

RISK ASSESSMENT ALONG MUDI RIVER.

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DECLARATION

I, **Charles Asima**, hereby declare that the work presented in this research report is an outcome of my own research effort and that the use of all materials from other sources has been properly and duly acknowledged by reference. No part of it has been submitted previously for a Degree at Malawi University of science and technology or any other institution for a degree or any award.

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ABSTRACT

Flooding is a global hazard resulting in disasters worth billions of dollars in losses. With the current trend and changes in climate, the frequency of flooding has increased over the years with once flood free areas being exposed to flooding. The intensity of flooding is being exacerbated by socio-economic problems that are forcing poor people to settle in hazard prone areas.

The study aimed at analysing the flood risk associated with Mudi river by assessing the rainfall patterns, vulnerabilities, number of elements at risk and the exposure of the elements at risk at Manase and Manyowe communities. Due to the limited number of weather stations in Malawi, Chichiri weather station was selected because of its proximity to the two communities. The decision was reached under the assumption that both locations share uniform rainfall patterns. The maximum daily rainfall amount of every year between 2000 to 2020 was used to calculate temporal probabilities and return periods. The number of elements at risk was determined through field observation and absence the damage to the elements at risk was assessed based on potential damage given a specific hazard intensity. An exposure map was created to show the exposure of elements at risk. Based on analyzed data the assessment was able to conclude that Manase and Manyowe settlements located within 50 meters from the river are at risk of flooding. Five houses are more likely to be damaged annually due to flooding. The assessment was also able to determine that the level of risk varies depending on the type of element at risk and its underlying vulnerabilities. Considering the topography of the area the assessment reasoned that cascading hazards such as landslides and waterborne diseases are also likely to occur. The results reported in this study can be used as baseline data for other assessments and remedial projects.

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Table of Contents

1. CHAPTER 1. INTRODUCTION 1
1.1. Background information 2
1.2. Problem Statement 3
1.3. Research Hypothesis 4
1.4. Main and Specific Objectives 4
1.5. Research Questions 4
1.6. Significance of the Study 5
2. CHAPTER2. LITERATURE REVIEW 6
2.1. Introduction 6
2.2. Flood Hazard assessment 7
2.3. Vulnerability Assessment 8
2.4. Flood Risk Assessment 10
3. CHAPTER 3. RESEARCH METHODOLOGY 11
3.1. Study Area 11
3.2. Sampling Techniques 12
3.3. Research Design 13
3.4. Methods 13
4. CHAPTER 4. RESULTS AND DISCUSSION 17
4.1. Temporal Probability and Return Period 17
4.2. Frequency and Magnitude Relationship of Rainfall. 18
4.3. Exposure of elements at risk 19
4.4. Amount of Elements at Risk 20
4.5. Vulnerability Assessment 21
4.6. Risk Quantification 22
4.7. Derived Events 24

4.8. Limitations 24
5. CHAPTER 5. CONCLUSION AND RECOMMENDATIONS 25
5.1. Conclusion 25
5.2. Recommendations 25

ACRONYMS/ABBREVIATIONS

AAL:	Average Annual Loss
DoDMA:	Department of Disasters Management Affairs
DRM:	Disaster Risk Management
GIS:	Geographical Information System
IPCC:	Intergovernmental Panel on Climate Change
MK:	Malawian Kwacha
PDNA:	Post Disaster Needs Assessment
UNISDR:	United Nation International Strategy for Disaster Reduction
USAID:	United States Agency International Development
WHO:	World Health Organisation

LIST OF FIGURES

Figure 1: Study area of Manase and Manyowe. 11
Figure 2: A graph showing the frequency and Magnitude relationship of rainfall at Chichiri Station. 19
Figure 3: An Exposure map showing elements at risk. 19
Figure 4: showing the total number of elements at risk based on category of households. 20
Figure 5: showing the amount of elements at risk based on category of households. 20
Figure 6:is a graph showing vulnerabilities of different types of houses based on the depth-damage function. 21
Figure 7: showing the risk curve 23

LIST OF TABLES

Table 1: showing the Temporal probabilities and return periods of potential flood causing 24 hr maximum rainfall. 17

Table 2: showing a list of vulnerabilities with corresponding flood depth 22

Table 3 summarizing the variables required for risk calculation 22

1. CHAPTER 1. INTRODUCTION

In 2019 Malawi experienced one of the worst Tropical cyclones (cyclone Idai) that formed in the Mozambican channel bringing heavy rains and strong winds which left 60 people dead, 672 injured, 86 970 displaced and affected 975 000 people (Malawi 2019 Flood Post Disaster Needs Assessment). Prior to that in 2015 Malawi experienced the worst recorded flood in 15 districts that left an estimated 1,101,364 people affected, 230 000 displaced, 106 killed and 172 reported missing according to the Malawi 2015 Post disaster Needs Assessment. These disaster events have had a significant impact on people's lives, livelihoods and socioeconomic infrastructure in the affected areas, pushing many people into poverty and food insecurity. The most common weather-related shocks affecting Malawi include floods, drought, stormy rains and hailstorms. Over the past five decades, Malawi has experienced more than 19 major floods and seven droughts, with these events increasing in frequency, magnitude and scope over the years (PDNA 2019). Floods are anticipated to happen more strictly and regularly in the future because of climate change, unplanned rapid urbanization, change in land use pattern, poor watershed management and decline recharge of groundwater by extension of impermeable surfaces in urban areas. This means that many urban areas across the globe are likely to be under serious threat of floods, the adverse impacts of which are already believed only next to that of earthquakes (Nasiri 2016).

Natural phenomena's like cyclone Idai create the need for flood risk assessments since people tend to gather close to rivers and lakes because water is a resource before being a threat (UNISDR 2017). Flood risk can be analyzed through the lenses of the main terms of the risk equation: hazard, vulnerability, exposure and capacity. Flooding occurs most commonly from heavy rainfall when natural watercourses lack the capacity to convey excess water. Risk is then created when the excess water interacts with a communities' vulnerability. Vulnerability which has been defined by the UNISDR (2009) as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard, represents a crucial step in properly

evaluating flood impact. Vulnerability assessment is closely related to the ability to properly characterize the exposed elements to floods (UNISDR 2017).

Chikwawa and Nsanje districts are where flood hazard is mainly localized in the Shire valley because it is the main drainage basin of the southern region. Most flood risk assessments focus on the Shire river however this study turned its attention to a slowly emerging threat in Blantyre especially on Manase and Manyowe communities as they face hazard from Mudi river.

Mudi river has no history of flooding and up to date its latent factors are yet to propel experts to assess flooding along the river. The lack of national headline surrounding Mudi river can be attributed to the once absence of settlements along its banks but as stated in the Pressure and Release model (Wisner 2003), economic and demographic are part of the variables under root causes of vulnerability. These two variables coupled with the changing climate and heavy rainfalls are slowly activating the latent factors surrounding Mudi river as economic hardship and the ever-growing population forces poor urban settlers to erect temporary to permanent buildings along Mudi river. Thus, the introduction of the human element on the banks of Mudi river propelled this study as that is a game changer as far as hazards are concerned. The study aims at investigating the level of flood risk mudi river poses to Manase and Manyowe communities. .

1.1. Background information

The National guidelines for the development of disaster risk management (2020) stated that, ‘Geographically, the number of districts and communities that are annually affected by disasters is also on the rise. Although the Department of Disaster Management Affairs (DoDMA) recognises 15 districts as disaster prone, recent disaster events have demonstrated that such prescriptions may no longer hold. Districts that were previously considered not disaster prone, including urban areas, are being affected every year. At times, the impact has been more severe than in the traditional disaster-prone districts. New risks are being created or worsened, particularly in urban areas.’ The

guidelines realise the growing numbers of disasters in new and once disaster free areas thus the study will focus on Mudi river. The event on its own is nothing more than a natural phenomenon courtesy of atmospheric conditions. The dangers manifest only and after the human element is introduced to the equation and the event operates on people`s vulnerabilities causing widespread suffering. And as it stands the human element is being slowly introduced as poor urban settlers are erecting houses along the banks of Mudi river. Now does Mudi river receive that much water to cause flooding or its lack of national headline is a result of its dormant nature when flooding is concerned?

1.2. Problem Statement

In 2019 heavy rains caused a stream passing through Manase to flood affecting several houses in the process. No death was recorded but there was substantial damage to houses lined along the stream as some of them saw walls on one side collapse forcing the owners to temporarily cover the exposed side with black polythene plastic papers. Such kind of events happen a lot but hardly capture the attention of the nation as they do not have the much-needed political momentum to spearhead a risk assessment. Just like the river above, Mudi river has no record of flooding hence it is poorly documented, but the introduction of settlements poses a significant threat to human lives. Malawi has time and time again prioritized post disaster activities over pre-disaster activities which has led to loss of life and property that could otherwise have been saved. This study therefore intends to bridge the gap and engage in a pre-disaster activity on Mudi river as it strives to fill the vacuum created by lack of information on Mudi river. It realizes the hazard, the presence of settlement and the losses that can be incurred.

1.3. Research Hypothesis

The null hypothesis is that Mudi river is not going to flood and that there is no risk faced by the communities.

1.4. Main and Specific Objectives

The study aims at quantifying risk so as to determine the level of flood risk faced by Manase and Manyowe communities

Other specific objectives include:

- To determine the Temporal probability and return period of potentially flood causing rainfall amount.
- To investigate the frequency and magnitude relationship of extreme rainfall events.
- To determine the exposure of elements at risk.
- To determine the amount of exposed elements at risk.
- To determine the vulnerabilities of the built environment due to flooding.

1.5. Research Questions

This study will answer the following question, To what degree are the residents of Manase and Manyowe exposed to the impacts of flooding? how much losses are the two communities likely to face in case of flooding? What is the peak rainfall amount to likely cause flooding?

1.6. Significance of the Study

Disaster risk management activities in Malawi has been primarily focused on known disaster districts. Little or no attention has been given to potential disaster destinations as such this study fully recognizes the lack of publicity surrounding Mudi river. It recognizes the impact of climate change on the environment and the increase in frequency of extreme events hence it is determined to investigate the likelihood of Mudi river causing a disaster considering the growing population along its banks. It will consider vulnerabilities, coping capacity, exposure with flooding as the operating hazard.

2. CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

Risk of disaster is a compound function of the natural hazard and the number of people, characterized by their varying degrees of vulnerability to that specific hazard, who occupy the space and time of exposure to the hazard event. There are three elements here: risk, vulnerability, and hazard (Wisner 2003).

Coppola (2015) states that, “risk is the likelihood of an event occurring multiplied by the consequence of that event, were it to occur. “Likelihood” can be given as a probability or a frequency. “Frequency” communicates the number of times an event will or is expected to occur within an established sample size over a specific period of time”. A hazard is “a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage” (Roxan et. Al 2013). Vulnerability refers to a function of exposure, sensitivity, and adaptive capacity (IPCC 2007) or “the inability of a system to withstand against the perturbations of external stressors” (Paul 2013). Risk combines vulnerability with the probable level of loss to be expected from a predictable magnitude of hazard hence it can be expressed in terms of the probability of exceeding specific levels of direct losses (in physical and monetary terms). Risk assessment therefore comprises of three distinct steps. a) An identification of hazards likely to result in disasters, e.g. what hazards events may recur? b) An estimation of the risks of such event, e.g. what is the possibility of such event? c) An evaluation of the social consequences of the derived risk (Kates 1983)

“The term disaster risk therefore refers to the potential (not actual and realised) disaster losses, in lives, health status, livelihoods, assets and services, which could occur in a particular community or society over some specified future time period. It should be noted that the effect of a hazard (of a

particular magnitude) would affect communities differently. This is true because of the level of the coping mechanisms within that particular community. Poorer communities are therefore more at risk than communities that do have the capacity to cope" (USAID 2011).

2.2. Flood Hazard assessment

A flood is a natural process that occurs when the quantity of water in a watershed exceeds the capacity of stream, river and lake. Usually it is a temporary overflow of water onto normally dry land because of heavy rainfall or river backflows (Disaster Risk Management handbook 2013). Malawi is no exception when it comes to flooding as is evident by current Chikwawa woes. "In studying flood risk, it is useful to classify floods to: (a) coastal floods which can occur on the coast and along the banks of large lakes; (b) river floods that occur seasonally when spring rains water fills river basins too quickly, and the river will overflow its banks; (c) flash floods are short-term floods in small region such as part of the city which kill and damage the most" (Nasiri 2016). Mudi being a river experiences river flooding. The DRM handbook (2013) further on went to state that floods can be caused by excessive rainfall, storms, blockage of drainage systems and breaking of natural or artificial dams/ reservoirs. Most floods that occurs in Malawi are because of heavy rainfall that generates excessive runoff in river channels, causing them to swell and inundate flood plains.

The goal of flood hazard assessment is to understand the probability that a flood of a particular intensity will occur within a given period of time. This relationship between the probability of a flood and its intensity gives rise to the concept of return period (also known as recurrence interval), expressed in terms of years. Flood hazard assessments usually aim to estimate the flood intensity for a range of exceedance probabilities, for example from 0.1 to 0.001 International Bank for Reconstruction and Development / The World Bank (2016).

With the global awareness of climate change flooding is but guaranteed to increase in frequency. For the most part, little systematic work has been done in making effective linkages between

climate databases and the increasing number of national, regional and global databases on disaster statistics. Meteorological information, especially seasonal prediction, when packaged well and provided to users in good time can aid planning activities (WHO 2002).

2.3. Vulnerability Assessment

Vulnerability may be defined as the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area (Dey & Sing 2006). Vulnerability concept varies among different communities , but there are two main perspectives on this : (i) engineering and natural science, and (ii) social science. From the engineering and natural science viewpoint, vulnerability is defined as the susceptibility of exposed elements (e.g., assets, people) to flood hazards . In this sense, vulnerability is often limited to a physical vulnerability where the vulnerability of structures and assets is estimated based on a given flood depth. In other words, the degree of damage is estimated using quantitative methods, mostly based on the depth-damage functions (vulnerability curves), ranging from zero (no damage) to one (total damage). From the social scientists' perspective, the vulnerability can be identified as an inherent characteristic of the system (people or community) before encountering the external hazard event (Hadipour 2020).

According to Hajari Nasiri (2016) there are a variety of vulnerability assessment methods which are different in their vulnerability description, theoretical framework, variables and methodology. The methods can be categorized in four distinct groups. The first group of methods is vulnerability indicators which use available data to provide a logical Image of the place vulnerability. The deductive approach is built on a theoretical framework for selecting appropriate indicators and considering their relationship while inductive approach selects indicators regards to statistical link with observed vulnerability consequences. The next group of methods is vulnerability curves which studies the relations between flood risk and elements at risk through fragility curves. A

sample of items in each selected class is picked and a list of possible subjects is arranged. The data for all samples of each component class is averaged and step-damage curves created. The third group of methods is disaster loss data which is constructed on data collection from real flood hazard. The final group is modeling which can evaluate depth, elevation and velocity of flood with using frequency, magnitude and shape of the hydrograph (Nasiri 2016). This research will use vulnerability curves to determine vulnerability.

A study by Baky (2020) conducted in Bangladesh offers more insight on vulnerability assessment and the production of vulnerability functions. It emphasized that the first step to vulnerability assessment is the identification of elements at risk. Through analysis of satellite images in a GIS environment element at risk were identified, followed by field observations and interviews to verify the elements identified. Baky (2020) realised that the quantification of vulnerability depends on the susceptibility of 'elements at risk' which could be termed as the degree of loss to a given element at a given severity level. Vulnerability is usually expressed on a scale of 0 (no damage) to 1 (total loss) unit. The study by Baky considered 'depth of inundation' as the main parameter for assessing flood damage functions for croplands and rural settlements. The study further considered the direct economic damages of floods. Considering depth as the flood damage parameter, depth–damage relationships (alternatively called loss functions or vulnerability functions) were developed for different elements at risk: crops and settlements. Depth–damage relationship presents information on the relationship of flood damage of a certain element to a certain depth of flooding (or stage). This study adopted a similar approach with flood depth being replaced by flood height during construction of vulnerability functions.

It has to be stressed here that vulnerability is a highly dynamic component. The level of vulnerability can change rapidly, e.g. after the impact of a disastrous event or slowly with changing personal, communal or national conditions such as economic development (Muller et al,. (2011).

2.4. Flood Risk Assessment

Rivers have always been used as a water resource for food and hygiene needs as well as for agricultural and industrial harvesting, however, rivers are subjected to variations of flow with periods of low water and high water which are often the origin of floods (Luu 2020). Due to its unique geo-climatic conditions Malawi has been traditionally vulnerable to floods and this prompted the world bank (2009) to implement a program called the Global Facility for Disaster Risk Reduction Track 11. The program closely examined the dynamics of vulnerability of Malawian agriculture and infrastructure to droughts and floods. The program as many of its kind in Malawi focused on Lower Shire Valley in the southern part which is the most commonly flooded place. The flood risk assessment considered population, households, roads, railways and agriculture as exposed elements at risk. The Rural development Project (RDP) level was used to assess the population and household risk with the household risk categorized into permanent, semi-permanent and traditional types. These are the same types that were adopted by this study.

The world bank (2009) program recognized that hazard and risk quantifications depend on spatial specifications (e.g., area of interest and spatial resolution of data) with much emphasis put on two parameters (water level and duration) that correlate well with damage. The flood risk assessment was able to determine that traditional houses were more vulnerable compared to the other two types of houses and that an average, 26,000 people and 6,000 households were likely to be affected by flood due to inundation each year with an Average Annual Loss (AAL) for households found to be USD 6.5 million.

3. CHAPTER 3. RESEARCH METHODOLOGY

3.1. Study Area

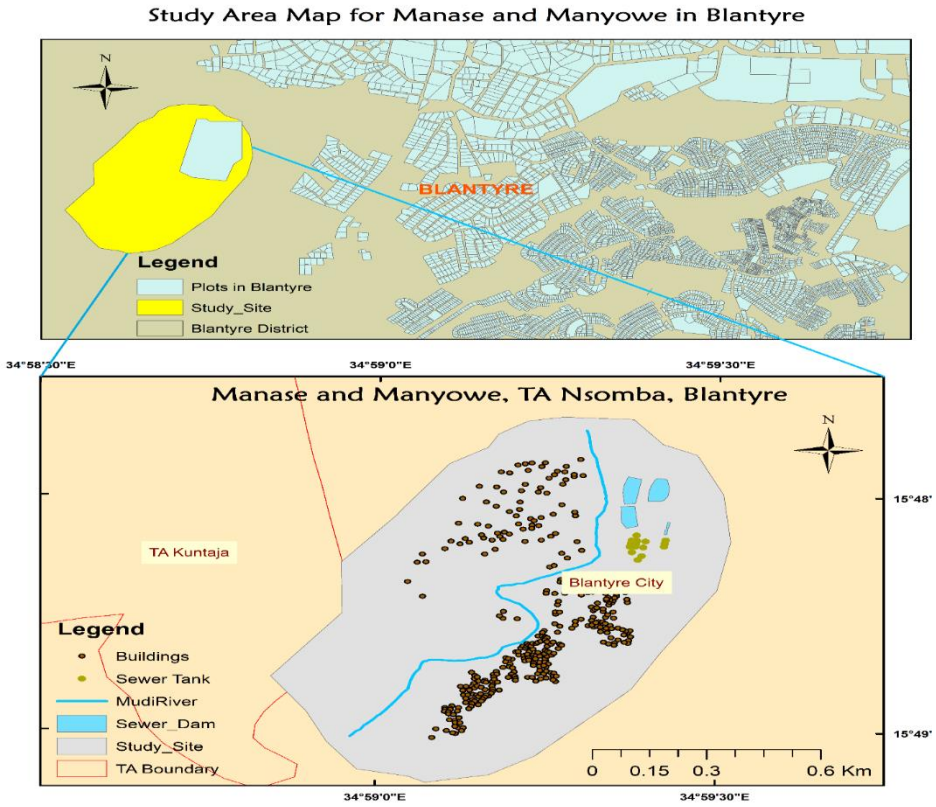


Figure 1: Study area of Manase and Manyowe.

Blantyre City is located at $15^0$47'10" S 35^0 0'21" E with an elevation of 1,039 meters above sea level and covers an area of 228 km^2 in the Southern Region of Malawi. Blantyre City is located in a hilly area with varied topography ranging from an elevation of 780 to 1, 612 meters above the sea level. Some ecological features include hills, plateau, ridges and drainage systems such as rivers and streams. Blantyre City's drainage system is mainly formed by distinct catchment areas i.e. Likhubula, Mudi, Naperi, Nasolo, Lunzu and Chisombezi Rivers. The study will however put much emphasis on Manase and Manyowe to determine downstream activities as well as exposure of those communities from upstream activities (Disaster Risk Management Plan 2018).

Manyowe and Manase are nearby residential areas situated close to Blantyre central business district. In 2011 they had a combined population of 15093 people living in unplanned areas with Manase accounting for 6600 and Manyowe 8493 according to a report by UN HABITAT (2011). The said population does not necessarily mean that they all lived along Mudi river but a fraction of that population was of people living within the banks of Mudi rivers. The two residential areas are demarcated by Mudi river hence they all have common potential risks posed by Mudi. They are connected by two bridges, one running from sunnyside residential area to Manyowe and another one which is for people only that connects directly from Manyowe to Manase close to the sewage system. The two residential areas are highly populated with low income families with a large number of the population located uphill safe from flooding hence the main focus is on the few households that are in close proximity to Mudi river.

3.2. Sampling Techniques

Stratified sampling was used as it captures data that represents everyone in the population. The mechanism adopted stratified sampling which is an excellent way to try and ensure that a sample looks just like the population but smaller. The population was broken into three different groups, or strata, and then randomly sampled from each group. The first group was made up of permanent houses, the second group comprised of semi-permanent houses and the third group was of those with traditional houses. The whole idea was rooted on the fact that the level of vulnerability on individual or household level is different from family to family. Some families have more resources than others hence how they are affected by a hazard differently. Since the actual number of households around is not known the sample size was determined by

$$n = \frac{z^2(1-p)p}{e^2}.$$

where n is the sample size; Z is value of a normally distributed standard variate which for a 90% confidence interval takes on the value of 1.645. P is the proportion of the participants with the

attribute under study out of the total population in that area. If this proportion is unknown, use 0.5 as a value for P; e is the allowable error which is 10% or the desired level of accuracy. The confidence value was taken from introduction to statistics by Woodbury (2002).

$$n = \frac{1.645^2(1-0.5)0.5}{0.1^2} = \frac{2..706(0.5)0.5}{0.01} = 67.6$$

n = 67.

3.3. Research Design

The research was designed in such a way that it provides values on variables needed to answer the risk quantification equation ($R_S = P_T * P_L * V * A$) to assess flood risk whereby:

- R_S is the specific risk
- P_T is the temporal probability (annual probability)
- P_L is the locational probability
- V is vulnerability
- A is amount of element at risk

It employed both qualitative and quantitative methods as well as the use of physical and geomorphic techniques, which investigated boulders along streams, water transported debris along walls of bridges and historical record of events.

3.4. Methods

To determine Temporal Probability of the risk equation maximum 24 hours rainfall recorded at Chichiri Station, Blantyre for each year between 2000 to 2020 was compiled, sorted and ranked. The first step was to calculate the return period using the equation below:

$Tr = \frac{N+1}{M}$ equation 2.

Where:

- Tr is the return period
- N Is the number of recorded rainfall amounts
- M is the rank

The second step was to calculate the right probability (Pr) which represents a recurrence of the same rainfall intensity by using the equation below

$\Pr = \frac{1}{Tr}$ equation 3.

The third step was to calculate the left probability (P_L) which is the opposite of the right probability by using the equation below

$P_L = 1 - \frac{1}{Tr}$ equation 4.

The elements at risk considered were houses which were categorized based on building materials with:

- unburnt bricks constructed with mud and a thatched roof making up the traditional housing.
- unburnt bricks constructed with mud and plastered with cement or burnt bricks constructed with mud and plastered with Dambo sand making up the semi-permanent housing.
- burnt bricks constructed with cement plastered or not with cement forming the permanent type.

Flood depth was recorded on three different locations,

- on the pedestrian bridge connecting Manyowe and Manase which was reported to have been completely submerged in water and un passable.

- on the brick wall of a house that was a meter away from the river. The measurement was based on the height of the entire stonewall
- On an eroded sidewalk using the top most eroded part as the flood height.

An exposure map showing elements at risk was generated through Bing aerial imagery and digitized in a GIS environment. Digitization was done on objects of interests namely, Mudi river, houses and a sewer system. Buffer analysis using geoprocessing tools created the zonation necessary to show the three levels of exposure of elements at risk.

The amount of elements at risk was determined through observation, counting and recording. Thus houses were counted and allocated into the three different types. The pricing of the houses was a product of interviews and it was analysed in excel to give the mean price in each household category. Damage data of houses was a result of the input from residents through interviews and the mean repair costs of each household category was generated in excel As a substitute for flood modelling, interviews with local residents were conducted to determine flood depth that corresponded with historic evident and damages incurred.

Vulnerability analyses assessed the possible damage to the built environment. Damage data was used to create vulnerability curves in excel. The return period of high rainfall amount was key as it gave the hazard intensity which in this study was flood depth. A graph of damages to the infrastructure against the flood depth was created to determine vulnerability. This was done through determination of houses that would be affected given a certain flood depth, considering previous behaviour or damage of houses belonging in the same category.

To calculate annual risk, a risk curve was developed and the area under the curve was divided into triangles and rectangles. The triangles connected the straight lines between two points with the height being the difference in probability between two hazards of different return period. The X

axis representing the base have difference as difference between the losses of the two scenarios. The rectangles filled up the remaining part under the curve. The formula for calculating area of a triangle which is:

$\frac{1}{2}$ base * height

as well as calculating area of a rectangle which is

length * width

were used and the values added to come up with the annual risk.

NB: P_L is not relevant to this study and the probability will be indicated as 1

4. CHAPTER 4. RESULTS AND DISCUSSION

4.1. Temporal Probability and Return Period

The temporal probability given by the right probability was calculated from rainfall amounts recorded at Chichiri Station stretching for 21 years and the table below shows different Temporal probabilities and return periods of rainfall.

Table 1: showing the Temporal probabilities and return periods of potential flood causing 24 hr maximum rainfall.

YEAR	RAINFALL AMOUNT (mm)	SORTED	RANK	RIGHT PROBABLITY	LEFT PROBABILITY	RETURN PERIOD
2000	86.0	398.0	1	0.045454545	0.954545454	22
2001	95.0	142.7	2	0.09090909	0.909090909	11
2002	112.0	112.0	3	0.136363636	0863636363	7.333333
2003	56.0	105.0	4	0.181818181	0.818181818	5.5
2004	83.0	102.1	5	0.227272727	0.772727272	4.4
2005	47.5	101.7	6	0.272727272	0.727272727	3.666666667
2006	78.5	95.0	7	0.318181818	0.681818181	3.142857143
2007	102.1	86.0	8	0.363636363	0.636363636	2.75
2008	60.0	83.3	9	0.409090909	0.59090909	2.4444
2009	73.5	83.0	10	0.454545454	0.5545454545	2.2
2010	83.3	79.4	11	0.5	0.5	2
2011	55.7	78.5	12	0.545454545	0.454545454	1.833333
2012	79.4	76.1	13	0.59090909	0.409090909	1.692307692
2013	70.8	74.0	14	0.636363636	0.363636363	1.571428571

2014	39.3	73.5	15	0.681818181	0.318181818	1.46666667
2015	398.0	70.8	16	0.727272727	0.272727272	1.375
2016	142.7	60.0	17	0.772727272	0.227272727	1.294117647
2017	76.1	56.0	18	0.818181818	0.181818181	1.22222222
2018	74.0	55.7	19	0.863636363	0.136363636	1.157894737
2019	105.0	47.5	20	0.909090909	0.09090909	1.1
2020	101.7	39.3	21	0.954545454	0.045454545	1.047619048

There are four Temporal probabilities significant to this study which are: 0.045454545, 0.09090909, 0.136363636, 0.181818181. These probabilities are of rainfall amounts high enough to cause flooding on Mudi river.

4.2. Frequency and Magnitude Relationship of Rainfall.

The frequency and Magnitude relationship showed that high rainfall amount like that of 2015 do not happen frequently unlike low rainfall amount accustomed by the residents of Manyowe and Manase. Thus the graph in figure 2 shows that rainfall follows an inverse relationship.

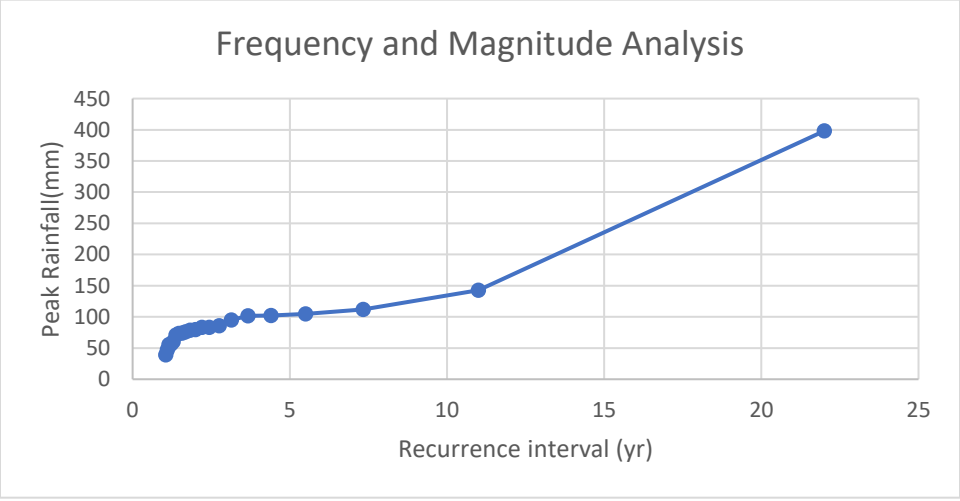


Figure 2: A graph showing the frequency and Magnitude relationship of rainfall at Chichiri Station.

4.3. Exposure of elements at risk

The exposure map below shows elements at risk within the different zones. As seen in figure 3, buildings present in the red zone were those that are within 50 metres from the river and are highly exposed to flooding. Those that fall in the green zone were the ones that are within 100 metres from the river with medium exposure and the ones in the yellow zone are within 200 metres from the river and have very low exposure. The red zone is where the impact zone is and in that zone buildings are subjected to extreme damages.

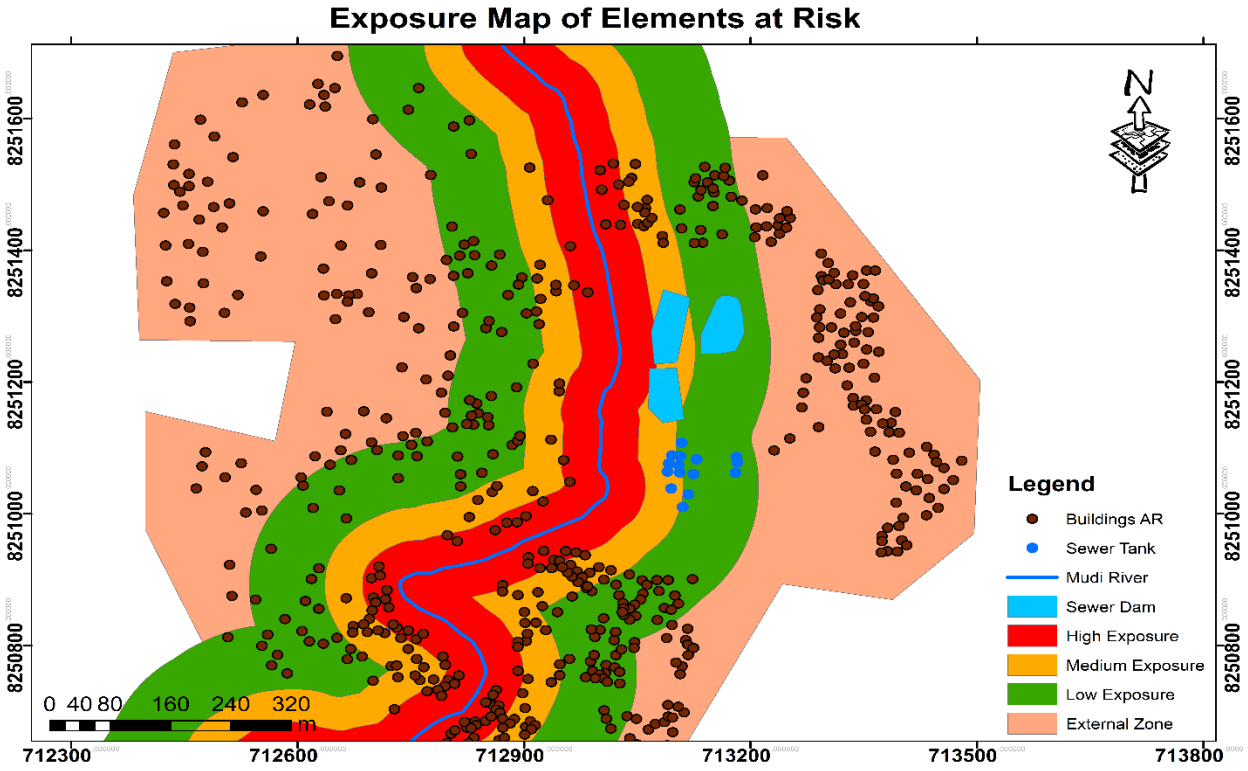


Figure 3: An Exposure map showing elements at risk.

4.4. Amount of Elements at Risk

Elements at risk are accounted for in the figures below and the houses 3 m above the ground were not accounted for as they are not within the impact zone. Figure 4 shows the number of elements at risk that were within the red zone. figure 5 shows the total amount of each category of households that are present in the red zone.

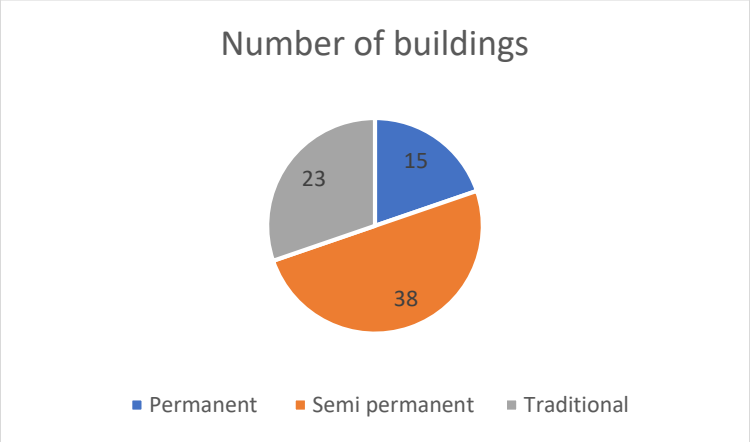


Figure 4: showing the total number of elements at risk based on category of households.

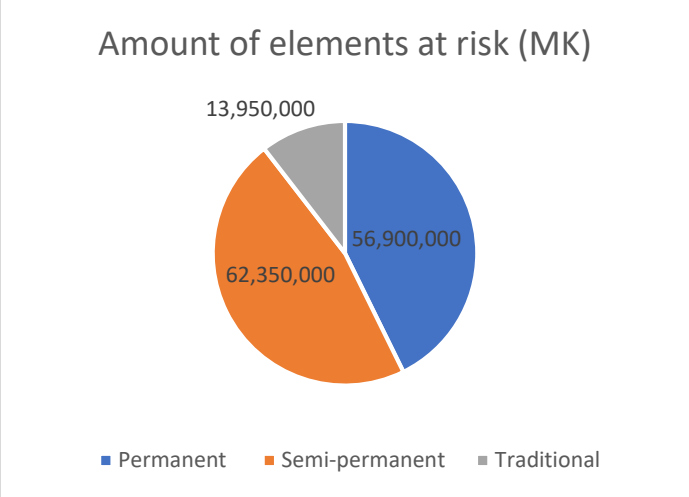


Figure 5: showing the amount of elements at risk based on category of households.

4.5. Vulnerability Assessment

Houses shown in figure 4 are subjected to external forces or flood hazard (hazard in this case indicated by depth) resulting in total collapse or partial damage. Damage data was calculated based on the amount used to rebuild, repair or maintain houses that were affected by floods of a given extreme rainfall return period. Pit latrines, brick walls, straw and reed walls were all placed in the three housing categories based on material used, to include the cost that was used to repair or rebuilt such.

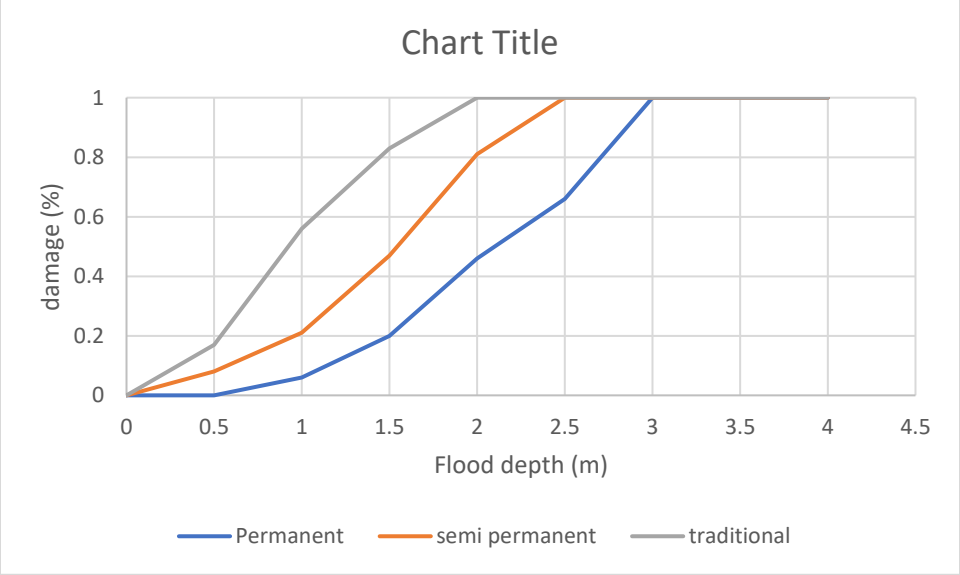


Figure 6:is a graph showing vulnerabilities of different types of houses based on the depth-damage function.

The return period of four different rainfall amounts high enough to cause flooding was correlated with the flood depth to generate the vulnerabilities as shown in the table 2below

Table 2: showing a list of vulnerabilities with corresponding flood depth

	Vulnerabilities			
	0.5 meters	1 meter	1.5 meters	2 meter
Traditional house	0.17	0.56	0.83	1
Semi-permanent	0.08	0.21	0.47	0.81
Permanent	0.00	0.06	0.2	0.46

4.6. Risk Quantification

Using the vulnerabilities in Table 2, and their corresponding return period the risk quantification table 3 below was generated. The amount of elements at risk was calculated from the average repair cost of an element at risk multiplied by the number of elements at risk in a given flood depth. The table is a summary of the variables required to calculate annual risk using the risk curve which is figure 7.

Table 3 summarizing the variables required for risk calculation rounded off to the nearest whole number

	T_R	P_T	A	V	V*A	∑ V*A
Permanent	22	0.045454545	2,439,347.82	0.46	1,122,100	
Semi-permanent	22	0.045454545	14,276,315.92	0.81	11,563,816	
Traditional	22	0.045454545	5,106,000.00	1	5,106,000	
						17,791,916
Permanent	11	0.09090909	1,030,434.78	0.2	206,087	
Semi-permanent	11	0.09090909	8,289,473.76	0.47	3,896,053	
Traditional	11	0.09090909	421,800.00	0.83	350,094	

						4,452,234
Permanent	7.3	0.136363636	343,478.26	0.06	20,607	
Semi-permanent	7.3	0.136363636	3,684,210.56	0.21	773,684	
Traditional	7.3	0.136363636	2,886,000	0.56	1,616,160	
						2,410,451
Permanent	5.5	0.181818181	0	0.00	0	
Semi-permanent	5.5	0.181818181	1,381,578.96	0.08	110,526	
Traditional	5.5	0.181818181	888,000.00	0.17	150,960	
						261,486

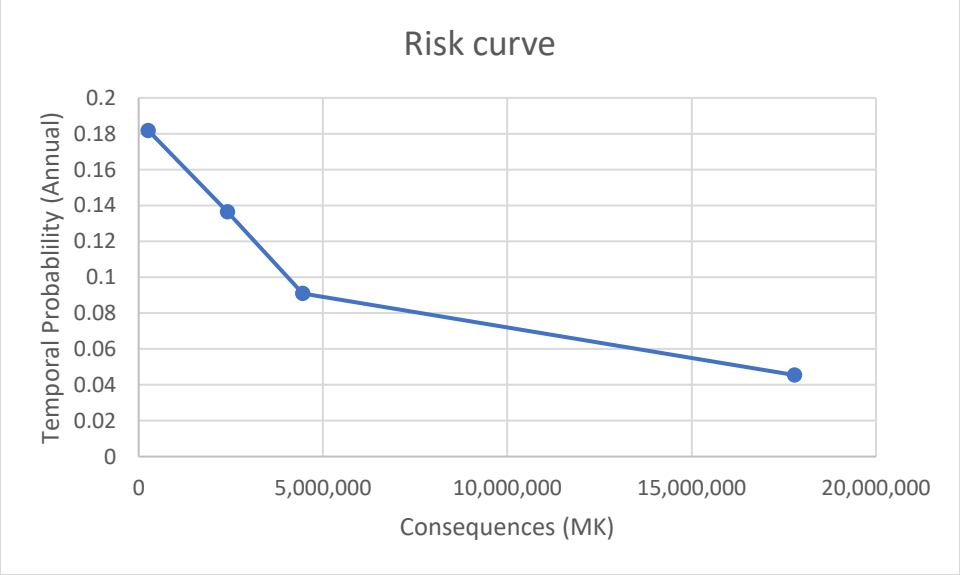


Figure 7: showing the risk curve

The risk curve shows that MK 1,519,083 worth of losses will be incurred annually due to flooding. The specific risk for the maximum rainfall recorded in 2015 given by $R_S = P_T * P_L * V * A$ shows that MK 808,723.44 was lost due to flooding. Due to cheap prices of plots within the impact zone, poor people are inclined to buy the plots and resort to build traditional houses with little or no defence

mechanisms hence increasing their vulnerability. Land is still available and should the sale of land continue more traditional houses will be built in the coming years increasing the annual risk.

4.7. Derived Events

The communities are situated within a valley and are subjected to landslides which also causes flooding. The level of erosion observed provided a warning sign on a disaster in the making and the presence of a sewage system puts people`s lives at risk of water borne-diseases. The residents complained more on the smell and chemical composition of the water than they did of flooding. The structural measures put in place are meant to combat flooding and yet still leave the residents defenceless to water-borne diseases.

4.8. Limitations

During the first visit the residents were undecided and uncooperative at times due to fear of eviction as they thought that the study was from the local government despite producing the reference letter. During the second visit the resident guessed on the cost of repairing their houses with some talking of normal maintenance or repairs that had nothing to do with flooding. Some land owners were not available hence the tenants were responsible for the data generated. The pricing of houses was highly based on an expectation of compensation hence it did not tally with the cost of materials used.

5. CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Mudi river poses flood risk to those that are living along its bank as such the null hypothesis is rejected. The flood risk though from the same source is not equally distributed as vulnerability differs on individual basis. Traditional houses are more likely to collapse absent defence mechanisms compared to the two other types of houses. Besides the threat from flooding, the communities within the study area are also exposed to cascading hazards ranging from landslide that could cause flooding, to waterborne diseases as a result of flooding.

5.2. Recommendations

The study unearthed a few underlying vulnerabilities and issues that needs to be addressed. Therefore, the following points needs immediate consideration.

- A comprehensive assessment into the rate of soil erosion as houses are subjected to mass movement. The river is undercutting slopes were houses are built.
- A comprehensive chemical composition assessment before and after the sewage system to determine if the sewage system is putting people`s lives at risk
- Installation of an early warning system up stream.
- Relocation of houses within 50 metres from the river. Due to high exposure to risk the land is cheap and attracting the poor whose dominant type of housing is Traditional and very vulnerable.

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Appendices

Appendix 1. Flood depth measurements points



Appendix 2: Pictures showing some of the houses within the impact zone and part of a sewer system.



Appendix 3. Table of damages with their corresponding flood depth.

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water depth	Permanent	semi permanent	traditional
0	0	0	0
0.5	0	0.08	0.17
1	0.06	0.21	0.56
1.5	0.20	0.39	0.83
2	0.46	0.87	1.00
2.5	0.66	0.95	1
3	1.00	1.00	1
3.5	1	1	1
4	1.00	1.00	1

Appendix 4: showing the amount of houses and the incurred damages

Type of House	Permanent	Semi-permanent	Traditional
Total price of houses (MK)	56 900 000	62 350 000	13 950 000
Average price (MK)	3 793 333. 333	1 640 789.47	606 521. 74
Repair costs(MK)	3 330 000	17 500 000	7 900 000
Average repair costs (MK)	222 000	460 526.32	343 478.26