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

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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.

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 the 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

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. 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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1.INTRODUCTION

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).

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.

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.

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.

Table 1: Specific Objectives

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

No.	Specific Objective
1.	To identify the cause of the recent flood problem.
2.	To assess the flash flood characteristics of the area.
3.	To assess the perception of the community towards the flash flood hazard.
4.	To analyse the current coping strategies employed at the household, community and governmental levels.

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.

2. MATERIALS AND METHODS

2.1 Data Collection

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. In-depth interviews with the local authorities with in the institutions were also undertaken.

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.

2.2 Questionnaires and Interviews

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.

2.3 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.

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 1, 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.

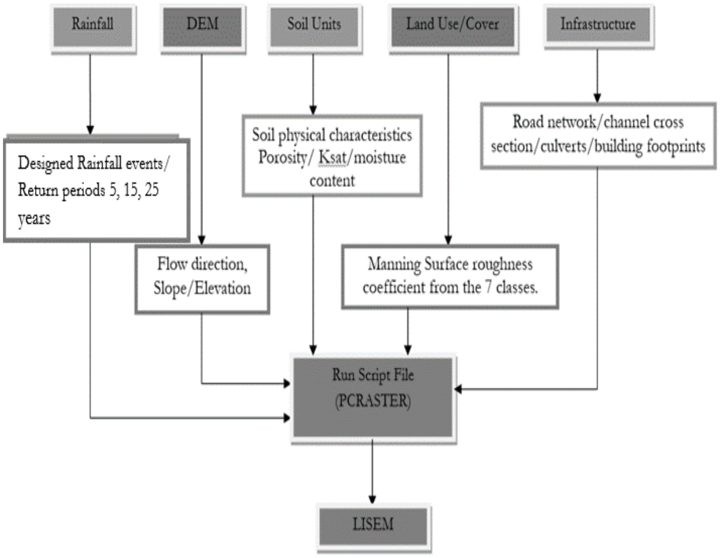

Figure 1: Main input maps required to run OpenLISEM Source (Jetten.V 2013)

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:

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

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

3. RESULTS AND DISCUSSION

3.1 Analysis of Rainfall Data

The rainfall analysis was carried out to get a better understanding of the rainfall patterns within study area. From the records obtained year 1971 – 2013, the annual maximum daily rainfall was determined, the highest maximum daily rainfall recorded was at 106.7 mm in the year 1987.

The Gumbel extreme value distribution method was also used 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 2.

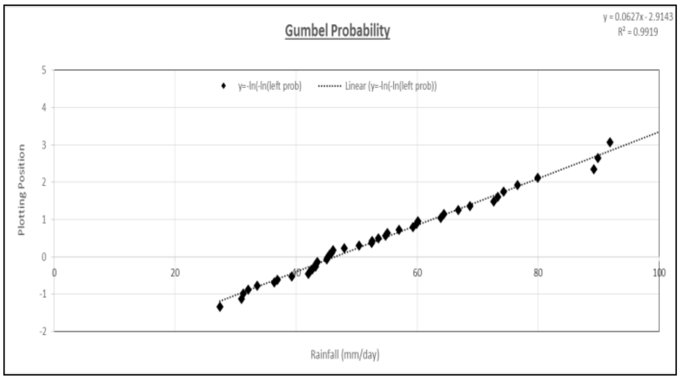

Figure 2: Gumbel Probability Graph

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 3.

Table 2: 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

3.2 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. The results further show that majority of the structures were in shallow water of <0.5 m deep. 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, as shown in Figure 3

Verification of the Model

The collected measured depths were 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.

3.3 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.

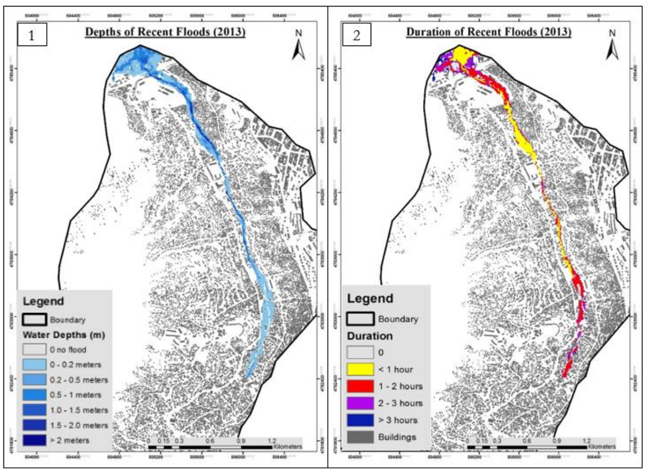

Figure 3: Simulated results of flood depth and duration maps for the recent flood event in 2013

From the results of the model simulation, as shown in Figure 4, 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, the flood proagation becomes more promimet with incresing return periods.

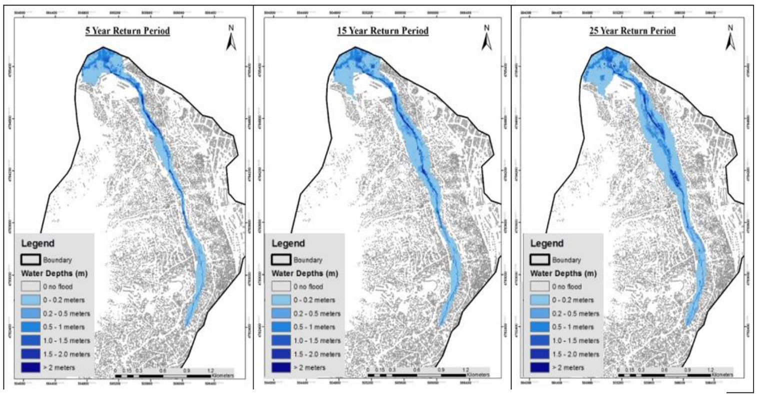

Figure 4: Spatial distribution of the maximum water depths of the three simulated return periods of 5, 15, and 25 years

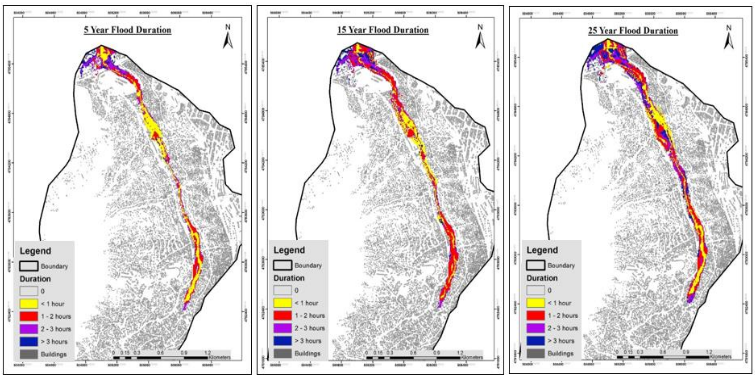

Figure 3: Flood duration of the simulated return periods 5, 15 and 25 years

3.4 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. These include; the unplanned urban expansion, deforestation in the upslope areas which eventually leads to the accumulation of debris, hence this slows down the flow of the rain water, during a rainfall event and lack of proper maintenance of the drainage networks.

Picture 1: Inappropriate use of the Primary Channel by the residents of the catchment

3.5 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.

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.

3.6 Coping Mechanisms

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. These can be further broken down into two types; the physical coping strategies, which in this context refers to the structural measures and the social coping strategies, which include 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.

Table 3: 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**

Table 4: 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**

Picture 2: Coping Measures implemented by the residents and local authorities

Right after the 23 February 2013 flash flood event that took place, and in anticipation, for future flooding, various 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 6.

Table 5: 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

4. CONCLUSION AND RECOMMENDATION:

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. 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.

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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