)Earth	3). Ceramic tiles	4). Other	
Wall Material	1)Burnt bricks with cement and sand mortar	2) Burnt bricks with mud mortar	3)Sun-dried bricks (zidina) with mud mortar	4). Wood/timber	5)Other
Roof material	1). Galvanized iron sheet	2) Grass and plastic thatch	3) Grass thatch	4)Other	
Height from the foundation (m)					
Height of window (m)					
Type of window					
Type of door	1) Wooden	2) Tin	3) Grass	4)Other	
No. of households/ building	1)Single	2) Semi-detached	3) Multi		
Maintenance	1) Good	2) Fair	3)Poor		
Proximity to the river (m)	< 30 m	31-50m	51-70m	71-90m	>90m
Slope of terrain	1) Flat	2) Gentle slope	3) Steep		

Number of people per household					
Household head	1). Male headed	2). Female headed	3). Child headed	4). Other	
Age of Household heads	≤18	19 -30 Years	31- 64 Years	≥ 65Years	
Source of Income	1) Formal employment	2) Piece works (ganyu)	3)Business (vending)	4) Other	
Income per month	≤MK30,000	MK31.000-60,000	MK61,000 100,000	≥MK100,00	
Level of education	1) Primary	2)Secondary	3) University /tertiary	4)None	
Ownership of house	1) Owner	2) Rented	3)Other		
Period of stay	≤ 2years	3-5 years	6-8 years	≥ 9 years	

2.2 Household population characteristics (Modified from Uwakwe, 2015)

3 Floods Occurrence and its damage

3.1 Flood occurrence

How high was the level of floodwater outside the building on 16 December 2017 (cm)		
How long was the duration of the floods on 16 December 2017 (hrs)		
How did the flood water enter the building	1) Front door	2)back door
	3) Window	4) Other
What was the maximum height or level of flood that happened in this building on 16 December 2017? (cm)		
How long did flood water take to subside or gush out (hrs)		

3.2 Flood history

How many (number of) flooding occurrences have been experienced in the area	Once	Two times	Three times	≥ Four times
In which years were the flood events experienced				
Which flood event was the most devastating/ caused deaths and damages to property				
What was the cause of the flooding				

3.3 Flood Damages and Losses (16 December 2017 and 11 January 2019)

3.3.1 Damage to a building structure

What was the impact of the flood on the building structure? Specify

Section	Depth (cm)	Damage magnitude (C; HC; NH)
Floor		
Wall		
Door		
Window		

Note: C = Collapse HC= Half Collapse NH= Nothing Happened

How much was the cost of repair?

Section	Damage	Cost (MK)
Floor		
Wall		
Door		
Window		

3.3.2 Damage to Contents and Outside Properties (modified from Uwakwe, 2015)

i. **Building contents**

At what level of floodwater did the damage occur and at what magnitude

Items	Water Level (≤0.1m; 0.2-0.5m; 0.6-0.9m; 1-1.5m; 1.6-2m; >2m)	No Damage	Partial Damage (50%)	Completely Damaged	Cost of Repair (MK)
1. Electric Appliances					
- Radio					
- Refrigerator					
- Television set					
- Cooker/stove					
-Computer					
-Iron					
Cell phones					
Electric fans					
2. Food items					
3. Clothes and beddings					
4. Furniture					
Sofa set					
Dining set					
Beds					
Chairs					
Table					
Cupboard					
Carpet/mats					
Wardrobes					
Curtains					
5. Kitchen utensils					

ii. Outside property damage magnitude and floodwater level

- What property was outside the buildings during a flood event and what type of damage occurred to the property?

Property	Water Level (cm)	Damage Magnitude (Total damage; Partial Damage; None)	Cost of Repair

4. Flood Coping Measure/ Strategies (modified from Banda, 2015)

a) What action do you take before a flood occurrence to mitigate its impact on your household?...

....

b) What action do you take during floods to reduce its impact on your household...

....

c) What action do you undertake to mitigate the future flood impacts on your household

....

....

....

d) What are the challenges you face when undertaking the coping measures mentioned above?

....

....

e) If you have not taken any coping measures before, during and after a flood event, what can be the reason?

....

....

5.During the flood event, where do you live?

....

....

a) Where do you keep your household assets during floods?...

b) Have you ever considered moving from this place?..

1.What is the reason that keeps you here or makes you stay here?....................................

....

Thanks for your cooperation and help

Note:
....
....

6.**KEY INFORMANTS INTERVIEW GUIDE** (modified from Banda, 2015)

My name is Chresceuntia Matambo-Msasa, an MSc student at Mzuzu University studying Geographic Information Systems. I am collecting data for my dissertation and I would like to ask you some questions relating to the flooding events in Kawale 1 and Mchesi in Biwi Township. This information will be used for academic purposes only in the writing of my thesis.

FLOODING HISTORY IN KAWALE1 AND BIWI - ALONG MCHESI

1. How many flood events have been recorded in Kawale 1 and Mchesi?

2. When did the last flood occur in these areas?

3. In comparison to other recorded flood events, which flood occurrence was more devastating and how can this flood event be ranked in terms of impact?

MAJOR CONTRIBUTING FACTORS TO FLOOD IMPACTS ON HOUSEHOLDS

4. What are the major causes of flooding in the areas?

5. In what way do these problems influence the nature of flood impacts experienced by households?

CHARACTERISTICS OF MOST AFFECTED BUILDINGS

6. During the recorded flood events, which categories of buildings in terms of wall, floor and roof materials characteristics were most affected?

7. What type of damages do the affected people mostly report to your office?

OBSERVED COPING MECHANISM BY AUTHORITIES

8. Do you know of any activities that households in flood-prone areas undertake to mitigate flood impacts on their households?

9. If yes, what type of activities do people in these flood-prone areas undertake before, during and after a flood event?

CHALLENGES TO COPING STRATEGIES

10. Do you know of any challenges that people in the Kawale1 and Biwi flood-prone areas face when undertaking their activities aimed at mitigating flood impacts?

11. Do you have any suggestions on how the household's flood impact mitigating activities can be supported?

APPENDIX D: LILONGWE CITY COUNCIL AUTHORIZATION

LILONGWE CITY COUNCIL

ALL CORRESPONDENCE TO BE ADDRESSED TO THE CHIEF EXECUTIVE OFFICER

Our Ref : LCC/ ADMIN/7

P.O Box 30396
Lilongwe 3
Malawi
Tel. (265) 773
144
Fax: 01 770 885

4th December, 2018

Mrs. C Msasa
C/O The Malawi Polytechnic
Private Bag 303
Blantyre

Dear Mrs. C Msasa

RE: REQUEST FOR PERMISSION FOR LILONGWE CITY COUNCIL TO COLLECT DATA RESEARCH ASSESSMENT OF HOUSEHOLD PHYSICAL VANERABILITY TO FLOOD IN KAWALE AND MCHESI.

We acknowledge receipt of your letter dated 30th November, 2018, requesting permission for Lilongwe City Council to collect data research assessment of household physical venerability to flood in Kawale and Mchesi in the City of Lilongwe starting from 3rd December 2018.

The Council wishes to inform you that permission has been granted and you can proceed with your planned program.

However, the Council will avail the required support upon your request.

Yours faithfully

Charles Kalemba
CHIEF EXECUTIVE OFFICER

CC: Director of Health Cleansing and Social Welfare