Flash Flood Hazard and Coping Strategies in Urban Areas: Case Study in Mpazi Catchment, Kigali Rwanda

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March, 2015

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ABSTRACT

Globally, floods are the most frequent natural disaster, which are becoming a common phenomenon in today`s cities. This is mostly prominent in the developing countries that are facing rapid growth. In particular, the Mpazi Catchment in Kigali/ Rwanda, which suffers from frequent flash flood events, due to the increasing impervious surfaces within the urban environment, which have come to affect a large proportion of the population. Therefore, this research focused on understanding the flood dynamics within this catchment area, as well as analysing people`s perception and the coping mechanisms implemented to mitigate the flash flood problem in the area. Different forms of data collection techniques were applied, which included: field observation and measurements, household surveys and key informant interviews.

In this case, the hydrological model OpenLISEM, was used by to simulate different rainfall runoff events, where the characteristics of the simulated floods, were then analysed based on the depths, duration and extent, as they were classified to be the most important by the community. It was found out that these flood events were brought about by other factors, such as topographic nature of the catchment and the extensive and rapid growth, which led to the increase of the unplanned human settlements. The lack of appropriate maintenance of the channels, both by the residents and the authorities in charge. Lastly, the combination of the loose soils and debris originating from the steep hills, and the vast amounts of solid waste deposited within the channels tend to block the culverts. Which in turn restricts the flow of water during a rainstorm.

The perception of the residents, in relation to the flash floods, was dominated in the moderate to low level. Totally, 48% of the respondents had moderate level risk perception, while 35% had low level risk perception. As majority of the respondents had the perception that the floods were caused by the lack of maintenance of the channels, and the rapid deforestation rates that are taking place. Through the multiple linear analysis, the gender, length of stay and experience with the floods showed to have an influence on the level of perception by the residents, in relation towards the floods.

As for the coping measures, the residents have come to implement various coping measures, which were categorized into three levels, the physical/structural, social and economic coping measures. Which were implemented due to the damages incurred from the very first event. In anticipation for future flash flood events, the local authorities plan to implement various structural and non-structural measures, which include the repair of the channels, additional culverts and improving the early warning systems.

Keywords: Flash flood, Mpazi catchment, OpenLISEM simulation, coping mechanisms.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

KIST	Kigali Institute of Science and Technology
MIDIMAR	Ministry of Disaster Management and Refugee Affairs
NISR	National Institute of Statistics Rwanda
RMA	Rwanda Meteorological Agency
RNRA	Rwanda Natural Resources Authority
SPAW	Soil - Plant - Air - Water
SPSS	Statistical Package for the Social Sciences
UNISDR	United Nations secretariat of the International Strategy for Disaster Reduction

1. INTRODUCTION

1.1. Background

Floods are considered the most common and highly damaging of all hazards, and it has been predicted that they are likely to become more frequent, more prevalent and more serious in the years to come (Muchtar & Bahar, 2010) especially in fast growing cities of the global south. Compared to other types of natural disasters, they account for approximately 20-40% of the events which are reported (Sene, 2008). Their nature is governed by various factors, which include the properties of the drainage, rainfall characteristics and the management in the area (Muchtar & Bahar, 2010).

According to (Jha, Bloch, & Lamond, 2012), the global trend in urbanization, is the current defining trend in the 21st century. Particularly, the growth in low to middle income developing countries, and the human induced environmental changes, are the two major themes which are leading us to believe that the number and scale of impact of flood events, will continue and possibly accelerate in the next 50 years (Mendel, 2006). The nature of occurrence of flood is governed by diverse factors, including rainfall characteristics, properties of drainage catchment and land water use and management in a catchment area (Muchtar & Bahar, 2010).

Various researchers are highlighting how urban development and human action influence flood behaviour (Borga et al., 2011, Brody et al., 2008). The problems associated with flash floods, according to (Douglas et al., 2008) have been grouped into socioeconomic and environmental problems. The socio-economic problems include tangible direct losses, tangible indirect losses as well as the intangible human losses (Razafindrabe et al., 2012).
Tangible direct losses are related to the destruction of physical and utility infrastructure, building, loss of human life and the associated economic loss, while the environmental problems are related to the land degradation and the destruction of the ecological system (Douglas et al., 2008). These conditions reflect reality for the urban poor who are more vulnerable and are faced with little or no option in dealing with such a disaster (Bizimana & Schilling, 2010).

The rate of urbanization in most developing African cities is increasing at a rapid rate, and it does not take into consideration, the previous environmental functions and services provided earlier within these areas (Parkinson, Tayler, & Mark, 2007). In addition, these conversions are undertaken without considering the suitability of the area for urban expansion. Which include, occupying floodplains and blocking small tributaries with buildings and infrastructure (Parkinson et al., 2007). Due to these land use/land cover changes, they transform the natural behaviour of floods and runoff, modifying the natural absorption and regulation capacity of the terrain, thus obstructing the natural channels (Douglas et al., 2008). This therefore, increases the flood risk in cities, due to local changes in the hydrological and hydro-meteorological conditions (Huong & Pathirana, 2013). This eventually leads to flash floods due to the fast and voluminous runoff and the reduced time of overland flow.

In Rwanda, floods are a common phenomenon, as they are the most often occurring disaster (MIDIMAR, 2013). They are predominantly of two types of floods, localised floods caused by exceptionally heavy rains and run-offs and widespread floods caused by overflowing rivers and their tributaries. But most of these floods are not only related to the extreme rainfall and climatic events, but also to the changes in the built-up areas/ urbanization (Huong & Pathirana, 2013).

The relationship between urbanization and informal settlements growth in flood prone areas has been observed in the city of Kigali, where nearly 20% of these developments are informal settlements, which are located on wetlands (Tsinda et al., 2013). The city of Kigali in Rwanda, has experienced rapid expansion and urbanization over the last decades, with the annual growth rate at 2.6%, which is considered to be amongst the highest in Africa. According to Rwanda Ministry of Infrustructure (2007), the population density of the Kigali urban area, increased to around 86 people/hectare, the population density of 2012 is presented in Figure 1.1.

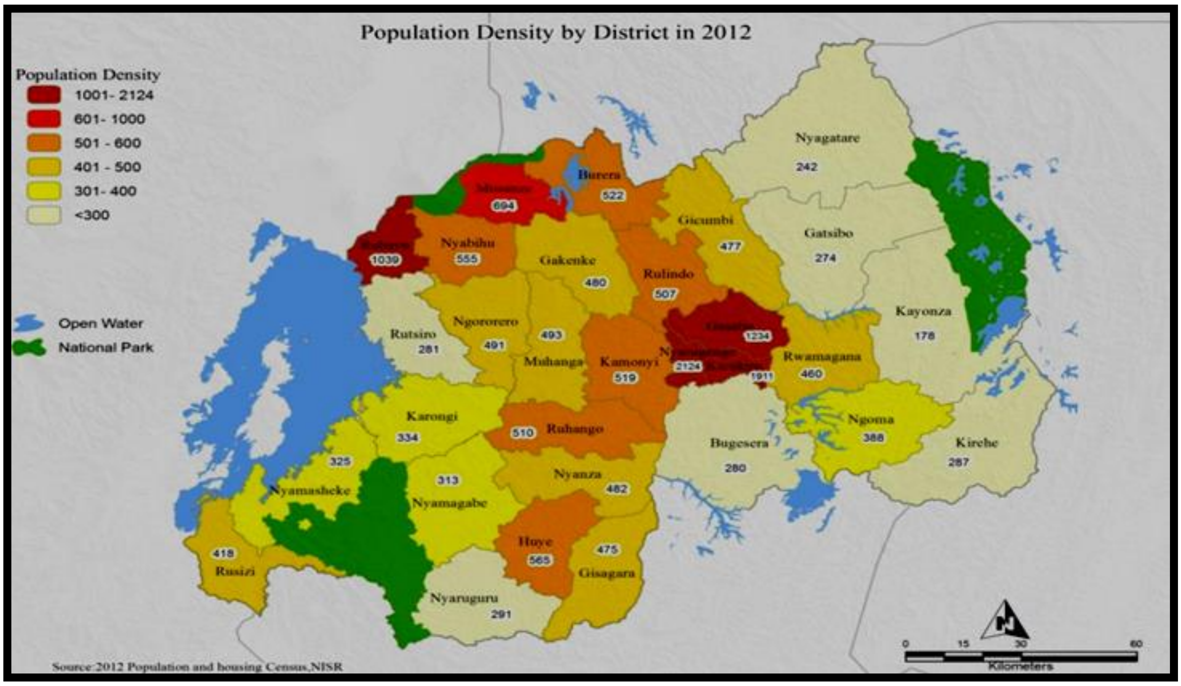

Figure 1-1 Population density in Rwanda *(MIDIMAR, 2013)*

Thus, a great part of the population are highly exposed to the flash floods (MIDIMAR, 2013). Despite the increasing flood risk awareness, unplanned human settlements continue to develop in flood prone areas due to the need of land, which lead to the creation as well as the expansion of informal settlements in the high risk zones (Adelekan, 2010). Although the population have learned to cope with the adversity, vulnerability of the local people to this threat of flood still exists, which therefore calls for appropriate measures to be implemented so as to mitigate the effects.

There are a number of strategies in the management of flash floods that ought to look at all aspects of both the flood behaviour and the urbanization process. This include both the structural and non-structural interventions, which have to complement each other (Shrestha & Bajracharya, 2013). The structural focus more on the physical protection such as dikes, diversions, floodway and improvements on the channel, whereas the non-structural, focus more on the flood warning, watershed management, evacuation and enhancing the coping capacity of the affected population (Allen, 2006).
It has become apparent that top-down approaches alone fail to address the specific local needs of the vulnerable communities, often ignoring the local capacities and resources (Cadag & Gaillard, 2012). One of the cornerstones of hazard assessment is the information of the local community at risk (Cançado et al., 2008). However, expert judgment is commonly used, and the local communities that are more conversant with the situation at hand, are rarely involved in the process. According to Van Westen, 2013, communities have the ability to provide information of the historical events that have occurred. This research is aimed at

creating awareness and enabling the local citizens to actively participate, for the purpose of the decision making process. This through communication and contributing to the mitigation plans developed by the local government and other stakeholders. In turn, this will provide the local government with accurate and contextualized strategies in the management of disasters.

1.2. Problem Statement

Rwanda is vulnerable to a range of disasters, but amongst them, floods and landslides, have become more frequent, which constantly affect localized area of the country (Nsengiyumva, 2012). Flooding is a prominent feature in Kigali, and the local authorities have difficulty in managing the city`s physical development of the informal housing sector. Therefore the affected population have to learn to cope and overcome the impacts. Their strategies are mainly influenced by their perception towards the flash floods and by learning from their past experiences (Douglas et al., 2008).
Urbanization itself increases flood risks and Kigali City faces this problem along the Mpazi sub-catchment, which is a heavily urbanized area that suffers from flash floods. This catchment has very steep slopes in the upper part and has elevation of approximately 400 m.
Although the urban drainage system has been developed, it is indicated that the Mpazi channel, could be the root cause of the flash flood events in the area. This is due to the degraded steep slopes and the dense unplanned settlements, which are often close to the channel. The channel also has an extreme low retention capacity, that any high intensity and slightly prolonged rainfall, would generate an extreme flood wave response in the channel system (SHER Ingénieurs-Conseils s.a., 2013).

On the other hand, the bridges and the clogged culverts become too small to cope with the increased flows from upstream, due to the unorganized drainage systems which are heavily choked with solid waste dumped in the Mpazi channel.

The recurring flooding events, have had profound effects in the area, which clearly show the efforts made by the local government to mitigate the flash floods are not sufficient to handle the problem.
Ever since the implementation of a data logger, by the Rwanda Natural Resource Authority, so as to measure the flood waves within this catchment. It has so far registered 16 floods, 12 of them happened to be small scaled while 4 of them caused a lot of damaged, in which out of the four two were reported. They occurred on the 23rd 02 2013 and the 13th 12 2013 (SHER Ingénieurs-Conseils s.a.., 2013).

Even though there is an established disaster management planning unit within the Ministry of Disaster Management and Refugee Affairs, their level of implementation is weak, mostly due to insufficient resources, to enable to implement the plans effectively (Tsinda et al., 2013). Therefore, there is great need to produce appropriate flood hazard maps, which will provide detailed information on the characteristics of these flash floods. This is to better understand their dynamics as well as simulating different scenarios for different return periods and magnitudes.

1.3. Research Objectives

The main objective of this research is to assess the flash flood dynamics and people`s coping strategies, in Kigali, Rwanda. The specific objectives and research questions are presented in Table 1.1.

Table 1-1 Specific Objectives

No.	Specific Objective	Research Questions
1.	To identify the cause of the recent flood problem.	1.1 What was the recent flooding situation in the area? 1.2 Are the floods caused by the increase in population? 1.3 Are the floods caused by the changes in land use? 1.4 Are the floods caused by increase in precipitation? 1.5 What is the nature of the existing drainage system?
2.	To assess the flash flood characteristics of the area.	2.1 What was the magnitude of the recent flash flood? 2.2 What are the flood levels, extent and duration of the recent flash flood events? 2.3 What is the return period of the recent flood? 2.4 What will be the magnitude and the return period of a major event?
3.	To assess the perception of the community towards the flash flood hazard.	3.1 What is the perception at the community level towards the flash floods hazard? 3.2 What is the perception at the governmental level towards the flash floods hazard?
4.	To analyse the current coping strategies employed at the household, community and governmental levels.	4.1 What are the coping strategies applied at the Household and Community level? 4.2 What measures do coping strategies used at the government level address? 4.3 What are the local institutes and local government doing to improve coping strategies? 4.4 What are the government's preparation plans in case of a major event

1.4. Organization of the thesis

Chapter 1 Introduction: This describes the general overview of the research; background, problems, and the research objectives with specified questions to be addressed and a brief description of the research approach.

Chapter 2 Literature Review: This chapter gives a detailed description of the different concepts and theories related to the research topic in this particular field.

Chapter 3 Study Area: This chapter gives a description of the study area giving information on location, extent and generally the characteristics of the area.

Chapter 4 Methodology: Details on the approach and tools used to accomplish the proposed objectives including the data collection, data preparation, analysis and application of flash flood model.

Chapter 5 Flash Flood Assessment: This chapter examines the flood dynamics of the Mpazi catchment, describing the characteristics of the flash floods in terms of extent, duration and frequency to inform simulation of different return periods and magnitudes. It also analyses the changes that have occurred to trigger the onset of the frequent flash floods in the area.

Chapter 6 Perception: This chapter discusses the local people perceptions in relation towards the flash floods.

Chapter 7 Coping Mechanisms and Role of Government: This chapter explains the various methods of coping mechanisms that have been employed before, during and after flood. This is at household, community as well as at the authorities' level. It also analyses the different strategies that the government has set in place to mitigate the floods effects.

Chapter 8 Conclusion and Recommendations: The chapter contains a brief conclusion of the entire research by examining and presenting the answers of the proposed research questions and the recommendations for further research work.

2. LITERATURE REVIEW

2.1. General Understanding of Flood Hazards

Hazards are usually defined as potentially damaging physical events, phenomenon or human activities that cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (UNISDR, 2004). There are many types of hazards that occur at different spatial and temporal scales and have different damaging effects. Which can be induced by human activities and natural processes (Twigg, 2004).

The most common are the flood hazards, which can be defined as the chance of a certain magnitude of flood event to occur in a given area and period of time (Alkema, 2007). They result from a combination of meteorological and hydrological extremes, as well as, human based activities, such as unplanned growth and development of floodplains (Dewan, 2013, Borga et al., 2011). Understanding flood hazards is the first step towards getting a better comprehension of the types and causes of flooding, their probability of occurrence and the expression in terms of extent, duration, depth and velocity (Jha et al., 2012). Describing and categorizing floods usually vary, and they can be characterized into fluvial floods, pluvial floods, coastal floods and flash floods (Sene, 2013).

They are measured by the probability of occurrence of their damaging values, conceived generally as flood risk, or by their impact on the society. To better understand the flood hazards, one requires both qualitative and quantitative flood data and also by integrating the use of GIS and RS (Sene, 2008).

2.2. Floods in the Urban Context

Cities around the world face a tremendous challenge in dealing with flood related problems (Dewan, 2013). As urban areas are more at risk, and have been hit particularly hard these flooding events. For example, flood events that occurred in Sri Lanka and the Philippines that is in the late 2010 and early 2011, also in Southern Pakistan and large areas in Thailand (Jha et al., 2012). This caused tremendous damage, and a large number of the population were affected.

These urban floods are taking place more frequently than the past due to the massive urbanization, industrialization movement and economic development (Zheng, Qi, & Xu, 2012). They arise due to a complex set of interactions. This is between the surface and sub-surface drainage networks and features in the urban environment, and intensify with the increase of impervious surfaces, such as roofs, roads, parking lots and pavements (Sene, 2013).

Other factors include the changing climate, increasing frequencies of abnormal rainfalls, all coupled with environmental degradation which is caused by urbanization (Schanze, Zeman, & Marsalek, 2006). According to (Jha et al., 2012)urban areas are notably more susceptible to flash floods. This is due to the modifications that change the hydrological cycle, including the timing, intensity and the extent of inundation (Dewan, 2013).

2.3. Characterization of Flash Floods

There are different types of floods that occur, and flash floods have been considered to be one of the most significant and the most dangerous natural phenomenon's (Brody et al., 2008). Despite being a serious natural hazard, that affects countries across the world, they remain poorly understood and documented (Gaume et al., 2009). They can be defined as the sudden-onset floods of peak discharge far in excess of normal river flows, which are generally small in scale (Smith, Carrivick, Hooke, & Kirkby, 2014). This is due to their tendency to occur spontaneously, reaching full peak in only a few minutes up to a few hours. Which makes them difficult and almost impossible to forecast (Jha et al., 2012)).

Flash floods mostly occur within highly urbanized areas, and are caused by short duration, high intensity, localized rainfall events, which differ from most fluvial floods, in that the lead time for warnings is generally limited (Lumbroso & Gaume, 2012). Their occurrence is of concern in hydrologic and natural hazards science (Borga et al., 2011), due to their suddenness and difficulty to predict them, which makes it hard to warn people for evacuation.

2.4. Flood Hazard Assessment

The estimation of the flash flood hazard is usually the first step towards combating the risk of a flood occurring, with in an area. It is done using various approaches and techniques, which can be either the statistical or hydrological and geomorphological (Schanze et al., 2006). It normally takes into consideration different parameters. This includes the probability of return period, temporal and spatial occurrence, the magnitude and its parameters such as depth, velocity, impulse, rising water level, warning time and duration of the floods (Dewan, 2013).

A flood hazard map with all the aforementioned characteristics is usually the final result of the flood hazard assessment. These flood hazard maps caters to different users (Borga et al., 2011). It provides detailed information which addresses the spatial and temporal probabilities of the floods, and they depict the past and also the future of possible hazards that may occur (Sene, 2008).

Flood mapping is a tool used to assess the types and extent of flooding. The most important hydrologic and hydraulic variables relevant for flood hazard assessment are meteorological data that is the rainfall intensities, magnitude and frequency of flood peak discharges, plus the location and size of the flooded area (Dewan, 2013).

2.5. Flood Frequency Analysis

The concepts of magnitude and frequency are essential for the assessment of flash floods (Stedinger & Cohn, 1986). The consequences of floods, are measured using return periods, which gives an indication of its characteristics (Meirovich, Ben-zvi, Shentsis, & Yanovich, 1998). This can be done by determining the key triggering factors which cause the floods. The investigation of the spatial extent of the historical events, have been used to improve the estimation of the flood frequency and magnitude relationship (Mujere, 2011). That normally involve the fitting of a probability model to a sample of flood peak recorded over a period of observations, for a catchment (Pegram & Parak, 2004). To determine and quantify the flood frequency and flow variation within a given area, a probabilistic tool is used such as the Gumbel.

The Gumbel extreme value distribution aims to build the relationship between the probability of the occurrence of a certain event, its return period and its magnitude (Bayliss & Reed, 2001). With this information one can easily predict the extreme events of large recurrence intervals, and can be prepared based on specified flood frequencies or return periods, for example 1:10 years, 1:25 years, or to more extreme events such as the 1:1000 year return period for different scales (Jha et al., 2012).

2.6. Flood Modelling

Modelling is usually the process of simulating real life situations, and exploring the different ways that situation could develop, given different influencing factors (Stedinger & Cohn, 1986). It usually helps us understand the current and the future flood risks (Lumbroso & Gaume, 2012). These models can be regarded as stochastic or deterministic, where Stochastic models take into consideration the chance of incidence or probability distribution of the hydrological variables, and the deterministic models simulate the physical processes operating in the catchment to transform precipitation into runoff (Beven, 2004).

Various flood dynamic models have been used to simulate floods that occur all over the world. Depending on the purpose of the study, one has to choose a model that suits to their specification. With the increased flood events that are occurring, it has prompted researchers to improve the existing flood models, and in the process several models have been established.

Flood models require several considerations that ought to be addressed as they all tend to differ in the structure and treatment of the different parameters of the hydrological process as well as the assumptions they hold (Ward & Robinson, 1991). The main distinction between the different hydraulic model types is the number of dimensions in which the physical process is represented. which can be classified according to the number of dimensions in which they represent the spatial domain and flow process (Mani, Chatterjee, & Kumar, 2013). To date, dynamics of the varying flows have been predominantly been treated with the one dimensional 1D and the two dimensional 2D models which takes flow direction into account (Horritt & Bates, 2002).

2.7. Risk Perception

The perception of flood risk in a given community plays an important role to know how they anticipate the negative impacts of the flood. Perception of risk has been defined by (Fatti & Patel, 2013)as the recognition, of potential threat of disaster through the intuitive judgement of individuals and groups. According to Bradford et al., (2012), they consider risk as an individual's interpretation or impression, which is based on an understanding of a particular threat that may potentially cause loss of life or property, or simply as the way that individuals process information.

The perception of risk solely depends on the individual`s judgement and involves great subjectivity, that is influenced by both internal and external factors (De Risi et al., 2013). The internal factors include the frequency and intensity of the personal experience toward the past events. While the external factors are related with the characteristics of the hazard, which includes magnitude, duration, frequency and source of information (Sjoberg, 2000).

The level of perception on risk can consist of the individual's manifestations or collective influences, as (Ho, Shaw, Lin, & Chiu, 2008) define risk perception as the way the community at large , perceive, evaluate and rank the level of risk.

Understanding perception towards risk, by the community at large, is highly important when developing policies and the various management strategies. This is done, in order to understand how local authorities and the community, view and also respond to disasters, their knowledge of the hazard and experience. But perception of the risk towards a hazard also depends on the individual`s social context, which are not homogenous within a community (Pagneux, Gísladóttir, & Jónsdóttir, 2010).

Tobin & Montz, (2004), identified two main components that influence how people perceive risk, which are situational factors and cognitive factors. Cognitive factors include psychological and attitudinal variables, such as political ideologies, an individual's personality and religious beliefs, while the situational include the physical and the socio-economic factors, which include the demographic variables (Education, age, income levels) and the characteristics of the event, in terms of the duration, magnitude and its frequency.

2.8. Coping Mechanism

According to Twigg, (2004), coping is defined as the management of resources in difficult situations. Knowing the coping strategies, is an important factor in determining the type of risk reduction measures that should be implemented in an area. Coping mechanism is defined by the UNISDR, (2009) as the ability of people, organizations and systems, using available skills and resources to face and manage adverse conditions, emergencies or disasters.

The coping mechanisms are a set of measures, primarily developed, so as to protect and regain from the losses and damages caused by the flood hazards (Wisner, Blaikie, Cannon, & Davis, 2003).

Different individuals as well as communities, have different ways and a variety of measures to reduce their exposure to a hazard. In order to cope with flood hazards, the affected communities have to take all the measures, with necessary polices and strategies of implementation, in which they may apply to alleviate the consequences of flooding. Blaikie, Cannon, Davis, & Wisner, 1994; emphasized that all types of coping mechanisms, that are implemented, are perceived to have a set of actions before, during and after an event. Which aimed at meeting the following objectives;

1. Hazard reduction and Avoidance, this is to limit or avoid current and future hazards,
2. Vulnerability reduction, to reduce the current and future vulnerability to hazards,
3. Preparedness for response,
4. Preparedness for recovery.

Twigg, 2004, divided coping mechanism into four categories: Structural / Technological: Which is related to the different land management systems, and enhanced engineering techniques, building materials and construction methods. The Social / Organisational: Which involves the formation of kinship networks, mutual aid, and self-help groups. The Cultural: Which relates to how individuals perceive risk with religion been am main factor and Economic/ Material: Which emphasizes on the economic diversification, which is having more than one source of income. The analysis of the different coping mechanisms that are applied within a community, is deemed as useful especially for decision makers, so as to aid in the designing of more suitable and sustainable measures.

3. STUDY AREA

3.1. Location

The study area is located in Kigali, the capital of the republic of Rwanda, which is geographically located in central Africa between 1°04' and 2°51' latitude south and between 28°45' and 31°15' longitude east. It is bordered by Uganda in the north and Tanzania in east while in the south and west are Burundi and the democratic republic of Congo, respectively.

The city of Kigali, is located in the central part of the country. It is further, divided into three districts, Gasabo, Nyarugenge and Kicukiro. The area of study is located in Nyarugenge district, which is in the west of the city, with an area of 134.2km2. The current population is about 237,000 people, and it is the most densely populated district of Kigali with an average density of 34 persons/ha (NISR, 2012). The district is bounded by Nyabugongo River, which runs along almost the entire western and southern edge of the district. This is displayed in Figure 3.1.

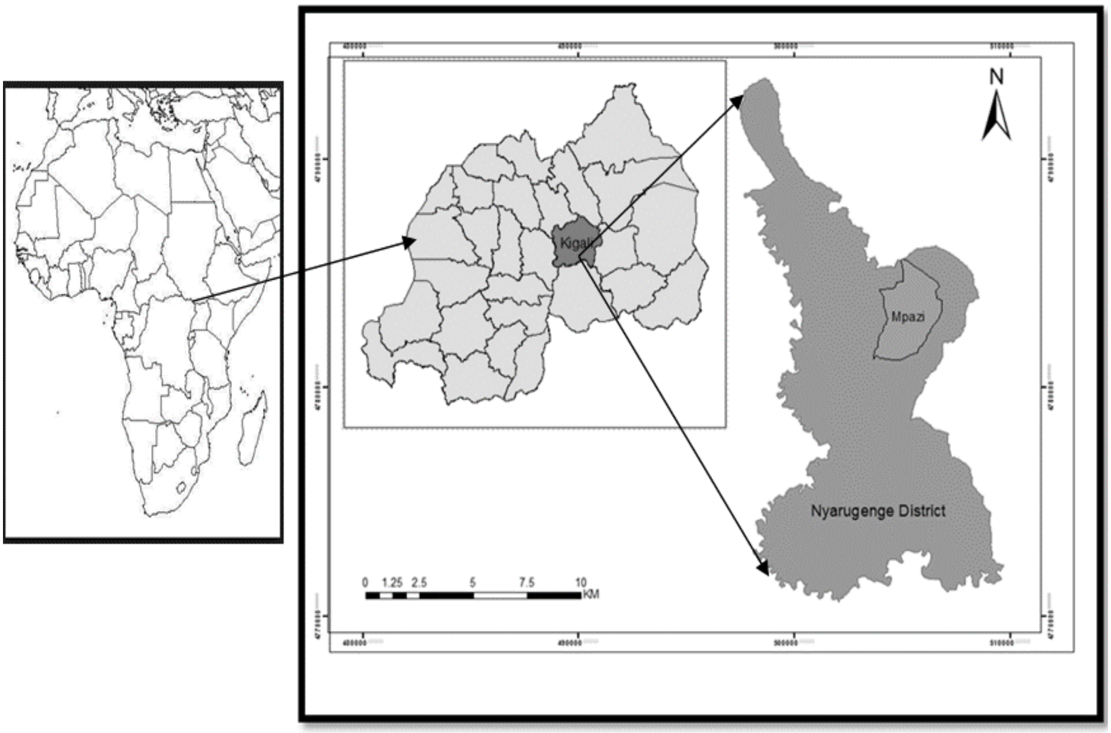

Figure 3-1 Rwanda and its location in Africa, including the location of Kigali and the main area of study, Mpazi Catchment

3.2. Topography

The area is hilly and has four distinct topographic features, which are: areas of gentle slopes (less that 20% gradient) on the ridges and along the wetlands, areas with steep slopes (more than 20% gradient), linear ridges running along the length of the sectors and alluvial plains along the rivers Nyabarongo and Nyabugogo. The elevations range from 2071m to 1335m, and has an average elevation is 1000m above sea level. This is shown in the Figure 3.2 below:

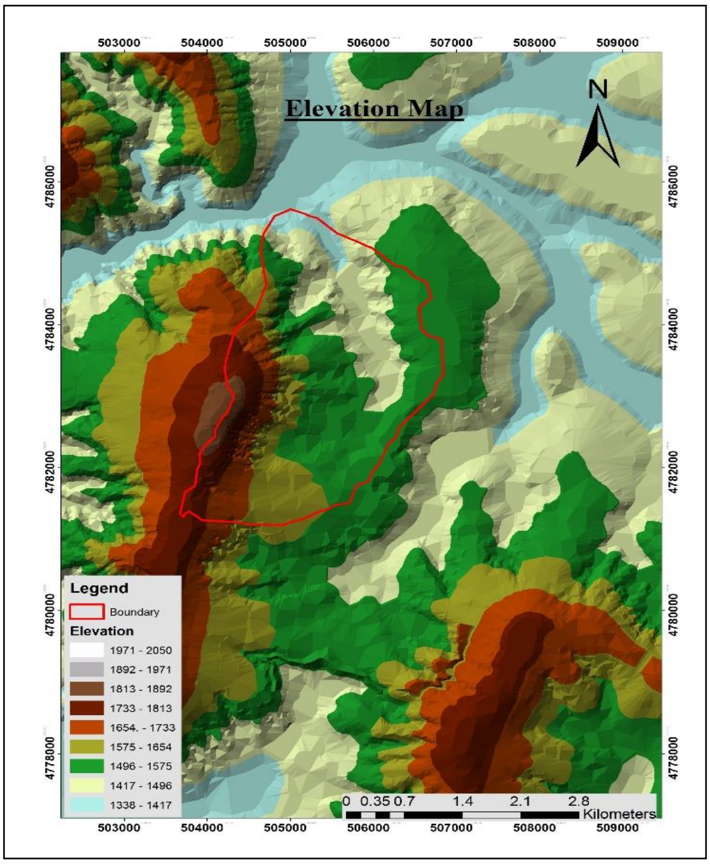

Figure 3-2 Elevation Map of Mpazi Catchment

3.3. Climate

Rwanda has a tropical temperate climate. The hottest months of the year are February and March, while June and July are the coldest. The average annual temperature ranges between 16°C and 20°C, without significant variations. There are two rainy periods that generally occur from February to May and from November to January. March through May is the rainiest time of the year in Kigali with an annual average rainfall of 1,295 mm. However, the climate is complex with wide variations across the country and strong seasonality. The monthly average rainfall and average daily temperature for Kigali are shown in Figure 3.3.

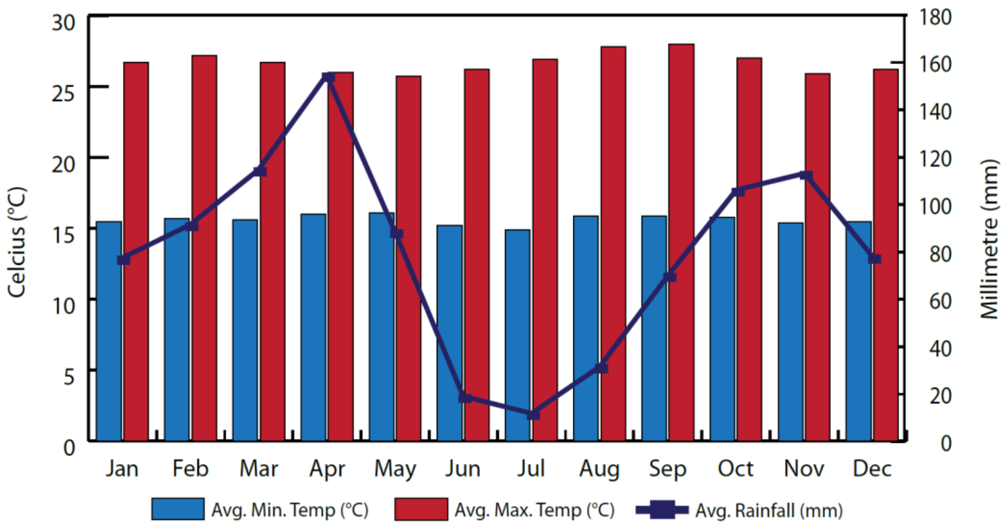

Figure 3-3 Graph of average daily temperature and monthly rainfall *Source: (REMA, 2013)*

3.4. Geology and Soils

Granitic and meta-sedimentary rocks underlie the City of Kigali; these include schists, sandstones and siltstones. Lateritic soils, rich in iron and aluminium, dominate the city's hillside surfaces.
While alluvial soils (fertile soil deposited in river valleys) and organic soils are found in the lowlands and wetlands. Rwanda is characterized by having six major types of soils namely; Soils derived from schistose, sandstones and quartzite formations (50%), Soils derived from granite and gneissic formations (20%), Soils derived from basic intrusive rocks (10%), Soils derived from recent volcanic materials (10%), Soils derived from old volcanic materials (4%) and Alluvial and colluvial soils (6%). The soil types found in the study area are Acrisols, Alisols, Cambisols, Ferralsols, Gleysols and Regosols, this is displayed in Figure 3.4. However the most dominant type are Regosols. This is according to the World soil classification system that was developed by the Food and Agriculture Organization (FAO).

3.5. Land Use

Due to the topographical constraints, almost 83% of the City is natural unplanned areas and rural agrarian land. Urban land uses such as residential, commercial, industries, and social and infrastructure facilities occupy around 17% of the City's land. This study will have its focus mainly within the most affected areas in Gitega and Kimisigara sectors, which are largely urbanized, with the land use compromising mainly of the heavily dense residential and commercial areas which are prone to frequent flash floods. This is shown in Figures 3.5 below, and the distribution of the existing land use types is shown in table 3.1.

Table 3-1 Distribution of the existing Land Use in Nyarugenge District

Land Use Type	Area in (SqKm)	Percent %
Residential	67.58	9.2
Commercial	21	2.9
Infrastructure	20.84	2.8
Bare	15.63	2.1
Agriculture	461.37	63.1
Forest	141.98	19.4
Water Bodies	2.905	0.5
Total	589.325	100

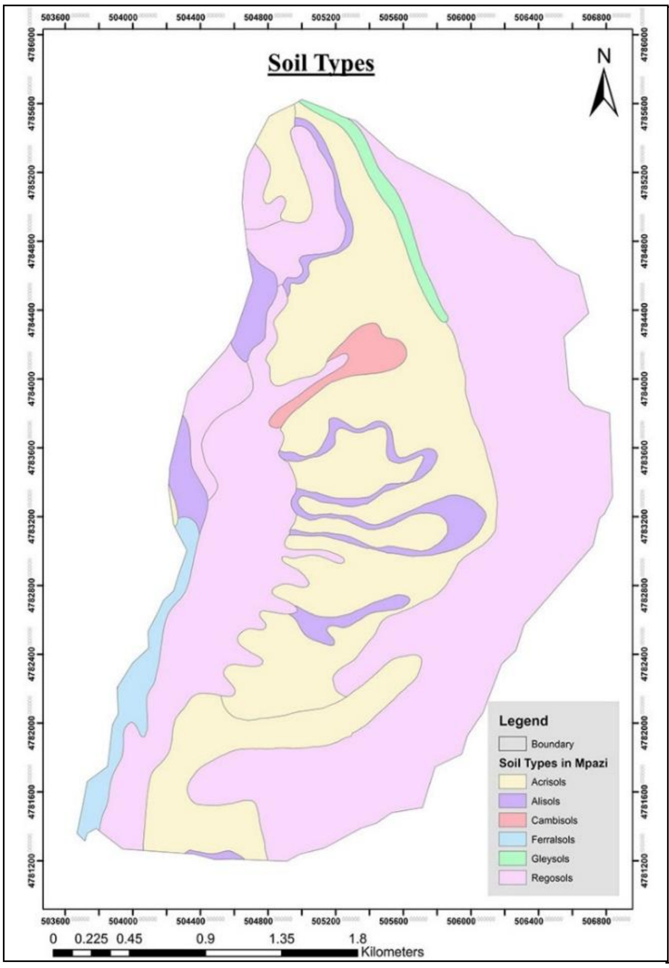

Figure 3-4 Soil types in Mpazi Catchment

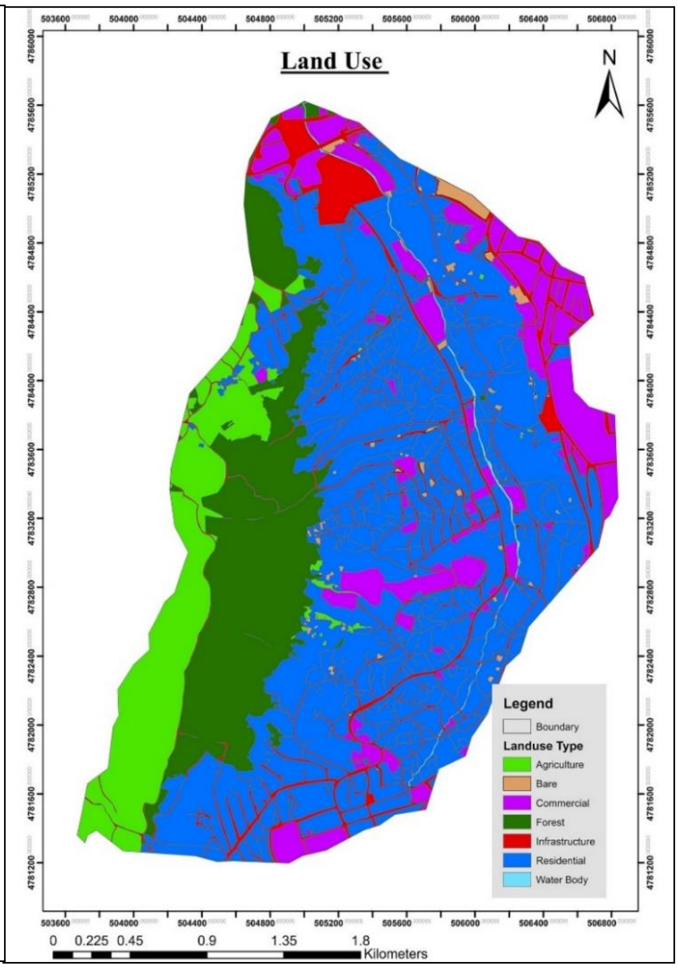

Figure 3-5 Land Cover of the Catchment Area

Figure 3.6, depicted below presents a general overview of the study area. The descriptions are as follows:

1. The commercial area, found in the lower part of the catchment. One of the area's most prone to flooding.
2. Rain water flowing through the culverts at the beginning of a rain storm. Which gets filled up very fast, due to the amount of solid waste restricting the flow of water.
3. One of the secondary channels, along the main road
4. A section of the secondary drains, along the settlements, filled up with solid waste.
5. A part of the natural drains, which collects rain and waste water, from the settlements within the catchment.
6. Part of the primary channel, filled with debris and loose sediments, that originate from the hills around the catchment
7. Encroachment of the settlements into the forested zones
8. A section of the Primary channel, as one can see the amount of debris and sediments that originate from the hills around the catchment.

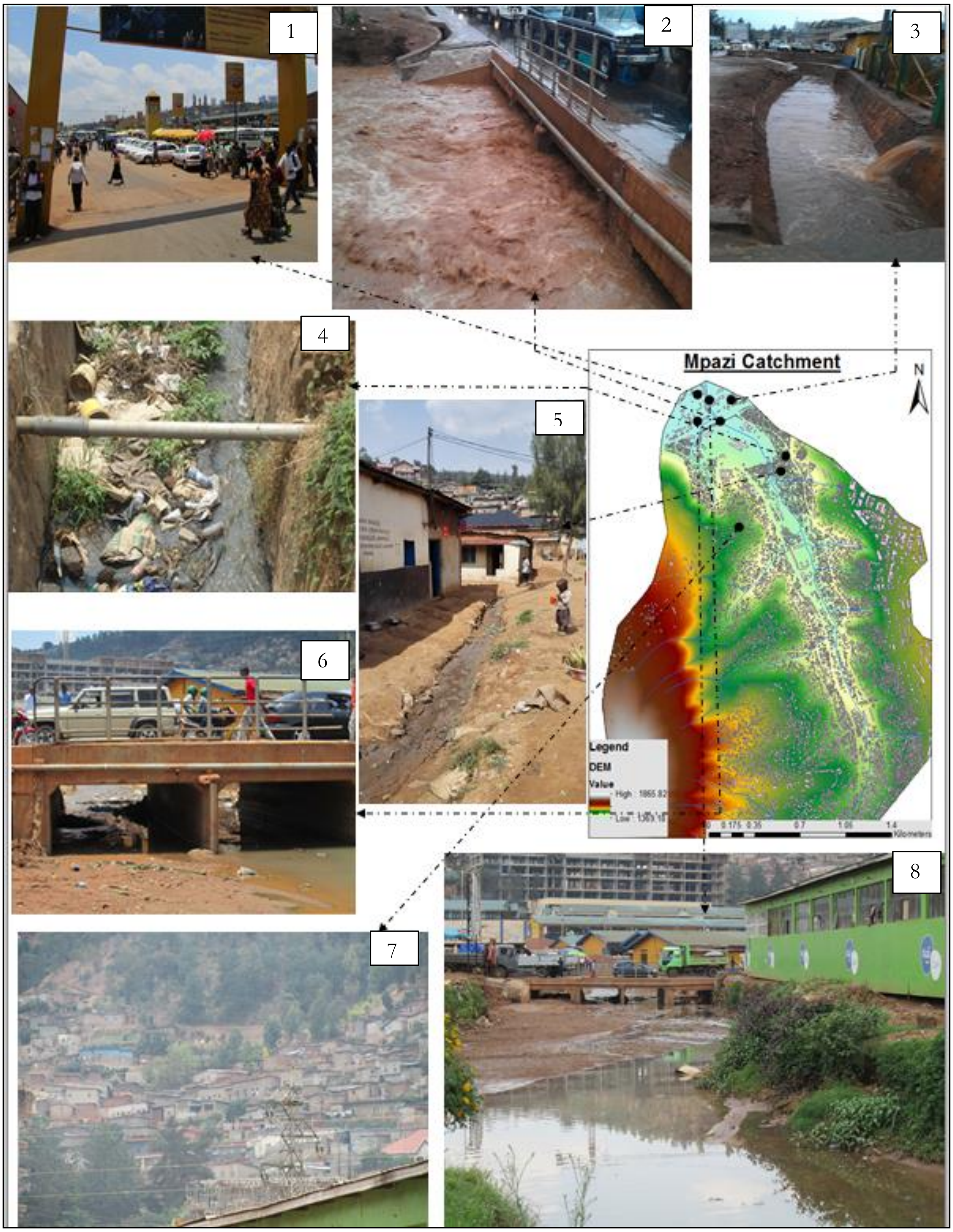

Figure 3-6 General overview of the Mpazi catchment

4. RESEARCH METHODOLOGY

4.1. Data Collection

Assessing the dynamics of a flood event, required several sources of information. The research methodological flowchart is presented in Figure 4.1.

As this study uses OpenLISEM as the main tool for flood simulation, the focus of data collection was based on the inputs required by this model, as well as additional data to assess the root cause of the flash floods in the area.

As part of the field visit Rwanda Natural Resource Authority (RNRA), Kigali City Authorities (One Stop Centre), Kigali Institute of Science and Technology (KIST), Ministry of Disaster Management and Refugee Affairs (MIDIMAR), National Institute of Statistics Rwanda (NISR) and Rwanda Metrological Agency (RMA), were part of the institutes visited to collect secondary data.

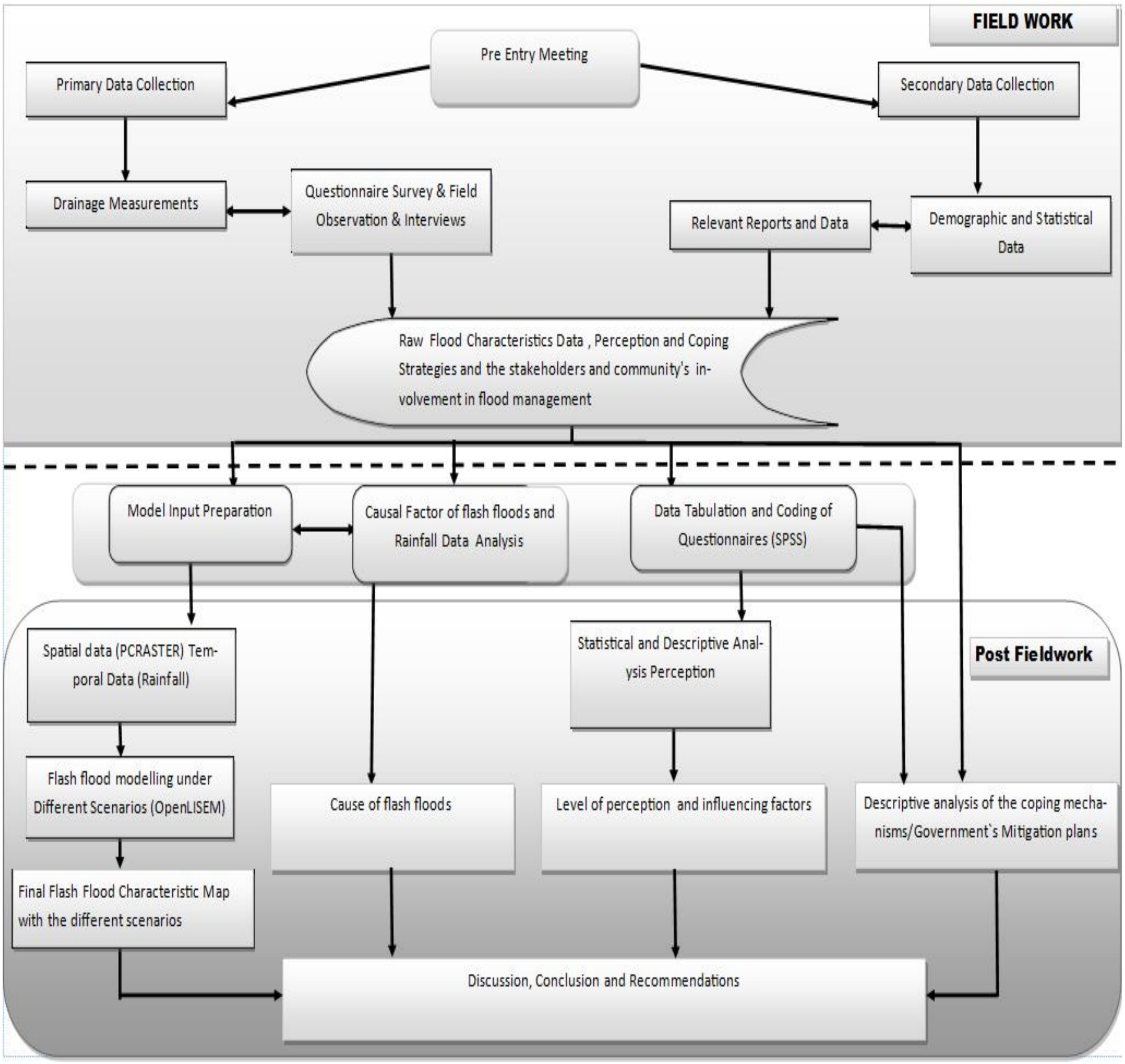

Figure 4-1 Research Flowchart

4.1.1. Questionnaires and Interviews

To achieve the objectives of the study, primary data was collected. This included drainage measurements, the socio- economic profiles of the respondent, and their perception towards the flash floods, and the type of coping mechanisms that has been implemented, by using the questionnaires (see appendix 1). Before going into the community, the researcher also conducted in-depth interviews with the local authorities with in the institutions as aforementioned above. This was to get permission and also attain a general overview related to the flash flood occurring in the area.

The survey methods used to obtain the data from the respondents, was in form of questionnaires and interviews, with the community and key stakeholders. The purposive sampling method was used to select the respondents that is the individuals who were highly affected by the flash floods, this is depicted in Figure 4.2. A total of one hundred respondents were sampled.

The purpose of undertaking the household interviews using the questionnaires was to get detailed information, regarding the general perception of the flooding. This is in terms of the extent, flood depth, flood duration, the socio- economic condition and the local knowledge, in relation to the flood hazard in the area. In this case, the 13th December 2013 flash flood event appeared to be more vivid, as it was the most recent flooding event that had a major impact to the community. This process also included, gathering information on the various strategies set in place by the individual household as well as the community as a whole, on the types of coping mechanisms used in the area.

The questionnaire was divided into three sections, the first was the respondent`s information that is their socio- economic profile (sex, age, education level etc.). The second part was set to obtain information on the level of perception, while the third section was on the coping mechanisms that have been implemented. The interviews lasted between 15 to 30 minutes.

Figure 4-2 Interviews with the Respondents and Governmental Representatives

Figure 4.2 (1): Household interviews in Gitega and Muhima Sectors
Figure 4.2 (2): Office Interview with Governmental Officer at MIDIMAR

4.1.2. Secondary data from Offices

The field work was conducted in Kigali, Rwanda from the 29th September 2014 to 19th October 2014. The secondary data and information was collected in form of both hardcopy and softcopy, from different governmental ministries as aforementioned, previous research studies etc. The secondary data that were collected are indicated in the table 4.1 below:

Table 4-1 List of Collected Data

No.	Type of data	Source	Method
1.	Topographic data Resolution 10*10m	Kigali City Authorities(One Stop Centre)	DEM from SRTM
2.	Land cover/ Land use 2013	Kigali City Authorities (One stop Centre)	Obtained from the Landsat TM and ETM scenes.
3.	Daily Rainfall Data	Rwanda Meteorological Agency	Daily Measurement taken, for a period of 43 years and recorded at Kanombe and Gitega stations
4.	Soil Map (1:50.000) Soil	Rwanda Natural Resources Authority	Laboratory and field measurements done in 2009 by the Ministry of Agriculture and Animal Resources, in conjunction with Ghent University
5.	High Resolution Images Quick Bird 2004 and Google Earth 2014	(Rwanda Natural Resources Authority)	
6.	Building Footprint Map 2014 and 2004	Secondary – Kigali City Authorities) One stop Centre)	Digitized using ArcGIS (Corrected due to some errors in topology)

4.1.3. Drainage Channel Measurements

Measurements of the entire drainage is necessary for accurate modelling of the flood dynamics. Due to the lack of ground data measurements, the field work was an opportunity to attain the information of the primary and secondary drainage system in the Mpazi catchment. To enable the determination of the capacity of the drainage channels, measurements were taken using BOSCH PLR 50 Laser Rangefinder and the 8 meters measuring tape. The point taken and measured are shown in Appendix 2.

4.2. Data Processing

In this chapter, data processing and the methods applied for this research are presented. This research has been organized into three main parts. The first part analyses the changes that have occurred in terms of population, land use /land cover changes as well as climate, in terms of analysing the rainfall data. The second part aimed to develop a rainfall runoff model. Where the baseline data related to the runoff generation and propagation, is prepared and are to be used as input in simulating different scenarios. Finally the third part takes into consideration the perception of the population towards the flash floods and identifying the current coping strategies analyses, as well as what the government has done so far to mitigate the effects of the flash floods and suitable recommendations.

4.2.1. Rainfall data

For any hydrological modelling rainfall is an important factor. As aforementioned, it can be from ground based measurements or from satellite estimates. Ground based measurements are usually considered to provide the most accurate value, but the spatial coverage of such measurements is very poor especially in developing countries.

The ground based rainfall data from the Rwanda Meteorological Authority was collected. This was specifically for the catchment area, where there is one ground based gauged rainfall station that is located in Gitega. They had records that date back to 1970, although there are major gaps present in the data sets. This was due to the lack of proper data entry management and also, after the 1994 genocide meteorological data was not recorded, right until 2010. However, to get a better understanding of the annual rainfall pattern, the rainfall data recorded at the Kigali International Airport (5 km away from the catchment), was also used, since it contained no gaps

The annual maximum daily rainfall for Mpazi catchment was sorted and analysed. This was to get a general understanding of the rainfall pattern, and to better understand the relation between magnitude and frequency, using the Gumbel extreme value distribution. The objective of this distribution is to evaluate the relationship between the probabilities of occurrence of a certain event, its return periods of rainfall and discharge, which can be determined.

The steps to calculate the return periods, using the Gumbel Variate (Y) is determined as follows, as per the rainfall data set from the year 1970 up to 2013.

1. Ranking of the yearly annual maximum daily values from low to high, then assigning lowest rank 1 to the lowest data value and assigning the highest rank N to the highest data value.

2. Calculation for each observation the left sided probabilities using the following equation:
   $P_L = R/N + 1$ (Where P_L = left sided probability), (R = Rank) and (N = Number of Observations)

3. Determining the right probability using the following equation:
   $P_R = 1 - (R/N + 1)$
4. Calculation of the return period for each observation using the following equation;
   $RP = 1/P_R$
5. To determine the plotting position for each observation the following equation is used:
   $y = -\ln(-\ln P_L)$

4.2.2. Field interview data on flood hazard perception and coping strategy

The data from the questionnaires were analysed, using both statistical and qualitative methods. This was to derive information on flash flood risk perception and the coping strategies that have been applied at household level, community level and also at the government level. Errors were adjusted, tabulated and coded, into the statistical package SPPS. This is in order to arrange the data in a systematic manner giving certain parameters and codes.

In this, descriptive methods and the multiple linear regression analysis were used to describe the basic features of the data. The descriptive method usually provides summaries about the measures and the samples. For this research it was used to analyse the characteristics of the respondents that is the age, gender, education levels, occupation, the length of stay, the size of the households and the experience with the flash floods.

As for the multiple linear regression analysis, it is normally used for predicting the unknown value of a variable from the known value of another variable. It is basically used to describe the possible relationship between variables. For this research this method was used so as to identify the factors that influence the perception that the respondents have towards the flash floods risk. With the null hypothesis where the independent variables which include (age, gender, household size, level of income, level of education, occupation, the length of stay and experience with the flash floods) have no significant influence on the dependent variables (respondents perception). This hypothesis was taken based on the value of the significance probability (P-value) and significance level (α) = 5%, therefore if the p-value > α (0.05) then the null hypothesis is accepted, but if the p-value ≤ α (0.05) then the null hypothesis is rejected

4.3. Flash Flood Modelling

The simulation of the most 13 December 2013 event was carried out so as to understand the nature of the flash floods and its characteristics using the OpenLISEM Model. In order to generate a flood hazard map for an area one should have an understanding the propagation characteristics. That is the flood extent, depth, velocity in order to produce an appropriate flood hazard map. To generate these maps, it may be done through a combination of field observation, as well as using, 1D2D flood models, so as to simulate different scenarios, to better understand the risk of the floods in an area.

In this study the Limburg Soil Erosion Model LISEM was used to assess the flood dynamics of the catchment. It is a free spatial modelling software that is used to analyse runoff and erosion problems in small to medium sized catchments (Jetten.V, 2013). It is also a raster based model that is used to simulate the surface water for each grid cell with spatial and temporal details. This model is designed to simulate the effects of detailed land use changes or conservation measures on runoff, flooding and erosion during and immediately after rainfall events.

The hydrological processes that have been integrated in the model include precipitation, infiltration, interception, surface storage and overland flow as indicated in Figure 4.3.

OpenLISEM is a data intensive tool, which requires at least 24 maps for the runoff simulation, however it uses a PCRaster script, which derives the parameter maps from the five basic maps. It derives the 1D domain, which usually calculates on the grid level, the rainfall (mm/h), interception (mm), infiltration (mm/h), and surface storage (Jetten.V, 2013). It also calculates runoff and channel flow and shallow flooding from the drainage channel networks, within the spatial domain. It normally uses high spatial and temporal resolutions of rainfall, as the input data can be in form of rain gauge networks or rainfall intensity maps.

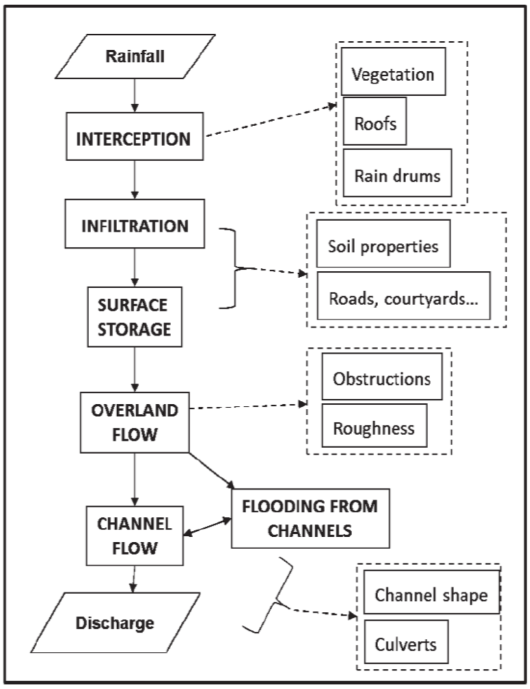

Figure 4-3 Flowchart of the main variables needed as maps for OpenLISEM *Source (Jetten.V, 2013)*

4.3.1. Input data for the OpenLISEM

OpenLISEM, is process based which requires a significant amount of input data. It uses various spatial data, in order to simulate a rainfall event on a landscape. All the needed input maps were derived from basic maps as shown in Figure 4.4, which include maps on rainfall, land use or land cover, percentage of house cover with storage capacity, channel properties, infiltration properties of the area, and the Digital Elevation Model.

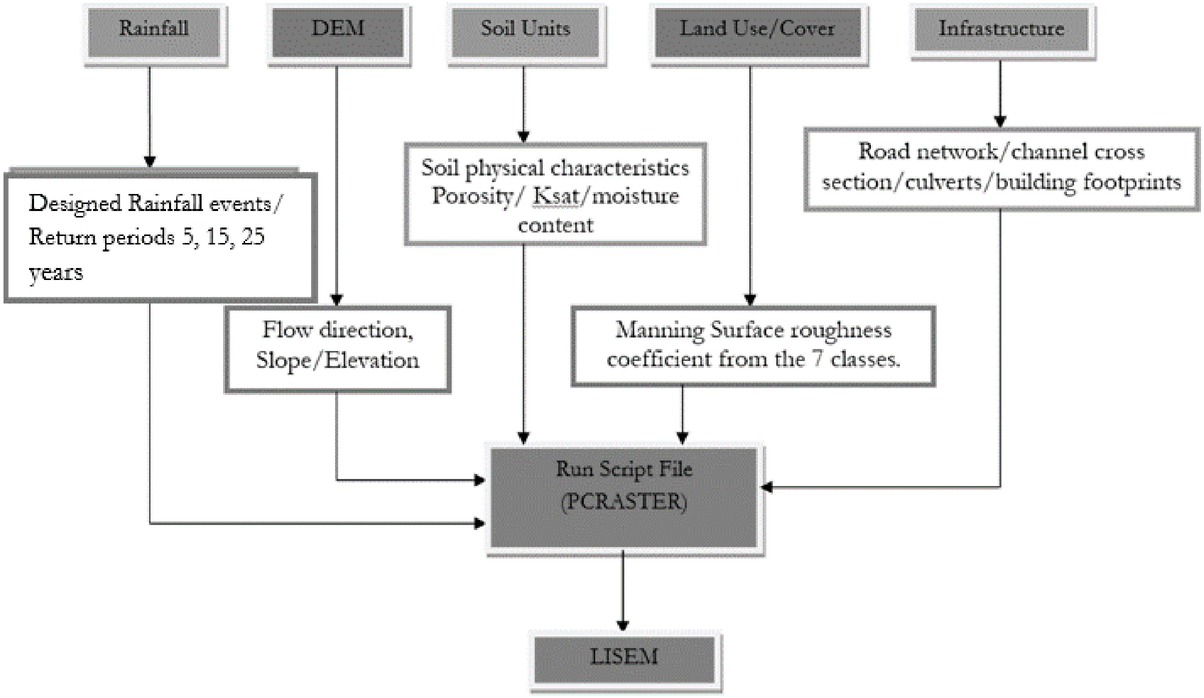

Figure 4-4 Main input maps required to run OpenLISEM *Source (Jetten.V, 2013)*

As OpenLISEM is grid based, all input maps used in the model were converted into raster format all having a grid size of 10m by 10m. The maps are provided as either maps of grid files in PCRaster format or in tables in text file format. Several attribute maps are derived using a PC Raster script which has been adopted from previous studies, and adjusted accordingly.

All the maps for the LISEM Model are presented in Table 4.2, where the LISEM environment allows the user to upload the run file, which contain the model input parameters and directories for the maps, rainfall table as well as the output results. It also allows the user to specify the simulation time, the beginning, the end time and the time step to which the output will be recorded. Where the model has option panels that allow the user to switch on/off runoff, erosion, channel infiltration, channel flow, and allowing flooding in the channels, urban interception and to include rainwater harvest. While the output options allows one to specify the directory for the results and formats for the data outputs.

Table 4-2 Input maps for the OpenLISEM model

Variable Name	
Rainfall	
ID	Rain gauge zone file
Catchment	
DEM	Digital Elevation Model
Gradient	Sine of slope gradient in direction of flow
LDD	Local surface drainage direction network
Outlet	Main catchment outlet corresponding to LDD map
Points	Reporting points for hydrograph
Land use	
Units	Classifies land unit maps for output of erosion values
Cover	Fraction surface cover by vegetation and residue
LAI	Leaf area index of the plant cover in a grid cell (m^2/m^2)
Height	Plant height (m)
Road Width	Width of impermeable roads (m)
Surface	
RR	Random Roughness
N	Manning`s n (-)
Stoniness	Fraction covered by stones (affects only splash det.) (0-1)
Crust	Fraction of grid cell covered with crust (0-1)
Compacted	Fraction of grid cell compacted
Hard Surface	No interception/ infiltration/detachment (0-1)
Infiltration	
1st layer Green & Ampt	
Channels	
Channel Properties	
LDD	LDD of main channel (must be 1 branch connected to the outlet
Width	Channel Width
Side angle	Channel side angle
Gradient	Slope gradient of channel bed (-)
N	Mannings of channel bed (-)
Cohesion	Cohesion of channel bed (kPa)
Houses	
House cover	Fraction of hard roof surface per cell
Roof Storage	Size of interception storage of rainwater on roofs (mm)
Drum Store	Size of storage of rainwater drum (m^3)

4.3.2. Digital Elevation Model

The DEM was derived from the 10 m contour map that was already available. The DEM is used for flow direction in the runoff part of the model and the elevation is used for the modelling and also creating a flow network using the steepest slope.

4.3.3. Soil Data

The Digital (ArcGIS) format of the soil, which was represented at a scale of 1:250000, originates from a soil survey that was undertaken in 1981. It was then later updated in 2009 by the Soil Survey Unit in the Ministry of Agriculture and Animal Resources, in conjunction with Ghent University (Belgium).

The soil map has an attribute table, which contains sufficient information to derive the texture classes. From this given information the Saturated Hydraulic Conductivity and Moisture Content of the soil within the area of study, was obtained using the SPAW Hydrology software. The soil type map has been converted into a raster map and has been reclassified to numeric codes.

From the SPAW interface, it was able to derive the saturated hydraulic values as well as the field capacity according to the soil texture.

4.3.4. Land Use /Cover

The random roughness and the manning's coefficient were used in this parameter to determine various processes including infiltration, surface storage and velocity of overland flow. These maps are based on the land use/ land cover types. The manning`s coefficient is derived based on the land cover types found in the study area which was retrieved from literature, these considered as surface flow resistance.

4.3.5. Building Density Map

This map was generated from a building footprint map. Having a building density map is important whistle running the model, because it influences the interception of the rainwater, and the flow velocity. The map was rasterized to 1 m resolution and then resampled to 10 m *10 m building density.

4.3.6. Model Calibration

To run a model, one requires to input several parameters in order to simulate and get as close as possible to the reality, although it will be not 100% fit with nature. Therefore model calibration is undertaken, to fine tune/ adjusting the values of the model parameters. This is to achieve more realistic results, in order to reduce the differences or deviations between the model results and the actual observed data (collected in the field). In this case the Manning coefficient values were used for the calibration of the model, all based on literature review that best fits the land cover types of the study area.

4.3.7. OpenLISEM Outputs

OpenLISEM usually produces different output information on water and sediments at catchment and sub catchment level, it usually produces tables, amps and time series maps of the drainage discharge, flood duration infiltration, rainfall, runoff, the total flooded area, and hydrographs that are then used by the user for other spatial analysis. Based on this study, different flood scenarios were run, with the aim to understand the flood dynamics characterizing Mpazi catchment, using different return periods and applying different flash flood risk reduction strategies.

4.3.8. Model Validation

Hydrological models ought to be validated, so as to note whether they match up to actual flood events that have occurred. For this research, the model performance was checked against the measurements that were obtained from the respondents, which was done based on the flood depths. The comparisons were done using the RMSE statistical method. This usually measures the magnitude of the accumulated errors and the accuracy of the hydrological model, based on the simulated results in reference to the field measured results. The equation is presented as:

$$\boldsymbol{RMSE} = \sqrt[2]{\frac{\sum_{i=1}^{n}(\boldsymbol{Sim}-\boldsymbol{Obs})^2}{\boldsymbol{n}}}$$

(*Sim* – Simulated result measurements, *Obs* – Observed measurements and *n* – The number of sampled points).

5. FLASH FLOOD HAZARD ASSESSMENT

This chapter presents the results and discussions on the flood dynamics at the Mpazi catchment. It explores various scenarios, using OpenLISEM, which was achieved by simulating different return periods that were obtained from the Gumbel probability method. The results of the simulated 13th December 2013 flooding event, were then compared to the perceptions of the respondents, in terms of the depths and durations. This chapter also explores different aspects, to find out the actual causal factors of the flash floods.

5.1. Analysis of Rainfall Data

The rainfall analysis was carried out to get a better understanding of the rainfall patterns within study area. A good number of the population believe that the rains have become shorter with higher intensities, which is assumed to be the main cause of the flooding events. From the records obtained year 1971 – 2013, the annual maximum daily rainfall was determined and the results are presented in Figure 5.1. The highest maximum daily rainfall recorded was at 106.7 mm in the year 1987.

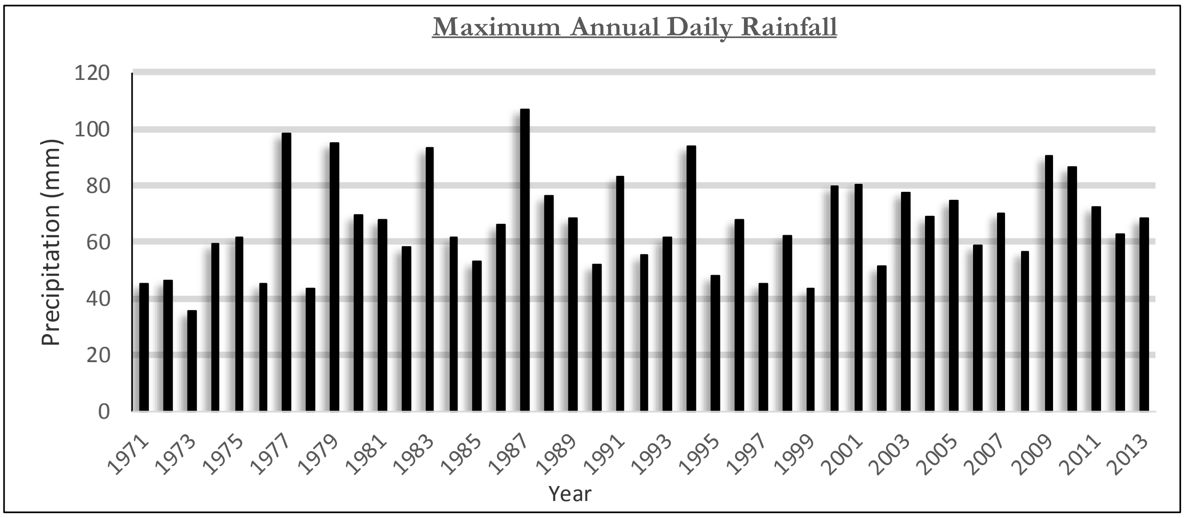

Figure 5-1 Annual daily rainfall averages from the years 1971 - 2013

Initially, as there were no data on runoff production from the Mpazi catchment before December 2012, the Rwanda Natural Resource Authority, equipped the main channel with a data logger to measure the flood waves. The records of the runoff, since it was installed, measured the flood waves and had a total of 16 registered floods, 12 of them were minor, while the other 4 were major (SHER Ingénieurs-Conseils s.a.., 2013). Out of the four events two of them caused severe damage to the area, which occurred on the 13.12.2013 and 23.2.2013. The Figure 5.3, below gives the output from the data logger for the flood event of the 23rd of February 2013 (left hand diagram with water level) and the corresponding calculated discharge (right hand diagram). (SHER Ingénieurs-Conseils s.a.., 2013)

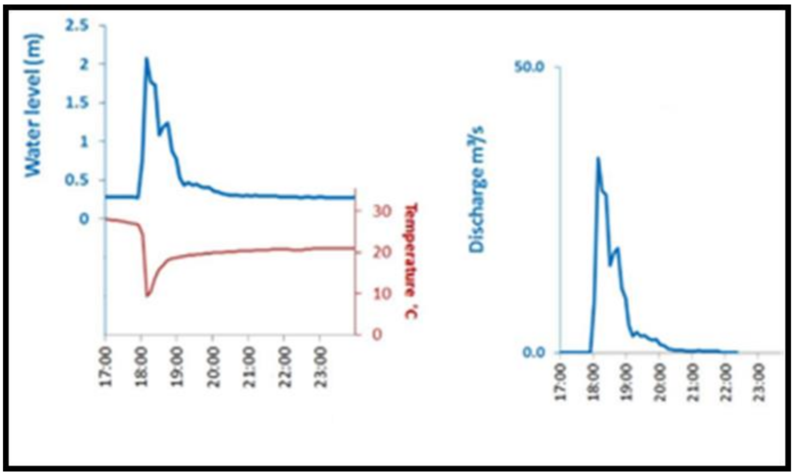

Figure 5-2 Observed flash floods in the Mpazi catchment *Source SHER Ingénieurs-Conseils s.a.., 2013*

In order to determine the return period of the last flooding event, 13th December 2013, the Gumbel extreme value distribution method was used. This was to determine the relationship between the magnitude of the highest rainfall event and its frequency. The method usually follows a simple statistical approach which calculates the probabilities of occurrence for different records. In this case, it is used since it is assumed that the extreme rainfall is likely to cause the flash floods. The observed annual maximum daily rainfall (mm/day) from 1971 to 2013, recorded at the Kanombe Metrological Station, was used for extreme value analysis (see appendix 3). The results show that the rainfall that caused the flood problem in 2013, has a return period of approximately every 2 years The Gumbel plot results is shown in Figure 5.3.

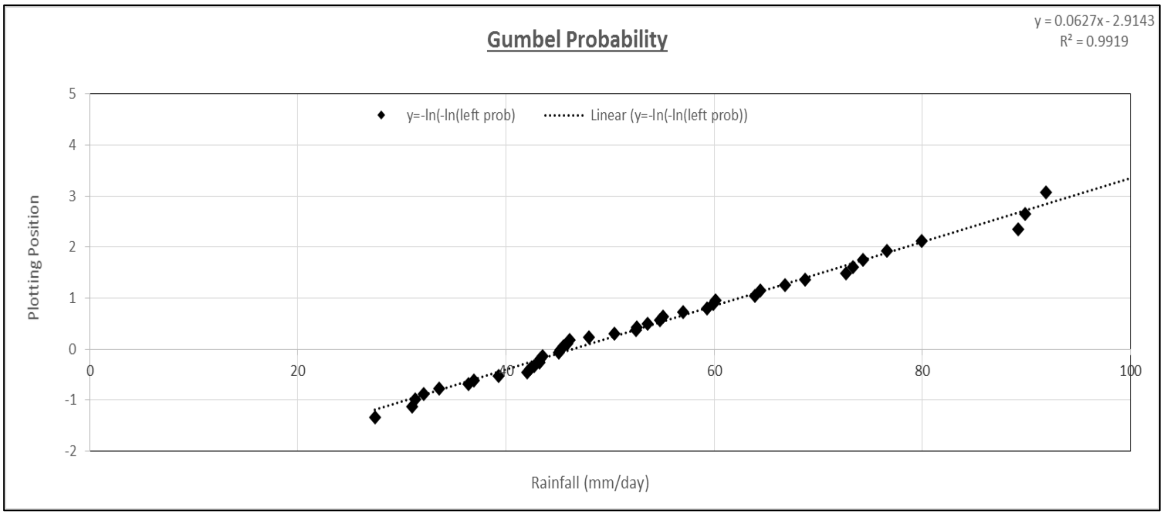

Figure 5-3 Gumbel Probability Graph

This shows the plotting positions of each observation against the annual maximum daily rainfall with the trend line that gives the Y formula, which is used to calculate the return period of a rainfall event. Using this plot it is possible to estimate the maximum daily rain for different return periods eg. 5, 15 and 25 years, as shown in Table 5.1.

Table 5-1 Return periods of different rainfall events

Return Period (Years)	Probability	Plotting Position (Y)	Rainfall (mm)
5	0.2	1.49	70.4
15	0.07	2.67	89.1
25	0.04	3.19	97.4

5.2. Flash flood modelling

The required spatial data that was needed for OpenLISEM, was created using the PCRaster software. Where a script was used to derive the different catchment maps from the basic maps.

The simulation in this section, used the rainstorm that took place on the 13th December 2013, which was 54.5 mm. Different scenarios, were simulated based on the return periods that were calculated using the Gumbel probability method. The results of these scenarios, were therefore analysed so as to compare the different flood characteristics. This was based on their spatial extent, flood duration and the maximum water depths. As these were the characteristics that majority of the respondents identified to be important, so as to estimate the level of impact of the inundation.

The representation of the depths in Figure 5.5 and Figure 5.6 are light blue for the shallow parts, to the dark blue which represents the deeper parts. The building footprint shape file was added, for visualization purposes, so as to establish the relationship between the inundated areas and the location of the settlements. From the simulated results of the rainstorm event, the total area that was flooded was 0.13 km². This had an average inundation depth was 1.45 m, with some areas experiencing a maximum depth of 2.0 m, which mainly occurred within the lower parts of the catchment, as shown in Figure 5.5 (1). The results further show that majority of the structures were in shallow water of <0.5 m deep, as shown in Figure 5.4. The exposure of the structures to the floods, decreased as the depths increased. As for the flood duration maps, they show the behaviour of the flood waters, by giving the estimated time the water remains at a given location, or rather it explains the period of water inundation. In this case, in reference to the results, there were a number of areas that were inundated for < 1 hour. Which is mostly prominent in the lower parts of the catchment and along the channels. While very few areas, were inundated for > 3 hours, as shown in Figure 5.5 (2).

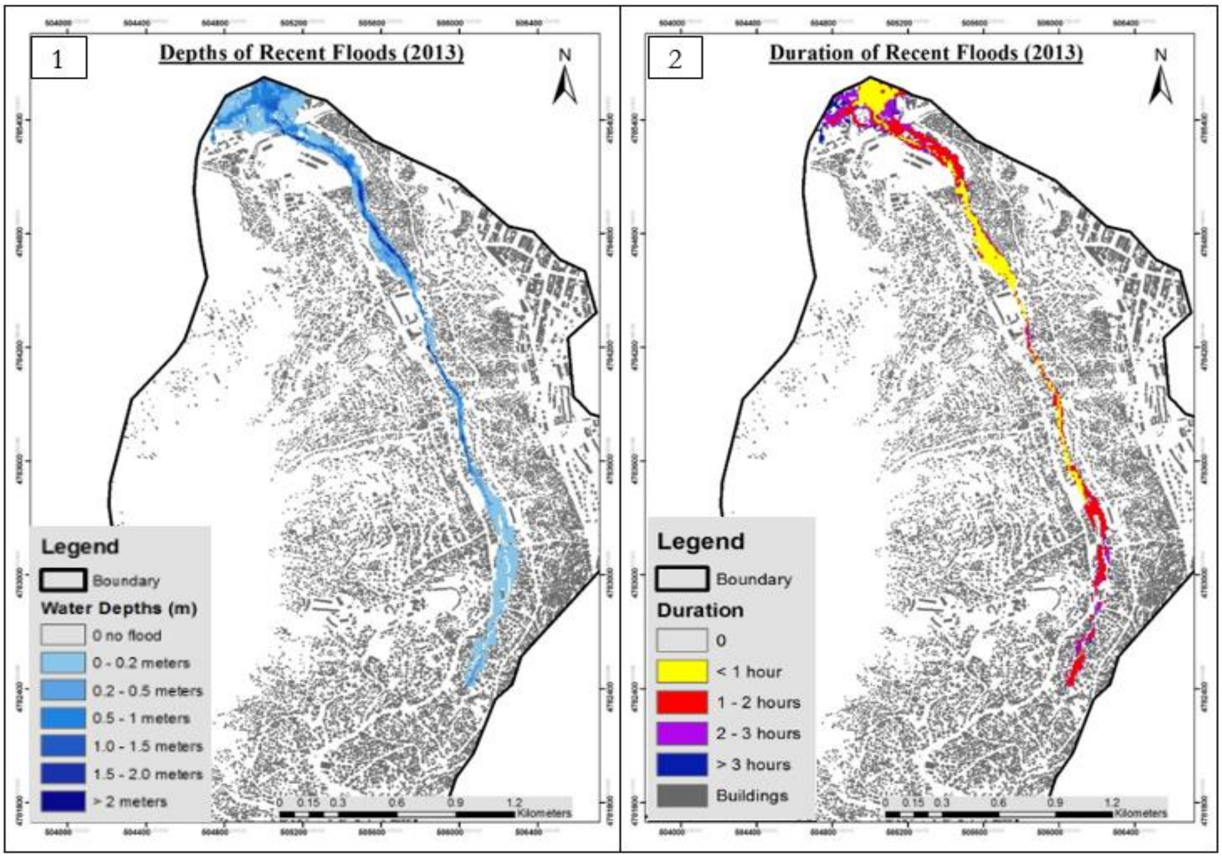

Figure 5-4 Simulated results of flood depth and duration maps for the recent flood event in 2013

5.2.1. Field data and verification on the 2012 flood

One of the main aims of the field survey, was to collect detailed information on the highest flood depths, as well as the durations, from the respondents in order to validate the model results as well as to get people`s perception on hazard and coping strategy. The measurements were done according to the height of man, in terms of ankle level to knee level etc. As presented in Table 5.2, majority of the respondents (50%), said the floods levels were of 0.2 meters in height. While only 9 % said that the levels were 2 meters in height. The spatial distribution of the measured flood points, is shown in Figure 5.8. As for the duration Majority of them (76%,) claimed that the duration of the floods, lasted between 0 – 1 hours, as 14 % of the respondents said the flood duration was between 1 - 2 hours, while 11% of them, said the area was inundated for more than 2 hours.

Table 5-2 Measured flood depths of the recent floods based on the respondents

Flood depth	No. of respondents	Percentage %	Flood Level
0 – 0.2	48	50	Very Low
0.2 – 0.5	26	28	Low
0.5 - 1	12	13	Moderate
1 - 2	9	9	High
Total	**95**	**100**	

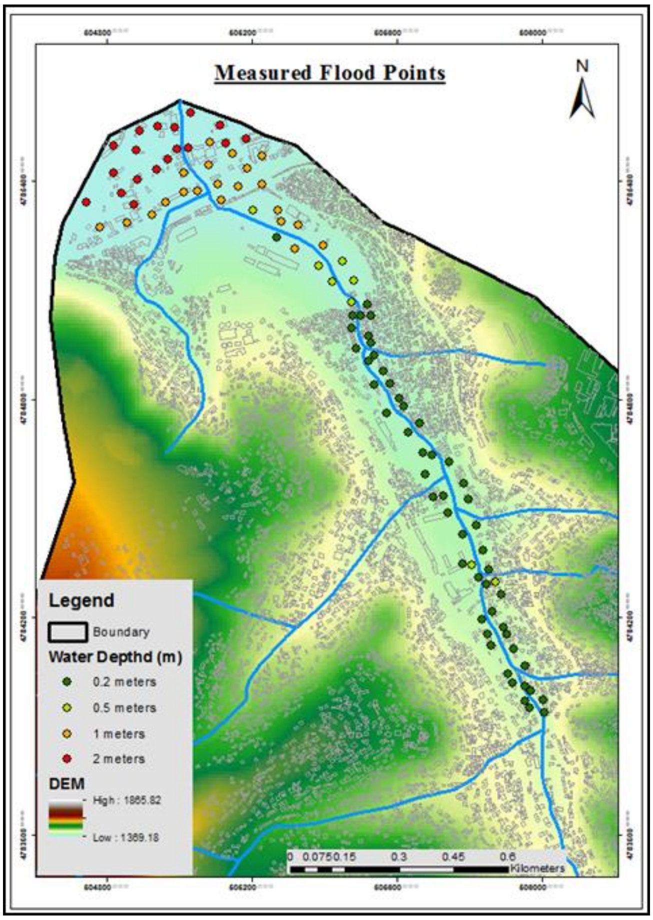

Figure 5-5 Measured flood depth points

These measured depths were then compared with the simulated flood depths, in order to validate the model. The simulated flood depths were extracted with reference to the measured depths and the statistical method the Root Mean Square Error (RMSE), was used to check the performance of the hydrological model. In which if the RMSE values is close to 0, it indicates that the model performance was excellent. Therefore based on the results, the calculated RMSE was 0.51.

5.2.2. Flood Scenarios

The flash flood characteristics, of the Mpazi catchment were further analysed, based on different return periods of maximum daily rainfall, this included the 5, 15 and 25 year return periods.

From the results of the model simulation, as shown in Figure 5.7, the 5 year return period event, showed to cover an extent area of 0.21 km², where the average depth was 1.55 m. But had some areas especially within the lower parts of the catchment, been exposed to maximum depths of 2.4 m high.

However, with the 15 years return period storm event, the results of the model simulation showed that the total inundated area was 0.32 km², where the average maximum depths were of 1.8 m with some areas having a maximum depth of 2.7 m. The same case applied to the 25 year return period storm event, where the results, indicated that an extent of 0.4 km², of the area was inundated, with the average depth of 2.1 m, and some areas within the catchment having a maximum depth of 3.1 m. With each return period, the depths became more prominent in the lower parts of the catchment, and along some areas of the primary channel. While the extent of the total flooded area, also increased. As for the duartions as shown in Figure 5.8, the flood proagation becomes more promimet with incresing return periods.

In this case the number of structures that were exposed to the floods, as shown in Figure 5.6, the 25 year return period had higher number of structures that were inundated in all the flood levels, which was mostly prominent between flood depths of 0 – 0.5 m.

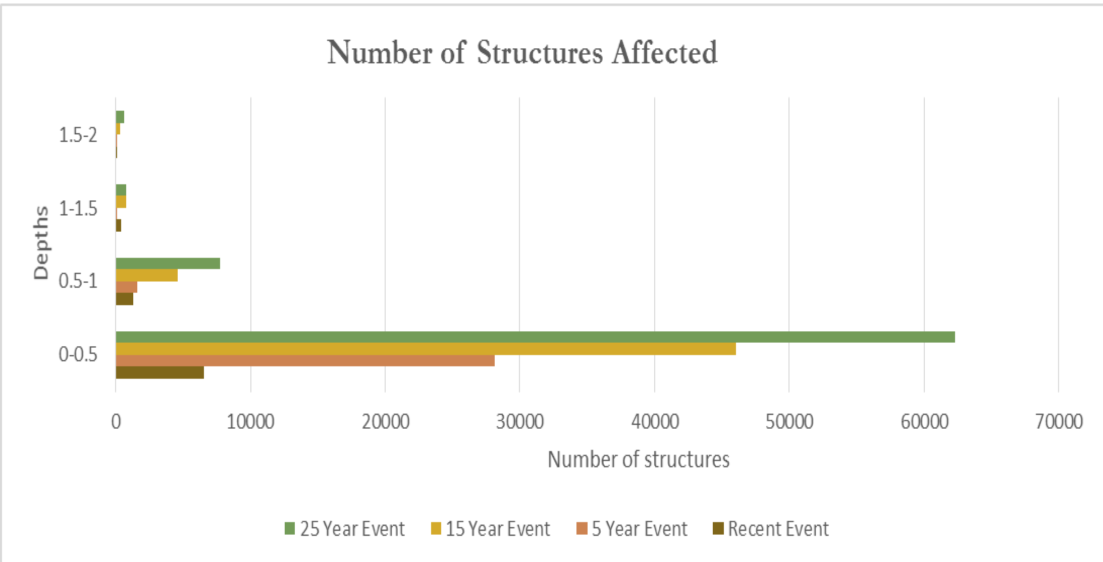

Figure 5-6 Number of structures affected by flooding

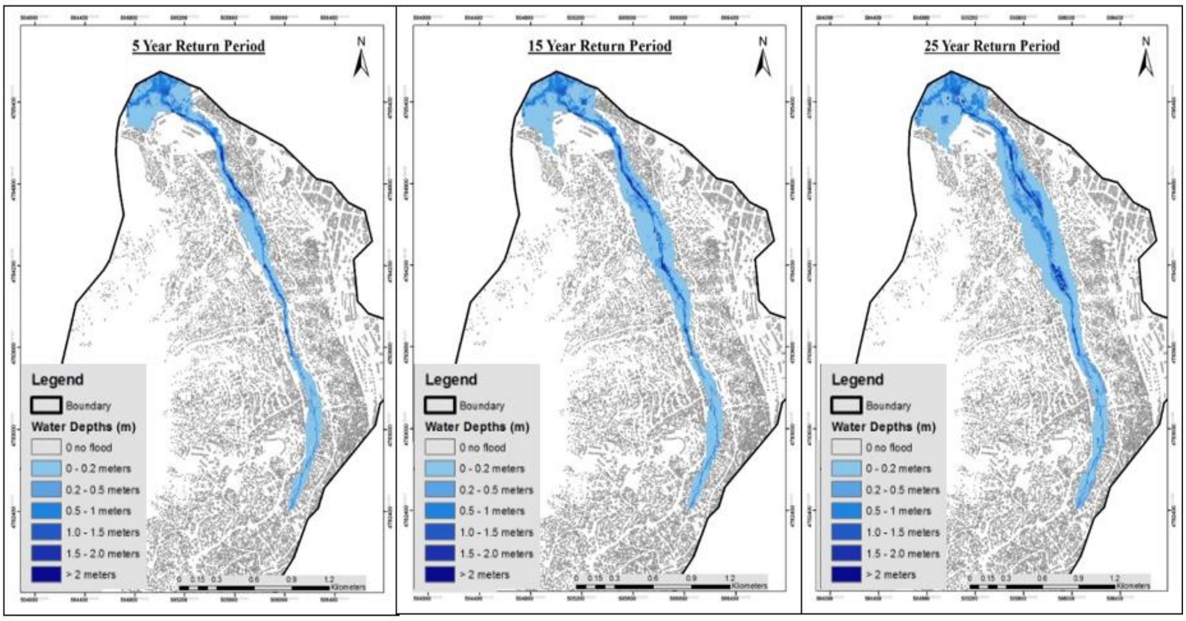

Figure 5-7 Spatial distribution of the maximum water depths of the three simulated return periods of 5, 15, and 25 years

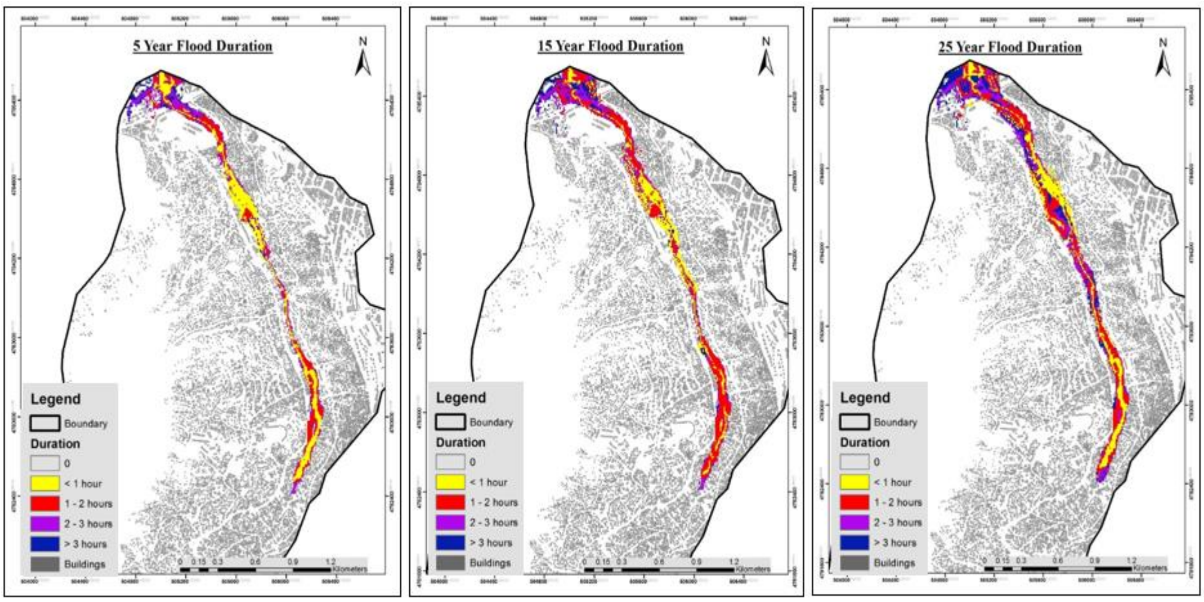

Figure 5-8 Flood duration of the simulated return periods 5, 15 and 25 years

5.3. Factors Responsible for flood problem in Kigali

As aforementioned, the return period of the rainfall event, that caused the flash floods was found to have a return period of approximately every 2.5 years, which became problematic in the year 2012. Since there were no occurrences of these flood events in the previous years, this gives an indication that other factors other than rainfall caused the floods. It is reported that the flash floods have killed 10 people and, it has caused tremendous damage to the surrounding area.

5.3.1. Unplanned urban expansion

This catchment is not only covered by housing developments, but also commercial and industrial developments. As reported by various respondents during the fieldwork, the flooding events mostly occur at the downstream of this catchment. The flood events are triggered by a combination of factors, which have built up overtime, with the effects been currently experienced. These range from the changes in the natural environment, due to increased human activities. To the changing pattern of rainfall in which, majority of the residents say to have increased in intensity and become shorter in duration. The flood problems, are mostly caused by the rapid urban growth that is occurring, as the City of Kigali has undergone phenomenal expansion in the last few years as shown in Figure 5.9.

A verbal communication with an officer in the urban planning sector (Mr. Icyishaka), revealed that the city of Kigali lacks an appropriate human settlement development plan. This has largely contributed to the expansion of the unplanned residential areas within the urban centres. And due to the poor physical planning that has been present over the years, it has resulted into the mushrooming of the unplanned and disorganized settlement patterns. Therefore, the proliferation of these informal settlements, increases the impervious surfaces. It has been approximated that 90% of the catchment is densely urbanized. As it was noted during fieldwork, the banks of the channel are also under high pressure. This is due to the informal infrastructures constructed near the primary channel. Therefore, some parts of the channel collapse, Figure 5.7 (1), and the dwellings too close along the channel, are at risk of sudden damage and washing away during any rainstorm. In addition, field observation also revealed that the observed nature of development could be due to the proximity of the area, to the Central Business District as it is convenient to most of the population.

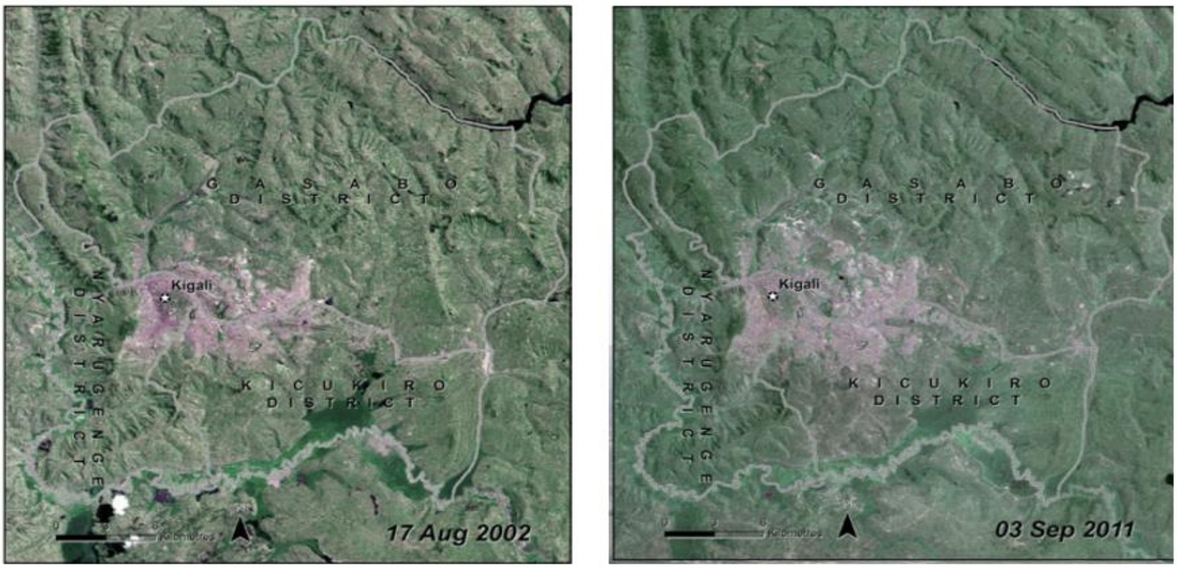

Figure 5-9 Urban growth of Kigali city from years 2002 to 2011 *Source (REMA, 2013)*

5.3.2. Deforestation in the upslope area

With this increase in population, the demand for land is also present. As a result, this has led to the encroachment of settlements into the forested zones and the wetland areas as shown in Figure 3.5 (point 7). As a consequence, major deforestation has taken place in the upslope area, therefore leaving minimal natural deterrents to intercept the rain water. With the increased number of hard surfaces, where little to infiltration can occur, increases the runoff, which tends to wash away the loose soils. This has led to accelerated soil erosion in the upslope areas and deposition of sediments in the drainage channels as it was evident from the amount of sediment found within the channels. Thus, the accumulation of debris and loose sediments, which mostly occurs in the lower regions of primary channel, as it was identified to be one of the major hotspots prone to flooding. Consequently, this accumulation of debris slows down the flow of the rain water, during a rainfall event.

5.3.3. Lack of proper mainatence of the drainage networks

In Kigali city the open channels are the most prominent type of storm water drainage facility. They are provided as side drains along the collector road and covered in some areas for health purposes or stand-alone drains for erosion protection. Their sizes vary from trapezoidal to rectangular form. The old drains were constructed using concrete during the time cement was cheap, and the current tendency is construction of cobblestone storm drains, which is cheaper. The drainage channels/systems in this catchment were of three different levels, which include the Primary channel, Secondary channels and the Tertiary Channels, this is depicted in Figure 3.5 (point 3, 5 and 8).

The main Mpazi channel is trapezoidal in shape, with a bottom width of 6.0 meters, 7.5 m width at the channel board and 2.0 m in height. It is made of stone masonry that collects rain water from Gitega, Kimisagara, Muhima and Nyabugogo sectors.

The Primary channel of the catchment were converted to rectangular / trapezoidal stone masonry channels, with the effect that higher water stages travel faster than lower ones and flood waves. For the secondary channels, as noted from field observation they are the ones that collect storm water from the individual buildings and roads. The last level of channels are the tributaries or natural channels that vary in size, which are 1 m to 10 m deep. They tend to form due to the combination of the constant erosion taking place, and the intensity of the rainfall. They drain water from the hills and join into the secondary channel. Both the Primary and Secondary channels are paved, while the Tertiary channels are unpaved.

The additional factors that were identified, based on observation during the survey, was the poor management of the channels both by the local governments, to the individual respondents. As part of the main channel is in poor conditions, degraded and partially destroyed. Therefore, as expected there is an assumption that there is lack of coordination and communication between the local institutes, that are in charge of that specific catchment. The residents and the governmental representatives, both identified the lack of proper management of the channels as a contributing factor for flood problem in the Kigali city. On one hand, the residents claim that the local authorities in charge, do not take any measures to maintain and repair the already degraded drainage channels. On the other hand, the local authorities state that the residents are the ones to blame, due to the misappropriate use of these channels. As there are high amounts of solid waste, been dumped into the channels and they tend to inappropriately use the channel for various purposes, as shown in Figure 5.7 (2). Hence, it interferes with the flow of water, due to the amount of blockage occurring, especially at the culverts which then, accelerates the formation of flash floods.

Considering all the aforementioned factors, even an average amount of rainfall maybe enough to cause a flood. Nonetheless, most of the respondents claim and believe that there has been slight changed in the rainfall patterns, where they have become more intense and shorter in duration.

Figure 5-7 Inappropriate use of the Primary Channel by the residents of the catchment

6. SOCIO-ECONOMIC CHARACTERISTICS AND PERCEPTION TOWARDS THE FLOODS

This chapter describes the socio - characteristics of the respondents, it also analyses their perception towards the flash flood risk with in the area. This is based on the characteristics of the most recent flash floods (13 December 2013).

6.1. Introduction

As aforementioned, the two categories that influence the perception of individuals are situational factors and cognitive factors, and in this study the situational factors were identified so as to analyse the level of perception of the community at large. Therefore, identifying the characteristics of the population, helps to understand the level of local people`s perception towards the floods, where there is an assumption that the description of the characteristics directly as well as indirectly influence the level of perception of the population. Several parameters were assessed on the age, gender, level of education, household size, occupation, level of income, and people`s experience to the flash floods. This information could help to understand how the respondents react towards the floods, as these factors are known to influence the perception of respondents. Therefore, to determine the characteristics of the population and their perception, a sampling technique was applied to 100 respondents, which was spread randomly within the areas identified by the community as the most affected and highly susceptible to the flooding. However, out of the 100, only 95 were valid to be analysed and a descriptive statistical analysis was used to analyse the characteristics of the respondents.

6.2. Characteristics of the Respondents

6.2.1. Age Distribution

The variable of age is used for this research with a presumption that the age of the respondents has a correlation with the way they perceive the various flood characteristics. The age of the respondents that were samples ranged from 20 to 70 years old. Overall the respondents interviewed are mostly from the productive ages ranging from 20 – 40 years old. Only 6% of the total of the respondents are from the elder generation, which is 61-70 years old. The distribution of the respondents on their age is shown in Table 6.1.

Table 6-1 Distribution of respondents based on age

Age (Years)	No. of respondents	Percentage (%)
20-30	**36**	**38**
31-40	29	30
41-50	12	13
51-60	12	13
61-70	6	6
Totals	**95**	**100.0**

6.2.2. Gender

The gender of the respondents is considered as one variable that influences the way risk is perceived within a community. From the interviews it appeared the percentage of the male respondents was slightly higher at 53.7% than the female respondents (46.3 %). As shown in Figure 6.1. This is reasonable since most male household members run their own businesses as well as working in the informal sector, whereas majority of the females interviewed worked as housewives who are ever present with in their homesteads.

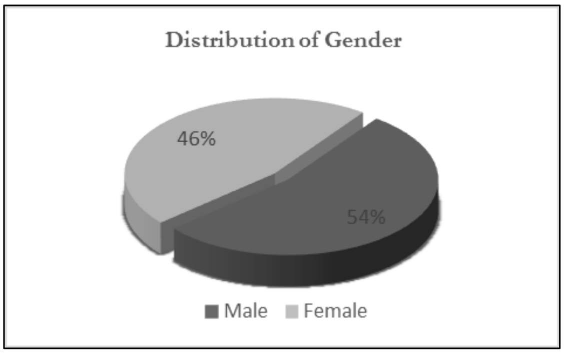

Figure 6-1 Distribution of respondents based on gender

6.2.3. Education

The level of education of the respondents is illustrated in Figure 6.2, which composed of four levels, from the uneducated Primary level, Secondary and University levels. The results show that majority of the respondents 43% have the basic primary education, while 34% have the upper level secondary education, and 9% graduated from the university. However, 14 % of the respondents have no form of education.

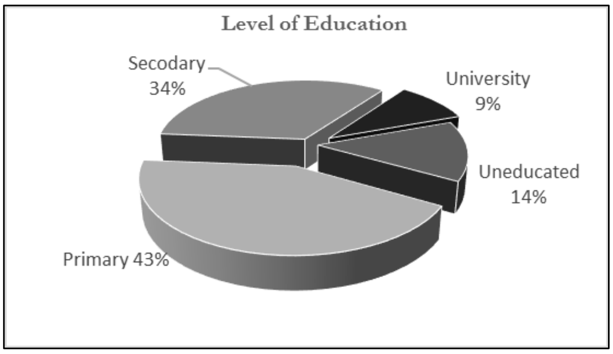

Figure 6-2 Distribution of respondent`s based on level of education

6.2.4. Occupation Type

There were five types of the respondent's occupation found during the interviews. A large percentage of the respondents (30%) had their own businesses, then 22% of the respondents were labourers in manual jobs e.g. construction workers. Majority of the female respondents were housewives at (25%). While the rest were teachers/lecturers 9%, retired officers 5%. The percentage of the unemployed was 7%. Table 6.2 shows the distribution of the respondents based on their occupation.

Table 6-2 Distribution of respondent`s based on occupation type

Occupation	No. of Respondents	Percentage (%)
Business Owners	**29**	**30.5**
Lecturers/Teachers	9	9.5
Housewives	24	25.2
Labourers	21	22.1
Unemployed	7	7.3
Retired	5	5.2
Totals	**95**	**100**

6.2.5. Household Size

The household size of the interviewed respondents ranged from 1 to 7 members of the family. Majority of the households was dominated by the household with 4 to 6 family members at 55%, followed by the 4 to 6 family size at 38% and 7% with more than 7 members. The distribution of the respondent's based on the number of family members is shown in Figure 6.3.

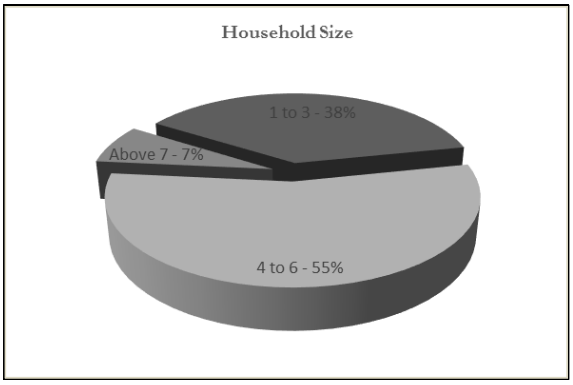

Figure 6-3 Distribution of respondent`s based on Household Size

6.2.6. Level of Income

The income per month of the respondents was taken according to the recommended minimum wage that is by the government, which ranges from 1000Rwf to 6000Rwf per day, this is based on the minimum standard of living. Hence the income per month of the respondents was set into two levels, first been less than 30,000Rwf and the second level as more than 30,000Rwf.
From the interviews 64% of the respondents have an income of less than the 30,000Rwf and 36% respondents have an income of more than the 30,000Rwf.

6.2.7. Length of Stay

From the data that was collected, 47% of the respondents have been living within this catchment for over 6 years, 19% of the respondents have lived there for 4-6 years, 23 % of the respondents lived there for 2 – 4 years and < 2 years there have been 11% of the respondents living there. Figure 6.4 shows the distribution based on length of stay.

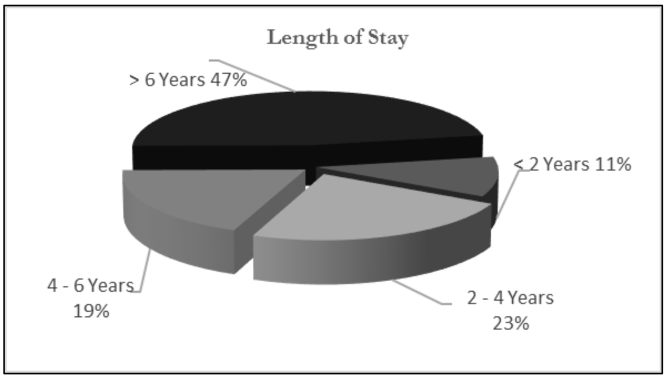

Figure 6-4 Distribution of respondent`s based on length of stay

6.3. Respondent`s Perception Towards the Flash Floods

The perception of risk usually plays an important role of knowing how the population anticipate the negative impact of floods. They all generally have a high level of understanding of the term floods, although only 58

% of the respondents knew of the flash flood problems in the area, while 42% never knew there was a flooding problem. This can be explained by the fact that the ones who knew have lived in the area much longer than the ones who did not. 80% of the respondents recall the three most recent events due to the amount of damage it caused, as the 20% only remember the most recent one that occurred during the month of December 2013. The other flash flood events occurred in February 2012 and February 2013. According to all of the respondents the duration of the floods in the area varies from three to maximum of five hours at maximum.

6.3.1. Cause of Flood

From the field survey and the household interviews with the local respondents, the perception regarding the casual factors of the occurring flash floods is presented in the Table 6.3.

Table 6-3 People` perception on causal of floods

Causal Factors of floods	No. Of Respondents	Percentage %
Lack of Drainage Maintenance	**44**	**46.3**
Heavy Intense Rainfall	29	30.5
Deforestation	13	13.7
Poor Sewer Systems	9	9.5
Others	0	0
Total	**95**	**100**

During the household survey, majority of the respondents believe that the cause of the flash floods is the mismanagement of the drainage channels from the upstream hence causing the accumulation of water at the downstream where most of the population are affected. But, based on the analysis, 46.3% of the respondents presume that the lack of proper drainage maintenance is the casual factor of the flash floods, while 30.5% of the respondents have the perception that there is now heavy and intense rainfall, followed by respondents who claim that deforestation plays as a casual factor with 13.7% and poor maintenance of the sewer system with the least at 9.5%. Overall the lack of the proper maintenance of the drainage channel, with the heavy intense rainfall were what the majority of the local people thought to be the main cause of the flash floods within the catchment.

6.3.2. Severity

The flash floods that occur have an impact mostly on the households that are near the drainage channel and in the lower part of the catchment. But the impacts of the flash floods usually influence almost all the people living within that area, either directly or indirectly. The respondents perception of how severe the flash floods were, was classified into three levels; no problem, nuisance and disastrous. As shown in Table 6.4, 33% of the respondents perceived it as no problem, reason been it did not interfere with their day to day activities as compared to the 47% of the respondents who claimed that the flash floods was a nuisance due to its negative impact, of destroying their properties, but not life threatening. However, 20% of them claimed that the flash floods were disastrous, due to fact that majority lost their homes during the previous events and some losing their relatives to the floods.

Table 6-4 People`s perception on severity

Flood Severity	Frequency	Percentage %
Nuisance	**45**	**47**
No Problem	31	33
Disastrous	19	20
Totals	**95**	**100**

The spatial distribution of the perception on flood severity is shown in Figure 6.5. The areas with a flood level of >1 meter were perceived to be disastrous, as they are the lower parts of the catchment that have lower elevation levels. On the other hand, the areas that were perceived as no problem, have a higher elevation hence the accumulation of water is minimal, where the flood depths are of <=0.5 meters.

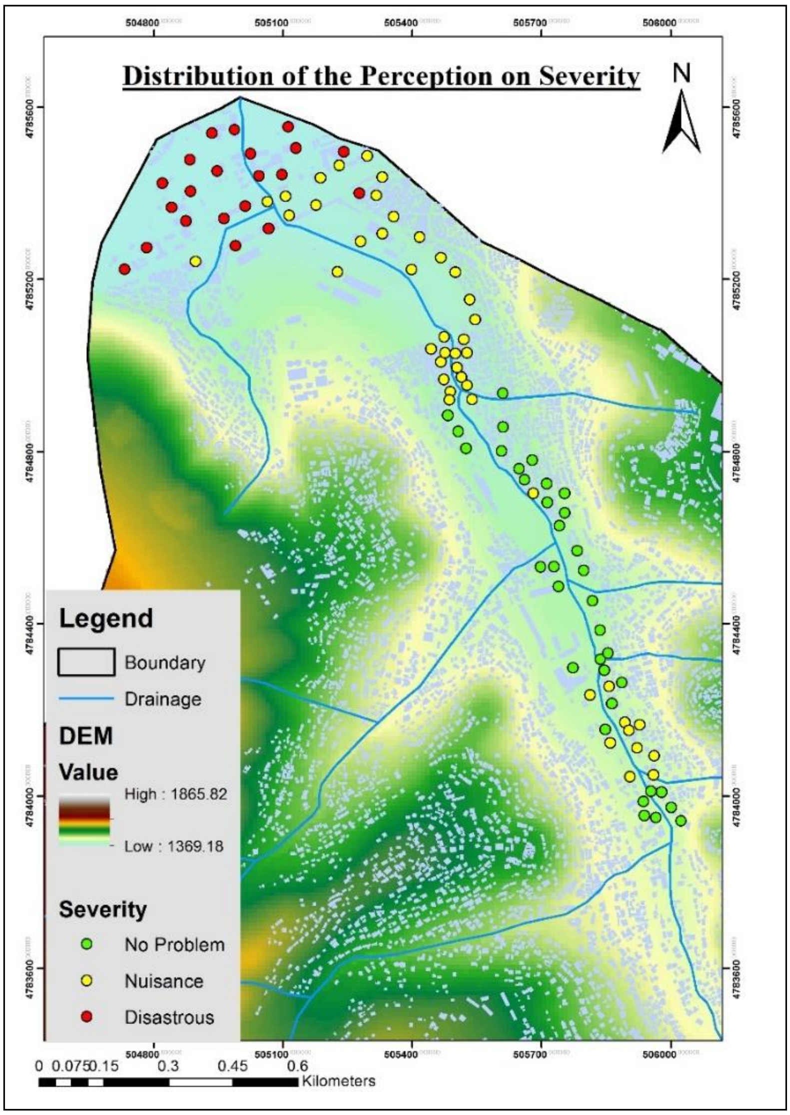

Figure 6-5 Spatial distribution of perception on severity

6.3.3. Negative Impacts

The negative impacts of the flash floods towards the community as perceived by the respondents are shown in Table 6.5. Where 47% of the respondents perceive it to be a destruction to their property. 12% claim that it disrupts the transport network in the area, while 32% perceive it to be a negative impact since it disrupts their daily activities and 7% of the respondents see it to cause loss of life.

Table 6-5 Respondents' perception on negative impacts

Negative Impacts	Frequency	Percentage %
Destruction of Property	45	47
Disruption of the Daily Activities	32	34
Disruption of the Transport Network	11	12
Loss of Life	7	7

Total	**95**	**100**

The areas of lower elevation is where most people perceived that the major negative impact was the loss of life and disruption of the transport network. This is deemed as reasonable since the flood depths within this area are of mostly 2 meters high. Majority of the respondents in the slightly elevated parts of the catchment, where the water levels were between 0.5 - 0.2 meters high, claimed that the flash floods disrupted their daily activities as well as damaging their properties.

When asked whether they would consider to move to safer areas, 30% said they would since they perceived their lives are at danger, and the major loss of their personal property, that was lost during the previous events. This distribution is shown in the Figure 6.6, where the 30% of respondents are located in the lower part of the catchment, and it's within this area where the flood depths are of 1–2 meters high. While 65% of the respondents, in the slightly elevated areas, said they would not consider moving since they have learnt to cope with the flash floods, as it's not a major threat also partly due to the fact that they have nowhere else to go.

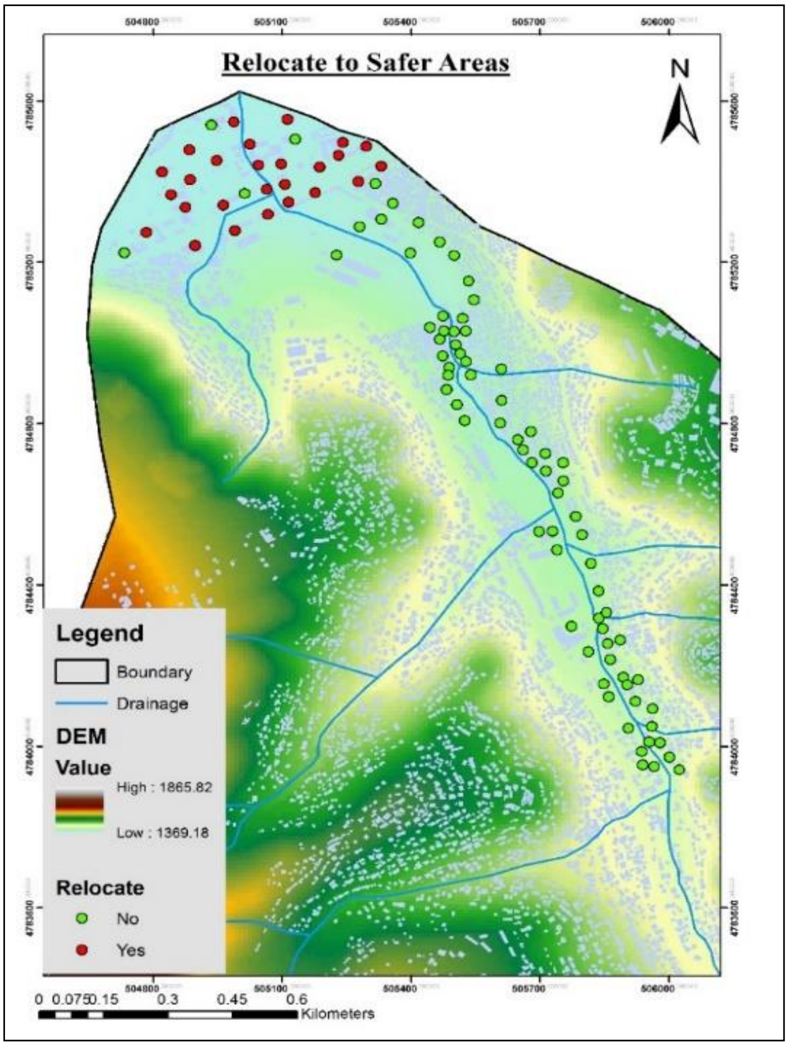

Figure 6-6 Spatial distribution of respondents based on relocation to safer area

6.3.4. People`s Reason for Staying

There are various reasons related to why the respondents keep staying in the flash flood prone areas. This is shown in Table 6.6, where majority of the respondents, 34% stated that their reasons for living in the area was due to the cheap price of the housing, while 26% of the respondents choose to stay since the property was ancestral, inherited from their parents, and 25% own the property. 7% of the respondents decide to live in the area due to the comforts of their environs and 6% of the respondents find the proximity to their places of work convenient.

Table 6-6 People`s reason for staying

Reason for Living in Prone Area	Frequency	Percentage %
Cheap Price	32	34
Inheritance From the Parents	24	26
Owns Property	23	25
Ease of access to work	10	11
Comfortable neighbourhood	6	6
Total	**95**	**100**

6.3.5. Perception on the Flood Mitigation Measures set by the Government

Based on the cause of the floods, majority of the respondents 96%, had the perception that the government is doing very little to curb out the problem at hand. The respondents that were interviewed, claim to see no action been taken by the local government, to mitigate the flash floods. To which, they only respond to the flood problem once it has occurred and damage already done, and they have the perception that the government is very much capable of implementing simple measures that can alleviate the problem.
Hence, this group of respondents perceive that there are no mitigation measures set in place to properly deal with the flash floods. Although there are plans that are underway to rehabilitate the channel only 4% of the respondents had this perception and that the government has set up measures to mitigate the floods, such as cleaning of the channel, and providing sandbags to the residents to control the problem.

6.4. Perception of Flash Floods at Government Level

From the interviews that were undertaken with the key governmental officers who included representatives from the RNRA, the MIDIMAR, and from the Urban Planning Sector, who all had more or less similar perceptions on the various factors that would contribute to the occurrence of the flash floods.

Firstly, that the onset of the flash floods was due to the lack maintenance of the channel, which is one of the contributing factors, as the primary channel was said to be 10/11 years old and during this period no maintenance was done, apart from some cleaning of waste. The structural elements of the primary channel (plaster, stones, concrete), received no attention and inspection either, therefore over the years the channel degraded as well as eroded away and lost its capacity to hold vast amounts of water. They also perceive that over the years there has been a rapid expansion in the number of settlements with in the catchment area, therefore, leading to a decline in the percentage of the forested/vegetated zones, which would aid in the infiltration of the excess water. Others had the perception that due to the vast amounts of eroded material, from the upper part of the catchment, which has contributed to the clogging two bridges, and the channel been heavily silted at the lower parts of the catchment.
Lastly one of the interviewed officers at the RNRA, Mr. Muhinzi, claimed that there was lack of proper communication between the relevant bodies in charge of the catchment area so as to take appropriate measures to curb out the problem, which is in dire need and ought to be sorted.
Moreover, the lack of sensitizing the individuals living along the channel, has led to the inappropriate use of the channel as people tend to waste their dump in the channel.
On the severity 100% of them had the perception that it was disastrous, due to the number of people that lost their lives and the damage caused to the infrastructure, causing high losses, and disruption of the road networks.

6.5. Factors Influencing Flash Flood Perception

There are two categories that have been defined to have an influence on perception (Tobin & Montz, 2004). The situational factors and the cognitive factors and this study looks into the situational factors.
This analysis was undertaken so as to understand the unique contribution of the independent variables, so as to know whether these factors (age, level of income, occupation, length of stay, experience with floods, household size, gender and level of education), have a relationship with the dependent variable.
Therefore, to find the factors that influence the level of perception toward the floods, this study is based on the level at which the respondents felt threatened in terms of their lives and livelihoods. This was grouped into three levels, where 35% of the respondents perceived it as a low level of threat, while 48% perceived it as moderate and 17 % of the respondents, perceived it as a high level of threat.

In this case, a multiple linear regression analysis was done so as, make stronger casual inferences from the observed association between two or more variables and to determine the correlation between the dependent variables and the independent variables. The above mentioned analysis produced four different results that are discussed below.

There were certain factors that were already pre-assumed to have a correlation with the level of perception, which include gender, level of education, occupation, level of income, the age, and experience with the floods. Therefore, the null hypothesis (H0) in this analysis is that these independent variables have no correlation with the dependent variable (people's perception), with the probability value of 0.05, the hypothesis would be accepted if the value of the *Sig (1 tailed)* > 0.05.

With the results of the correlation analysis presented in Table 6.7, it shows that the variables that were undertaken to determine the factors associated with the level of perception, the four independent variables (age, household size, occupation and income levels) have values <0.05, therefore these variables have no correlation with the perceptions of the local respondents. Only three socio-economic variables from this study have a role with the variability or have a correlation with the flash flood perception that is the Length of stay, Flood experience and Gender.

Table 6-7 Correlation analysis of respondent`s perception

Correlations	
Independent Variable	**Sig. (1-tailed)**
Gender	.076
Age	.000*
Education	.000*
Occupation	.001*
Household Size	.037*
Income	.000*
Flood Experience	.364
Length of Stay	.278

*P≤0.05

The first output from the multiple linear regression shown in Table 6.8, where the R- value represents the strength of the relationship between the dependent and the independent variables, with this value been 0.659 which is > 0.5, it shows us that the relationship between the two variables is strong. As for the Adjusted R square, which usually measures how much of the variability in the outcome is accounted for by the predictors and from the model, had a value of 0.527, which means that the linear regression explains 52.7% of the total variability in the level of perception is explained by the predictor variables (independent variables), or rather, the variance in the dependent variable, that is the level of perception is explained by the model. The Standard Error of the Estimate, measures the accuracy of the predictions, and the smaller it is the more appropriate it will be for the regression model, so as to predict the dependant variable, and in this case it is 0.358.

Table 6-8 Model summary of respondent's perception

Model Summary [b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.659[a]	.601	.527	.358
Predictors: (Constant), Gender, Age, Household Size, Occupation, Ex with Floods, Level of Education, Income, Length of stay				
Dependent Variable : Respondents Perception				

The second output from the analysis was the Analysis of Variance, (ANOVA) Table 6.9, which presents the statistics *F- test* which tests whether the model is reliable, or rather good at predicting the outcome.
With the null hypothesis that states that, the independent variables do not have any significant influence on the level of perception of the respondent, or rather there is no linear relationship between the two variables. In this case, the test statistics of the *calculated F,* is 25.155, which is highly significant and using the value of F – table, shown in Appendix on significance ∝ 0.05, and degrees of freedom 1 = 8 and degrees of freedom 2 = 72 gives us the value of *F- table* which is 2.070. Therefore, since the test statistics is much larger than the critical value, (*calculated F > F-table*), we reject the null hypothesis, where we can conclude that the independent variables jointly influence the respondents level of perception, which is the dependent variable.

Based on the probability value, which shows that the *significant value,* is 0.000, one can still reject the null hypothesis since the Probability value (P-value) is <0.05, therefore stating that the independent variables jointly influence the dependent variable.

Table 6-9 Anova table of respondent's perception

ANOVA [b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.911	8	3.489	25.155	.000 [a]
	Residual	11.336	72	.027		
	Total	42.247	80			
a. Predictors: (Constant), Gender, Age, Household size, Occupation, Ex with Floods, Level of Education, Income, Length of Stay						
a. Dependent Variable: Respondents Perception						

The final result of the multiple linear regression is the coefficients of the respondents, where it gave the results of the influence of the individual independent variables towards the dependent variable the level of perception. The response of these three significant variables can be seen in the *Unstandardized Beta Coefficients* which tells you how strongly is the independent variable associated with the dependent variable, this is shown in Table 6.10, where the constant coefficient has a positive value of 2.256, therefore it raises the assumption that the absence of predictor variables increases the level of the respondents perception. The regression coefficient of the two predictor variables length of stay, and experience were positive (.294 and .375), therefore assuming that the absence of the other independent variables, the increase in both of these variables would be followed by the raise in the respondents perception.

Table 6-10 Coefficients of respondents perception

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.256	.383		3.870	.000
	Age	-.005	.004	-.118	-1.047	.000
	Gender	.206	.111	-.215	-1.852	.401
	Level of Education	-.010	.006	-.264	-1.719	.001
	Household Size	-1.010	.006	-.187	-1.713	.091
	Income	-.781	.492	-.172	-1.588	.117
	Occupation	.000	.008	.006	.040	.968
	Ex with Floods	.375	.116	.351	3.049	.003
	Length of Stay	.294	.044	.066	.595	.554

With the results given it can be concluded that there three variables that have a significant influence towards the respondents perceptions on the flash floods, that is the Length of Stay, Gender and the Experience with the Floods. As people who lived in the area longer perceived a lower degree of threat, since they have learned to manage and cope with the flash floods as compared to those who have lived in the area for a shorter period of time. This also links up to the experience with the floods, which had a significant causal relationship with the perception towards the flash floods, as the people who have had experience with them would have a lower degree of threat, as compared to those who have never experienced it or had a single encounter with the flash floods. Gender is also shown to have a significant influence in the perception towards the flash floods, as the most of the female respondents perceived a higher degree of threat with relation towards the flash floods as compared to their male counterparts, who perceive it as no to minimal threat.

7. COPING MECHANISMS

This chapter explores the coping mechanisms that are employed at household level, community level as well as at the governmental level within the area of study. These coping strategies are classified into three flooding stages; before, during and after the flooding. Each stage is differentiated into three types of coping mechanisms; economical, physical and social coping mechanisms.

7.1. Introduction

Communities are known to employ a wide range of proactive measures, so as to reduce and adapt to the risk at hand, this both well in advance, during and following the hazard they deploy ad hoc response and recovery measures (Wamsler & Brink, 2014) . These measures are not only applied by the community but as well as the governmental and non-governmental bodies, which can be categorized into three levels of action (Cadag & Gaillard, 2012):

1. The reduction of the physical vulnerability
2. The reduction of the economic vulnerability and lastly
3. Strengthening the social structure of the community to better withstand the effects, for a quicker recovery.

The people living in this area have applied specific measures to cope with the flash floods, this is at the individual household level, at the community level as well as the strategies the local authorities have employed as coping mechanisms, this are discussed in the following sub section.

7.2. Household and Community Coping Mechanisms

Majority of the respondents living in the area were aware that they lived in a flood prone area, but as years passed by, the vast amounts of activities and developments taking place within the catchment area, intensified the impacts of the floods to become more serious and severe, and after the first event that occurred in December 2012, the households and the communities have in this case, employed certain coping measures, to try and mitigate the flooding problem. As aforementioned the coping strategies were divided into three types, which were structural, economic and social coping strategies, this is in terms of before, during and after the flash floods.

7.2.1. Physical Coping Strategies

This type of coping mechanism, in this context refers to the structural measures that are employed, by the households living in the flood prone area, such as the way they construct their houses and the type of material materials used for their construction, in order to alleviate the impacts of a flash flood. However, the type of coping measure applied varied across the community, as each household have their own capacities and capabilities. Table 7.1, shows the coping mechanisms applied by the individual households.

Table 7-1 Physical coping mechanisms before, during and after the floods

	Coping Strategy	Frequency(f)	Percentage (%)
Before Flooding	Raising the foundation of the house	8	8
	Putting sandbags in front of the house	68	72
	Building house using concrete material	6	6
	Do nothing	13	14
Total		**95**	**100**
During Flooding	Lock all the windows and doors	9	9
	Evacuate things to a higher place	66	69
	Do nothing	20	21

Total		**95**	**100**
After Flooding	Repair of the damaged part of the house	12	13
	Cleaning the house and furniture	83	87
	Do Nothing	0	0
Total		**95**	**100**

Based on table majority of the respondents 68% of them, put sandbags around their houses and businesses as shown in Figure 7.1 (2). As they claimed it to be the easiest and most affordable method. As it's mostly influenced by their low levels of income, and furthermore the local government assist them with the provision of these sandbags. Of the total only 8% of the respondents were able to raise the foundation of the houses to approximately 0.3 meters high, as they found it to be a long lasting solution, this is shown in Figure 7.1 (3). The same applied for the 6% that built their houses with concrete. However, this kind of strategy is rarely applied due to the lack of financial capacity of the people. As for 14% of the respondents they choose not to do anything since the flood depths were not a nuisance to them.
During the floods, 69% of the respondents evacuate their properties to a higher place inside the houses so as to avoid their goods getting damaged, especially for the business owners. 21% of the respondents choose to do nothing, in relation to employing any physical strategies during the floods, while 9% lock their windows and doors to act as an obstruction to avoid any water seeping in through, as they evacuate to safer places until the water recedes. As the water recedes, majority of the respondents, (87%) clean their houses and furniture and only 13% have the financial capacity to repair any damages caused to their houses.

7.2.2. Social Coping Mechanisms

The social or organizational strategies are the activities that usually involve the network within the community, who assist each other to overcome and mitigate the effects if any event was to occur. One of the main social strategy usually involve the help from the governmental institutions. Therefore there were certain social mechanisms that the respondents employed, this is shown the table 7.2.

Table 7-2 Social coping mechanisms before, during and after the floods

	Coping Strategy	Frequency(f)	Percentage (%)
Before Flooding	Cleaning of the channel	57	60
	Discussing best action to protect community	8	8
	Working together to clean the solid wastes from their surroundings	30	32
	Do nothing	0	0
Total		**95**	**100**
During Flooding	Help each other evacuate	62	65
	Placing properties in neighbours or relatives place	25	26
	Disseminate information about the floods	8	8
	Do nothing	0	0
Total		**95**	**100**
After Flooding	Working together to clean the debris and mud	73	77
	Do Nothing	22	23
Total		**95**	**100**

Based on the results, majority of the respondents, before the flood events, 60%, work together to clean the channel in order to avoid obstruction. Another 30%, indicated to work together to clean their surroundings from the solid wastes to anticipate the rainy season. This is normally conducted at the end of the every month, and none of the respondents claimed that they do nothing, hence showing the level of willingness and commitment to work together.

During the floods 65% of the respondents indicated that they help each other to evacuate. While 26% move their belongings to their neighbours' house, which mostly applies to the households that live right next to the channel. Of which only 8% disseminate information about the floods, by warning each other, especially for children to leave the channel when a rainfall event begins, because of the danger.

In the next phase after the flooding, there are no many coping strategies that can be applied, as 73% of the respondents indicated that they work together to clean off the debris, as shown in figure 7.1(1) and mud after the rainfall event, ad 23% did nothing since they resume to their normal activities

7.2.3. Economic Coping Mechanism

The main principal element in this type of coping mechanism is economic diversification, whereby one has more than one source of income. This can again be classified into the three stages, before flooding during flooding and after flooding has occurred. Based on the results not much was done within this aspect, and majority of the respondents, did nothing in terms of their economic coping mechanisms, due to the limited options that they have.

Before the floods 42% of the respondents save money as the strategy to cope with the floods in anticipation in case the floods last longer than usual, while 18% of them put their valuable belongings in safer areas. However 40% do nothing, due to the minor influence of flooding and the lack of appropriate financial stability.

During the floods, majority do nothing once again due to the limited options they have, but 15% of the respondents take all their valuable documents for safe keeping, such as their birth certificates, educational certificates, etc. While 8% of the respondents ask for financial support from their relatives. After the floods, almost all of the respondents 89% apply no coping strategy in relation to economical action. While only 6% borrow money from some saving schemes, to rebuild their damaged houses or find an alternative job to cater for the losses encountered. The results from the interviews are presented in Table 7.3 below.

Table 7-3 Economical coping mechanisms before, during and after the floods

	Coping Strategy	Frequency(f)	Percentage (%)
Before Flooding	Save Money	40	42
	Putting valuable belongings in a higher / safer areas	17	18
	Do nothing	38	40
Total		**95**	**100**
During Flooding	Ask help from relatives	8	8
	Taking the valuable documents as they evacuate	14	15
	Do nothing	73	77
Total		**95**	**100**
After Flooding	Borrowing Money	6	6
	Find alternative job	4	4
	Do Nothing	85	89
Total		***95***	***100***

7.3. Local Authorities Coping Strategies

Ever since the first severe flash flood that caused a lot of damage, the local authorities set out to come up with various coping mechanisms that could be easily adapted by the local community. The type of coping mechanisms is dependent on the resources availability. Which mainly involve social and structural measures, and none at the economic level, as none was mentioned during the interviews with the representatives from the various institutions.

In anticipation of the floods, the social strategies mainly involve the cleaning of the channel and the surrounding areas together with the community, as they provide the materials and means to do the cleaning. This normally takes place once a month and during this exercise they normally sensitize the community on the appropriate measures to avoid the mismanagement of the channel. During the flash flood event, the local authorities' help in the evacuation process, making sure all persons are not endangered, and after the event they ensure all the families that were affected are provided with shelter in form of tents, as they help in cleaning of all the debris and mud that has accumulated.

As for the structural measures, they usually provide the local community with materials to protect their houses from destruction, this include the provision of the sandbags, they also repair the damages caused to the channel.

7.4. Local Government Mitigation Plan

During the fieldwork phase, it was identified that different stakeholders, are involved in the process of coming up with suitable solutions to combat the flash floods which became problematic in the year 2012, as it begun unexpectedly , that no one foresaw it coming. With the increase of urbanization, within the area, it consequently changed how water flows through the catchment, and has had a range of adverse impacts.

Therefore, the ministries in the city of Kigali, that are assigned and involved to deal with this particular problem are the RNRA, Kigali City Authorities (Urban Planning), MIDIMAR, Ministry of Public Works and the Police force. Together they are ought to combat the occurrence of the floods in the near future, but due to the lack of clear communication between these ministries, the author noted that they lacked an integrated approach towards the management of the floods at the Mpazi Catchment.

However, after the 23 February 2013 flash flood event that took place, and in anticipation, for future flooding, these ministries together developed and enhanced the previous mitigation activities in which they are currently trying to implement, so as to protect the areas that are vulnerable to inundation, by applying certain measures that are structural and non-structural, this is presented in Table 7.4.

Table 7-4 Structural and non-structural measures that are to be implemented

Structural	• Redesigning and the repairing of the Mpazi drainage
	• Creation of flood retention ponds
	• Rainwater harvesting
Non Structural	• Raising the awareness to residents
	• Reforestation of the upper Mpazi catchment

7.5. Structural Measures

In the category of structural measures for the flash flood risk mitigation, the RNRA and the Ministry of Public Works are the main actors involved in implementing these measures.

7.5.1. Redesigning and the rehabilitation of the Mpazi drainage

According to the records, provided by the RNRA, the Mpazi drainage channel was constructed 10-11 years ago, and since then, due to the mismanagement of the channel it has never been maintained to handle the pressure of the growing population, hence as aforementioned, parts of the channel degraded and eroded away, and some sections become themselves obstacles when large debris and boulders deposit haphazardly across the damaged section.

The redesigning of the channel by the Ministry of Public Works, which is currently underway, as shown in Figure 7.1 (4), will be able to cater for the vast amounts of rain water and reduce the flow velocity. Additional culverts at the bridges are to be constructed so as to handle the incoming flow of rain water during a storm, while the damaged parts of the channel are to be repaired.

7.5.2. Rainwater Harvesting

Rainwater harvesting usually consists of the collection, storage and the subsequent use of the rainwater as a supplementary source of water. The RNRA and the MIDIMAR, are in the process of implementing this particular mitigation measure. This will consist of the single household rainwater tank, small irrigation ponds, institutional rainwater harvesting at schools, health centres, municipal buildings, etc. As for the single households it would involve a high number of small modular storage tanks, which is a practical solution in high density housing areas. Hence, they could be used to store water in the catchment and also reduce the runoff. Although, the challenge remains, as this approach is not for immediate application and it should be expected that the costs of this measure are substantial. However, it is deemed to be extremely suitable for runoff control in Mpazi catchment.

7.6. Non Structural Measures

Non-structural measures are an alternative complementary to structural measures that may reduce the loss of human life and economics. These include: catchment management, raising awareness, hydrologic forecasting and early warning. The ministries involved in implementing these measures include, the MIDIMAR, the Police force, civil protection units and the Non-governmental body the Rwanda Red cross team.

7.6.1. Raising awareness to residents

The local government, with the Ministry of Disaster Management and Refugee Affairs (MIDIMAR) as the key role player, have implemented activities to raise the awareness of the flash floods, within the community. From verbal communication with Mr. Ntazinda one of the officers at MIDIMAR, they stated that due to poor man power, they have so far not done as much as they could. After the first flooding event, they were able to train and instruct the police and the civil protection unit, on the appropriate ways to protect the population at specified dangerous locations. As well as to manage the traffic situation during intense rainfall, this is until a suitable solution has been established.

Therefore, their long term arrangement is to continue to warn the residents about the danger of flash flood events. This is during and after a rainfall event, especially within the lower parts of Mpazi channel, through meetings and also installing highly visible signs along the channel and roads at channel crossings. They are also currently using the media platform to raise awareness, and spread the information concerning the flood risk. Informing them not to cross roads that are flooded, as well as informing people on the appropriate methods, of how to keep the channel clean free from any obstruction.

7.6.2. Reforestation of the upper Mpazi catchment

Certain measures were identified and are to be included in city planning to increase infiltration where possible, with green vegetated areas, and forest areas. But with the high rate of deforestation occurring, due to the increased urban expansion, the Rwanda Natural Resource Authority together with the, Kigali City Authorities, urban planning sector have zoned out areas that are to be preserved and reforested. This is one of their long term solution, which will increase the infiltration rates and in turn reduce runoff.

7.6.3. Early Warning System

Monitoring of meteorological parameters should be given prominence. Although, the few existing meteorological monitoring stations are run down due to a lack of maintenance and expertise to track the hydrological conditions. The available data is however, always stored in a database, at the Gitega meteorological station. All this together contributes to the early warning system that the MIDIMAR, have implemented. Where they monitor the duration of the rainfall and the water level, and if they meet a certain critical point, the system automatically warns the operator. Therefore, through a toll free number, it alerts some members of the community, to start the evacuation process, the local police also get this alert, who immediately come on site. With this system in place, the residents have ample time to prepare themselves for evacuation before the flood occurs.

Although, the government plans to gradually strengthen its meteorological service by adopting and implementing a meteorological policy and strategy, this is by establishing an upper air observatory and establishing an atlas on the spatial and temporal distribution of rainfall, temperature and humidity over Rwanda.

Figure 7-1 Coping Measures implemented by the residents and local authorities

Figure 7.1 (1): Residents of the Mpazi catchment together clearing up the mud and debris following the a flash flood event Source MIDIMAR, 2013.
Figure 7.1 (2): The use of sandbags as a protective measure
Figure 7.1 (3): Raising the foundations of the houses, as a physical coping mechanism
Figure 7.1 (4) Structural measures currently underway

8. CONCLUSION AND RECOMMENDATION

8.1. Conclusion

The main objective of this research was to evaluate the flash flood dynamics and coping strategies implemented at the Mpazi catchment in Kigali, Rwanda. In order to understand the characteristics of the flash floods, OpenLISEM was used to simulate the storm event of the 13th December 2013, together with different return periods that were generated from the Gumbel probability method. The storm events that were used, were the 5, 15, and 25 years. The event that caused the floods, showed to have a return period of approximately every 2 years. The outputs from the simulations, which included the depths, extent and durations, were then evaluated, as these were the characteristics the respondents deemed as important. From the results, there were significant differences with each scenario, where the 25 year return period, had a wider flood coverage of 0.4 km², with maximum depths reaching to 3.1 m high, where more areas as compared to the other scenarios had a propagation of more than 3 hours. It was further identified that the rainfall runoff at the Mpazi catchment was mostly ignited by the nature of development, where vegetated areas especially in the upslope regions, had been cleared to pave way for physical developments. The poor conditions and the inadequate capacities of the existing drainage channels that were mostly clogged with vast amounts of sediments, debris and solid waste, which restricted the flow of water. Therefore, the combined influence of these factors, not only influenced the natural flow of the rainstorm runoff, but also it increased the flood risk to the settlements in the lower parts of the catchment, as it was evident from the simulated rainstorms.

The flash flood risk perception, consisted of various characteristics of the floods perceived by the local respondents. From this study, one can conclude that there was little to no significant differences with the degree of flood risk perception amongst the respondents, since they all had more or less similar perceptions concerning the frequent flooding events. Where majority had the same ideologies, in terms of the causal factors, and the negative impacts they have had in the area. Various socio- economic factors were taken into consideration, to test whether they had any significant influence on the way the respondents perceived the flood risk. Which included, the age, gender, level of income, level of education, length of stay in the area and experience with the flash floods. As for most of the tested social economic factors, they showed little to no significant influence on the way floods are perceived. This was done based on the level at which the respondents felt threatened in terms of their lives and livelihoods. Which was grouped into three levels, where 35% of the respondents perceived it as a low level of threat, while 48% perceived it as Moderate and 17 % of the respondents, perceived it as a high level of threat. From the multiple linear regression, only Length of Stay, Experience with the Floods and Gender, were the variables which had a role in the variability of the perception towards the flood events.

Based on the results, there were three types of coping mechanism that were employed by the local residents, economic, social and physical coping mechanisms. After the floods, only 13% of the respondents could repair the damaged parts of their houses as the rest cleaned their houses. The economical coping strategy, was mainly influenced by their level of income, where majority of the respondents preferred to do nothing. As for the social, it focused more on activities that included the involvement of the entire community. Such as the "*umuganda*", where once a month they get together to clean their surroundings, which includes the channel.

In this case, the flash floods, was an unexpected event, as the first one took place in the year 2012, and as no one was prepared for it, the mitigation measures were non-existent. Thereafter, the local authorities did have a major role, to try and implement viable mechanisms, in order to cope with the floods. So far, they have been able to implement the structural and social mechanism, which are mainly focused on improving the public facilities, such as the main Mpazi channel, the early warning system and raising the awareness concerning the flood risks, and how best to mitigate them.

8.2. Recommendation

- It is recommended for further research that an extensive soil study for the Mpazi catchment should be undertaken, in order to have reliable information, in regards to the soil characteristics. Which are used as parameters in the hydrological model.
- Various Flash flood reduction scenarios can be simulated using OpenLISEM, so as to know which strategies, would be more effective for the area. This include the rooftop rainwater harvesting, infiltration trenches etc.
- Further research can be undertaken, in order to assess on the social vulnerabilities and map out the key elements at risk.

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APPENDIX

Appendix 1: Questionnaire for Risk perception and Coping Mechanism Identification

ITC Faculty of Geo-Information Science and Earth Observation of the University of Twente, Netherlands

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RESEARCH TITLE: FLASH FLOOD HAZARD AND COPING STRATEGIES IN URBAN AREAS: CASE STUDY IN MPAZI CATCHMENT, KIGALI RWANDA

This information will only be used for scientific research only

Questionnaire Number: ………………………..
Date: ……………………………………………………
Time of Interview: …………………………………
GPS: Lat …………………. Long …………………

Location: ………………………………………………

Section 1: Personal Profile

Name: ………………………………………………………..
Age: ……………………
Sex: …………………….
Marital Status: Single ☐ Married ☐ Widower ☐
Education Level: ……………………………………………………………………….
Origin: ……………………………………………….
Length of stay in the area: …………………………………………………….
Occupation: ………………………………………………………………………..
Income per Month …………………………………………………………….

Household Size: ……………………….

Age	Sex	Education Level	Occupation

Section 2: General Information

1. Is there increase of number of people living in the area? ………………………………… ………………………………………………………………………………………………… ………………….
2. Do you know what floods are? ....
3. Are there any flood problems in this area? …………………………………….
4. Do you have any experience with any flood event? Yes ☐ No ☐

5. Date of the last flash flood event you experienced? ………………………………………..

6. How long was the flood duration? …………………………………………..

7. How did it affect you?…………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………….

8. Was your home/shop flooded? ……………………………………………………………………….. ……………………………………………………………………………………………… ……………………….

9. What was the highest water level measured in the most recent flood? ……………………… ……………………………………………………………………………………………… ………………………

10. How often do they occur within a year? ………………………………………………..

Section 3: Impacts/ perception of the Flash Floods:

11. Were you aware of the flood problems in this area? Yes ☐ No ☐

12. In your opinion what could be the cause of the flash floods

Heavy Prolonged Rainfall ☐ Lack of Maintenance of the drainage ☐

Loss of natural deterrents/ Buildings ☐ Poor Sewer system ☐

Others ………………………………………………

13. Is the floods in your area threatening you daily lives and your livelihoods?

	Not in danger		Moderate	Very much in danger	
Life	1	2	3	4	5
Home/Livelihoods					

……………………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………………………………………

14. What do you think of the level of the flash floods in the area?
No problem ☐ Nuisance ☐ Disastrous ☐

15. Do you consider moving to another place for safety? Yes ☐ No ☐

16. Do the flash floods affect or disrupt transportation (the road network)? Yes ☐ No ☐
……………………………………………………………………………………………… ……………………………………………………………………………………………… …………………………………………………………………………

17. What damage is caused to the area after a flash flood event?
…………………………………………………………………..……………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

18. What are impacts of the flash floods:
Immediate
…………………………………………………………………………………………………
…….. ……………………………………………………………………………………..
…………………………………………………………………………………………………

Post
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………….

19. How high or low do you estimate the probability of future flooding in your surrounding?
Very Low ☐ Low ☐ Moderate ☐ High ☐ Very High ☐

Section 4: Coping Mechanisms:

20. What is the reason you live here?

Ancestral Properties ☐	Own Properties ☐	Cheap Price ☐
Comfortable neighbourhood ☐	Easy access to business Centre ☐	Others:
Easy access to work place ☐	Easy Access to school/Edu Institute ☐	

21. Do you know what coping mechanisms are?
Yes ☐ No ☐
22. As a Household have you applied any flash flood coping mechanism for protection? Yes ☐ No ☐

23. Coping mechanism in physical aspect

Before Flooding	**During Flooding**	**After Flooding**
Put sand bags in front of the house ☐ Construct the house using concrete material ☐ Other………………………… …………. …………….. ……………………………..	Evacuate personal goods ☐ Evacuate yourself or parts of your family ☐ Other ……………………………….. ……………………………… ……………. …………….	Repair the damages ☐ Cleaning the mud from the house ☐ Other ………………………………… ………………………………… ………….. ……………..

24. Coping Strategies in Social Aspects

Before Flooding	**During Flooding**	**After Flooding**
Cleaning of the Channel ☐	Disseminate information ☐ Help each other evacuate ☐	Clean up the mud and debris after the flood together with neighbour ☐

Discussing with other Households about action plan to cope with the flash floods ☐ Others................................ ………………………… …….. ………	Others ………………………………. ………………………………… ……….	Others …………………………………. …………………………………… ………. ……

25. **Coping Strategies in Economic/Material Aspects**

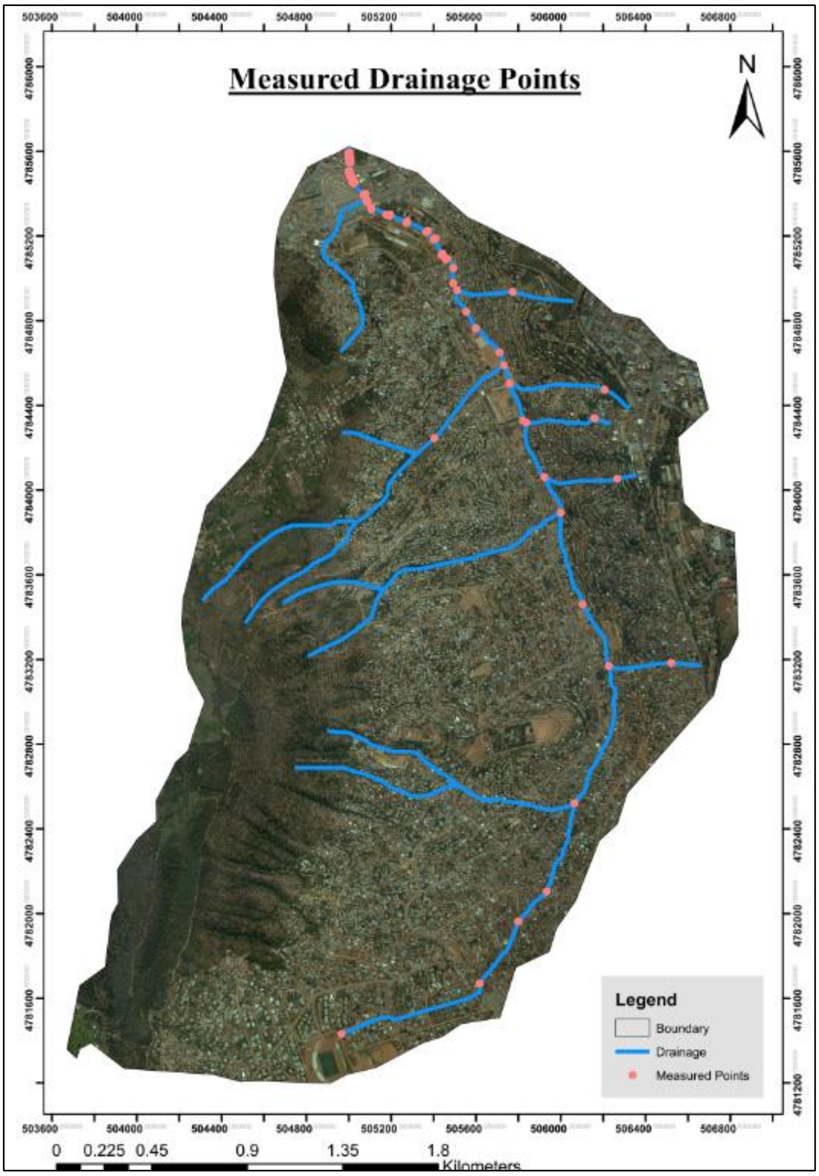
Before Flooding	**During Flooding**	**After Flooding**
Saving Money ☐ Lend Money from relative ☐ Placing things in a safer place ☐ Others …………………….......... ……………………………… ………… …	Find alternative Jobs ☐ Extra Money from buying goods ☐ Other …………………………………. ... ………………….................... ………………………..	Lend money from relative / friend ☐ Sell goods to get extra money to repair house ☐ Other ……………………………….. . ……………………………… ………………………………

26. Following a flood event is there any assistance received?
    Government; Yes ☐ No ☐ Specify
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………

    NGO/Local Institute Yes ☐ No ☐ Specify
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………..
27. Are there coping strategies used by local institutes to reduce impact of the flood? Yes ☐ No ☐
    Specify
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    …………………………………………………………………………….
28. Are there coping strategies used by the Government to reduce impact of the flood?
    Yes ☐ No ☐
    Specify..…………………………………………………………………………………………
    ……………….

Thank You.

Appendix 2: Measured Drainage Points



Appendix 3: Gumbel Probability Analysis

Year	Max. Annual Daily	Sort	Rank	Left Probability	Right Probability	Return Period	y=-ln(-ln(left prob)
1971	45.1	27.4	1	0.023	0.977	1.023255814	-1.330831765
1972	46.1	31	2	0.045	0.955	1.047619048	-1.128508398
1973	42	31.3	3	0.068	0.932	1.073170732	-0.987895731
1974	32.1	32.1	4	0.091	0.909	1.1	-0.874591383
1975	36.4	33.6	5	0.114	0.886	1.128205128	-0.776914507
1976	45.5	36.4	6	0.136	0.864	1.157894737	-0.689355082
1977	98.5	36.9	7	0.159	0.841	1.189189189	-0.608830072
1978	43.3	39.3	8	0.182	0.818	1.222222222	-0.533417353
1979	73.3	42	9	0.205	0.795	1.257142857	-0.461823423
1980	89.9	42.3	10	0.227	0.773	1.294117647	-0.39312565
1981	66.8	42.7	11	0.250	0.750	1.333333333	-0.32663426
1982	91.9	43.2	12	0.273	0.727	1.375	-0.261812562
1983	60.1	43.3	13	0.295	0.705	1.419354839	-0.198227941
1984	59.9	43.5	14	0.318	0.682	1.466666667	-0.13552018
1985	63.9	45.1	15	0.341	0.659	1.517241379	-0.073380038
1986	33.6	45.2	16	0.364	0.636	1.571428571	-0.011534137
1987	106.7	45.5	17	0.386	0.614	1.62962963	0.050266149
1988	76.6	45.9	18	0.409	0.591	1.692307692	0.112253243
1989	68.7	46.1	19	0.432	0.568	1.76	0.174650271
1990	52.5	48	20	0.455	0.545	1.833333333	0.237676951
1991	42.3	50.4	21	0.477	0.523	1.913043478	0.301554929
1992	31	52.5	22	0.500	0.500	2	0.366512921
1993	43.5	52.6	23	0.523	0.477	2.095238095	0.432791982
1994	55.1	53.6	24	0.545	0.455	2.2	0.50065122
1995	48	54.8	25	0.568	0.432	2.315789474	0.570374288
1996	45.9	55.1	26	0.591	0.409	2.444444444	0.642277094
1997	45.2	57	27	0.614	0.386	2.588235294	0.716717249
1998	54.8	59.3	28	0.636	0.364	2.75	0.794106012
1999	59.3	59.9	29	0.659	0.341	2.933333333	0.874923756
2000	52.6	60.1	30	0.682	0.318	3.142857143	0.959740519
2001	74.3	63.9	31	0.705	0.295	3.384615385	1.049243922
2002	79.9	64.4	32	0.727	0.273	3.666666667	1.144278086
2003	64.4	66.8	33	0.750	0.250	4	1.245899324
2004	39.3	68.7	34	0.773	0.227	4.4	1.355458281
2005	27.4	73.3	35	0.795	0.205	4.888888889	1.474725338
2006	43.2	74.3	36	0.818	0.182	5.5	1.606090045
2007	57	76.6	37	0.841	0.159	6.285714286	1.752894273
2008	31.3	79.9	38	0.864	0.136	7.333333333	1.920023791
2009	42.7	89.2	39	0.886	0.114	8.8	2.11504395
2010	89.2	89.9	40	0.909	0.091	11	2.350618656
2011	36.9	91.9	41	0.932	0.068	14.66666667	2.650476338
2012	50.4	98.5	42	0.955	0.045	22	3.067872615
2013	53.6	106.7	43	0.977	0.023	44	3.772716896