URBAN DESIGN WITH SUSTAINABLE DRAINAGE SYSTEMS
"A Case Study for Kampala's Expansion"

EPELI NADRAIQERE
March, 2014

SUPERVISORS:
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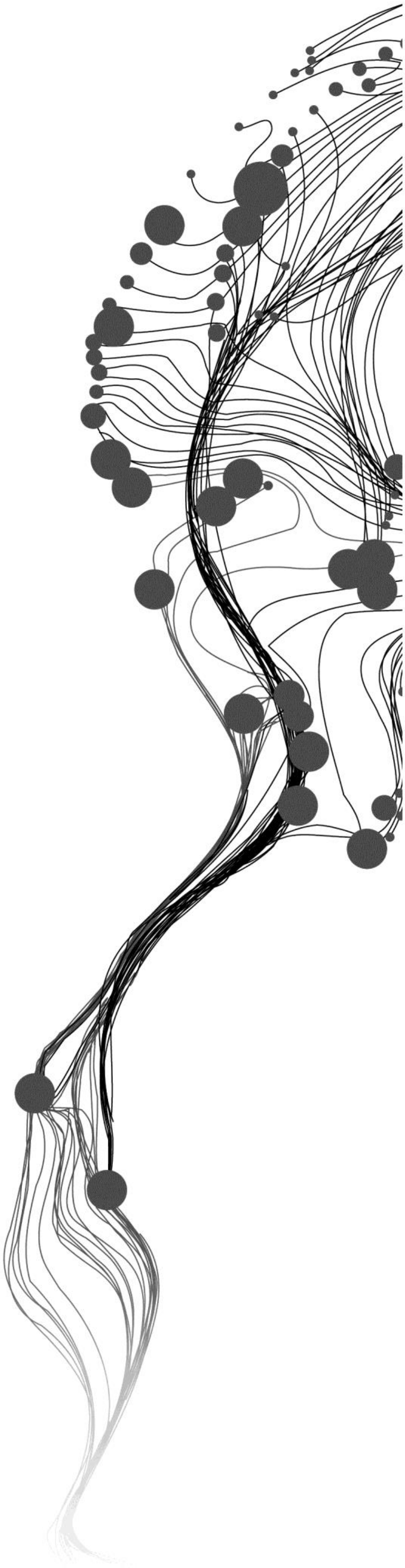

URBAN DESIGN WITH SUSTAINABLE DRAINAGE SYSTEMS
"A Case Study for Kampala's Expansion"

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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ABSTRACT

The world has become increasingly urbanised over the past decades which has brought about several problems to our urban areas. One of the major problems that are highly related to urbanisation is urban flooding. As cities continue to grow, unprecedented pressure is being placed on our natural (soils, waters, forests, etc.) and physical resources (shelter, infrastructures, services, etc.) for the purpose of meeting the demands of our economies and also the needs of our people. This has contributed enormously to various kinds of pollution (land, water and air), increased emissions of greenhouses, deforestation and land use change, expansion of urban areas coupled with unplanned development, and the inability of the existing infrastructures and services to handle the growth that is taking place within the urban areas. As expected that most of these new urbanites will be poor, their future, the future of their cities, the future of humanity itself, all depend very much on decision made now in preparation for this urban population growth.

Part and parcel of the urban population growth is the increase in impermeable surfaces (concrete, tarmac, tile, etc.) which lead to greater runoff volumes and shorter runoff travel times as rainwater could no longer infiltrate into the soil surface. Thus, the proportion of storm rainfall that goes to surface runoff is increased and the proportion that goes to evatranspiration, groundwater recharge and baseflow is reduced. This is indeed the major cause of many flash floods problem on low lying areas.

Since the conventional drainage system which conveys storm and waste water has become increasingly unsustainable due to the continuous increased flow of runoff, an alternative solution to address this worldwide problem becomes more crucial than ever. This is how the concept of Sustainable drainage systems (SuDS) was revitalise as it has the potential to address the drainage and flooding issues that most urban areas are currently facing. This approach tries to manage water as closely as possible to what nature has intended, before it enters the watercourses, therefore removing the water quickly and efficiently in a sustainable manner.

This research looks into the case of Kampala, Uganda, which is one of the fastest growing African cities. Like any other city in the world, Kampala has its own fair share of problems and one which is considered as serious is the issue of flash floods since it is causing a major disruption to the lives of its people. The answer to this problem can be found on the various SuDS principles which are considered as the best alternative method in dealing with runoff as compared to the traditional drainage approach. The study examined the possibility of incorporating the SuDS principles into Kampala's urban design where the runoff is properly managed and no one is flooded.

The actual findings revealed some positive implication of this approach in which the provisions of SuDS components within the study area has led to the reduction in runoff fraction by 46%; reduction in peak discharge (l/s) by 9%; reduction in total discharge (m^3) by 45%; reduction in the maximum flood volume by 52%; reduction in maximum flood depth by 0.81m; and the reduction in the maximum flooded area by 66% as compared to the current development scenario. This indeed has proven the potential and significance of adopting this approach into the city's urban design as a solution for addressing the flooding issue nowadays.

Keywords: Urban Design, Sustainable Drainage Systems, Urbanisation, Flooding, Runoff/Flood Model

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1. INTRODUCTION

This introductory chapter provides a background review of the extent for this research. It starts with a brief discussion of urbanisation in Africa's region, leading to the research problem, which help establishes the research objectives, sub-objectives, and research questions. The conceptual framework sets out the concepts that underlie this study by identifying key elements that have an influence on the surface water runoff and flooding, together with the drainage options (including SuDS) that could be utilised in order to avoid flooding problems downstream. This together with the research design establishes the framework for this research.

1.1. Background

The African region has become increasingly urbanised over the past decades. It was envisaged by the United Nations Population Division that by the year 2035, more than half of Africa's population (which accounts for more than 858 million) will be residing in the urban areas and it is anticipated that the urban population percentage will rise to nearly 60% by 2050 (United Nations Population Division, 2012). Table 1 below reveals this fact of increasing urbanisation in the African region. As expected that most of these new urbanites will be poor, their future, the future of their cities, the future of humanity itself, all depend very much on decision made now in preparation for this urban population growth.

Table 1: Percentage of Africa's region Urban Population between 1950 – 2050

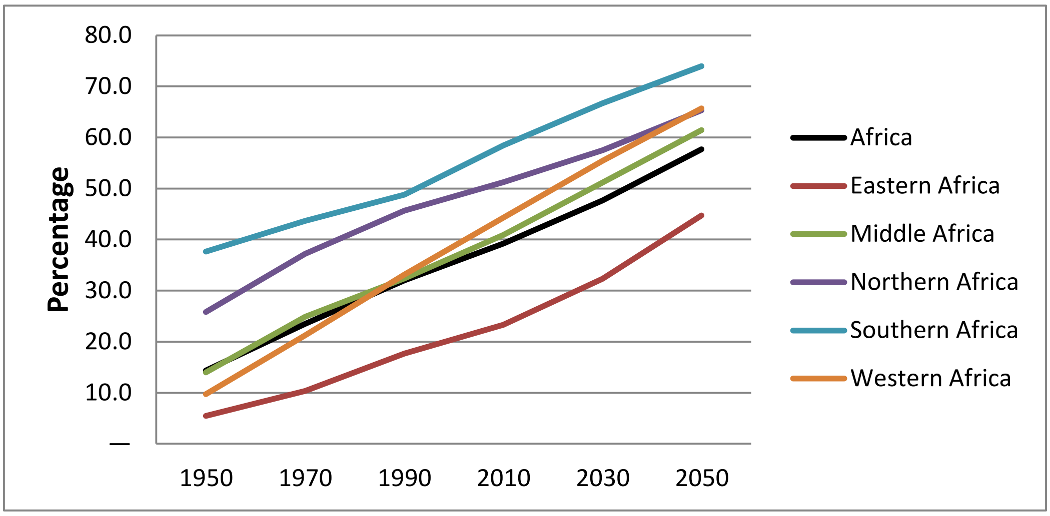
Region	1950	1970	1990	2010	2030	2050
Africa	14.4	23.5	32.0	39.2	47.7	57.7
Eastern Africa	5.5	10.4	17.7	23.3	32.4	44.7
Middle Africa	14.0	24.9	32.4	40.9	51.2	61.5
Northern Africa	25.8	37.2	45.6	51.2	57.5	65.3
Southern Africa	37.7	43.7	48.8	58.5	66.7	74.0
Western Africa	9.7	21.3	33.2	44.3	55.4	65.7

Source: United Nations Population Division (2012)

As Africa's (and global in general) urban population continues to rise, unprecedented pressure is being placed on the natural (soils, waters, forests, etc.) and physical resources (shelter, infrastructures, services, etc.) for the purpose of meeting the demands of its economies and of course the needs of its people. This has contributed enormously to various kinds of pollution (land, water and air), increased emissions of greenhouses, deforestation and land use change, expansion of urban areas coupled with unplanned development, and the inability of the existing infrastructures and services to handle the growth that is taking place within the urban areas (Patz et al., 2011). Figure 1 shows the past and projected trend of urban population in Africa.

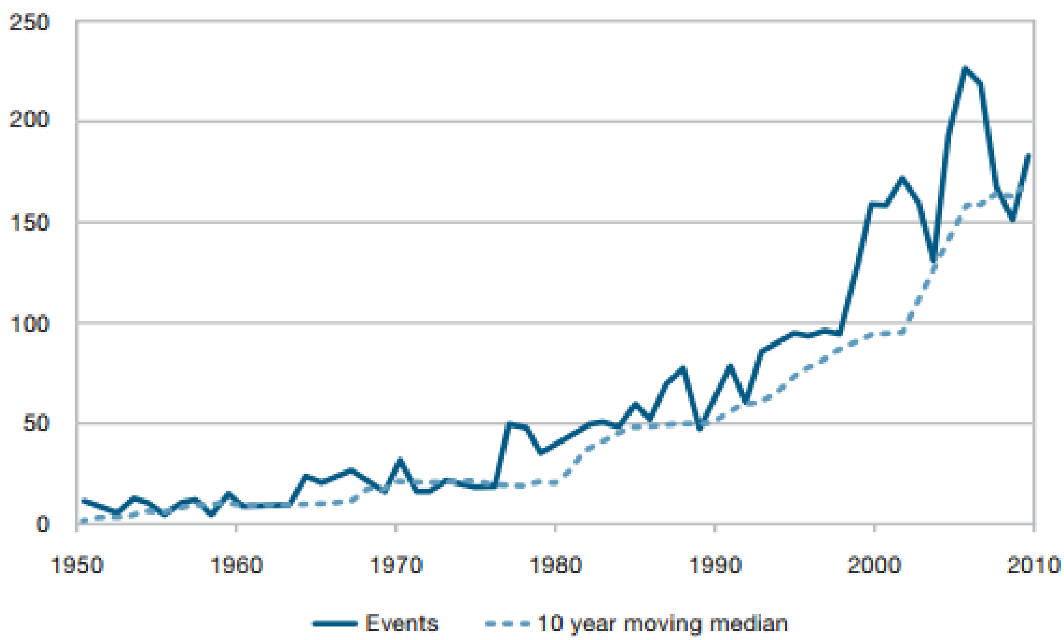
The changes in land use which is associated with urban development or urbanisation has an impact on urban flooding, which poses a serious challenge to development and lives of people, particularly to the poor residents of the rapidly expanding towns and cities (Jha, Bloch, & Lamond, 2012). Flooding can be considered as a natural and seasonal phenomena which plays an important environmental role, however when it occur within the built environments, many losses of different kinds are expected. This problem is aggravated by the continuous removal of vegetation, and the increasing rate of impervious surface which lead to greater runoff volumes and shorter runoff travel times (Maathuis, Mannaerts, & Islam Khan, 1999). Previous data reveals that the occurrence of floods is the most frequent among all natural disasters. The African continent is not exempted as it is also one of the regions that have increasingly experienced severe flooding in the past years. To name a few, worst and deadliest flooding events occurred in Mozambique in 2000 and 2007; the African floods (over 14 countries) in 2005; Ethiopia in 2006; Namibia and Benin in 2008; and the West Africa floods in 2009. Figure 2 below illustrate the global frequent trend of flood events over the past 60 years. The graph shows that the trend becomes increasingly significant and more frequent over the past two decades as compared to the 1950's and 1960's.

Figure 1: Percentage of population residing in urban areas by various regions 1950 – 2050



Source: United Nations Population Division (2012)

Figure 2: Number of reported flood events



Source: EM-DAT/CRED adapted from Jha et al. (2012)

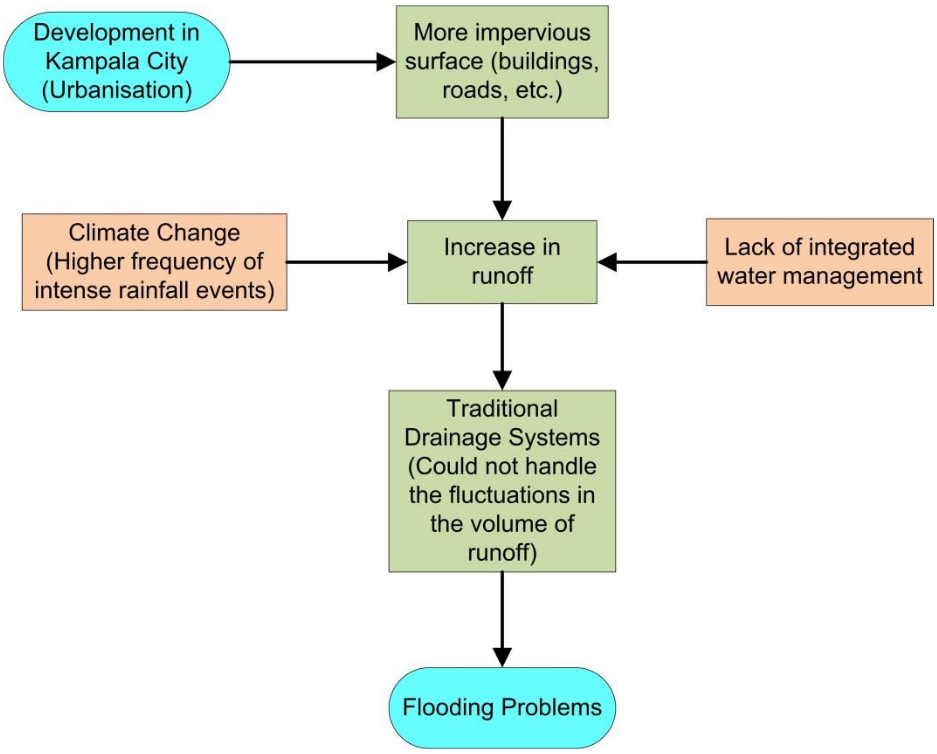
The growth of cities undoubtedly led to greater urbanisation problems and increased magnitude and frequency of urban floods. The conventional drainage systems which conveys storm and waste waters has become unsustainable due to the increased flow of runoff, which tend to create more flooding problems downstream. At the same time, towns and cities become subjected to possible degradation in the environment, problems relating to health and sanitation, and also to disruptions in city services. The introduction of more "impervious" surfaces (concrete, tarmac, tile, etc.) inhibits infiltration and reduces surface retention. Thus, the proportion of storm rainfall that goes to surface runoff is increased and the proportion that goes to evatranspiration, groundwater recharge and baseflow is reduced. This increase in surface runoff is combined with an increase in the speed of response (Packman, 1980). For this reason, an approach that is both sustainable and feasible as far as the drainage systems are concerned became a vital challenge to be dealt with (Miguez, Veról, & Carneiro, 2012). Thus, the concept of Sustainable drainage systems (SuDS) provides an alternative solution when dealing with surface water runoff and it has become an increasing important approach nowadays. This approach tries to manage water as closely as possible to what nature has intended, before it enters the watercourses, therefore removing the water quickly and efficiently in a sustainable manner. It is essential that surface water runoff from buildings is removed as quickly and as safely as possible; and in doing so, stormwater runoff poses no risk to people or the environment through flooding or pollution (Yu, 2013) and ensures better quality of communities' life.

1.2. Research Problem

Urban flooding is considered as one of the major environmental and planning problem in Kampala and its frequency and intensity has increased tremendously in many parts of the city in the last 10 to 15 years (Bamutaze & Lwasa, 2004). It has caused a major disruption to the lives of the people and has brought a high social economic cost when homes, businesses, sources of income, etc. are amongst the things that are highly impacted. Since flooding affects the people of Kampala in many different ways, the urban poor are the ones who are highly vulnerable and always severely affected due to their housing condition and location which in most cases constructed on flood prone areas such as the natural wetlands.

The flooding problem in Kampala continued to intensify when development within and around the city boundary further expand to its peri-urban and wetland areas. This increases the city's impervious surface which leads to more surface water runoff, which becomes a huge challenge to the Kampala Capital City Authority (KCCA) because it will require a more robust drainage systems to manage the increased surface water runoff in order to prevent any problems downstream and to avoid any disruption in the services of the urban sectors (Lwasa, Koojo, Mabiriizi, Mukwaya, & Sekimpi, 2010). However, the development of a more robust drainage system could be very costly and this approach itself is still unsustainable because it tends to just transfer the problem downstream. Hence, in order to reduce the negative implications of flash floods in Kampala and also to minimise the city's vulnerability to flooding, certain measures that are both sustainable and cost effective needs to be put in place to ensure the safety and welfare of its citizens. The research problem in this case is to investigate and evaluate the potential and significance of adopting the SuDS principles into the city's urban design for the purpose of addressing the flooding issue in Kampala. As the flooding problems tend to worsened with the increased urban development, it is indeed highly crucial to solve it in a sustainable way in order to avoid any future disruptions to the lives of the people and also to the socio-economic activities of the city. Figure 3 depicts the problem that Kampala city is currently facing as a result of more impervious surfaces, and is also partly due to the lack of integrated water management and the changing climate which is causing higher frequency of intense rainfall events.

Figure 3: Flowchart of a typical problem in Kampala



1.3. Research Objectives

The overall objective of this research is to assess the impact that urban development based upon SuDS principles could have on urban drainage issues and flooding in Kampala, Uganda. SuDS have been proposed as an answer to many urban drainage issues and as a means to diminish flooding in Kampala. Hence, the applicability of SuDS principles for the case of Kampala were explored in order to establish an evidence based research that can contribute to informed policy making on these issues when considering future urban development projects.

1.3.1. Sub Objectives

The following sub objectives establish the framework of this research:

1. To describe the key relationships between urban design, urban drainage, and urban flooding;

2. To compare the current development and runoff with a hypothetical greenfield state in the study area;

3. To assess the possible impact of a hypothetical urban design based upon SuDS principles on runoff and flooding;

4. To perform a qualitative evaluation of the implications of adopting SuDS principles in urban expansion policies.

1.4. Research Questions

The research questions are related to the four sub objectives listed above:

Sub objective (1) – To describe the key relationships between urban design, urban drainage, and urban flooding

- What is urban design?
- What is a typical process involved for undertaking an urban design project?
- What are the requirements for different types of urban drainage systems in conveying surface water runoff and how does this compare to the SuDS?
- What problems do these urban drainage systems face nowadays?
- What are the types and causes of urban flooding in Kampala?
- What is the relationship between urban design, urban drainage, and urban flooding in Kampala?

Sub objective (2) – To compare the current development and runoff with a hypothetical greenfield state in the study area

- What is surface water runoff and how it is generated?
- What factors affect surface water runoff in the study area?
- What is the total volume of surface water runoff that is generated from the current development in the study area and in a hypothetical greenfield state?
- What are the effects of land cover on runoff coefficient between the current built-up area and a hypothetical greenfield state of the study area?

Sub objective (3) – To assess the possible impact of a hypothetical urban design based upon SuDS principles on runoff and flooding

- What are the steps and factors to be considered when selecting the most appropriate SuDS technique in any given site?
- Which SuDS approaches and components are suitable for the study area?
- How to create a hypothetical urban design of the study area which is based upon SuDS principles that would enable a better management of surface water runoff on site or within immediate facilities?
- What would such a hypothetical urban design look like?
- What is the implication of the new hypothetical urban design on surface water runoff and land cover?

Sub objective (4) – To perform a qualitative evaluation of the implications of adopting SuDS principles in urban expansion policies

- Is it possible to plan and design the study area where the surface water runoff is reduced and the impact of flooding is minimized?
- To what extent does the urban development with SuDS principles differ from the urban development without SuDS principles?
- What are the implications of adopting SuDS principles in urban expansion policies for the study area (e.g. in terms of design process, roles of actors, space requirements, land cover, cost effectiveness, intuitional requirements, affordability, etc.)?

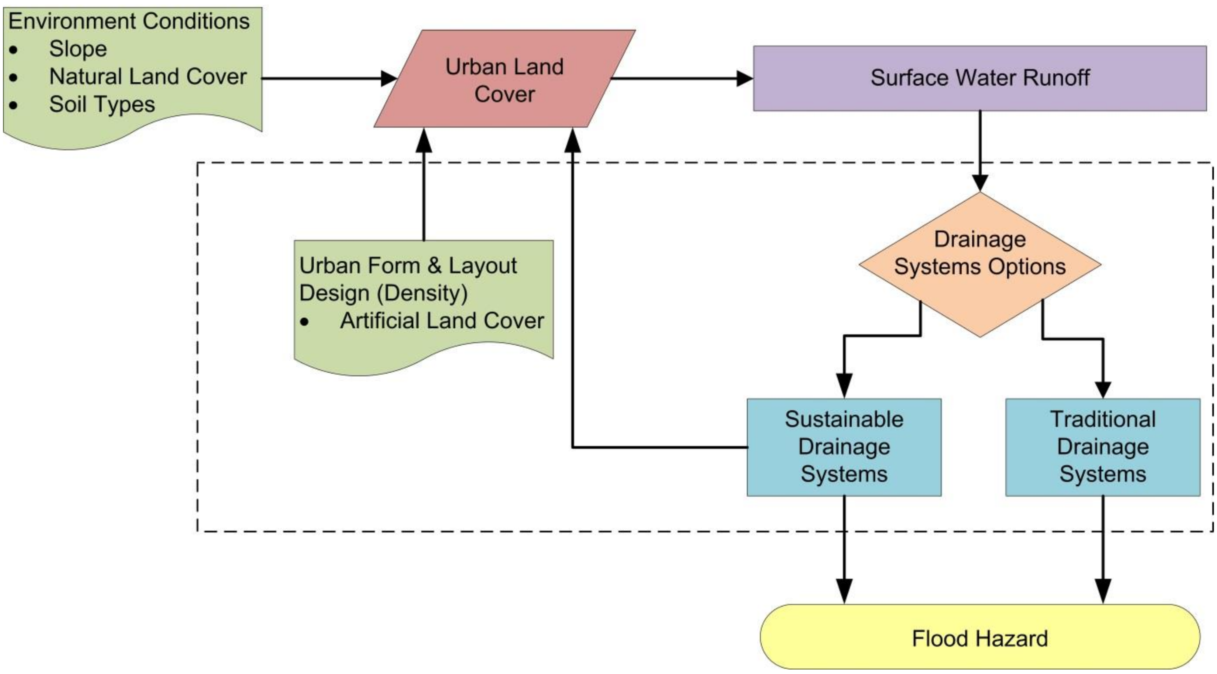
1.5. Conceptual Framework

The preferred course of action that was undertaken by this research is shown in the conceptual framework diagram in Figure 4. As can be seen on the diagram, the drainage systems are divided into two categories such as the sustainable drainage and the traditional drainage systems. The SuDS approach is a new concept that was incorporated into the urban design of the study area. It is basically a natural method of dealing with surface water runoff in order to reduce or eradicate flooding in the study area, which is a central goal of this research. However, the traditional drainage system is an existing approach of conveying runoff in Kampala. It is becoming unsustainable nowadays as it could no longer handle the increasing amount of runoff, which ends up in creating flooding problems downstream. Hence, both the SuDS and the traditional drainage systems are used interactively in managing surface water runoff.

Similarly to other cities, the volume of surface water runoff that it receives is highly dependent on the existing land cover of that city. For instance, if the land cover has more impervious surface, then more runoff should be expected and vice versa. This is one of the serious problems in Kampala as the city is growing at an annual rate of 5.8% which is contributing to more development within and around the city boundary. More development means more impervious surfaces if the SuDS principles are not taken into account, which is resulting to more frequent and intense flooding that the city has never experienced in the past.

Since the urban land cover plays a dominant role in the amount of runoff that is generated from the study area, any changes made to the urban land cover will have a direct impact (whether positive or negative impact) on the volume of runoff. The urban land cover in this case is influenced by the environmental conditions (slope, natural land cover, soil types), the urban form and layout design (artificial land cover), and the SuDS. The SuDS is a new "add on" technique where this research focuses on. It tries to influence the built environment through the provision of sustainable drainage systems. Thus integrating the SuDS principles into the urban design of the study area could help address the runoff and flooding problems in Kampala. The success of this approach was measured and verified by the runoff and flood models through the usage of PCRaster GIS and openLISEM software.

Figure 4: Conceptual Framework



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1.6. Structure of the Thesis

This thesis is organised into six chapters; commencing with chapters introducing the research and the study area, followed by the literature review, data and research methodology, results and discussion, and at last the conclusion and recommendations. The following provides a brief summary for each of the chapters:

Chapter One: Introduction

The purpose of this introductory chapter is to provide a background review of the extent for this research. It starts with a brief discussion of urbanisation in Africa's region, leading to the research problem, which help establishes the research objectives, sub-objectives, and research questions. The conceptual framework sets out the concepts that underlie this study by identifying key elements that have an influence on the surface water runoff and flooding, together with the drainage options (including SuDS) that could be utilised in order to avoid flooding problems downstream. This together with the research design establishes the framework for this research.

Chapter Two: Introduction to Kampala City

Discussions in this chapter provide the spatial context within which this research was carried out. It provides an insight about the study area in terms of its geography and urbanization challenges. Likewise, it also considers the study area's topography, infrastructures, and land tenure.

Chapter Three: Literature Review

This chapter provides a description of the relevant existing literatures about this research. It addresses relevant issues about rapid urbanisation, infrastructure development, climate change, surface water runoff, types and causes of urban flooding, and urban design. The key subject in this chapter is relating to the concept of both the Conventional and Sustainable Drainage Systems, and giving reasons as to why the SuDS approach is highly relevant in today's era.

Chapter Four: Data and Research Methodology

The methods of data collection in obtaining primary and secondary data are explained in this chapter. It further explains the technique used to carry out the urban design, runoff and flood modelling, and the analysis of the questionnaires.

Chapter Five: Results and Discussion

Discussed in this chapter are the actual findings and results of this research. It compares scenarios based on the hypothetical greenfield state, current development state, and the urban design with SuDS principles.

Chapter Six: Conclusion and Recommendation

The concluding remarks and recommendations on urban design with SuDS in Kampala, and its implications are entailed in this chapter.

2. KAMPALA CITY BACKGROUND

Discussions in this chapter provide the spatial context within which this research was carried out. It provides an insight into the study area, which is a sub-catchment from the main Lubigi catchment in the north of Kampala City (part of Kawempe Division), its geographic background and urbanisation challenges, its topography, infrastructures, and land tenure.

2.1. Geographic Background

Kampala is the capital city of Uganda, a landlocked country situated in East Africa and bordered by Kenya in the east, Sudan in the north, the Demographic Republic of Congo in the West, Rwanda in the southwest, and by Tanzania and Lake Victoria in the south. Kampala is situated at an average altitude of 3,910 ft (1,120m) above sea level and it sits on 24 low flat topped hills that are surrounded by wetland valleys. The city covers an estimated land area of 195 sq. km and is surrounded by the satellite towns of Entebbe, Wakiso, Mukono, Lugazi, and Gayaza (Lwasa et al., 2010).

2.2. Urbanisation Challenges in Kampala

The population annual growth rate in Kampala is 5.8% which is far higher than any other urban area in Uganda and is one of the fastest growing African cities (UBOS, 2012). It grows from 774,241 in 1991 to 1.72 million people in the mid-year of 2012 (UBOS, 2012), with an average population density of 6100 persons per km², and the slum areas rising to 30,000 persons per km² (UBOS, 2009). This growth is caused by a number of reasons such as the population dynamics, industrialisation, rural urban migration, and economic growth leading to labour ships (Lwasa et al., 2010).

Figure 5: Unplanned Development in the Study Area

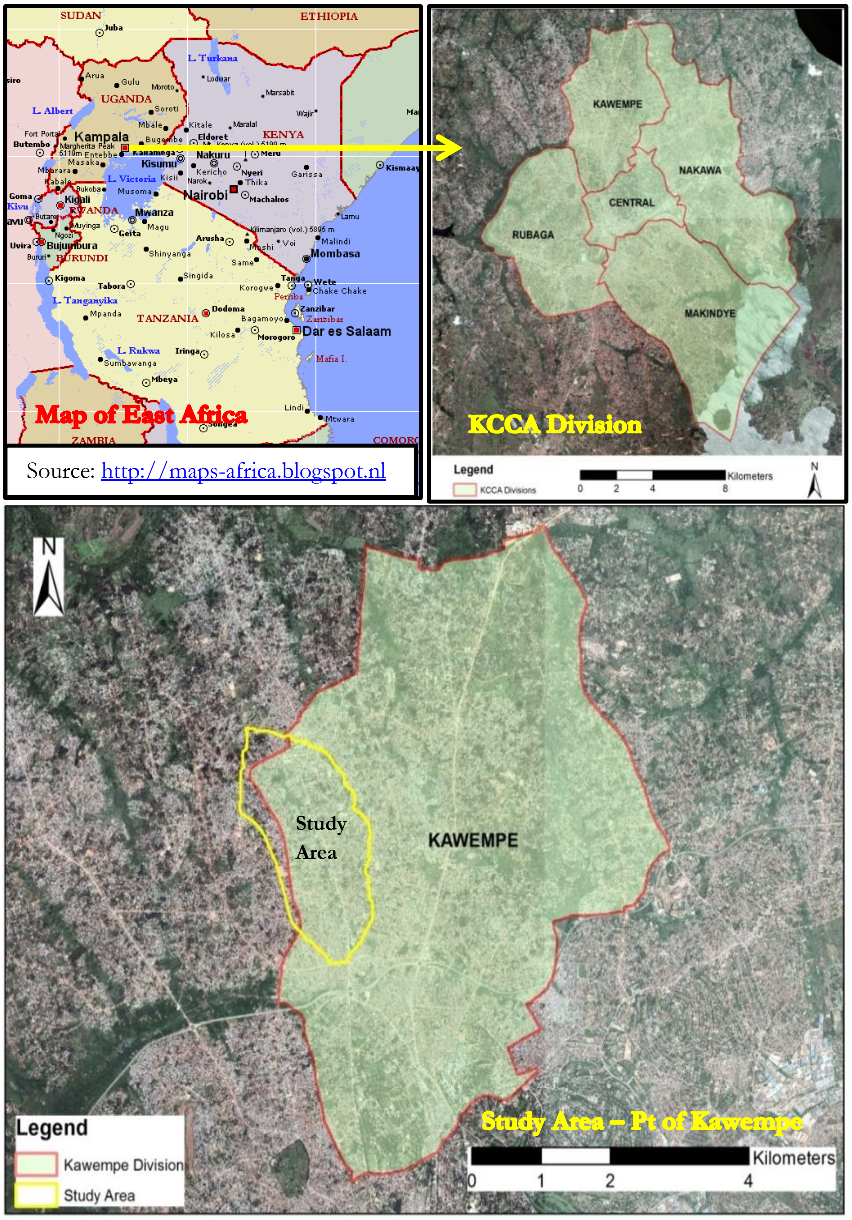
This urbanisation trend should not be seen as a problem, however the challenges and the negative implications that it brought are overwhelming. One of which is urban flooding and it is contributing to various kind of losses within the urban areas. This has posed a lot of challenges in the city itself in terms of the operational and planning matters of the Kampala urban region in trying to ensure that sustainability (environmental, economic, and social) is achieved. Figure 5 reflect the accelerating rate of development that is taking place within the study area. Most of which are not planned and the constructions are not approved by KCCA.

The rapid growth of Kampala city is indeed causing a major socio-economic and environmental problem that is lowering the quality of life of the urban dwellers. The city expanded with the slum dwellers which is calculated to be at least 21% of the total city area and for housing is 39% of the total city population in 2002 (UN-Habitat, 2007). Large parts of the recent residential informal settlements are constructed by poor immigrants in wetland area which does not comply with the environmental planning standards of the city (Vermeiren, Van Rompaey, Loopmans, Serwajja, & Mukwaya, 2012). The rapid urbanisation has also increases runoff which has an implication on flooding. This has placed a huge demand on the development of a more robust drainage system for managing storm water in order to prevent disruption to urban sectors such as public transportation and housing, social services, and the livelihoods of urban dwellers. Thus there is a need to relook at the various infrastructures and services of the city in order to respond to the inherent problems and the emerging impacts that are brought about by the city's rapid growth.

2.3. Study Area Overview

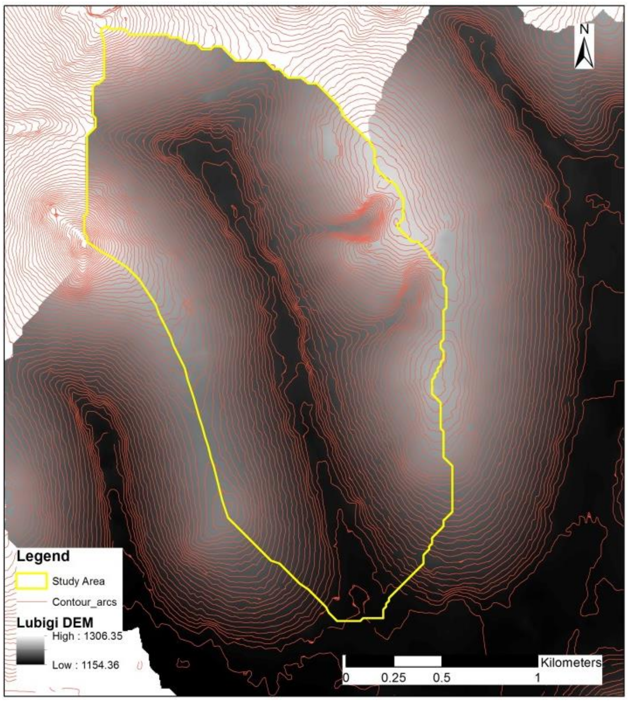
The exact study area for this research is a small sub-catchment from the main Lubigi water catchment. The area for the total upper Lubigi catchment is around 28km² whereas the study area sub-catchment is only 3.75 km² (375 ha). The selected sub-catchment falls under Kawempe district which is slightly above the district of Bwaise on the north of Kampala city. This sub-catchment was selected for this research due to two reasons. First, this sub-catchment already has a water logging instrument that is fitted into the site drainage system which actually measures the flow of water on the site; and second, most of the data regarding this catchment in terms of rainfall data, surface water runoff that is being generated, soil properties, etc. is already available. This indeed has saved a lot of time which is a crucial element in this research. Figure 6 below shows the locality map of the study area.

Figure 6: Study Area Locality Map (Part of Kawempe Division, Kampala)



2.4. Topography

Figure 7: Wetland and Topographic Map of the Study Area



The topography of the study area as shown in Figure 7 is very uneven in nature and it ranges from flat towards the downstream part (southern area) to gentle and steep slope on the upstream area. The low lying areas are the ones shown in black on the topographic map which is normally considered as a natural wetland or where the drainage channel are usually constructed, and the highest parts of the study area are those shown in greyish white which are the areas that rarely flooded. However, most of the wetlands within and outside of the study area are already built up which is again contributing to the flooding problems in Kampala. In between the study area is where the secondary channel runs which is more likely an elongated intervening valley that runs in between the two hills (on the east and west).

The relief of the study area ranges from 1154m (lowest point) to 1360m (highest point) above sea level.

2.5. Existing Infrastructures

Figure 8: Existing Road Network and Drainage Channel

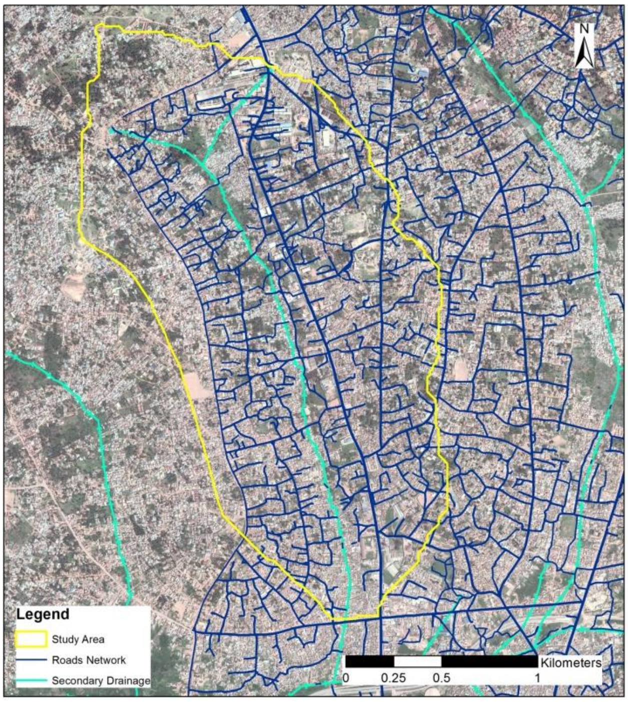
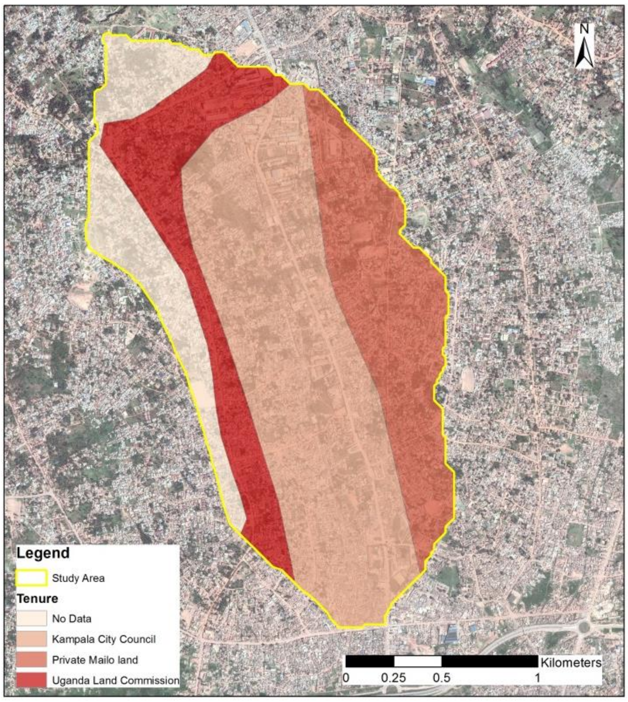


Figure 8 shows the existing road network and drainage channel within the study area. The major roads that run along the study area from north to south are Bombo (tarmac) and Kawaala (gravel) road. On the southern end, the two major roads that run from east to west are Nabweru road (tarmac) and the Northern Bypass. There are also some existing roads which connects Bombo and Kawaala road in the centre of the study area.

The secondary drainage channel that runs along the study area is clearly shown on the diagram which is designed in a 'Y' shape. This channel connects with the primary drain somewhere close to the Northern Bypass.

2.6. Land Tenure

Figure 9: Land Tenure Map

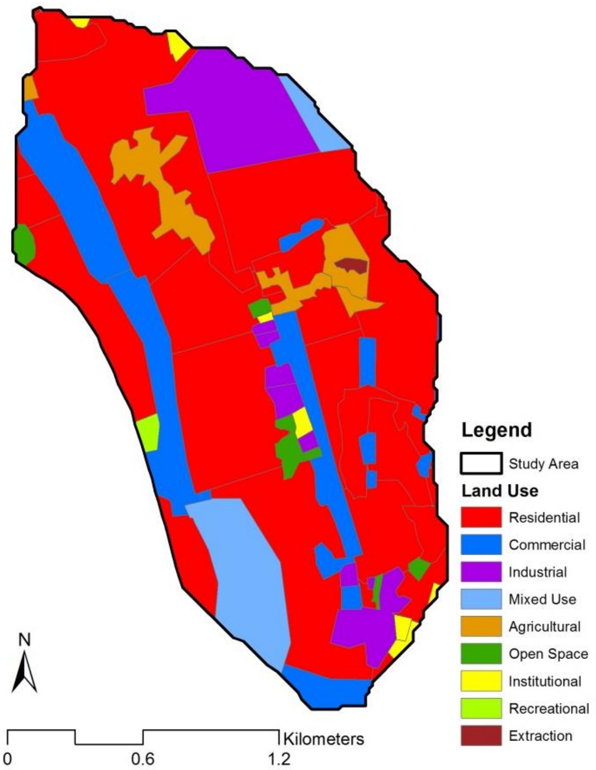


The three types of land ownership that exist within the study area are the Private Mailo, Uganda Land Commission, and the land that belongs to KCCA. The land owned by KCCA is the one on the centre of the study area where the drainage channel is constructed. This is also where most of the informal developments are taking place. Overall, KCCA owns about 46% of the land, Private Mailo 23%, and Uganda Land Commission 17%. The percentage of land with no data is the portion of land that slightly falls outside of the KCCA jurisdiction.

Tenure	Area (ha)	Percentage (%)
Private Mailo	86	23
Kampala City Council	172	46
Uganda Land Commission	63	17
No Data	54	14

2.7. Land Use Map

Figure 10: KCCA Land Use Map 2012



The study area is predominantly residential which is comprised of 62.8% of the total land area. This is followed by commercial (13.6%) and industrial (9.8%) activities. Other land uses that exist within the study area include agricultural, institutional, recreational, mixed use, extraction, and open spaces. Figure 10 depicts these land uses and their location on the ground.

Landuse	Area (ha)	Percentage
Residential	235.5	62.8
Commercial	51.0	13.6
Industrial	36.7	9.8
Mixed Use	23.0	6.1
Agricultural	17.8	4.7
Open Space	5.4	1.5
Institutional	3.8	1.0
Recreational	1.3	0.4
Extraction	0.7	0.2
Total	**375**	**100**

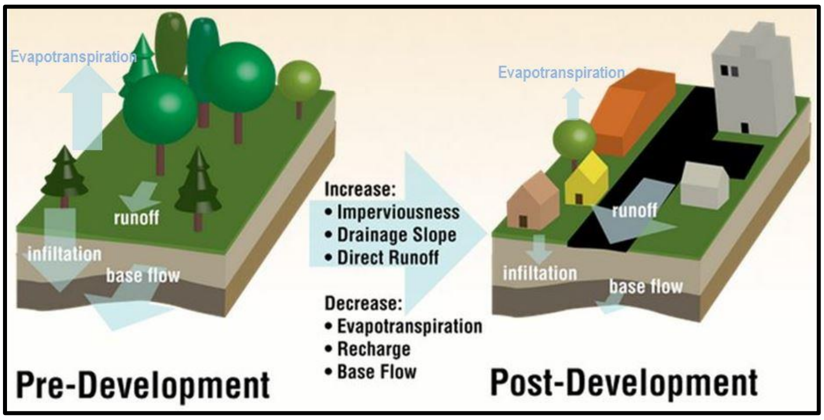
3. LITERATURE REVIEW

Urban areas are becoming more vulnerable to flooding due to the rapid urbanisation that is taking place all over the world, development of complex infrastructures which are not environmental friendly, and also partly due to the changes in the precipitation patterns that is caused by anthropogenic climate change (Willems et al., 2012). This chapter provides a description of the relevant existing literatures for this research. It addresses issues about rapid urbanisation, infrastructure development, climate change, surface water runoff, types and causes of urban flooding, and urban design. The key subject in this chapter is relating to the concept of both the Conventional and Sustainable Drainage Systems (SuDS), and giving reasons as to why the SuDS approach is highly relevant today.

3.1. Rapid Urbanisation

The land use in urban areas is continually changing due to the constant changes in demographic and socio-economic conditions of the population, which significantly changes the natural water balance equilibrium (Miguez et al., 2012). As the permeability of the land surface is reduced by development through the removal of greenfield areas which are being replaced by impermeable roofs, paved areas, and other infrastructures that could only be drained by either pipe or the channel systems. The natural surface vegetated soils are removed and the subsoil is compacted which reduces both infiltration and evatranspiration (Woods-Ballard et al., 2007). As a result, urban planners and designers must now cope with the increase in impermeable surface, reduction in infiltration, and the shorter response time of urban catchments, which boosted the volumes and capacities of storm water runoff beyond the capacity of existing drainage systems (Willems et al., 2012). Figure 11 and 12 clearly depicts this whole process.

Figure 11: Pre and Post Development Hydrological Processes



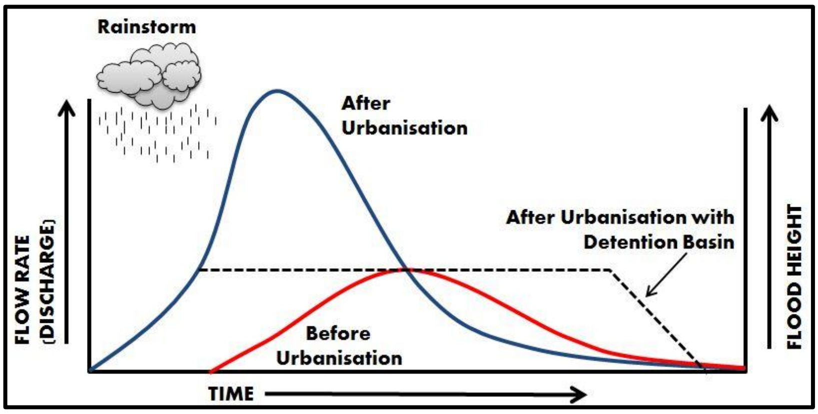
This diagram attempts to make a comparison between a greenfield situation (pre-development) and the post-development state.

It clearly shows how the pre-development site has a great infiltration rate, good base flow, and very little runoff as compared to the post development site.

Source: Invisible Structures (2011)

Moreover, the uncontrolled urban development has led to the occupation of natural flood plains areas and even on the riverbanks. This is something which is common in developing countries and it has in fact worsen the problem of flooding in urban areas, due to the fact that the spaces close to the riverbanks which are often used for flood water overbank flows has been used for construction of residential buildings, infrastructures, and other amenities. As a result, flood waters tend to spread over a large area in trying to find space and at the same time causing severe damages and producing great losses. Thus, the urbanisation process in flood plain areas has limited the space for flood waters which in return causing severe flooding in areas which are not subjected to floods before (Miguez et al., 2012).

Figure 12: Impact of urbanisation on stormwater runoff rates and volumes



The area under each curve represents the total volume of runoff, and urbanisation typically produces increased peak discharges and runoff volumes. Detention basins reduce local flooding by reducing peak flow rates, but do not reduce the total volume of runoff.

Source: Harbor (1994) adapted from (Burke, Meyers, Tiner, & Groman, 1988; Walesh, 1989)

This overall urbanisation process has proven the fact that the alteration of natural flow patterns (both in terms of the total quantity of runoff and the peak runoff rates) can lead to devastating results such as flooding and channel erosion downstream of the development. Likewise, the decrease in percolation into the soil can also lead to low baseflow in watercourses, reduced aquifer recharge, and damage to in-stream and streamside (Woods-Ballard et al., 2007).

3.2. Infrastructure Development & Runoff

Adequate supply of infrastructure services has been long recognised as an essential ingredient for productivity and growth, and in recent years, the role of infrastructure has received increased attention (Calderón & Servén, 2004) in many parts of the world. However, most of the infrastructure developments in most urban areas (in developing countries in particular) are so complex in a sense that they are contributing to more runoff which eventually leads to flooding. For instance, whenever it rains, water will either infiltrate into the soil's sub-surface or contribute to surface run-off. Whereas for complex infrastructure development in an urban area where it is completely covered with impermeable surface, nearly all of the rainfall becomes run-off that can result in flooding (Sharma & Kansal, 2013).

3.3. Climate Change

There is considerable scientific evidence which suggest that the earth's climate is changing. In Africa alone, the climate is predicted to become more variable, and extreme weather events are expected to be more frequent and severe, with increasing risk to health and life. This includes increasing risk of drought and flooding in new areas and inundation due to sea-level rise in the continent's coastal areas (United Nations Framework Convention on Climate Change, 2007).

Likewise in Uganda, the UNDP Climate Change Country Profile (2008) reveals that the mean annual temperature has increased by 1.3^{o}C since 1960, an average rate of 0.28^{o}C per decade. As a result, there is an increasing trend in the frequency of hot days and nights which is becoming increasingly significant. However, the cold days and nights has decreased significantly in all seasons. The report also projected that the mean annual temperature will increase by 1.0 to 3.1^{o}C by 2060 and 1.4 to 4.9^{o}C by 2090 which will further increase the frequency of hot days and nights. Likewise the projection of mean rainfall reveals that there will be an increase in annual rainfall which range from 0 to 15% by 2090 and this may affect the whole country throughout the year (McSweeney, New, & Lizcano, 2008).

Woods-Ballard et al. (2007) highlighted that frequent periods of intense rainfall will increase runoff from urban and agricultural land which will increase the input of pollutants to the water environment, particularly following periods of drought when land is hard and slow to absorb water. This may have considerable impacts such as:

- eroding topsoil, increasing inputs of sediment to surface water runoff, which may harm some fish species and increase contaminant concentrations;
- increasing flooding and the frequency of sewer overflows discharging untreated sewage into the water environment; and
- Increasing the input of pollutants from contaminated returning floodwater.

3.4. Surface Water Runoff

Surface water runoff as defined by Beven (2004) is "the water flow that occurs over the land when the soil is infiltrated to full capacity". Vinogradov (2009) defines it as "a natural phenomenon of free water movement within land under the influence of gravitational forces". Vinogradov (2009) further mentioned that the term "surface runoff" is unfortunately unequivocal. Simply in a narrow sense, it is a kind of runoff that is determine by the condition of its formation; and in a wider sense, it is all the remaining water running on land surfaces which are not taken into account by the hydrological cycle.

Runoff generation is the main process of the ground part of the hydrological cycle (Vinogradov, 2009). This cycle was firstly described by the book of Ecclesiastes (chapter 1 verse 7) which states that "All the rivers flow into the sea; yet the sea is not full. Then the water returns again to the rivers, there they flow again".

Specifically, surface runoff can be generated in a number of ways such as those which are listed below as highlighted by Nelson (2004):

- Through infiltration-excess overland flow – The groundwater storage which is the water that infiltrates into the ground surfaces can only store a certain amount of rainwater during rainy days. When the groundwater storage is completely filled up, rainwater could no longer infiltrate which resulted in overland flow. This is common in regions of high rainfall intensities.
- Through saturation-excess overland flow – High incidence of saturation-excess overland flow occurs in areas where the soils are easily saturated even with less amount of rainfall. Thus, during a long period of rainfall, the depression storage could no longer store more water when it's completely filled up; the rainwater which is no longer stored becomes runoff.
- Through antecedent soil moisture – Normally after a rainfall, the soil can retain a certain degree of moisture which has an impact on the soil's infiltration capacity. This is highly affected by the next rainfall event, causing different saturation rate in the soil. The soil become quickly saturated when there is a high level of antecedent soil moisture. Thus runoff occurs when the soil is completely saturated.
- Through subsurface return-flow – This is common in an elevated terrain where infiltration occurs on the soil located upstream. Since the flow of water in the soil is influenced by gravitational forces, in certain cases, water could also flow out of the soil in any location downstream, causing overland flow in those areas.

3.4.1. Factors that affect Surface Water Runoff

The various factors that affect surface water runoff from a drainage basin may depend on the following characteristics such as meteorological, physical, and human activities. These factors are described in detail below (Agriculture Information Bank, 2011).

Meteorological factors affecting runoff includes the following:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall duration
- Rainfall amount
- Rainfall intensity
- Direction of storm movement
- Distribution of rainfall over the drainage basin
- Precipitation that normally occurs earlier and resulted in soil moisture
- Other meteorological and climatic conditions that affect evatranspiration, such as temperature, wind, relative humidity, and season.

In addition, some of the physical characteristics which may affect runoff include:

- Soil type
- Vegetation
- Land use
- Elevation
- Basin shape
- Drainage area
- Drainage network patterns
- Topography, especially the slope of the land
- Ponds, reservoirs, lakes, sinks, etc. in the basin, which can prevent or delay runoff from flowing downstream

Moreover, in terms of human activities, it affects runoff as more and more people inhabit the earth, and as more development and urbanisation occur, more of the natural landscape is replaced by impervious surfaces, such as roads, houses, parking lots, and building that reduce infiltration of water into the ground and accelerate runoff to ditches and streams. In addition to increasing imperviousness, removal of vegetation and soil, grading the land surface, and constructing drainage networks increase runoff volumes and shorten runoff time into streams from rainfall. As a result, the peak discharge, volume, and frequency of flood increase in nearby streams.

3.5. Types and Causes of Urban Flooding

The types of flood can be classified into two such as the ones according to duration and those according to location. According to duration include the slow-onset flooding, rapid-onset flooding, and flash flooding. According to location on the other hand include coastal flooding, arroyos flooding, river flooding and urban flooding in impervious areas (National Institute of Disaster Management, 2011).

In terms of the causes, Reddy (2009) highlighted that it can be either by natural or human factors. These two causes are clarified below in detail.

Natural causes may include:

- Heavy Rainfall/Flash flooding – This is simply caused by heavy downpour which is very serious in urban areas where there are more impermeable surfaces as compared to the rural or agricultural land. Thus more runoff is generated in urban areas creating more flooding problems to those living downstream and it could be even more chaotic when there is an overflow from the drainage system or riverbanks.

- Absence of Ponds/Lakes – Wetlands such as ponds and lakes have the potential to collect and store additional runoff and at same time attenuate its flow. Thus when there is an absence of lakes, runoff volume and intensity are not well controlled which can lead to flooding problems.
- Silts – When the drainage systems are not regularly maintained, silt and other residues tend to accumulate along the drainage channel itself. This reduces the channel carrying capacity which can also result flooding.

Human causes may include:

- Increase in population – Due to the increasing number of people, more demands are being placed on our natural environment in order to accommodate the needs of our growing population. This could intensify the risk of flooding and soil erosion.
- Removal of forest (Deforestation) – Forest areas near rivers are cleared and the land are used for residential and infrastructure development. This can cause water overflow and flooding due to the raising of the drain beds.
- Development on stormwater drainage – Houses are constructed on top of the stormwater drainage systems which affects the smooth flow of water and completely prevented any maintenance work to be carried out on the channel itself, causing flooding problems during heavy downpour.
- Increasing urban dwellers (Urbanisation) – Rural to urban migration is creating more impermeable surfaces which is one of the leading cause of flooding in urban areas as more rain becomes runoff since it could no longer infiltrate or evaporate back into the atmosphere.

In Kampala, the causes of urban flooding may include the following:

- Heavy rainfall/flash floods (climate change)
- Urbanisation (fast urbanisation rate) and unplanned urbanisation
- Siltation of drains (discharge of sediments into drains, flow of sewerage, sullage and solid waste materials into storm water drains causing siltation which cannot carry full discharge in heavy rain)
- Trespassing on storm water drains – this is common in unplanned squatter settlements.
- Deficiencies in the drainage system – Most of the drainage development does not consider future urbanisation. As a result, drainage systems are facing overflow during heavy downpour since it could not handle the amount of surface water runoff.

Figure 13 depicts the situation in the study area which could be considered as the contributing factors to flooding. They ranged from unplanned urbanisation (a), discharge of solid waste into the drainage system (b & c), to blocked culverts (d), trespassing on storm water drainage (e & f), deteriorated drainage channel (g), overgrown drains (h), and landslide along the banks of the earth drains (i).

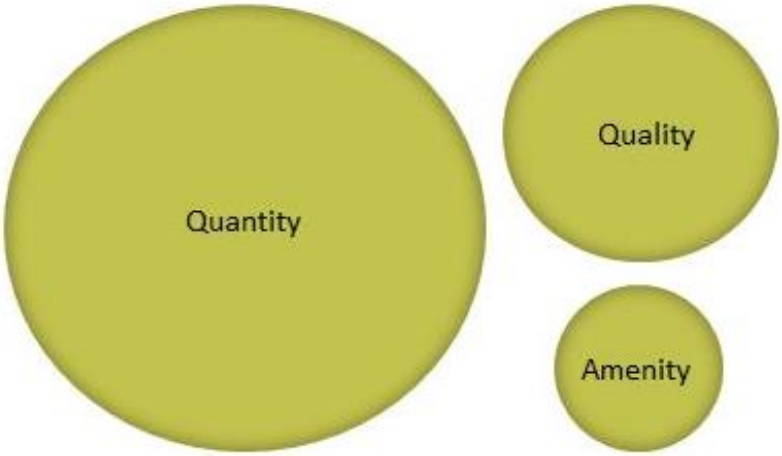
3.6. Conventional Drainage Systems

Several ancient civilisations as far as the Roman Empire Age, showed great care when constructing conventional drainage systems, which aims to collect rainwater, prevent nuisance flooding, and to convey wastes. Its role became very important when towns and cities started to grow during and after the industrial era when sanitation and waste disposal are becoming a great problem that contributed numerous kind of diseases, which led to the deterioration of public health (Miguez et al., 2012). The urban drainage helps to solve this problem together with improving conveyance of storm and waste water. However, the fast growth of urban population in the last century alone and the fact that more people are migrating into urban areas has posed a lot of problems to the conventional drainage systems.

Figure 13: Contributing factors to flooding in the Study Area

The conventional drainage systems are indeed widely used techniques. Its design is based on canalisation works, which adapt to the system of generated and concentrated flows. They consist of an inlet structures (inlets with gully-poys or catch basins), and drainage pipes which transport water to the nearest outfall (Burkhard, Deletic, & Craig, 2000). Its design are comprised of the following steps: (1) land areas are subdivided into sub-catchments; (2) the network which integrates urban patterns and natural flows are designed; (3) the design rainfall is clearly defined, taking into account a critical time of duration and a certain time of recurrence, linked with the time of concentration for each of the sub-catchment considered; (4) calculation of design discharges are made step by step for each drainage channel by using the rational method or other hydrological method that is convenient; (5) and a hydraulic design is made for each drainage network reached (Miguez et al., 2012). Mainly, it focussed on the drainage of impervious surfaces by rapid removal of water downstream, the notion being that by removing surface water from the urban environment, the intensity of flooding will be reduce (Pratt, 1999). However most of these drainage systems are designed to cater for specific flow rate and could not possibly handle the fluctuations in the volume of runoff which is being generated. Thus, conventional drainage systems seems to be ineffective in a highly urbanised area due to its inability to control both runoff quantity and quality (Sharma & Kansal, 2013). The increasing flood problems alone within the urban areas revealed the unsustainability of this traditional approach and new solutions started to be researched. Figure 14 below shows the conventional approach of dealing with surface water runoff. The main intention is to remove much water as quick as possible without taking into account the pollution that is attached to the water or any possible amenity benefits.

Figure 14: Conventional Approach



Source: Bregulla, Powell, and Yu (2010)

3.6.1. Problems faced by the Conventional Approach

Figure 15: Polluted Runoff in the Study Area

The natural hydrological cycle starts when rainwater falls on the ground and seeps into the soil. This process replenishes the groundwater supplies and fills the rivers. However, when the land is developed, the area of impervious surface increases and this interferes with the natural hydrological cycle. Thus when rainwater is conveyed in pipes to rivers or lakes, the time between the rainfall event and water entering the river/lake is reduced when compared to an undeveloped catchment, and large volumes of water converge on a watercourse in a short time period. However, in an urbanised catchment, peak flow in the river is higher and happens sooner than in an undeveloped catchment. These events can rapidly lead to flood conditions, especially in small watercourses with a highly urbanised catchment (Gleason, 2008).

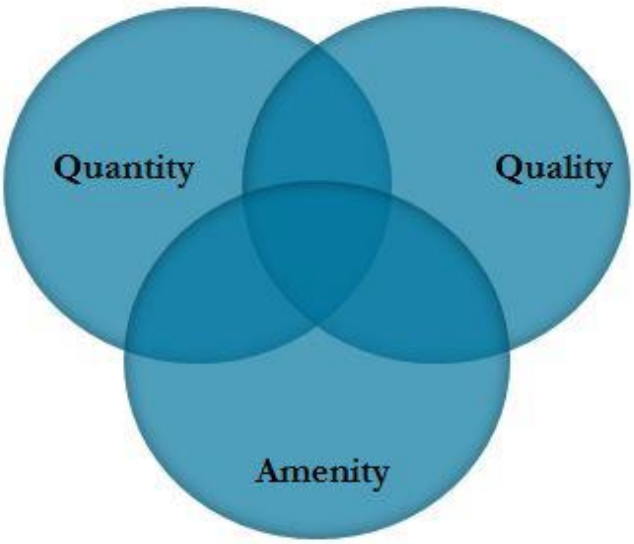
In addition to flooding, there is a problem of pollution in urban rivers. Much of this pollution is diffuse in nature, which means that the pollution arises from the land use and human activity within the catchment, and does not result from a point discharge of sewage or trade effluent. Rainwater mobilises the pollutants on the surfaces of car parks, roads, from roofs and yards areas, which are then carried into rivers. Figure 15 shows a highly polluted runoff carrying all kinds of pollution from upstream development which is something common in the study area after a heavy downpour.

3.7. Sustainable Drainage Systems (SuDS)

Sustainable Drainage Systems or SuDS are not a new concept. It is simply nature's way of dealing with rainfall. They have been around in the past but was later forgotten and replaced by the conventional drainage systems. However as modern urban development continues to rise coupled with the increase of impermeable surface, the conventional approach to surface water drainage, together with the potential effects of a changing climate, has contributed to some serious negative consequences on life, property and the environment which is evidence by the disastrous flooding (Essex County Council, 2012) of urban areas that is been experienced in many parts of the world.

SuDS are made up of a sequence of management practices, control structures and strategies which are designed to efficiently and sustainably drain surface water, while at the same time minimises pollution and managing the impact on water quality of local water bodies (Woods-Ballard et al., 2007). SuDS are increasingly used to mitigate excessive flows from stormwater and reduce the potential for pollution from run-offs in urban areas. They are often designed to replicate as closely as possible the natural drainage prior to any development. Their adoption and success will depend on many factors such as the local ground conditions (primarily type of soil) and groundwater tables in the area (Construction Industry Research and Information Association, 2004). Thus a survey of the ground conditions together with other factors will be necessary before deciding on a specific SuDS technique (Bregulla et al., 2010).

Figure 16: SuDS Approach



Source: Woods-Ballard et al. (2007)

SuDS are considered as the preferred approach for managing rainfall since they can be used on any site due to their different features that are available to suit the constraints of a site (Wilson, Bray, Neesam, Bunn, & Flanagan, 2010). Figure 16 describe the SuDS three-way concept together with its main objectives, that is to minimise the impacts from the development on the quantity and quality of the runoff (minimising runoff volumes and runoff rates), and to maximise amenity and biodiversity opportunities (Woods-Ballard et al., 2007).

Bregulla et al., (2010) highlighted a number of devices that is associated with SuDS which include storm water design features, pervious paving, soakaways, swales, infiltration trenches, filter strips, sand filters, bio retention filters/areas, green roofs, water harvesting systems, infiltration basins, detention basins, ponds and storm water wetlands, silt removal devices, pipes and conduits, and subterranean storage.

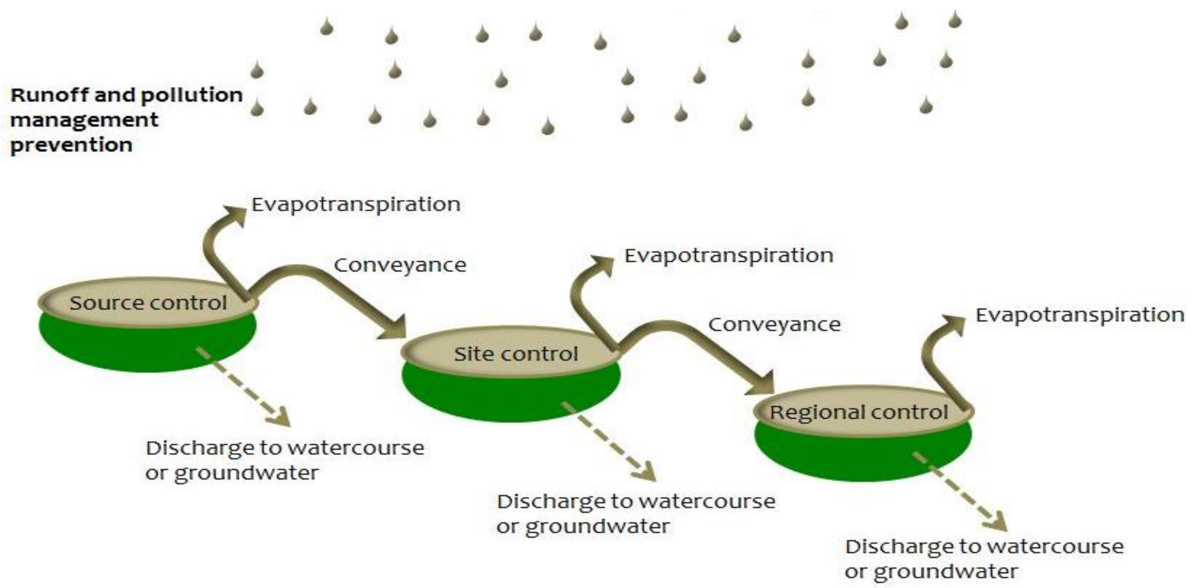
3.7.1. SuDS Management Train

A "management train" is required in order to mimic the natural catchment processes as closely as possible. In order to design a successful SuDS scheme, it is important to consider this concept as it tries to reduce pollution, flow rates and volumes in a series of drainage techniques.

Woods-Ballard et al. (2007) highlighted the various hierarchy of techniques which must be taken into account when developing the management train. These techniques are listed below:

- Prevention – to completely avoid any runoff or pollution by carefully considering the site layout design and the site housekeeping measures (for instance, clearance of dust and dirt within the property compound), and also through rainwater harvesting which can be used to meet other household water needs (for e.g. for toilets, watering the garden, etc.)
- Source control – controlling runoff at or somewhere close to its source (e.g. other infiltration methods, soakaways, pervious pavements, green roofs).
- Site control – referring to a local area or site where water can be carefully managed (e.g. detention or infiltration basin, routing water from car parks and building roofs to a large soakaway,).
- Regional control – referring to a particular site or numerous sites where runoff can be well managed, typically in wetland areas or a balancing pond.

Figure 17: The SuDS Management Train



Source: Adapted from Bregulla et al. (2010)

It is preferable for stormwater to be managed in a small, cost-effective landscape features located within small sub-catchments rather than being conveyed to and managed in large systems at the bottom of the drainages areas (end of pipe solutions). The techniques that are higher in the hierarchy are preferred to those further down so that prevention and control of water at source should always be considered as priority before site or regional controls. However, where upstream control opportunities are restricted, a number of lower hierarchy options should be used in series. Water should only be conveyed elsewhere if it cannot be dealt with on site (Woods-Ballard et al., 2007). The management train is summarised in Figure 17. It shows how stormwater should be managed in various stages.

3.7.2. Runoff Quantity Control Processes

Woods-Ballard et al. (2007) also highlighted several processes that can be used to manage and control the runoff from developed areas which include infiltration, detention/attenuation, conveyance, and water harvesting. Each management option can provide unique opportunities for stormwater control, flood risk management, water conservation, and/or groundwater recharge.

a. Infiltration

This is the soaking of water into the ground. It is different from conveyance and detention because it transfers water to a different part of the environment and can physically reduce the volume of drained runoff. This is the most desirable solution to runoff management because it restores the natural hydrological processes. However infiltration rates vary with soil type and condition, antecedent conditions, and with time.

b. Detention/attenuation

Detention or attenuation is the slowing down of surface flows before their transfer downstream. This is usually achieved through the use of a storage volume and constrained outlet. The storage volume can be accommodated within a dry basin, above a permanent pond volume or beneath the ground within subsurface structures. In general, although storage can help reduce the peak flow rate of runoff, the duration of runoff will be extended and the total volume of flow will remain the same.

c. Conveyance

Conveyance is the transfer of runoff from one place to another. It can take place through a range of systems including open channels, pipes and trenches. Uncontrolled conveyance to a point of discharge into the environment is no longer considered sustainable. Controlled conveyance is still an essential tool for managing flows and linking SuDS components together.

d. Water harvesting

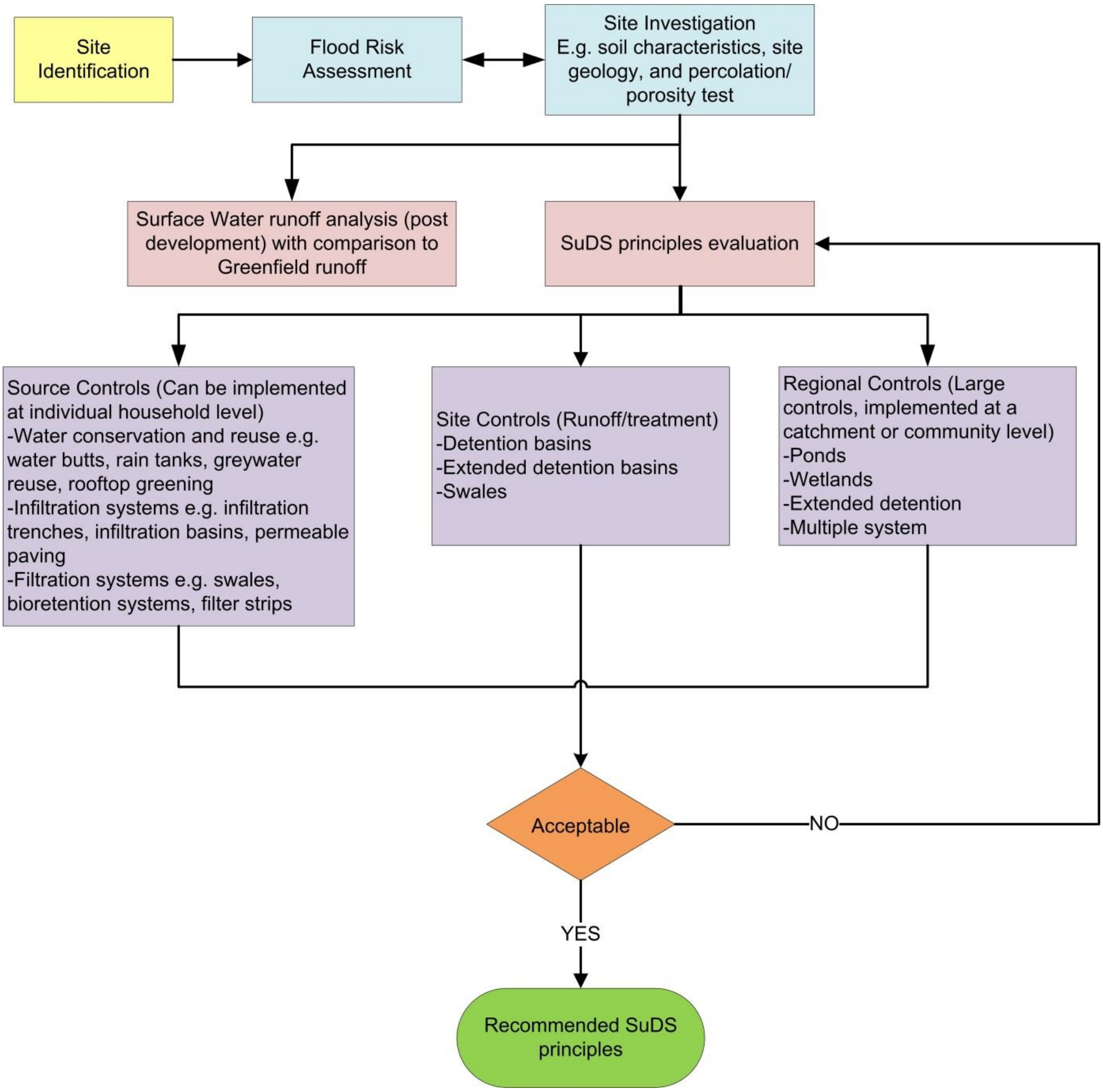
This is the direct capture and use of runoff on site. Rainfall runoff can be extracted for domestic use (e.g. flushing toilets, etc.), or irrigation of urban landscapes. The contribution of flood risk management from such systems will be dependent on the scale of the water harvesting system. Design will need to ensure that storage for runoff control is always available, and there is an acceptably low risk that the system will be full (and storage bypassed) when a flood occurs.

3.7.3. SuDS Evaluation Flowchart

SuDS planning and design may require a multi-disciplinary approach. Once the site has been identified, a flood risk assessment will be carried out on the site (if required) in order to ascertain the risk of flooding for the purpose of establishing a floodplain management program that is technically sound and scientifically effective. Likewise, a thorough on-site investigation should also be carried out which may include definition of soil characteristics, site geology and porosity/permeability tests.

In addition, a surface water runoff analysis needs to be carried out on the site by using recognised techniques. A comparison will be made between the greenfield runoff and the post development runoff in order to determine the amount of runoff that is generated from the site before and after development. Likewise a feasibility study evaluating the means of incorporating SuDS principles will be required in order to justify whether each SuDS principle is applicable on the site to ensure its long term positive implication.

Figure 18: SuDS Evaluation Flowchart



Source: Modified from Bregulla et al. (2010)

Moreover, three categories of SuDS principles (source control, site control, and regional control), will evolve from the SuDS evaluation. They are known as surface water management train which is fundamental to designing a successful SuDS schemes and provides a hierarchy of drainage techniques for improving quality and quantity (Wychavon District Council, 2009). The application of source controls will reduce the peak runoff rate, placing less stress on any facilities downstream. It can be incorporated into developments as small as the size of a single house. Site controls on the other hand serves individual developments such as swales and detentions basins. They handle water which could not be controlled at source and are applicable to sites such as the shopping centre, industrial area, or a residential development of 10 to 50 homes. Lastly, regional controls are the last line of defence which deals with water that could not be handle on site. It is similar to site control, except the fact that runoff will be dealt with on a catchment scale and are often end of pipe facilities. They contribute to the flow and quality of runoff and could be considered as water amenity features that provide habitat and encourage biodiversity.

Finally, the above techniques will then be incorporated into the site where it fits most. Should it be acceptable on the site, then the recommended SuDS principles will then be implemented. However, should it be rejected, then the SuDS principles evaluation shall again be repeated until a suitable SuDS alternative is achieved. Figure 18 depicts this whole process of SuDS evaluation.

3.8. SuDS Selection Criteria

(Woods-Ballard et al., 2007) highlighted many different SuDS components that can be used on a site. However, since different sites have different features, not all SuDS techniques are suitable for all sites, thus it is important that the opportunities and constraints are identified at an early stage in the design process. The three SuDS selection criteria or factors that must be taken into account first include the land use characteristics; site characteristics; and community, environmental and amenity performance. These three criteria are described below in detail.

3.8.1. Land Use Characteristics

The land use characteristics looks at which SuDS techniques are best suited to the proposed land use of the area that is draining to the system. The different land use types and the land use selection matrix are discussed in Table 2 and 3.

Table 2: Influence of Land Use on SuDS Selection

Land use	Required drainage system characteristics
1. Very low density development areas	These areas are likely to have lower pollution levels. They have a fully vegetated surface, lower sediment loadings compared to equivalent impervious surfaces. A full treatment train is unlikely to be necessary and a single stage should be sufficient.
2. Roofs	Roof runoff is unlikely to carry significant pollution loads and a single treatment stage (which appropriate pre-treatment) is likely to be sufficient.
3. Roads/highways	The design criteria for road drainage systems, set out at the outline planning stage, will depend on: o The sensitivity of the receiving water o The traffic conditions (traffic flow and types of vehicles) Drainage near roads should ensure not only that the road surface can shed water quickly, but also that the ground around the road and paths will not become saturated. Lack of free draining ground under the road can lead to loss of ground strength and frost heave. If drainage runs alongside roads, the carriageway will need to be defined and measures taken to avoid over-running on parking verges. Permeable paving systems may not be suitable for adoptable roads and any proposals should be discussed in detail with the adopting authority.
4. Commercial development (including shops, schools and offices)	Some small areas within these sites, such as fuel tanks or rubbish skips, should be treated as industrial (hotspot) sub-catchments. Unless the receiving water is particularly sensitive, two levels of treatment will typically be required. This might consist of source control followed by site or regional control.

Land use	Required drainage system characteristics
5. Industrial development/hot spot areas	Industrial areas pose a greater threat to the environment than other land uses. Runoff from these areas may include highly polluted runoff. So extra stages of runoff treatment are required, especially for sensitive receiving waters.

Source: Woods-Ballard et al. (2007)

Table 3: Land Use Selection Matrix

SuDS group	Technique	Low density	Residential	Local roads	Commercial	Hotspots
Retention	Retention pond	Y	Y	Y1	Y2	Y2
	Subsurface storage	Y	Y	Y	Y	Y
Wetland	Shallow wetland	Y	Y	Y1	Y2	Y2
	Extended detention wetland	Y	Y	Y1	Y2	Y2
	Pond/wetland	Y	Y	Y1	Y2	Y2
	Pocket wetland	Y	Y	Y1	Y2	Y2
	Submerged gravel wetland	Y	Y	Y1	Y2	Y2
	Wetland channel	Y	Y	Y1	Y2	Y2
Infiltration	Infiltration trench	Y	Y	Y1	Y2	N
	Infiltration basin	Y	Y	Y1	Y2	N
	Soakaway	Y	Y	Y1	Y2	N
Filtration	Surface sand filter	N	Y	Y1	Y2	Y2
	Sub-surface sand filter	N	Y	Y1	Y2	Y2
	Perimeter sand filter	N	N	Y1	Y2	Y2
	Bioretention/filter strip	Y	Y	Y1	Y2	Y2
	Filter trench	Y	Y	Y1	Y2	Y2
Detention	Detention basin	Y	Y	Y1	Y2	Y1,2
Open channels	Conveyance swale	Y	Y	Y1	Y2	Y2
	Enhanced dry swale	Y	Y	Y1	Y2	Y2
	Enhanced wet swale	Y	Y	Y1	Y2	Y1
Source control	Green roof	Y	Y	N	Y2	Y
	Rainwater harvesting	Y	Y	N	Y2	N
	Pervious pavements	Y	Y	N	Y2	Y1

Source: Woods-Ballard et al. (2007)

Y: Yes N: No

1. Depending on type and intensity of road use and receiving water sensitivity, it may require two treatment train stages

2. Depending on receiving watercourse sensitivity, it may require three treatment train stages

3.8.2. Site Characteristics

This criterion considers whether there are any site characteristics that may restrict or preclude the use of a particular SuDS technique. The site characteristics that can influence SuDS selection and the site characteristics selection matrix are discussed in Table 4 and 5.

Table 4: Influence of site characteristics on SuDS selection

Site characteristics	Required drainage system characteristics
1. Soils	The function of different SuDS is very dependent on the underlying soils. More permeable soils can enhance the operation of some practices, but adversely affect others, e.g. wet ponds or wetlands rely on a pool of water or saturated sub-soils to provide the basis for water quality treatment. Permeable soils will prevent the retention of a pool of water unless a liner is installed. Infiltration practices rely on the passage of water through the soil profile and more permeable soils transmit more water.
2. Groundwater: minimum depth to seasonally high water table	Infiltration devices will require at least 1m of soils depth between the base of the device and the maximum expected groundwater level. This is to ensure that the system operates efficiently during periods of exceptional wet weather and that the risk of system flooding from high groundwater levels is minimised.
3. Area draining to a single SuDS component	Practices that rely on vegetative or media filtering of runoff tend to be more appropriate for smaller catchment areas, as large flows may overwhelm their ability to treat the runoff. Ponds can be appropriate for larger catchment areas although, by using effective source control and SuDS management trains, ponds will most usually feature at the bottom of a train of upstream components. It should be rare that areas >2 ha drain to a single SuDS components.
4. Slope of contributing drainage area	Steeper slopes may eliminate the use of some practices, may require other practices to be modified, but may have little impact on others. Depending on the design, it is usually more difficult to achieve high pond/basin storage volumes on sloping sites. Swales may be adapted for steeper slopes if the swales are placed along the contours rather than up or down the slope. Biofiltration and filter strips require residence times that are generally only possible with gentler slopes. Infiltration practices are also limited to gentle slopes as they must provide storage of water until the water can soak into the ground. In addition, infiltration of water into a slope may cause saturation further down which could cause slope instability or re-emergence of storm water.
5. Head	Elevation differences are needed from inflow to outflow to allow certain SuDS techniques to operate under gravity. If sufficient head is not naturally available, it can often be artificially created by excavation or by using embankments.
6. Availability of space	Some techniques require more land take than others, though this is not necessarily a barrier.

Source: Woods-Ballard et al. (2007)

Table 5: Site characteristics selection matrix

SuDS group	Technique	Soils		Area draining to a single SuDS		Minimum depth to water table		Site slope		Available head		Available space	
		Impermeable	Permeable	0 - 2 ha	>2 ha	0 - 1m	> 1m	0 - 5%	> 5%	0 - 1m	1 - 2m	Low	High
Retention	Retention pond	Y	Y1	Y	Y5	Y	Y	Y	Y	Y	Y	N	Y
	Subsurface storage	Y	Y1	Y	Y5	Y	Y	Y	Y	Y	Y	Y	Y
Wetland	Shallow wetland	Y2	Y4	Y4	Y6	Y2	Y2	Y	N	Y	Y	N	Y
	Extended detention wetland	Y2	Y4	Y4	Y6	Y2	Y2	Y	N	Y	Y	N	Y
	Pond/wetland	Y2	Y4	Y4	Y6	Y2	Y2	Y	N	Y	Y	N	Y
	Pocket wetland	Y2	Y4	Y4	N	Y2	Y2	Y	N	Y	Y	Y	Y
	Submerged gravel wetland	Y2	Y4	Y4	Y6	Y2	Y2	Y	N	Y	Y	N	Y
	Wetland channel	Y2	Y4	Y4	Y6	Y2	Y2	Y	N	Y	Y	N	Y
Infiltration	Infiltration trench	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
	Infiltration basin	N	Y	Y	Y5	N	Y	Y	Y	Y	N	N	Y
	Soakaway	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
Filtration	Surface sand filter	Y	Y	Y	Y5	N	Y	Y	N	N	Y	N	Y
	Sub-surface sand filter	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	Y
	Perimeter sand filter	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y	Y
	Bioretention/filter strip	Y	Y	Y	N	N	Y	Y	N	Y	Y	N	Y
	Filter trench	Y	Y1	Y	N	N	Y	Y	N	Y	Y	Y	Y
Detention	Detention basin	Y	Y1	Y	Y5	N	Y	Y	Y	N	Y	N	Y
Open channels	Conveyance swale	Y	Y	Y	N	N	Y	Y	N3	Y	N	N	Y
	Enhanced dry swale	Y	Y	Y	N	N	Y	Y	N3	Y	N	N	Y
	Enhanced wet swale	Y2	Y4	Y	N	Y	Y	Y	N3	Y	N	N	Y
Source control	Green roof	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
	Rainwater harvesting	Y	Y	Y	N	Y	Y	Y	Y	Y			
	Pervious pavements	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y

Source: Woods-Ballard et al. (2007)

Y: Yes N: No

1 To be used with liner
2 To be used with surface baseflow
3 Only to be used unless it follow the contours
4 To be used with liner and constant surface baseflow, or high ground water table
5 This is possible, but is not recommended (implies appropriate management train not in place)
6 To be used only where high flows are diverted around SuDS component

3.8.3. Community, Environmental, and Amenity Performance

This factor determines whether the proposed SuDS components do meet all the community and environmental requirements at the site. Adaptations to the proposed solutions that may enhance the benefits of the system should also be considered.

Table 6: Influence of community and environmental factors on SuDS selection

Community/environmental factor	Influence on SuDS selection
1. Maintenance regime	The future management of the site can influence the choice of drainage system. A commitment to the long term maintenance of the drainage system should be established at early stages in the planning process.
2. Community acceptability	Some SuDS techniques may not be acceptable in close proximity to property, e.g. swales in gardens are not likely to be acceptable. Some ponds may only be acceptable providing a minimum level of operation and maintenance is on-going. Amenity considerations are site specific, but there may be opportunities to enhance/provide the following facilities for the local population: • Additional recreational open space • Opportunities for education • Enhanced levels of landscape maintenance • Improved visual impact (through integration of SuDS with local topography and site layout) • Water feature (including water bodies and conveyance channels)
3. Cost	Construction and maintenance costs can vary widely between techniques and the long term costs of SuDS should be considered at an early stage. In selecting a design from a series of options, both capital and operational costs should be considered using a whole life costing approach, and a cost-benefit analysis carried out.
4. Public safety	Good designs and education can help overcome concerns about safety. All drainage techniques have advantages and risks, and a balance must be struck. For example, culverts are confined spaces, whereas swales have sloping sides. The safest technique will depend on the site itself. Access to a water feature might be encouraged for education and recreation, and measures taken at particular areas to ensure this is safe. In other areas, access could be discouraged by the use of barrier planting, notices or low permanent fencing. However, the risks associated with open water features can be minimised by community engagement and careful design.
5. Habitat creation	SuDS can improve wildlife habitat. Ponds and wetlands offer the greatest opportunity, with aquatic and emergent vegetation providing a habitat for fish, insects, amphibians, reptiles, birds and mammals. Design of SuDS should try to maximise the species diversity. Local grasses, flowers and wetland vegetation should always be used and invasive species avoided. Ecological benefits are maximised where SuDS features are sited in proximity to undisturbed, natural areas or where links to these are created.

Source: Woods-Ballard et al. (2007)

Table 7: Community and environmental factors selection matrix

SuDS group	Technique	Maintenance	Community acceptability	Cost	Habitat creation potential
Retention	Retention pond	M	H*	M	H
	Subsurface storage	L	H	M	L
Wetland	Shallow wetland	H	H*	H	H
	Extended detention wetland	H	H*	H	H
	Pond/wetland	H	H*	H	H
	Pocket wetland	H	M*	H	H
	Submerged gravel wetland	M	L	H	M
	Wetland channel	H	H*	H	H
Infiltration	Infiltration trench	L	M*	L	L
	Infiltration basin	M	H*	L	M
	Soakaway	L	M*	M	L
Filtration	Surface sand filter	M	L	H	M
	Sub-surface sand filter	M	L	H	L
	Perimeter sand filter	M	L	H	L
	Bioretention/filter strip	H	H	M	H
	Filter trench	M	M*	M	L
Detention	Detention basin	L	H*	L	M
Open channels	Conveyance swale	L	M*	L	M
	Enhanced dry swale	L	M*	M	M
	Enhanced wet swale	M	M*	M	H
Source control	Green roof	H	H	H	H
	Rainwater harvesting	H	M*	H	L
	Pervious pavements	M	M*	M	L

Source: Woods-Ballard et al. (2007)

H: High
M: Medium
L: Low
* Public safety concerns must be addressed at the design stage

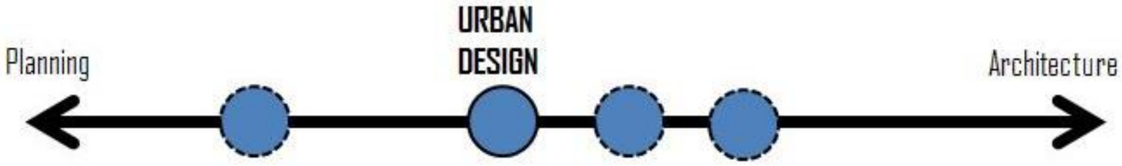
3.9. Urban Design

Urban design is far from a clear area of activity…. Despite its frequent appearance in educational and professional literature, urban design is still an ambiguous term (Madanipour, 1996).

The concept of urban design is open to much interpretation due to its multidimensional nature. Different groups of people – professionals, educators, researchers, the private sector, the lay public – have different definition and understanding of what urban design is all about. While some consider it as a discipline in its own right, others consider it merely an 'interface' between other disciplines (Arida, 2002). In spite of its long history and the recent increased attention to the field of urban design, the term still lacks clarity. However, no matter how varied the definitions are, there is some consensus about some of the basic components of urban design.

Urban design may be viewed as a multifaceted approach and response to urban change and development (Barnett, 1982b; Rowley, 1994). Principles, guidelines and considerations are constantly being formulated and evolve in relation to social, functional, aesthetic and emotional needs. Emphasis is placed on our use, perception and experiences with places over time (Rowley, 1994). With this knowledge, it is possible to attempt to define urban design as the art and process of designing, creating, making and managing spaces and places for people (Commissioner for Architecture and the Built Environment, 2001; Rowley, 1994). Moreover, it is the process of giving physical design direction to urban growth, conservation and change (Barnett, 1982a). It sits at the interface between architecture and planning (and related professions), and its emphasis on physical attributes usually restricts its scale of operation to arrangements of streets, buildings, and landscapes (Batty, Dodge, Jiang, & Hudson-Smith, 1998).

Figure 19: Urban design as the interface between planning and architecture



Source: Modified from Arida (2002)

From the above definitions, two things become apparent. First, urban design is creative and unique to each situation in which it is implemented. That is, it could not be employed as part of a blanket policy at a national level to be used in all places. Rather, urban design must be fostered at a more local level, through local authorities, the community and local businesses, where people have more experience with the specific urban design issues that need to be addressed (Commissioner for Architecture and the Built Environment, 2001). Thus, involving local stakeholders in urban design projects is key to creating places in which people want to live, work and recreate (Carley, Kenkins, & Smith, 2001).

Second, urban design is a process and the process is quite complex which involves various stakeholders, tasks, issues and feedback loops that form and influence urban design projects over time. Sustainability is also part of the urban design process, firmly and intimately embedded within the design. It is therefore fundamental that the urban design process is understood at a higher conceptual level because then the basic 'rules' will be known in order to discuss how and where the urban design process is influenced by sustainability. Moreover, it is possible to begin to comprehend how the particulars of various situations shape and are shaped by urban design and sustainability (Jacobs, 1961). There must also be an understanding of how that context influences the relationships between stakeholders, including dealing with aspects of conflict, (dis)trust, and (mis)understanding (Rydin, Holman, Hands, & Sommer, 2003). With this knowledge, existing urban design processes can be improved, which will help ultimately to improve a wide spectrum of urban design projects.

3.9.1. Urban Design Process

In the design and planning literature, several examples of processes and models are useful in considering a specific process for urban design. However sticking to a process does not necessarily guarantee a successful project. An organised process can aid in collaboration and can clarify expectations of all involved parties. It can also help to make the best use of available resources, including time and money (Palazzo & Steiner, 2012).

In 1980, the Royal Institute of British Architects proposed in the field of urban design a process model which is divided into four phases as in accordance with the list below [RIBA 1980, quoted in (Moughtin, Rafael, Christine, & Paola, 2004)]:

- Assimilation – the accumulation of general information and information specifically related to the problem
- General Study – the investigation of the nature of the problem; the investigation of a possible solution
- Development – the development of one or more solutions
- Communication – the communication of the chosen solution(s) to the client

In addition, Hamid Shirvani (1985) distinguishes six groups of design methods such as internalised, synoptic, incremental, fragmental, pluralistic, and radical. The internalised method is the intuitive one: "The designer first develops a design for the project in his or her mind, with the benefit and assistance of memory, training and experience. The synoptic method, which is also commonly described as "rational" or "comprehensive," is usually composed of seven steps which are listed below(Shirvani, 2001):

- Data collection, survey of existing conditions (natural, built, and socioeconomic);
- Data analysis, identification of all opportunities and limitations;
- Formulation of goals and objectives;
- Generation of alternative concepts;
- Elaboration of each concept into workable solutions;
- Evaluation of alternative solutions; and
- Translation of solutions into policies, plans, guidelines, and programs.

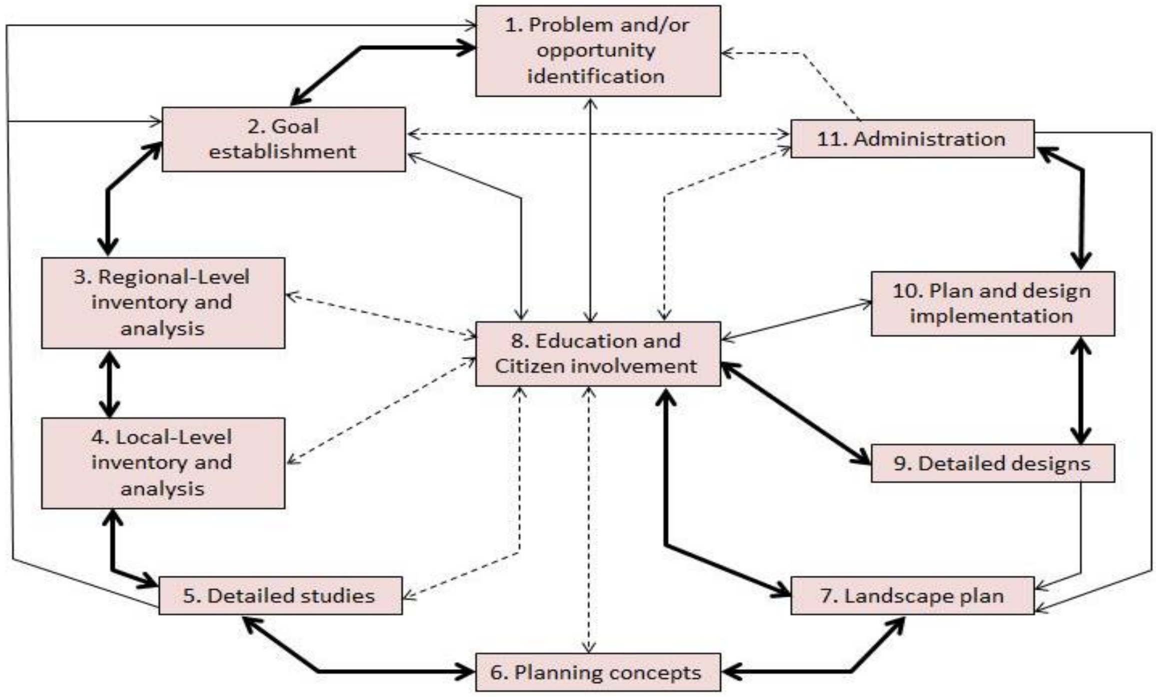
The incremental method is another version of the synoptic method in which "the designer establishes a goal and then develops incremental steps to achieve it". The fragmental process is similar to the synoptic, except that it is incomplete. The designer can "go through four out of the total seven steps suggested for the synoptic process". The pluralistic process is an approach that incorporates into the design process the inhabitants' value system and the functional/social structure of the urban area involved in the design. Shirvani's final approach, the radical process has an underlying concept that "in order to understand and design for a complex urban setting, social processes must be understood first.

Moreover, (Lloyd Jones, 2001) only highlights four steps of the urban design process which include the following:

- Defining the problem – starting from a study area appraisal and the project brief
- Developing a rationale – taking into account summary analysis on planning/socioeconomic context; built form/townscape; land use/activity; movement and access; physical and natural environment; public realm and social space; and perceptual and cultural factors
- Summarising development opportunities and constraints – balancing the potentials of the site for its projected use
- Conceptualising and evaluating design options – envisioning the possibilities for the study area with relative merits and shortcomings

Furthermore, Steiner (2008) proposes 11 steps of ecological planning process. These eleven interacting steps are shown in Figure 20:

Figure 20: Ecological Planning Model



Source: Steiner (2008)

Finally, urban design can be considered "a continuous process of trial-test-change, involving imaging (thinking in terms of solutions), presenting, evaluating, and reimagining (reconsidering or developing alternative solutions)" (Carmona, Tim, Taner, & Steve, 2003), a process characterised by cycles and iterations "by which solutions are gradually refined through a series of creative leaps or conceptual shifts" (Lloyd Jones, 2001).

3.9.2. Relation between Urban Design, Urban Drainage, and Urban Flooding

There is indeed a high correlation between urban design, urban drainage and urban flooding. Since the urban design process is the first step for any development activity, embedded in it is the future development of any urban area in terms of the type of development that needs to be carried out on the ground (according to the various types of land uses), how the development is to be carried out (based on regulatory requirements), and where is the actual development needs to take place (site location). Likewise, the urban design also contains the necessary infrastructural plans such as roads, drainage, utilities, etc. that needs to be developed by the developer as well. Thus in terms of the urban drainage, the urban design clearly clarifies the type and size of the drainage system that needs to be developed which should be based on some future calculation of the surface water runoff that will be generated from the site, etc. However, when the problem of urban flooding arises, it relates back to the overall urban design of that area which is the initial stage of the development process.

Nowadays as we continue to expand our urban environments, the risk of flooding also increases, which is also partly due to our changing climate. The question as to what strategies can designers, planners and engineers must put in place in order to mitigate its impact has been the subject of discussion as far as any physical development is concerned. Thus urban design plays a very important role in coming fourth with potential solutions to reducing urban flooding in our modern world.

4. DATA AND RESEARCH METHODOLOGY

The methods of data collection in obtaining primary and secondary data are explained in this chapter. It further explains the technique used to carry out the urban design, runoff and flood modelling, and the analysis of the questionnaires.

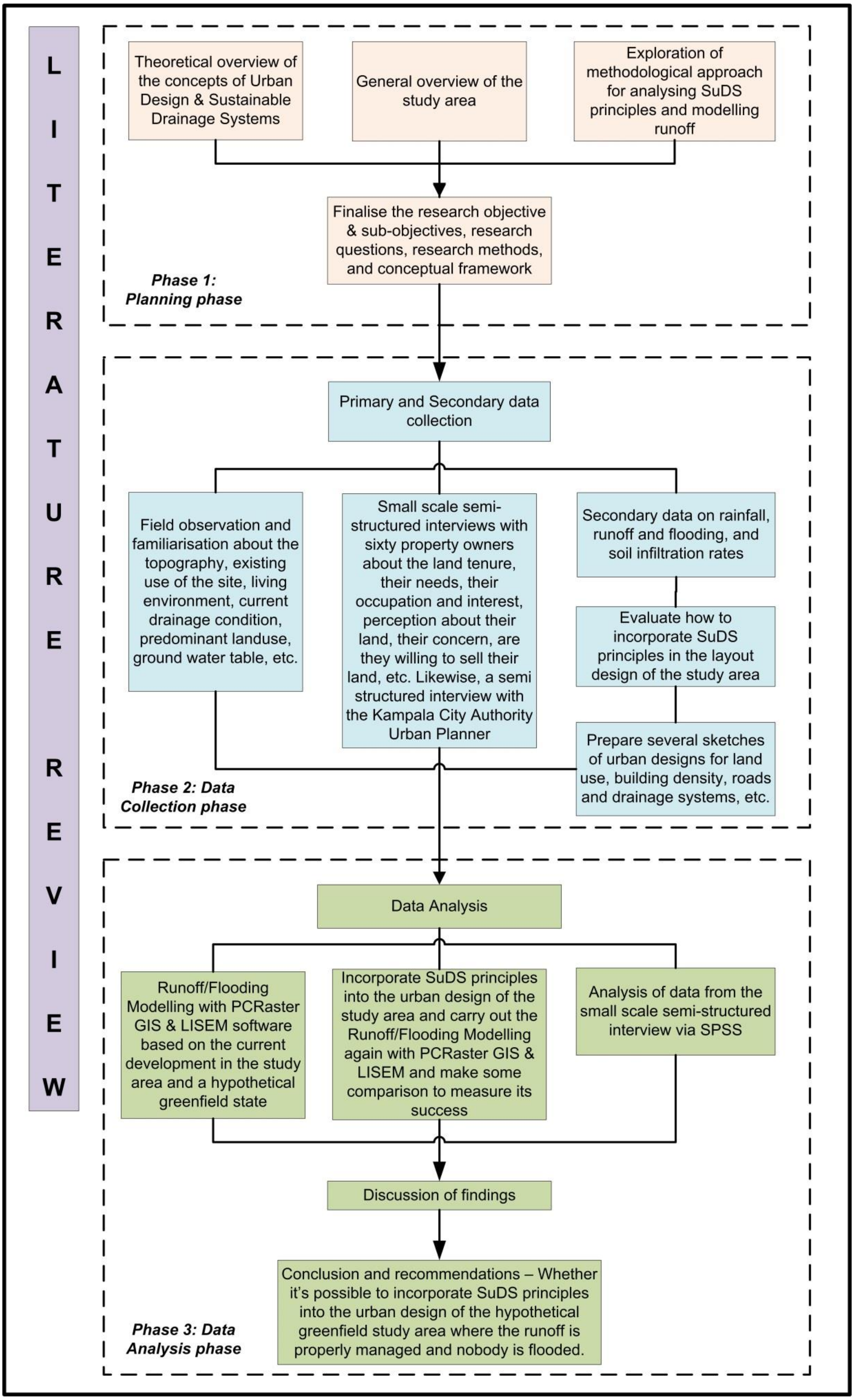
4.1. Research Design

This research was carried out in three phases as shown in Figure 21. Phase one was the pre-fieldwork or the planning phase where it involved a lot of literature search and understanding of the rationale of the research. It carried out an assessment on the range of existing materials about the research topic and provided an insight about the previous work. It thoroughly looked into the concept of Urban Design and SuDS principle, provided a general overview about the study area, and explored the methodological approach for analysing the SuDS principles and modelling of runoff. At the end of this phase, the research objective and sub-objectives, research questions, research methods, and the overall conceptual framework about this research were finalised.

Phase two was the fieldwork or the data collection phase where it involved primary and secondary data collection about the study area. The primary data includes the observational data about the topography of the study area, the existing use and the predominant land use, the living environment of the people, the current drainage condition, the existing ground water table, etc. Apart from the field observation, a small scale semi-structured interview was also carried out to sixty residents within the study area in order to obtain some insight about the land tenure, about their needs, their occupation and interest, perception about their land, about their concern, and whether they are willing to sell their land should the need arise for the purpose of implementing various SuDS projects. Likewise, a semi-structured interview was also carried out with the Kampala Capital City Authority Urban Planner in order to find out about the typical process involved for designing the city of Kampala, the types and causes of flooding in Kampala, and also to discuss some of the policies relating to urban expansion. In addition, the secondary data on the other hand involved the collection of data that have been recorded prior to this project. It includes data about the rainfall, runoff, flooding, and soil infiltration result. These data was used to evaluate the most probable SuDS principle that is suitable for the study area. Likewise, secondary data was also useful in making several urban design sketches about the land use, building density, roads and drainage systems, etc.

Lastly, phase three was the post-fieldwork or the data analysis phase where data collected from the field was processed and organised in order to extract useful information which were able to answer some of the key questions in this research. In this phase, several runoff and flood modelling was carried out by using the PCRaster GIS and openLISEM software. First, the runoff and flood modelling was made on the hypothetical greenfield state and the result was used as a baseline information. Second a runoff and flood modelling was made on the current development state in the study area with the intention of differentiating the amount of runoff that is generated by the two scenarios. Third, the relevant SuDS principles were incorporated into the urban design of the study area and again the runoff and flood modelling was carried out. It is expected that the result of the third scenarios (with SuDS principles) should be at least close or similar to the result from the hypothetical greenfield state. Moreover, other primary data collected was analysed via SPSS. Finally, a discussion about the findings was considered in this section as well together with the conclusion and recommendations. Thus, the question of whether it is possible to incorporate the SuDS principles into the urban design of the study area where the runoff is properly managed and nobody is flooded was clearly answered in this research.

Figure 21: Research Design Sequence



4.2. Research Approach

The approach of this research was both qualitative and quantitative. The earlier phase of the research was more of qualitative in nature since it involves collecting, analysing, and interpreting data by simply observing the people and their physical and natural environment, observing what they do and listening to what they say. It focussed more on understanding and familiarising the exiting situation in the study area and operationalizing the theoretical urban design with SuDS principles that can be applied. On the other hand, the last phase of this research was obviously quantitative in nature since it is more about numbers, objective hard data, and statistical data analysis. It has to do with site simulation and runoff and flood quantification.

4.3. Research Method and Justification

The research method was considered as both descriptive and experimental. It was descriptive in a sense that it obtained information on the current status of the study area as far as the flooding issues and management are concerned, and the fact that it relies heavily on observation and small scale semi-structured interviews as a means of collecting data. Moreover, it was also considered as experimental because it involved several manipulations on the design and layout of the study area together with the SuDS principles and its effects was thoroughly observed until it is acceptable when the runoff is properly managed and no property is flooded. Table 8 highlights in detail the various methods which were used for addressing each research questions. It included literature searches, small scale semi-structured interview, field observation, sketch design and evaluation with ArcMap GIS, runoff and flood modelling with PCRaster GIS and openLISEM.

Table 8: Research Objectives and Questions, Data Required and Data Collection Methods

Objectives	Research Questions	Data Required	Data Collection Methods
1. To describe the key relationships between urban design, urban drainage, and urban flooding	What is urban design?	Secondary Data	Literature Review
	What is a typical process involved for undertaking an urban design project?	Secondary Data	Literature Review
	What are the requirements for different types of urban drainage systems in conveying surface water runoff and how does this compare to the SuDS?	Secondary Data	Literature Review
	What problems do these urban drainage systems face nowadays?	Primary and Secondary Data	Field Observation supported by Literature Review
	What are the types and causes of urban flooding in Kampala?	Primary and Secondary Data	Semi-structured interview with KCCA Urban Planner & Literature Review
	What is the relationship between urban design, urban drainage, and urban flooding in Kampala?	Primary and Secondary Data	Field Observation supported by Literature Review
2. To compare the current development and runoff with a hypothetical greenfield state in the study area	What is surface water runoff and how it is generated?	Secondary Data	Literature Review
	What factors affect surface water runoff in the study area?	Primary and Secondary Data	Field Observation supported by Literature Review
	What is the total volume of surface water runoff that is generated from the current development in the study area and in a hypothetical greenfield state?	Primary Data	Runoff Modelling using PCRaster GIS and openLISEM software

Objectives	Research Questions	Data Required	Data Collection Methods
	What are the effects of land cover on runoff coefficient between the current built-up area and a hypothetical greenfield state of the study area?	Primary Data	Runoff & Flood Modelling Result in openLISEM
3. To assess the possible impact of a hypothetical urban design based upon SuDS principles on runoff and flooding	What are the steps and factors to be considered when selecting the most appropriate SuDS technique in any given site?	Secondary Data	Literature Review
	Which SuDS approaches and components are suitable for the study area?	Primary and Secondary Data	Field Observation, Soil infiltration results, and Literature Review
	How to create a hypothetical urban design of the study area which is based upon SuDS principles that would enable a better management of surface water runoff on site or within immediate facilities?	Primary Data	Field Observation and Sketch Designs using ArcMap GIS
	What would such a hypothetical urban design look like?	Primary Data	Sketch Designs using ArcMap GIS
	What is the implication of the new hypothetical urban design on surface water runoff and land cover ?	Primary Data	Runoff & Flood Modelling using PCRaster GIS and openLISEM software
4. To perform a qualitative evaluation of the implications of adopting SuDS principles in urban expansion policies	Is it possible to plan and design the study area where the surface water runoff is reduced and the impact of flooding is minimized?	Primary Data	Runoff & Flood Modelling result in openLISEM
	To what extent does the urban development with SuDS principles differ from the urban development without SuDS principles?	Primary Data	Runoff & Flood Modelling result in openLISEM
	What are the implications of adopting SuDS principles in urban expansion policies for the study area (e.g. in terms of design process, roles of actors, space requirements, land cover, cost effectiveness, intuitional requirements, affordability, etc.)?	Primary and Secondary Data	Semi-structured interview with KCCA Urban Planner supported by Literature Review

4.4. Process Methodology Flowchart 1 & 2

Figure 22 below shows a detail process on how to derive to the final urban design of the study area. Reiteration was expected in the modification of the urban design itself until an acceptable result was achieved. Acceptable result in this case means that the runoff is properly managed and the site is free from flooding.

Figure 22: Process Methodology Flowchart 1

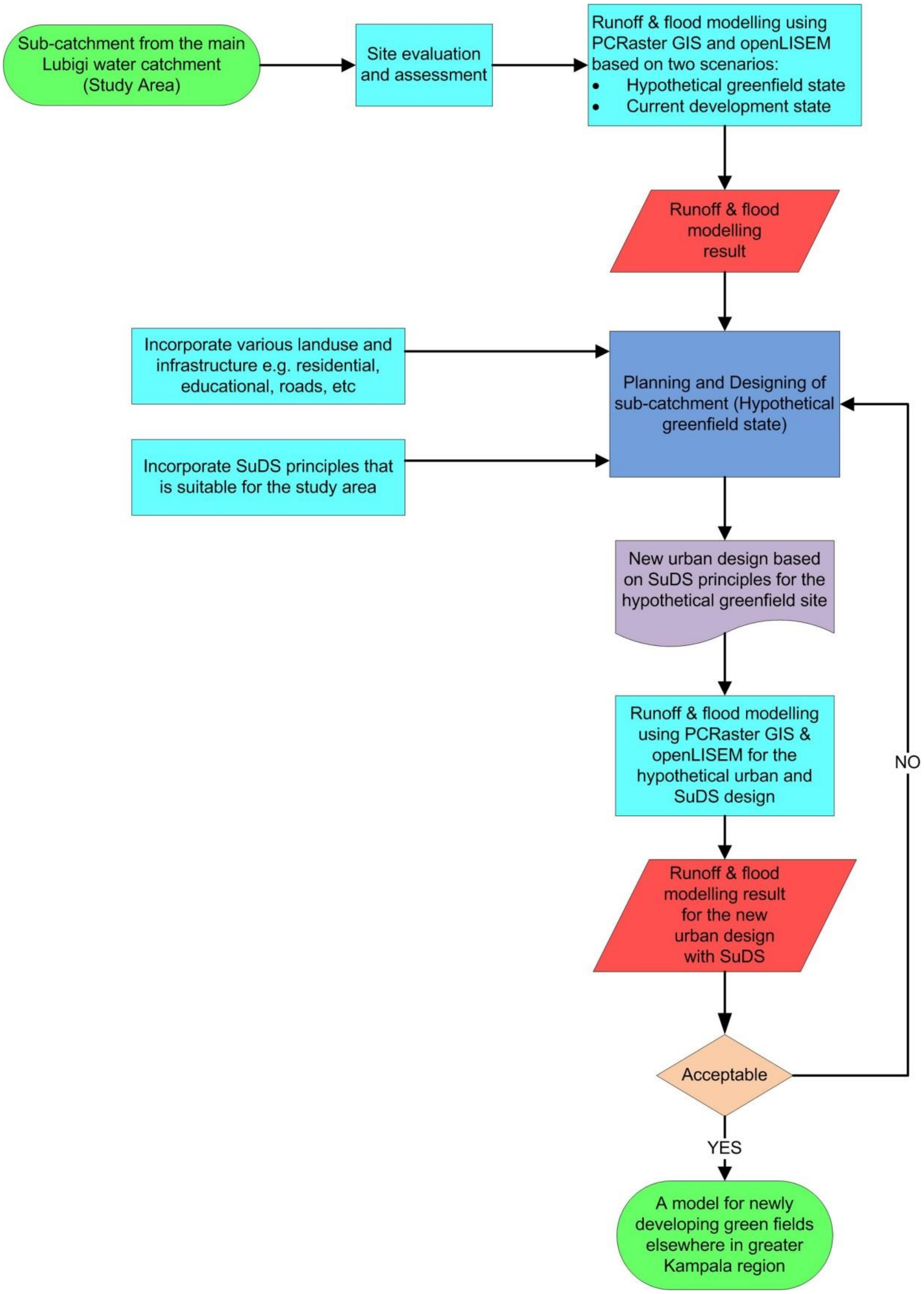
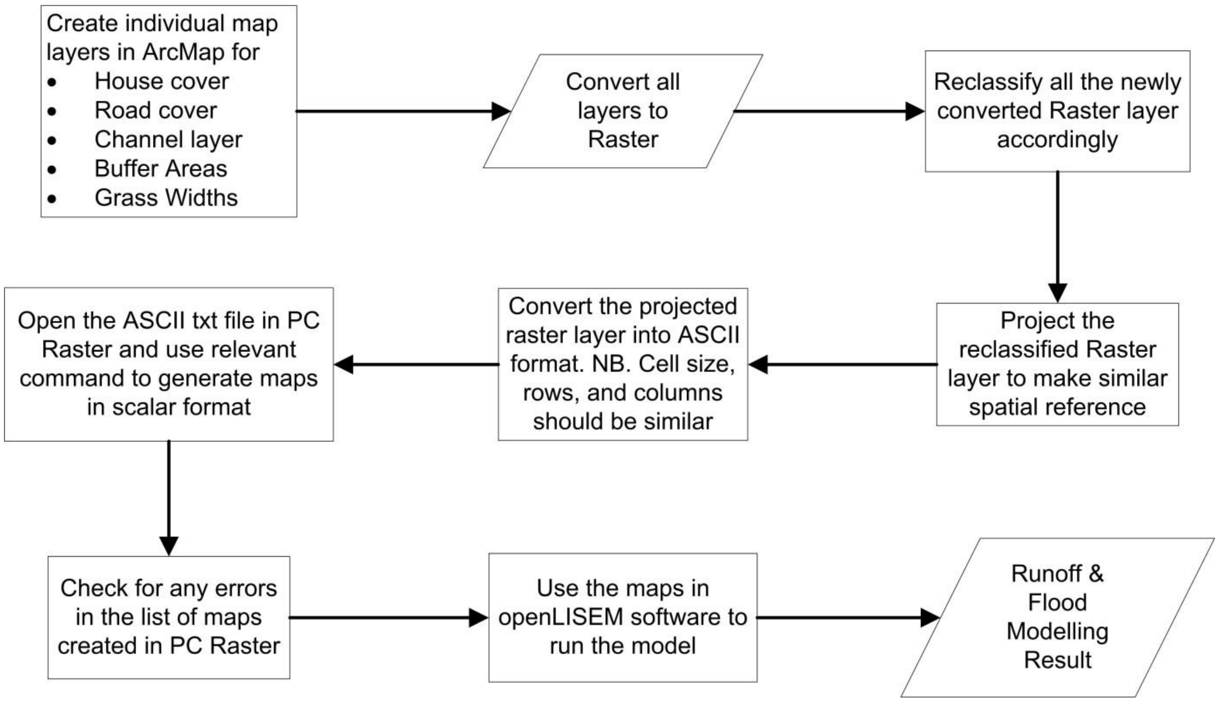


Figure 23 below briefly describe the process of how to arrive to the final runoff and flood modelling result after creating the new urban design with SuDS principles for the study area. Refer to Appendix 2 for a thorough description of this process.

Figure 23: Process Methodology Flowchart 2



4.5. Data Collolection

The field work was conducted in Kampala on the 29th of September to 18th of October 2013. Primary and secondary data were collected as in accordance with Table 9 below.

Table 9: Primary and secondary data collection

	Data Description	Source	Method
1	Urban design and SuDS	Primary	Interview with KCCA Physical Planner (Kawempe & Division)
2	Flooding and SuDS	Primary	Interview with residents within the study area (60 households)
3	SuDS technique selection	Primary	Detail field observation in accordance with the SuDS selection criteria
4	Rainfall	Secondary	Existing rainfall data which was use in the previous studies
5	Soil infiltration properties	Primary/Secondary	Carried out by Dr. Rossiter

4.5.1. Interview with KCCA Physical Planner (Kawempe Division)

A semi-structured interview was made with the Kampala Capital City Authority Physical Planner Ms. Jacqueline Mali in relation to the urban design process in Kampala, the existing urban expansion policies, and about urban planning in general.

4.5.2. Interview with Residents within the Study Area

A small scale structured interview was also carried out to sixty families who are residing within the study area. The questions were equally divided according to their location (upstream, centre, and downstream) and the questions are related to their land, their interest, their concern, and whether they are willing to sell their land for purpose of accommodating SuDS. This helps to generate more ideas about this research.

4.5.3. Field Observation

A thorough field observation was also made and it played a crucial role in this research. Direct personal observation about the people and their environment helps to answer some key questions in this research such as the urban drainage condition and problems; factors that affect the surface water runoff; etc. More importantly, field observation helps to identify sites within the study area that is highly suitable for developing SuDS.

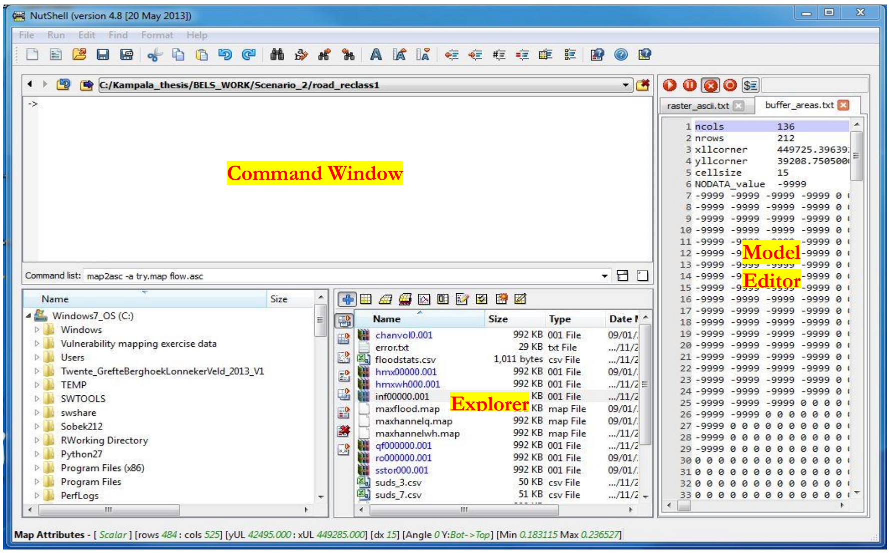
4.6. PCRaster GIS and openLISEM

PCRaster GIS and openLISEM are the software that was used in this study. The PCRaster GIS was used to create a database (the input database is generated with a PCRaster script) and for viewing modelling results while the openLISEM tool was used to carry out the actual runoff and flood modelling itself. It uses the PCRaster GIS maps to simulate the flash floods events.

4.6.1. PCRaster GIS

All input and output maps in openLISEM are in the PCRaster format, which is a GIS and modelling language produced by PCRaster environmental software. PCRaster is basically a command line driven by typing pcrcalc in a command to calculate a new map, and there are over 100 operations to choose from. The PCRaster nutshell application interface has three windows (refer to figure 24 below) such as the command window (upper left), the explorer (lower left) and the model editor (right).

Figure 24: PCRaster Nutshell Interface



4.6.2. openLISEM

LISEM is an open source software that is specifically used for the simulation of runoff, dynamics of sediment, and shallow floods both in a rural and urban catchment. This spatial hydrological model is based on a series of event that is suitable for catchment sizes ranging from 1ha to several $100km^2$, with a great temporal and spatial detail (Jetten, 2013b).

Rainfall, interception, surface storage, infiltrations, vertical movement of water in the soil, overland flow, channel flow (in man-made ditches), detachment by rainfall and through-fall, transport capacity and detachment by overland flow are some of the basic processes which are incorporated into the model in openLISEM. Likewise, the paved roads and surface sealing on the hydrological and soil erosion processes are all taken into account (Jetten, 2002).

Figure 25: openLISEM interface

The dashed rectangular shape line is where the proper directory names for input and output is given, and the global options to switch on various sub modules (urban environment option).

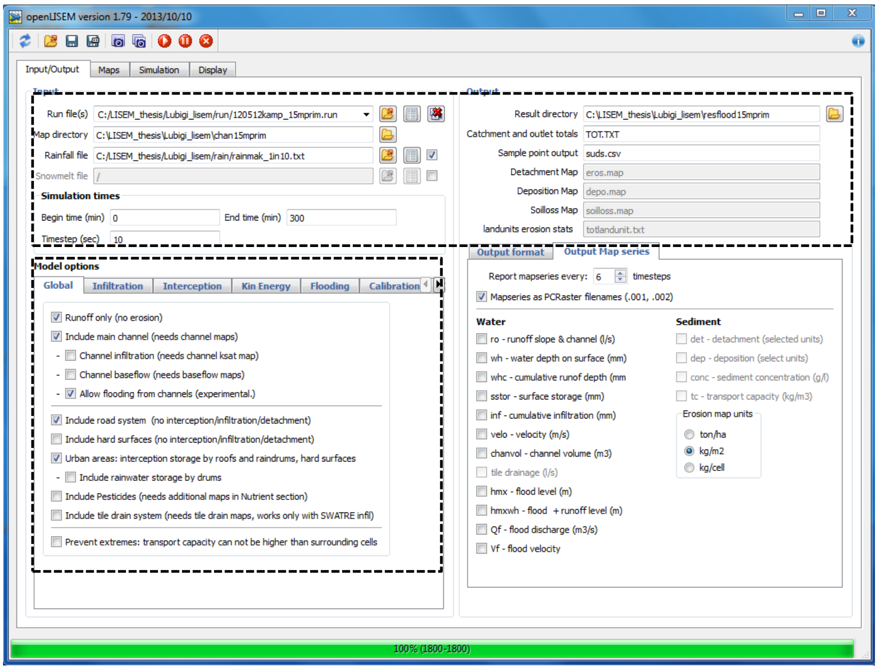
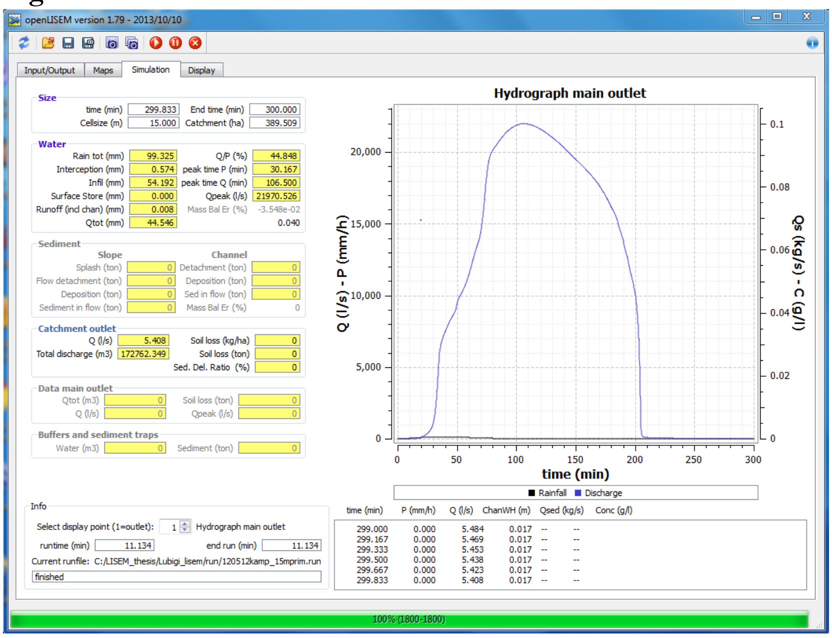
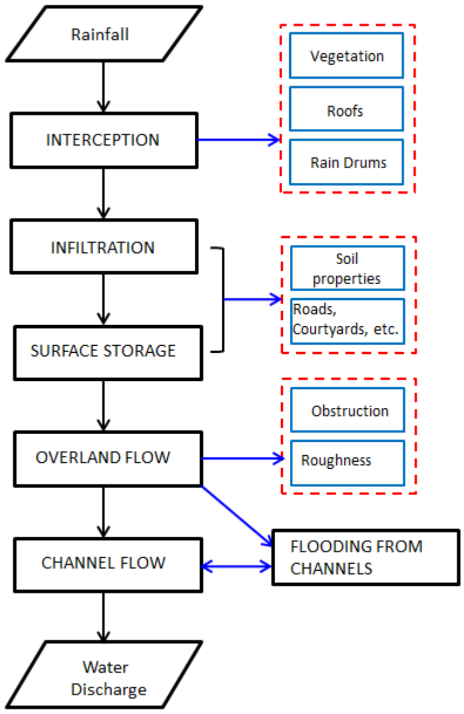


Figure 26: LISEM Simulation Interface



The simulation interface shows the result of the model in terms of the runoff fraction, peak discharge, and total discharge. Likewise it also displays the hydrograph when the simulation is over. The simulation and display interface are used simultaneously to visualize what is happening in the study area when model is still running.

Figure 27: Simplified Flowchart of openLISEM



Source: Jetten (2013a)

Figure 27 depicts the simplified flowchart of openLISEM model. As shown on the diagram, the processes which are incorporated into model include rainfall; interception in the form of vegetation, roofs, and rain drums; infiltration; surface storage; overland flow; and channel flow. These processes are described in detail below.

4.6.3. Rainfall

openLISEM is an event based model that needs detailed rainfall intensity data over short time intervals (such as 5 – 15 minutes), and the rainfall units are always in millimetre per hour (mm/hr.). The rainfall data can be entered in two ways such as by using a combination of rain gauge data and a map with corresponding zones, or by using the rainfall intensity maps directly (e.g. derived from satellite data or interpolated rainfall map series). The rainfall data is stored in a separate directory so that different rain storms can be used with the same spatial database (Jetten, 2013b).

This study uses existing rainfall data which was collected by the previous students from the Outspan Primary School in Bwaise III and from the automatic weather station at the Makarere University campus.

4.6.4. Interception

Rainfall interception is calculated for vegetation and for houses (roofs and rain drums interception which can be checked or unchecked). In vegetation, the interception is simulated by regarding the canopy as a fixed storage which fills up and overflows (Jetten, 2013b). The cumulative interception during an event is calculated as (Aston, 1979):

$$Cs = S_{max} * (1 - \exp(-k * P_{cum} / S_{max}))$$

Where Cs is the actual canopy interception (mm) in any given moment; Smax is the maximum canopy storage (mm); Pcum is the cumulative rainfall since the beginning of the event (mm); and k is a parameter related to the canopy openness (co) and determines how fast the canopy fills up. The parameter k depends on the Leaf Area Index (LAI in m^2/m^2): $K = 1 - \exp(-co * LAI)$

4.6.5. Infiltration

The rainfall/snowmelt interception processes result in a net amount of rainfall reaching the soil surface and it can be calculated on various sub-models depending on the data availability. Basically, there are two categories of infiltration processes available which are listed as follows:

- A simple 1 or 2 layer solution of the Darcy equations: following a Green & Ampt (Kutílek & Nielsen, 1994), Smith & Parlange model (Morgan et al., 1998) or simple subtraction of ksat. These options are coupled to a simple drainage function.
- A full multi-layered soil water balance, using the SWATRE model, using the Richards equation over a number of nodes in the soil profile.

4.6.6. Surface Storage

The surface storage is based on the micro relief that is characterised by the random roughness (Onstad, 1984), which is the standard deviation of surface elevation that is measured on a small scale and is usually done along a transect using a pin board (a board with pins every cm) or by scanning a surface of 1 to several m^2. It is calculated using the Maximum Depression Storage (MDS) which is the threshold value above which the surface micro depression overflow. This part of the model serves two purposes such as to calculate the amount of water stored by the micro relief that is not moving, and to calculate the width of the overland flow when runoff starts (Jetten, 2013b).

4.6.7. Overland and Channel Flow

The overland flow depicts the tendency of water to flow horizontally across land surfaces when rainfall has exceeded the infiltration capacity and the depression storage capacity (Horton, 1933). Water is routed downstream towards the catchment outlet with a kinematic wave function, which is based on the velocity (m/s) and is calculated with the following Manning's equation: $V = R^{2/3} * \mathrm{sqrt}(S) / n$

In which R is the hydraulic radius (m), calculated with the flow width and average water height; S is the terrain slope (sine); and n is a surface resistance parameter. The discharge Q (m^3/s) per cell is then calculated with (Te Chow, Maidment, & Mays, 1988):

$$Q = \alpha.A^{\beta}$$
$$\alpha = [n/\mathrm{sqrt}(S).P^{2/3}]^{\beta}$$
$$\beta = 0.6$$

in which A is the wet cross section (m^2) and P is the wet perimeter (m).

In regards to the distributed overland and channel flow routing, an implicit, four-point finite-difference solution of the kinematic wave is used together with the Manning's equation. The cells that have a channel receive a part of the overland flow, depending on the velocity, thus the velocity is considered as the average velocity existing in the cell. The channel is considered to be on the centre of the cell so that the distance from the edge to the channel is: 0.5*(DX – channel width). The fraction *f* of the water that flows into the channel is therefore (Jetten, 2013b):

$$f = V.dt / (0.5(dx - \text{channel width}))$$

4.6.8. Model Simulation

The runoff and flood modelling was carried in accordance with the three scenarios below:

i. Hypothetical Greenfield State (Baseline)
ii. Current development State
iii. SuDS principles incorporated into the urban design of the hypothetical greenfield state

A thorough comparison was made between the hypothetical greenfield state (baseline) and the current development in terms of the total discharge that is generated from the catchment, peak discharge, time to peak (response time of the catchment), and runoff fraction. This comparison has also assisted the model simulation for the third scenario (urban design with SuDS principles) to ensure that the total discharge generated from the catchment is somehow lesser than the current development state and closer or equal to the discharge generated from the hypothetical greenfield state (baseline).

4.7. openLISEM input Maps

openLISEM requires a significant amount of maps (approx. 24) in order to run the model and the minimum basic data that is needed to generate an input database for openLISEM includes the digital elevation model; a landuse map; a soil map; a table with soil physical properties; a series of channel maps (optional); a road network map (optional); housing densities, roof storage and rainwater storage (optional); and soil conservation measure maps which may include grass strips, buffers, sediment traps (optional) (Jetten, 2013a).

All the maps shown in Table 10 below were created in the PCRaster GIS software by using relevant commands (refer to Appendix 1 and 2 of this report to see the command used), which are then used in openLISEM for running the model. The scenario maps created for this research include the house cover map, road width map, grass width map, and detention basin and pond map (buffers). The maps have the same cell size of 15m by 15m and also have the same number of rows and columns. For the purpose of this research, the simulation time was 600 minutes at every 10 seconds time step.

Table 10: Input Maps for openLISEM

Variable name	Map name	Description
Rainfall		
ID	id.map	Rain gauge zone ID numbers, corresponds to columns (1, 2,…) in rainfall file
Catchment		
DEM	dem15m.map	Digital Elevation Model (m)
Gradient	grad.map	Sine of slope gradient in direction of flow
LDD	ldd.map	Local surface Drainage Direction network
Outlet	outlet.map	Main catchment outlet corresponding to LDD map
Points	outpoint15m.map	Reporting points for hydrograph
Landuse		
Units	landunit.map	Classified land unit map (integers 0-n) for output of erosion values
Cover	per.map	Fraction surface cover by vegetation and residue
LAI	lai.map	Leaf area index of the plant cover in a gridcell (m^2/m^2)
Height	ch.map	Plant height (m)
Road width	roadwidt.map	Width of impermeable roads (m)
Grass strips	grasswid.map	Width of grass strips (m)
Canopy storage		Maximum canopy storage (mm)
Surface		
RR	rr.map	Random Roughness (here standard deviation of heights) (cm)
n	n.map	Manning's n (-)
Stoniness	stonefrc.map	Fraction covered by stones (affects only splash det.) (-)
Crust	crustfrc.map	Fraction of gridcell covered with Crust (-) (see also ksat crust)
Compacted	compfrc.map	Fraction of gridcell compacted (e.g. wheel tracks) (-) (see also ksat compacted)
Hard Surface	hardsurf.map	No interception/infiltration/detachment (fraction 0-1)
Infiltration		
1st layer Green & Ampt/Smith & Parlange		
Ksat1	ksat1.map	Layer 1: Saturated Hydraulic Conductivity (mm/h)
Psi1	psi1.map	Layer 1: Average suction at the wetting front (cm)
Thetas1	thetas1.map	Layer 1: Porosity (-)
Thetai1	thetai1.map	Layer 1: Initial moisture content (-)
Depth1	soildep1.map	Layer 1: Depth (mm) to bottom layer 1

Special Surfaces		
Ksat Crust	ksatcrst.map	Ksat of crusts (all models except SWATRE) (mm/h)
Ksat Compact	ksatcomp.map	Ksat of compacted areas (all models except SWATRE) (mm/h)
Ksat Grass	ksatgras.map	Ksat of grass strips (all models except SWATRE) (mm/h)
Channels		
Channels properties		
LDD	lddchan.map	LDD of main channel (must be 1 branch connected to the outlet)
Width	chanwidt.map	Channel width (m)
Side angle	chanside.map	Channel side angle (tan angle channel side and surface: 0 is rectangular)
Gradient	changrad.map	Slope gradient of channel bed (-)
N	chanman.map	Manning's n of channel bed (-)
Cohesion	chancoh.map	Cohesion of channel bed (kPa)
Channel Flood		
Channel Depth	chandepth.map	Channel depth, zero (0) depth is considered infinite (m)
Barriers	barriers15m.map	Flood barriers and obstacles (houses, taluts, dikes, in m)
Channel Max Q	chanmaxq.map	Maximum limiting channel discharge, e.g. in culverts (m^3/s)
Channel Levee	chanlevee.map	Height of small channel levee on both sides of the channel (m)
Flood zone	floodzone.map	Forced area including (1) and excluding floods (0)
Buffers		
Buffer ID nr	bufferid.map	ID number for each buffer starting with 1 (0 is outside area)
Buffer volume	buffervol.map	Buffer volumes at the location of buffers (m^3)
Houses		
House Cover	housecover.map	Fraction of hard roof surface per cell (-)
Roof Storage	roofstore.map	Size of the interception storage of rainwater on roofs (mm)
Drum Store	drumstore.map	Size of storage of rainwater drums (m^3)

Source: Maps interface in openLISEM which was used to run the model

4.8. SuDS Hydraulic Design Criteria

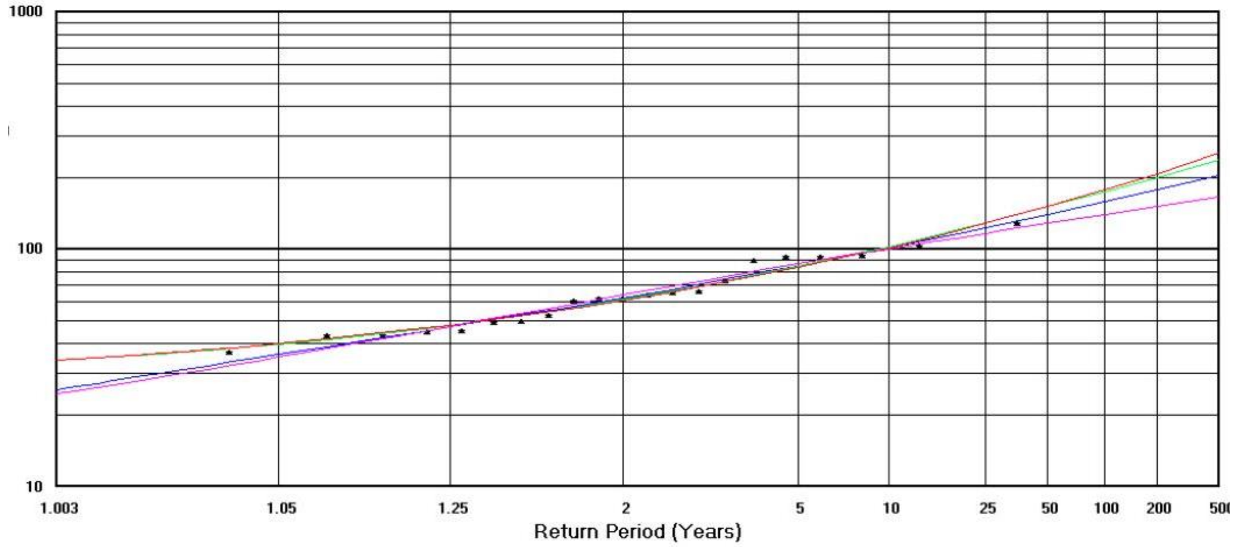
Below are some of the criteria that need to be taken into account when developing SuDS.

i. Drainage systems should aim to replicate the natural rainfall-runoff processes occurring on the site, pre-development
ii. An allowance should be made for climate change. More extreme events need to be considered where there is a risk to people
iii. Sites should take into account topography to maximise the benefits of potential storage at low-points
iv. The frequency of discharge rates from the new development is, wherever possible, equal to the frequency of discharge rates that would be discharged under equivalent greenfield conditions.
v. The frequency of volumes of runoff from the new development is, wherever possible, equal to the frequency of volumes that would be discharged under equivalent greenfield conditions.
vi. The actual rate of runoff for any given event will not replicate the greenfield runoff, due to the difference in drainage characteristics between the developed an undeveloped site but the frequency of the rates of runoff must be matched as closely as possible.

4.9. Rainfall Data & Measurement

Rainfall data used was taken from the Kampala Drainage Master Plan (2010). For the purpose of this research, a 1 in 2 year maximum rainfall depth was used which accounts for 66.2 mm of rain. This rainfall was also measured in the field previously in June of 2012. Figure 28 below clear shows the difference amongst the return period in years in relation to the amount of rainfall in millimetres.

Figure 28: Recurrence intervals of annual maximum daily rainfall in Kampala (in mm)



Source: (Kampala Drainage Master Plan, 2010)

4.10. Development Requirements

The plot area in the study area is in accordance with the National Physical Planning Standards and Guidelines (2011) for Kampala. However the plot coverage and the building line setbacks has been amended accordingly to suit the development situation of the study area. This is due to the fact that the study area has been subdivided into large parcel of land (0.96 to 17.5 hectares) which will be subject to further subdivision as in accordance with site standards requirement for residential, commercial, and industrial uses. Thus, further subdivision means that some land shall be kept aside for roads and drainage (which is swale in this case). This amendment was made in order to be realistic as possible when running the model in openLISEM.

Table 11: Site standards for residential development

Standards	Low Density	Medium Density	High Density
Plot Area (Sq. M)	1000 – 2000	600 – 1000	200 – 600
Minimum Plot Width (m)	25	20	12
Minimum Plot Length (m)	40	30	25
Maximum Plot Coverage	20%	30%*	40%*
Minimum Building Lines (m)			
(a) Front	13*	11*	8*
(b) Side	3	2	2
(c) Rear	12	8	2

Source: Modified from National Physical Planning Standards and Guidelines (2011)

*The front building setback for low, medium and high density residential has been increased accordingly to cater for the 6m service lane and 4m swale reserve (2m on both side of the road). This increase has result in the changes for the minimum plot coverage for medium and high density residential.

Table 12: Site standards for commercial development

Standards	Commercial 1
Plot Area (Sq. M)	450
Minimum Plot Width (m)	15
Minimum Plot Length (m)	30
Maximum Plot Coverage	60%*
Minimum Building Lines (m)	
(a) Front	7*
(b) Side	N/A
(c) Rear	5

Source: Modified from National Physical Planning Standards and Guidelines (2011)

*The front building setback for Commercial 1 and 2 has been increased accordingly to cater for the 6m service lane and 4m swale reserve (2m on both side of the road). This increase has result in the changes for the minimum plot coverage for both types of commercial development.

Table 13: Site standards for industrial development

Standards	Light Industrial	Medium Industrial
Plot Area (Sq. M)	4000	10,000
Maximum Plot Coverage	60%	30%
Minimum Building Lines (m)		
(a) Front	15	15
(b) Side	3.5	3.5
(c) Rear	10	10

Source: Modified from National Physical Planning Standards and Guidelines (2011)

*The front building setback for Light and Medium Industrial has been increased accordingly to cater for the 6m service lane and 4m swale reserve (2m on both side of the road). This increase poses no changes to the current minimum plot coverage for both industrial activities as it can still accommodate the changes made to the front building line requirements.

Table 14: Plot area requirements for primary schools

Facilities	Single-stream (Boarding)
Classrooms, hall, administration, etc.	1.0 ha
Playing fields, gardens	1.5 ha
Dormitories	0.4 ha
Staff Accommodation	0.8 ha
Total plot area	3.7 ha
Maximum Plot Coverage	60%

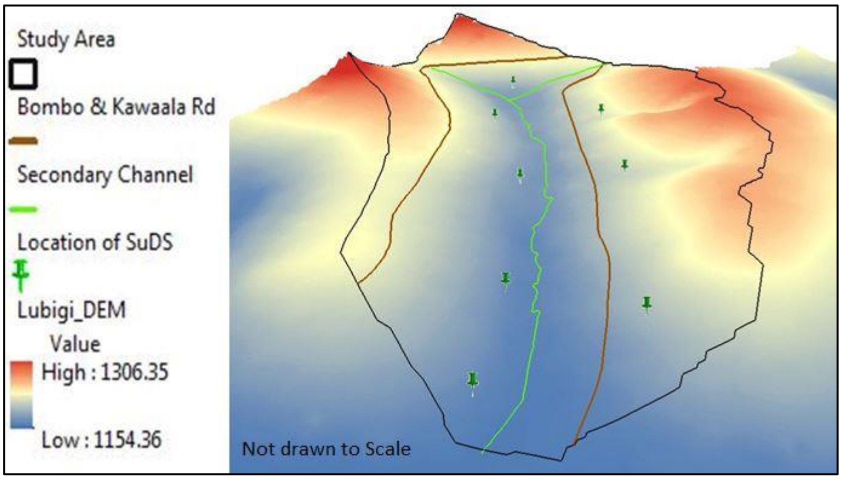
Source: National Physical Planning Standards and Guidelines (2011)

4.11. Detention Basin and Retention Pond Location

Prior to making any urban design, various SuDS selection criteria were thoroughly considered at first which includes the land use characteristics; site characteristics; and the community, environmental and amenity performance. They helped to identify various opportunities and constraints about the study area since different sites have different features, thus identifying the relevant SuDS technique that is applicable in the study area is at utmost importance.

As for this research, various sites within the study area were selected as potential sites for the location of detention basins and retention pond. These sites are shown in Figure 29, which has also been verified through site characteristics observation during fieldwork and are considered as favourable. Depending on the design, it is usually more difficult to achieve high pond/basin storage volumes on sloping sites. This is the sole reason why the pond/basin locations must be carefully selected.

Figure 29: Suitability Sites for the location of Basins & Pond



4.12. Research Limitations

1. Lack of prior research studies on the topic – There is a lack of prior research studies in this field in Kampala which was proven in the literature review section. This is one of the major shortcomings as none of the literatures are directly related to the incorporation of the SuDS principles into the city's urban design.

2. Data access – Trying to access some relevant data (e.g. cadastral map, other GIS data, etc.) from KCCA is quite challenging as there are certain protocols that needs to be followed before the data will be finally released. However, our attempt in trying to access spatial data was futile as no data was released at the end of the day.

3. Interviews – To make an interview with professional personnel (e.g. Engineer, Landscape Architect, etc.) at the KCCA may not likely to happen as in accordance with the research operational plan. This is highly due to the fact that most of these professional staffs are busy most of the time in serving the people of Kampala. Thus, availing their time for a detail and lengthy interview would be indeed challenging.

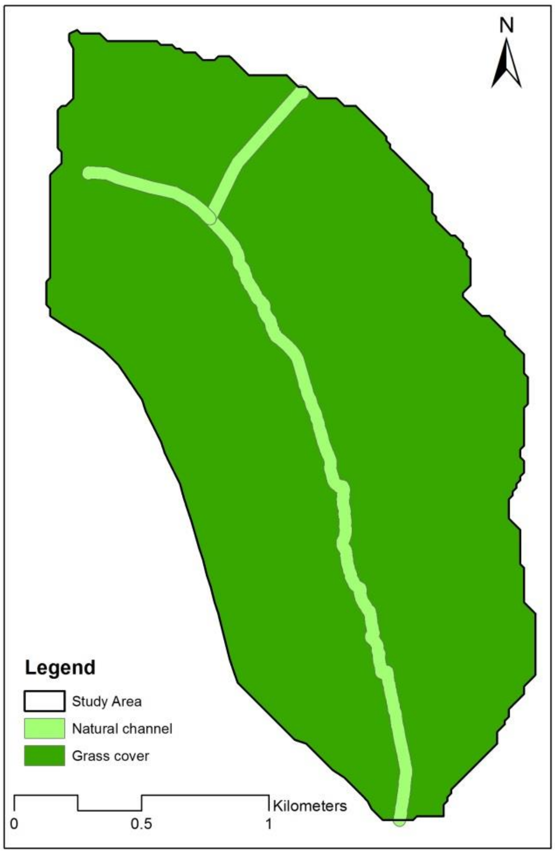
4. Implementation – There are many obstacles that this research will need to overcome for it to become a reality on the ground such as the amendment of urban policies where the SuDS approach is taken into account. This could be quite a long tern process.

5. RESULTS AND DISCUSSION

Discussed in this chapter are the actual findings and results of this research. It compares three scenarios such as the hypothetical greenfield state, current development state, and the urban design with/without SuDS principles.

5.1. First Scenario – Hypothetical Greenfield State (Baseline – Include the secondary channel as in a natural state, but exclude any roads and buildings)

Figure 30: Hypothetical Greenfield Situation



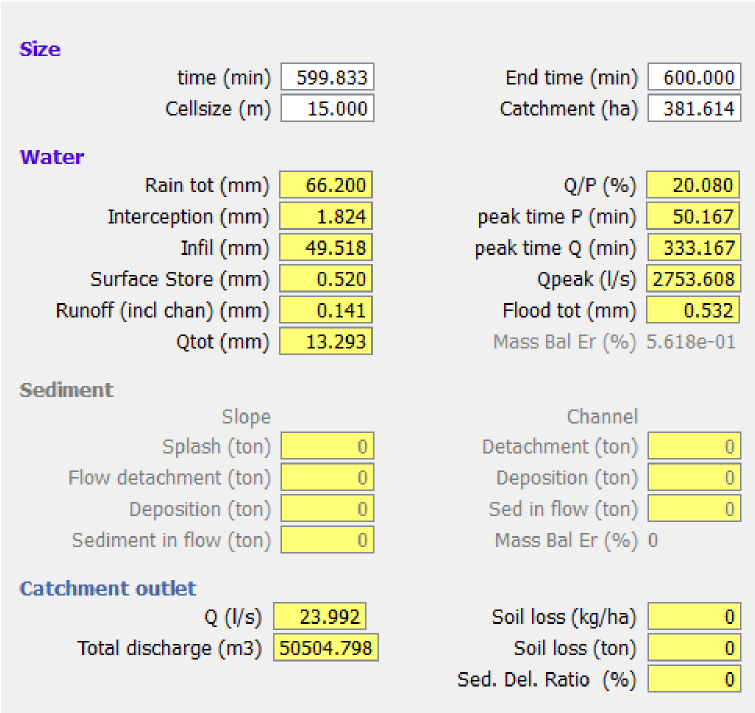
The first scenario in this case assumes that the study area is still greenfield where there are no physical development been present on the site (e.g. no roads and buildings), except for the secondary channel which is necessary to be present in order to run the model in openLISEM. However, the secondary channel is assumed to be in a natural state which means that it is not paved but only covered with grass. This scenario is comparable to a natural rural situation and the overall assumption is that the total grass cover in this situation is approximately 90%. Figure 30 clearly depicts this scenario.

Grass cover is selected instead of forest or other vegetation simply because in the peri-urban areas of Kampala, forest cover is quite rare as most trees have been cut down and used for various purposes. Thus using grass cover is considered as highly relevant as compared to other vegetation.

This scenario is considered as the "baseline scenario" because it will be used as a benchmark for comparison with the new urban design with SuDS principles. Thus the urban design with SuDS modelling result should wherever possible, be close or equal with the hypothetical greenfield situation in terms of the maximum flood volume, maximum flood level (depth), maximum flood area, and flood duration (time) that occurs within the study area. These are some of the key flood indicators that will be used for scenarios comparison.

Moreover, this scenario is considered as crucial in terms of scenarios comparison because in a natural greenfield situation, there is less threat of increased flood risk as compared to sites where physical development is predominant. Likewise, the greenfield situation manages its runoff in a more natural way which promotes high infiltration, high evapotranspiration, high ground water base flow, and low runoff volume. This is the exact opposite in the built environment where grass and trees have been replaced by impervious surfaces contributing to high runoff volume. Thus the intention of SuDS in urban areas is to manage its runoff in a manner that is closely as possible to the way greenfield areas manages its runoff.

Figure 31: Hypothetical Greenfield State Simulation Result



The simulation result for this hypothetical greenfield situation is shown in Figure 31 and the hydrograph diagram in Figure 32. It reveals that the total amount of runoff discharge produced in the study area as per this scenario is approximately 50,505m³, the peak discharge is 2,754 (l/s) and the runoff fraction is about 20% (total precipitation taken as runoff). It also showed that the study area has a high level of infiltration which is around 49.5mm, this accounts for 75% of the overall runoff that could be infiltrated, which is quite high due to the nature of this scenario where 90% of the total land area is covered with grass.

The peak dischage is clearly shown on the hydrograph diagram in Figure 32. The recorded time at which the hydrograph is at its peak is around 333 minutes, which is 283 minutes away from the rainfall peak time (when the discharge started to rise). Thus it implies that it took quite a long time for the rate of discharge to be at its highest point which can also be considered as a good flash flood indicator.

Figure 32: Hypothetical Greenfield State Hydrograph

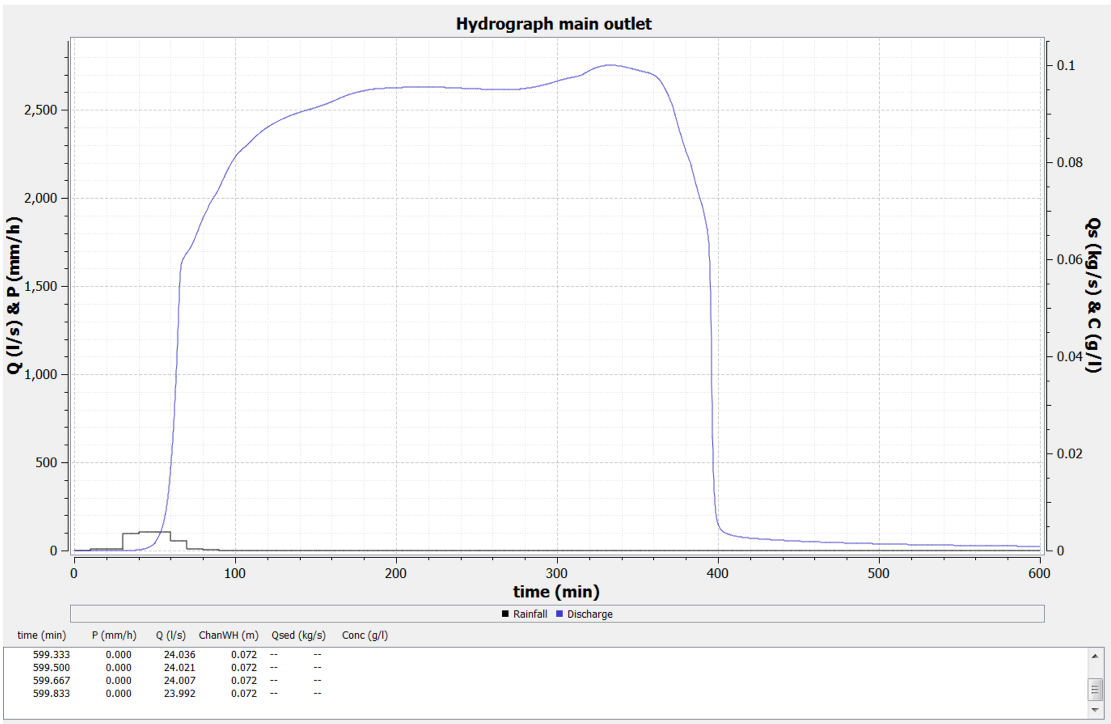


Table 15 below shows the model summary result for the hypothetical greenfield state scenario. It shows that the maximum flood volume is 31,505m^3 and the maximum flood area is 99,450m^2. Since the total runoff discharge is quite low (i.e. 50,505m^3), the maximum flood volume is also low resulting in less flooded areas. The maximum flood volume is subtracted from the total discharge and it cannot be more than the volume of total discharge.

The table also shows a wide variation between the percentage of runoff fraction (i.e. 20.1%) and percentage of infiltration (i.e. 75%) which is a positive indication of how the runoff can be well managed on site without causing any severe flash flooding event.

Table 15: Hypothetical Greenfield State Result Summary

Item	Total
LISEM results at time (min)	599.7
Total rainfall (mm)	66.2
Discharge total in mm	13.3
Total interception (mm)	1.8
Total infiltration (mm)	49.5
Total discharge (m^3)	50,505
Peak discharge (l/s)	2754
Peak time rainfall (min)	50.2
Peak time discharge (min)	333.2
Discharge/Rainfall (%)	20.1
Percentage of infiltration	75
Flood volume (max level) (m^3)	31,505
Flood area (max level) (m^2)	99,450

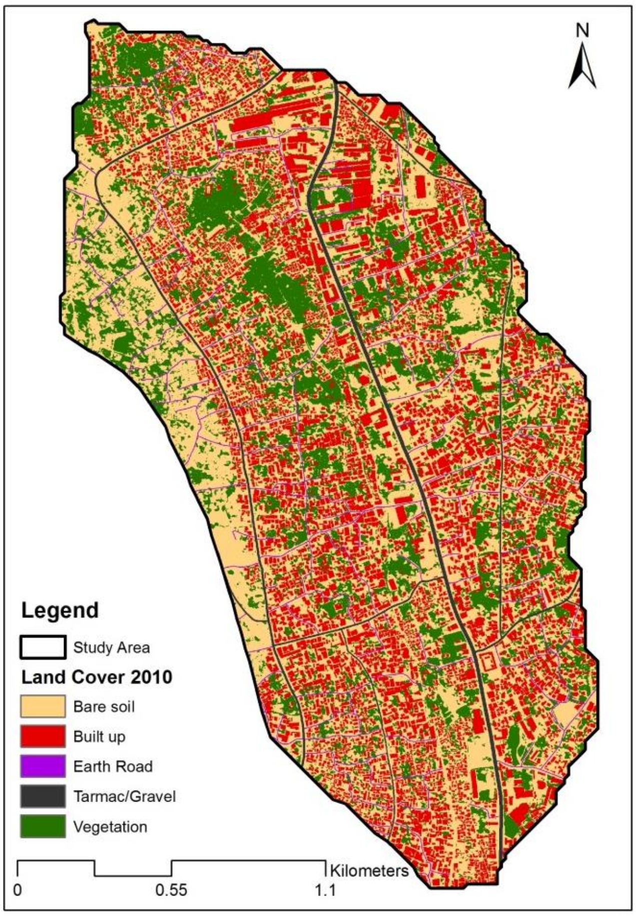
5.2. Second Scenario – Current Development State (Include the secondary channel, road systems and urban areas)

The second scenario considers the current development as it is by including all, the secondary channel, the roads, and the buildings, etc. as in accordance with the QuickBird high resolution image for the study area in September of 2010. Thus no improvement was made to the overall physical development in terms of the layout of roads, drainage, buildings, etc.

This scenario is also important because it closely examines the existing situation and how it manages its runoff, and where the flooding problems occur on the ground. This information is useful in a way where the urban design with SuDS could help address the flooding problems in specific areas. Moreover, since the current physical development situation is the reason behind many flooding problems in the study area, its model simulation result will also be used as a key comparison with the urban design with SuDS scenario. Thus the urban design with SuDS scenario simulation result is expected to be lesser than the current development state in terms of the peak and total discharge, and maximum flood volume and flood area. This will imply that the flooding problem has been addressed to some extent.

5.2.1. Current Development State Land Cover (2010)

Figure 33: Land cover image classification

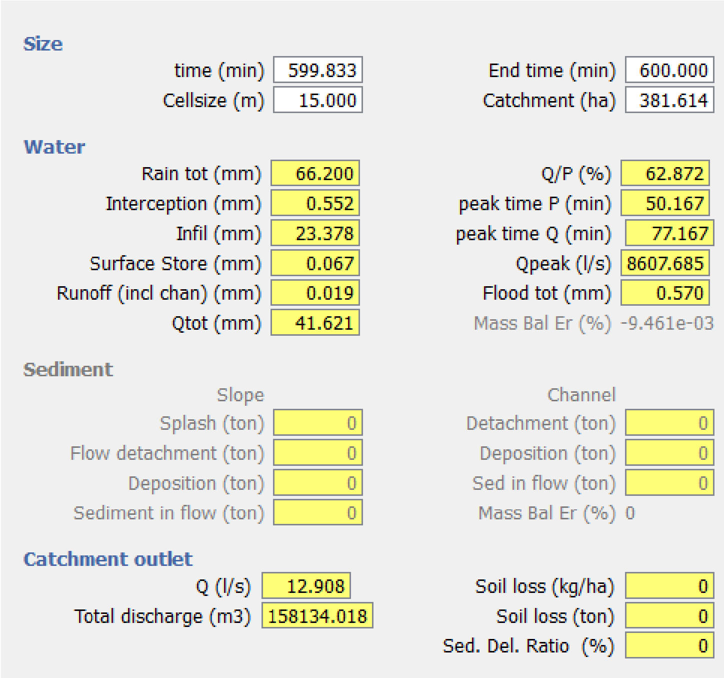


The digital image classification as shown in Figure 33 clearly shows the location of various land uses that are present within the study area. The house cover (built-up) are scattered all over the study area except on the western boundary line where most of the bare soil are present. Some of the remaining vegetation land is located near the main secondary channel (on the centre) in the northern part that is highly inconvenient or unfit for development which is the reason why it is still left as vegetation. This was proven during field observation. The bare soil and vegetation reflects the overall non-built-up land which accounts for 69.9% and the roads and house cover makes up the total of built-up areas which is 30.1%. Thus, 30.1% of the total land cover within the study area is made up of impermeable surfaces.

Land Cover	Area (ha)	Percentage
Bare soil	174	46.4
Built-up (house cover)	96	25.6
Earth road	8	2.2
Tarmac/Gravel road	9	2.4
Vegetation	88	23.5
Total	**375**	**100**

The simulation result for this scenario is shown in Figure 34 and the hydrograph diagram in Figure 35. It depicts that the total amount of runoff discharge produced in the study area is approximately 158,134m^3, the peak discharge is 8,608 (l/s) and the runoff fraction is about 63% (total precipitation taken as runoff). In addition, the total infiltration in this scenario is quite low, which is around 23.4mm, which accounts for only 35% of the overall runoff that could be infiltrated. This explains the reason why the total discharge is more due to more impervious surfaces. When the percentage of runoff fraction is more than the percentage of infiltration, then more flood volume is expected since the remaining runoff that is not infiltrated will contribute to the flood volume if it is not well managed.

Figure 34: Current Development State Simulation Result



The peak dischage is shown on the hydrograph diagram in Figure 35. The recorded time at which the hydrograph is at its peak is around 77 minutes, which is only 27 minutes away from the rainfall peak time (when the discharge started to rise). This revealed that the rate of dicharge is at its highest point within a short period of time, depicting that the volume of runoff accumulates very fast within such a short period which could result in many flash flooding at the dowstream part of study area.

Figure 35: Current Development State Hydrograph

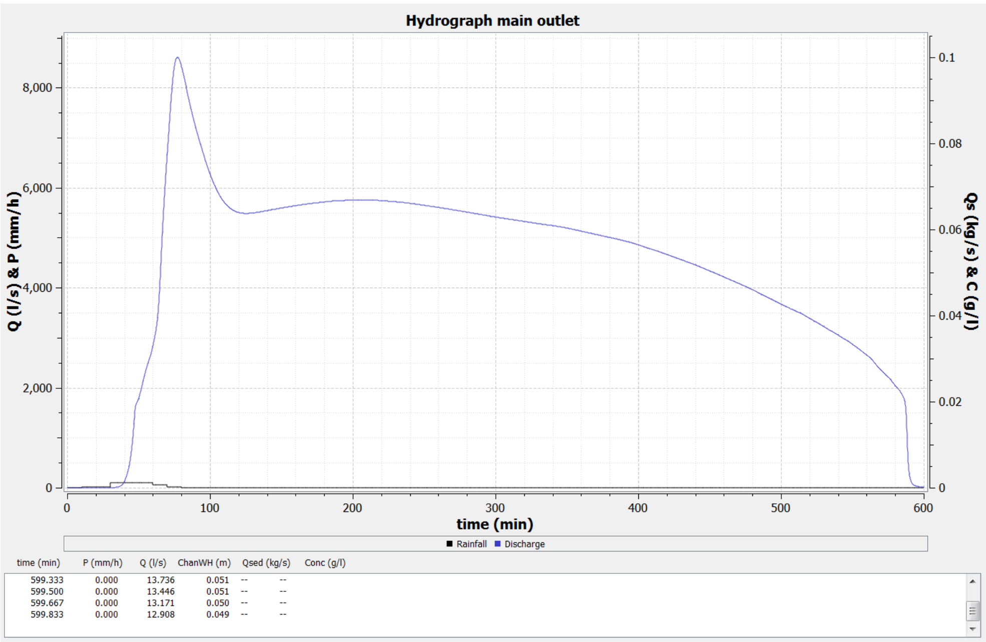


Table 16 below shows the model summary result for the current development situation. The maximum flood volume in this scenario is around 135,168m^3 and the maximum flood area is 207,900m^2. The variation in result between this scenario and the hypothetical greenfield state is now becoming apparent as the peak discharge, total discharge, maximum flood volume (m^3) and maximum flood area (m^2) in this scenario is quite high as compared to the hypothetical greenfield state.

Comparison wise, the maximum flood volume (i.e. 135,168m^3) is almost similar to the total volume of runoff discharge (i.e. 158,134m^3) which implies that around 85% of the of total runoff discharge contributes to flooding. This is quite enormous when considering the low percentage of infiltration that exists in this scenario. In fact, this scenario truly reflects the nature of physical development activities that is present in the study area where little or no attention at all been directed to the reduction of impervious surfaces or for the integrated water management for that matter.

Table 16: Current Development State Result Summary

Item	Total
LISEM results at time (min)	599.7
Total rainfall (mm)	66.2
Discharge total in mm	41.6
Total interception (mm)	0.6
Total infiltration (mm)	23.4
Total discharge (m^3)	158,134
Peak discharge (l/s)	8,608
Peak time rainfall (min)	50.2
Peak time discharge (min)	77.2
Discharge/Rainfall (%)	62.9
Percentage of infiltration	35
Flood volume (max level) (m^3)	135,168
Flood area (max level) (m^2)	207,900

5.3. Third Scenario – Urban Design with SuDS principles for the Hypothetical Greenfield State

This scenario attempts to make an urban design for the study area that takes into account the SuDS principles. The urban design is based on the assumption that the study area is still greenfield, thus it basically started the design from scratch, with an empty site in mind, and then slowly incorporated all the relevant land uses and infrastructure together with the appropriate SuDS principles on the site.

5.3.1. Urban Design with SuDS Development Guideline

The development guideline as explained in this scenario was carefully considered when making an urban design for the study area. These guidelines reflect the urban design plan as shown in Figure 36.

5.3.1.1. Plot Sizes

The plot sizes that were digitised ranges from 0.96 to 14 hectares. These plots are subject to further subdivision as in accordance with the development standard guidelines for residential, commercial, and industrial in Kampala. Thus relevant calculation has been made in order for these large plots to accommodate future roads and drainage (or swales) when they are further subdivided.

5.3.1.2. Roads

The roads are designed in accordance with the following requirements:

- Primary Residential Street & Secondary shopping street: 21m (15m plus 6m swales – 3m on both sides)
- Secondary Residential Street: 14m (8m plus 6m swales – 3m on both sides)
- Industrial Street Road: 31m (25m plus 6m swales – 3m on both sides)

Table 17, 18, and 19 shows the total areas that are reserved for roads, swales, and drainage development.

Table 17: Road Area Calculation

Road Type	Road Length (m)	Width (m)	Total (m²)	Total (HA)
Secondary Residential Street	18519.1	8	148152.9	14.8
Primary Residential and Secondary Shopping St	8744.6	15	131169.7	13.1
Industrial Road	2039.6	25	50989.7	5.1
Total			**330312.3**	**33.0**

Table 18: Swale Reserve Calculation

Swale Type	Swale Length (m)	Width (m)	Total (m²)	Total (HA)
Secondary Residential Street Swale	18519.1	6	111114.6	11.1
Primary Residential and Secondary Shopping St	2745.5	6	16473	1.6
Industrial Road Swale	2039.6	6	12237.6	1.2
Total			**139825.2**	**14.0**

Table 19: Digitised Drainage Area Calculation

Drainage	Drainage length	Width (m)	Depth (m)	Total (m2)	Total (HA)
Digitised Short Drainage	1739.6	3	1	5218.9	0.5
Digitised Long Drainage (3m both sides)	5999.1	6	1	35994.4	3.6
Total				**41213.3**	**4.1**

Table 20 below shows the various SuDS type with their length, width, and depth, together with the estimated volume of runoff that it can accommodate. The total volume for the detention basin will then be multiplied by 7 which is the number of basin present in the study area. The location of basin and pond plays a significant role in determining whether it has the potential to accommodate or capture this total volume of runoff. If it is located in the wrong place, it may not be able to capture the volume of runoff that it is designed to accommodate.

Table 20: Estimation of Runoff Volume that can be accommodated by SuDS

SuDS Type	Area (m^2)	Length (m)	Width (m)	Depth (m)	Total (m^3)
Channel Buffer	171,000	3800	45	1	171,000
Detention Basin (5:1 length width ratio)	14,000	100	20	3	6,000
Retention Pond (3:1 length width ratio)	7,500	150	50	2	15,000

5.3.1.3. Summary of Land Use Allocation for Scenario 3

In summary, the total land that is allocated for various uses within the study area is clearly shown in Table 21 below. The maximum development coverage assigned to each land uses determines the percentage amount of land that should be used for physical development.

Table 21: Total Land Use Area Allocation

Use	Area (ha)	Maximum Development Coverage (%)	Total Area Percentage
Education	5	60	1.3
Residential low density	65.6	20	17.5
Residential medium density	32.5	30	8.7
Residential high density	132	40	35.2
Commercial	19.3	60	5.1
Light industrial	23.9	60	6.4
Medium industrial	19.4	30	5.2
Channel buffer	19	100	5.1
Detention basin	1.4	100	0.4
Retention pond	0.75	100	0.2
Roads	33	100	8.8
Drainage	4.1	100	1.1
Swale Reserve	14	100	3.7
Miscellaneous (Bare)	5	0	1.3
Total	**375**		**100**

5.3.2. Hypothetical Urban Design with SuDS

Figure 36 depicts the final urban design with SuDS principles. It takes into account the land use area allocation as shown in Table 21. The residential high densities are proposed on higher grounds and the residential low densities are situated on lower flat areas. The reason being is to reduce the overall impacts of flooding in the study area should there be any overflow of runoff from the main secondary channel, as high densities development often accommodate more households and provide less spaces on their surroundings as it has a high plot coverage whereas the residential low densities could only accommodate less households but more free spaces since its maximum plot coverage is low. Thus during channel runoff overflow incidents, there is more open spaces than houses for water to move around freely in residential low density areas causing less damage and harm to the surrounding built environment. Moreover, the low and medium industrial activities are proposed at the downstream bottom part of the study area since they normally generate a lot of pollution. This also applies to the commercial uses depending on the type of commercial activity that is proposed on the site. Thus, locating them upstream would result in more pollution in the surface water runoff when it reaches downstream and this would affect the overall water quality.

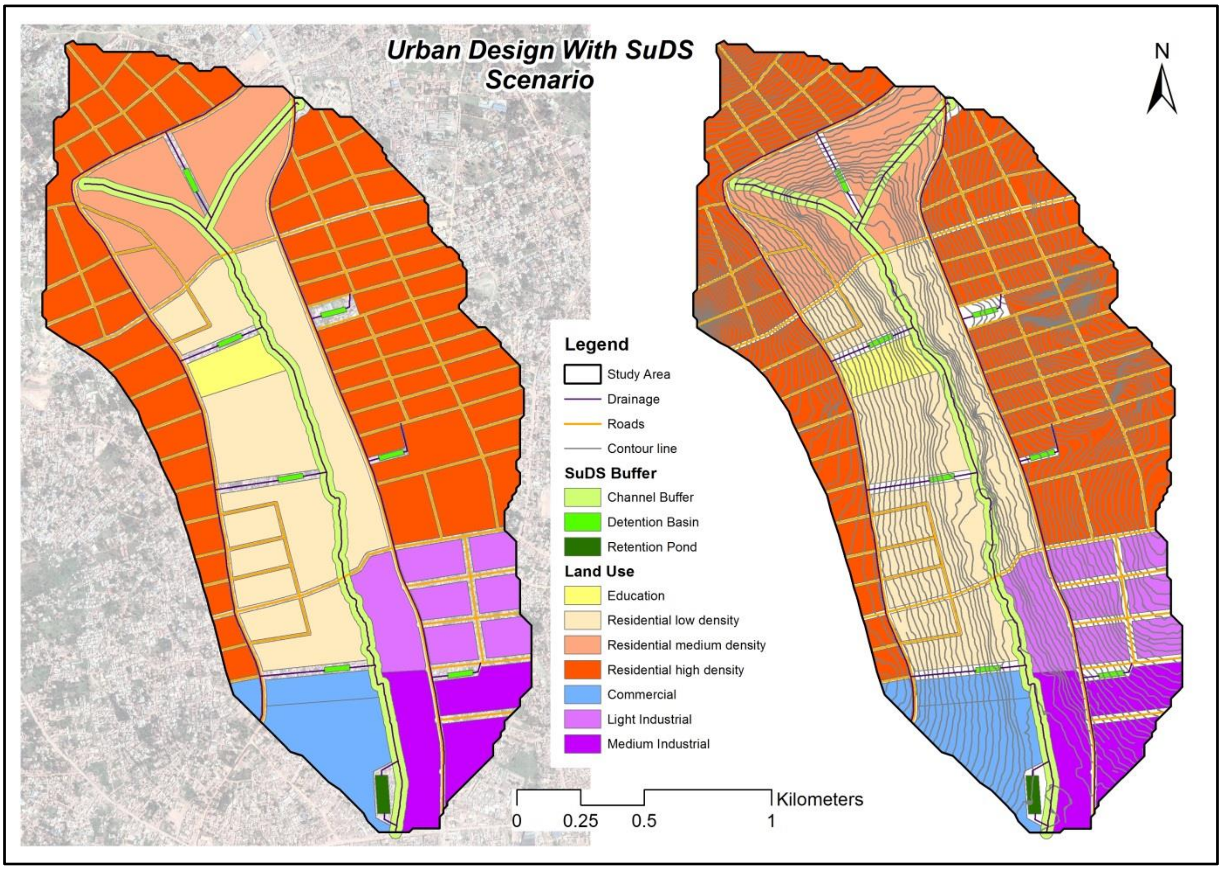
It is important to note that the proposed layout of roads in this urban design is made without fully considering the site characteristics details and should be subject to further amendments. It is made just to ensure that all parcel of land are accessible by vehicles and also for the purpose of flood modelling simulation. Likewise, since the land is still subdivided into large parcel at this stage of the design, it is expected that more roads are expected to be developed once these large parcel of land are further subdivided into the exact lot sizes for residential, commercial and industrial uses. The land area that will be needed by these futures roads are also taken into account in the urban design process.

In terms of the drainage system, only the secondary drainage are included in the design at this stage which include the one running in the middle of the study area, the one along Bombo and Kawaala road, and also the ones that are connected to the basins and pond.

In addition, the detention basins and pond are situated in various areas that may seem suitable such as on gentle to flat, low lying areas where it has the potential to detain more runoff from upstream depending on how it is going to be constructed on the ground. Its location is more dependent on the nature of the terrain and also on the SuDS management train theory where one basin or pond should serve a limited number of households. Thus, in order to maximise the use of the basins and pond, the swales/drainage needs to be developed in a manner where it could carry more runoff directly into them. However, another alternative option is for a hydrology study to be carried out in order to determine the exact movement of water in the study area and also for the location of where most of the water is concentrated. This could be the only solution of ensuring that the basins and pond are put to its maximum use.

Furthermore, in reality an urban design are made and finalise after carrying out a detail study of the study area in all aspects and also after a series of stakeholders and community consultations in order to obtain the people's views, concerns, or ideas about the way they want their city or neighbourhood to be developed in the future. Thus it is quite a lengthy and time consuming process where it could even take a year or two to complete the whole urban design process. However this was not case for this research, due to time limitation, the layout of development that is incorporated into the final urban design only reflects the views of the researcher and also it does not exactly take into consideration all the urban design process.

Figure 36: Final Urban Design with SuDS Scenario



Left – without contour lines Right – with contour lines

Table 22 below shows the detail land cover for the urban design with SuDS scenario (as in accordance with Figure 36) in comparison with the current development situation (in accordance with Figure 33).

The house cover and roads/drainage makes up the total built-up areas which are 39.2% of the total land cover for urban design with SuDS and 30.1% for the current development situation. In addition, the bare soil and vegetation are the non-built-up land which accounts for 60.8% for the urban design with SuDS and 69.9% for the current development state. Thus the urban design with SuDS is 9.1% more than the current development state in terms of the amount of impervious surface.

Table 22: Urban Design with SuDS Land Cover Allocation

Land Cover	Current Development Situation (2010)		Urban Design with SuDS Scenario	
	Area (ha)	Percentage	Area (ha)	Percentage
Bare soil	174	46.4	6	1.6
Vegetation	88	23.5	222	59.2
Built-up (house cover)	96	25.6	110	29.3
Earth road/Tarmac/Gravel/Drainage	17	4.5	37	9.9
Total	**375**	**100**	**375**	**100**

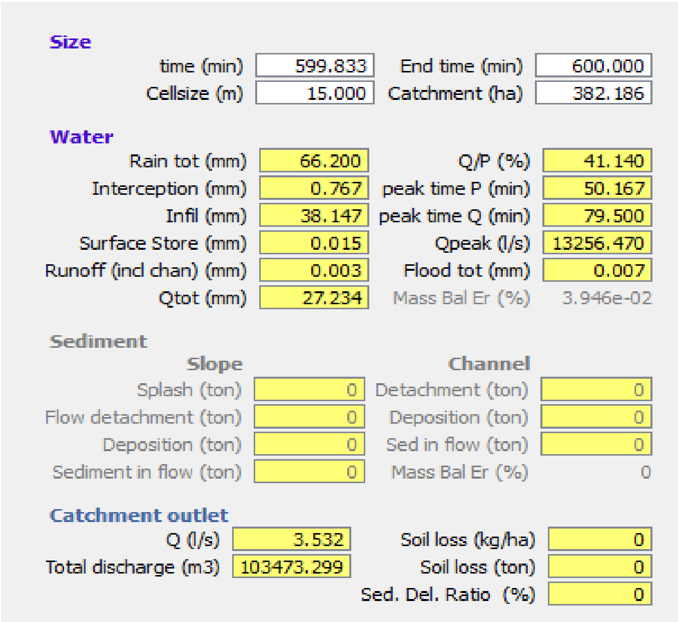
5.3.3. Hypothetical Urban Design Model Simulation

In order to clearly see the impacts of SuDS in the new urban design of the study area, the model simulation in this scenario has been divided into two which is (1) the urban design without SuDS and (2) the urban design with SuDS. This is simply done by checking and unchecking the grass width box in the conservation model options in openLISEM. In this manner, one could clearly justify the extent of SuDS effects and could clearly answer the question of whether the SuDS principles are actually making a difference on the new urban design.

5.3.3.1. Simulation 1: Urban Design without SuDS

The model simulation result for this scenario is shown in Figure 37 and the hydrograph diagram in Figure 38. The data shows that the total runoff fraction is 41% (total precipitation taken as runoff), the peak discharge is 13,256 (l/s), and the total discharge is 103,473m^3. In addition, the total infiltration for this scenario is around 38mm which accounts for 58% of the overall runoff that could be infiltrated. This is a good indication in this scenario where the total percentage of infiltration is greater than the total runoff fraction. This helps to reduce the volume of runoff.

Figure 37: Urban Design without SuDS Simulation Result



The peak discharge can be seen on the hydrograph diagram in Figure 38. The recorded time at which the hydrograph is at its peak for this scenario is around 79.5 minutes, which is just 29 minutes away from the starting rainfall peak time (when the discharge started to rise). This implies that the volume of runoff accumulates very fast within the shortest period of time which could also result in flash flooding in low lying areas. However the highest point on the hydrograph does not last for long as it started to decline just after the peak time, causing the peak discharge to drop significantly.

Figure 38: Urban Design without SuDS Hydrograph

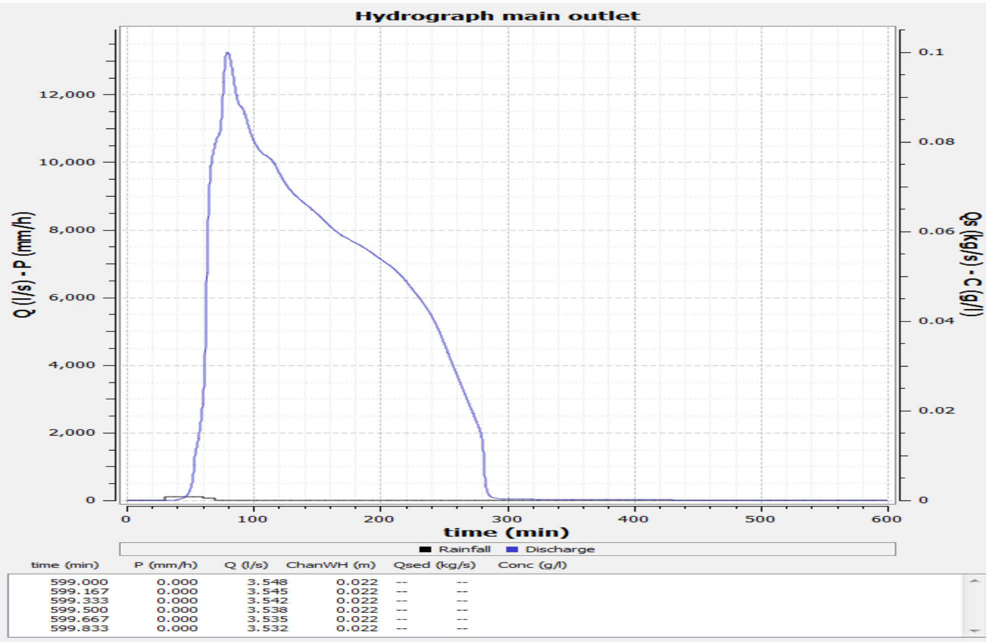


Table 23 below shows the model summary result for the urban design without SuDS situation. The maximum flood volume in this scenario is around 69,243m^3 and the maximum flood area is 70,425m^2.

The absence of SuDS is quite visible in this table which is reflected in the high peak and total discharge. However the flood volume and flood area is low, even though there are no SuDS. Comparison wise, the maximum flood volume (i.e. 69,243m^3) contributes to about 67% of the of total runoff discharge (103,473.3).

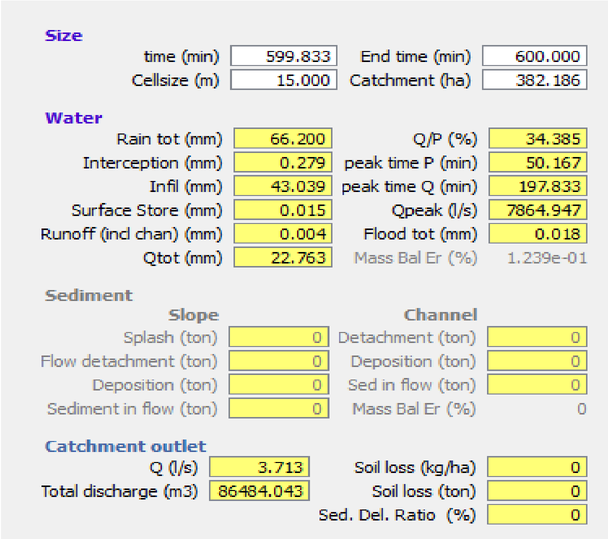
Table 23: Urban Design without SuDS Result Summary

Name	Total
LISEM results at time (min)	599.67
Total rainfall (mm)	66.20
Discharge total in mm	27.23
Total interception (mm)	0.8
Total infiltration (mm)	38.15
Total discharge (m^3)	103,473.3
Peak discharge (l/s)	13,256.5
Peak time rainfall (min)	50.17
Peak time discharge (min)	79.50
Discharge/Rainfall (%)	41.14
Percentage of infiltration	58
Flood volume (max level) (m^3)	69,243
Flood area (max level) (m^2)	70,425

5.3.3.2. Simulation 2: Urban Design with SuDS

The model simulation result for this scenario is shown in Figure 39 and the hydrograph diagram in Figure 40. The data shows that the total runoff fraction is 34% (total precipitation taken as runoff), the peak discharge is 7,865 (l/s), and the total discharge is 86,484m³. In addition, the total infiltration for this scenario is 43mm which is quite high as it accounts for 65% of the overall runoff that could be infiltrated. Thus the total percentage of infiltration is almost double the size of the runoff fraction which portrays a positive outcome.

Figure 39: Urban Design with SuDS Simulation Result



The peak discharge can be seen on the hydrograph diagram in Figure 40. The recorded time at which the hydrograph is at its peak for this scenario is around 198 minutes, which is 148 minutes away from the starting rainfall peak time (when the discharge started to rise). Thus it took a long time for the runoff discharge to reach its peak as compared to the urban design without SuDS situation and the highest point on the hydrograph also does not last for long as it started to decline just after the 200 minutes mark.

Figure 40: Urban Design with SuDS Hydrograph

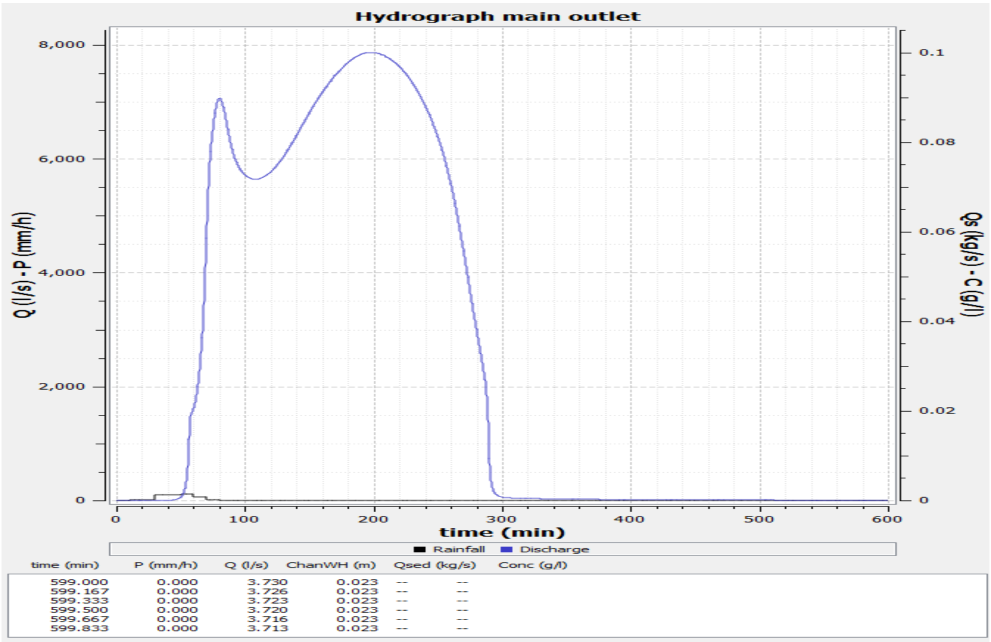


Table 24 shows the model summary result for the urban design with SuDS situation. The maximum flood volume in this scenario is around 65,137m³ and the maximum flood area is 70,200m². Again there are some variation between the urban design without SuDS and urban design with SuDS in terms of the peak discharge, total discharge, maximum flood volume (m³) and maximum flood area (m²) where the urban design with SuDS is more favourable as compared to the urban design without SuDS.

Table 24: Urban Design with SuDS Result Summary

Name	Total
LISEM results at time (min)	599.7
Total rainfall (mm)	66.2
Discharge total in mm	22.8
Total interception (mm)	0.3
Total infiltration (mm)	43.0
Total discharge (m3)	86,484.0
Peak discharge (l/s)	7,864.9
Peak time rainfall (min)	50.2
Peak time discharge (min)	197.8
Discharge/Rainfall (%)	34.4
Percentage of infiltration	65
Flood volume (max level) (m^3)	65,137
Flood area (max level) (m^2)	70,200

5.4. Scenarios Model Comparison

This section compares the modelling result for all the three scenarios listed below which was previously discussed:

- Hypothetical Greenfield State (Baseline: include secondary channel in a natural form but exclude roads and buildings)
- Current Development State (include secondary channel, roads and buildings)
- Urban Design without SuDS and Urban Design with SuDS

5.4.1. Runoff Fraction, Infiltration Percentage, Peak Discharge and Total Discharge Data

Table 25 and Figure 41clearly compares all the modelling result data from openLISEM as per the various scenarios. The discusion for each of the indicators are listed below as follows:

Table 25: Discharge Comparison Table for all Scenarios

Name	Hypothetical Greenfield State	Current Development State	Urban Design without SuDS	Urban Design with SuDS
Percentage of Impermeable Surface (Built-up Areas)				
% of Impermeable Surface	0	30.3	39.3	39.3
Runoff Discharge & Percentage of Infiltration				
Runoff Fraction (%)	20	63	41	34
% of Infiltration	75	35	58	65
Time to Peak (Rainfall): P (min)	50	50	50	50
Time to Peak (Discharge): Q (min)	333	77	80	198
Peak Discharge (l/s)	2,754	8,608	13,257	7,865
Total Discharge (m3)	50,505	158,134	103,473	86,484

- ***Percentage of impervious surfaces*** – the urban design with/without SuDS has the highest landcover of impervious surfaces which is 9% more than the current development state.

- ***Percentage of runoff fraction*** (fraction of runoff generated by the catchment) – the curent development state has the highest percentage of runoff fraction whereas the hypothetical greenfield state has the lowest. However the urban design with/without SuDS runoff fraction is lower than the current development state despite having high percentage of impermeable surfaces. This is a positive indication to to the overall success of the urban design that even without SuDS, its runoff fraction is still lower than the current development state.

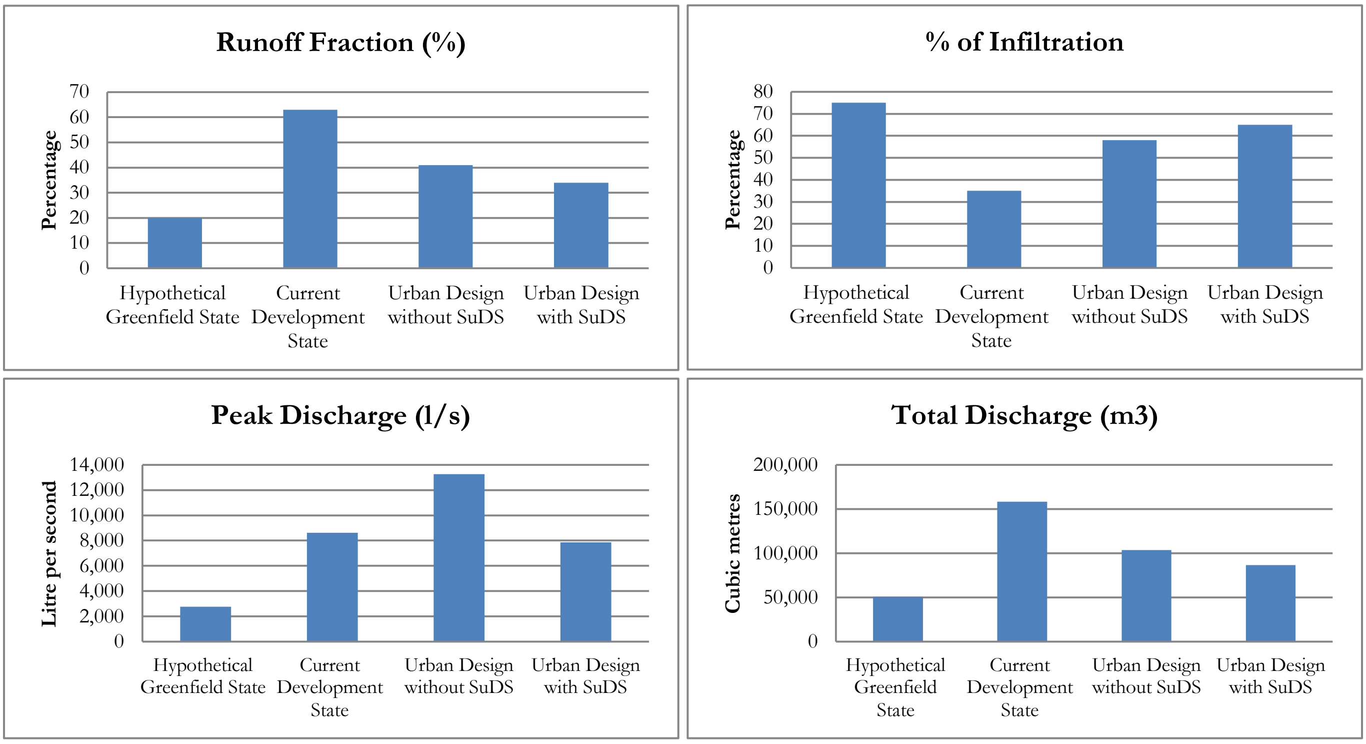
- ***Percentage of infiltration*** – The hypothetical greenfield state has a very high infiltration rate which allows more water to go into the soil which helps to reduce the runoff fraction whereas the current development state has a very low infiltration rate, which is the reason why its runoff fraction is higher. In addition, the urban design with SuDS infiltration rate is almost similar with the hypothetical greenfield state and is better-off than the urban design withot SuDS. This implies that the SuDS principles highly promotes infiltration as a method of reducing the volume of runoff. Overall, the urban design with/without SuDS is still considered as the best scenario in comparison with the current development state.

- ***Peak Discharge Time (Q) and Peak Discharge (l/s)*** – The current development state reaches its maximum flow within the shortest period of time. However its peak discharge is still better off than the urban design without SuDS where its peak discharge is 35% more and it reaches its maximum flow roughly about the same time as the current development state. This implies that the urban design without SuDS fails to successfully lower its peak discharge which is an indication of a bad design. However, the urban design with SuDS proves to be effective in terms of lowering its maximum flow by at least 9% and also by increasing the peak discharge time by 121 minutes as compared to the current development state, which would be an indication of a good design. Overall, the hypothetical greenfield state has the best result with a low maximum flow and longer time for discharge to reach its peak. Thus more amendment will be required in the urban design in oder to replicate the result of the hypothetical greenfield situation.

- ***Total Discharge*** (total amount of runoff that is generated from a site which exclude the water that has been intercepted by various means) – The total runoff discharge could be a good indication of floding. However more discharge does not necessarily mean more flooding unless the runoff is not properly managed. It is obvious that the hypothetical greenfield situation has a very low runoff discharge which is 68% lesser than the current development state, 51% lesser than the urban design without SuDS, and is only 42% lesser than the urban design with SuDS scenario. Again, even though the urban design with/without SuDS has more impervious surfaces, its total discharge is still lesser that the current development state.

- ***Overall conclusion*** – the general conclusion that can be drawn from the discharge comparison in Table 25 and the bar graph in Figure 41 is that the peak and total discharge is highly determined by the way a city or town is designed and developed. If our cities do strictly adhere to all planning development requirements and policies together with the provision of spaces to accommodate the various SuDS principles, the high percentage of impermeable surface may not necessarily pose a major threat to some extent as the various SuDS techniques (when used correctly) do have the potential to reduce the peak and total discharge which would simultaneouly reduced the maximum flood volume and area in any given site.

Figure 41: Runoff Fraction, Infiltration, Peak and Total Discharge



5.4.2. Hydrograph Comparison for all Scenarios

Figure 42: Scenarios Hydrograph Comparison

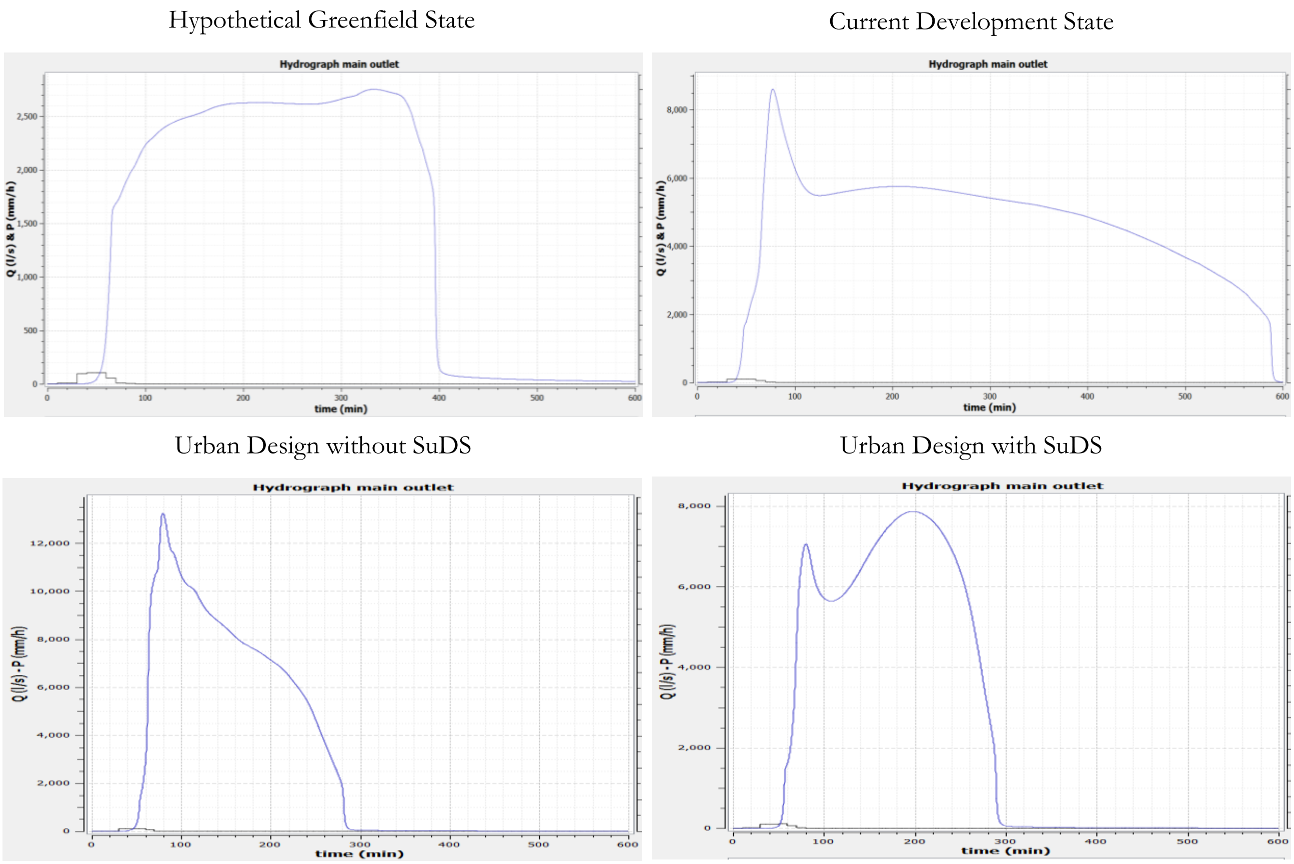


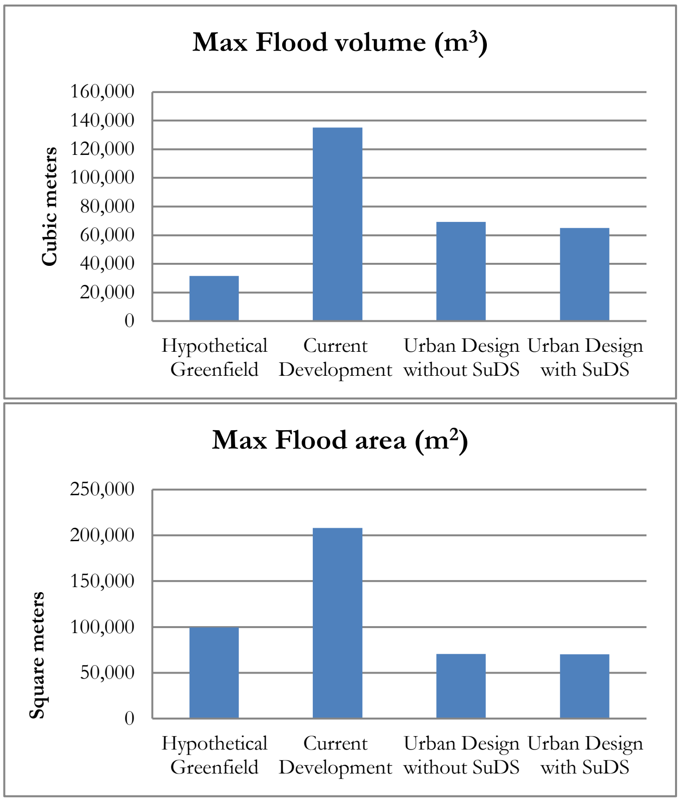
Figure 42 compares the different hydrographs for all the four scenarios (using the same rainfall event and simulation times) which clearly indicates the variation in peak discharge and peak time. The total discharge can also be seen here which is equal to the area under the hydrograph. It is obvious that the hypothetical greenfield state and the current development state hydrograph portrays a low peak and a longer hydrograph which implies that these two scenarios only slowed or delays the flows of runoff. This applies especially to the current development situation where the percentage of impervious surfaces is greater. Likewise, the hydrograph also indicate longer storm or discharge period as it reaches back to the base level after 400 minutes for the hypothetical greenfield state and exactly at the 600 minutes end time for the current development state.

However, the urban design with/without SuDS depicts an increased peak and shorter hydrograph duration which indicates that these two scenarios attempts to facilitate runoff removal. This is proven by the way the study area is designed by increasing the percentage of vegetation (based on the development requirements on the maximum plot coverage) which allows for more infiltration, reducing the total amount of runoff. In addition the hydrographs implies that it is also shortening the storm or the discharge period which is clearly shown by the time of the falling limb which is around 300 minutes. Moreover, the urban design with SuDS is much more favourable because it tries to lower the peak discharge and shorten the hydrograph duration at the same time which denotes that the SuDS techniques are quite effective in both attenuating the flow and also in reducing the amount of runoff.

5.4.3. Flood Volume and Flood Area

Figure 43 clearly demonstrated the difference amongst the four scenarios in terms of their flood volume and flood area. Obviously the current development state showed a high level of flood volume, which is 135,168m³, and flood area, which is 207,900m² (20.79ha). This is quite logical in the sense that the percentage of impervious surface in this scenario is far higher than the hypothetical greenfield state, and also the current development scenario only relies on the conventional drainage system as the only method of dealing with the surface water runoff.

Figure 43: Flood volume and area simulation result



Thus the flooding impacts for the current development state could be seen as highly severe and very destructive, and also the number of housing structures that could be flooded would be very high as compared to the other scenarios.

However, the flood volume and flood area for the urban design with/without SuDS scenario is quite less even though its percentage of impervious surface is more than the current development situation. Thus this has also proven that the integration of the SuDS principles into the study area's urban design could help reduce the flood volume and flood area, causing little or no flood at all to the buildings and infrastructures within the study area.

5.4.4. Flood Level

The maximum flood level maps in Figure 44 below clearly differentiated the three scenarios. The hypothetical greenfield state maximum flood level is about 2 meters and the urban design with SuDS is 1.6 meters. However, the maximum flood level for the current development state is 2.4 meters. Thus, the SuDS technique is also quite effective in this case since it could carefully manage its total flood volume and also reduces the maximum flood level within the study area.

Figure 44 also showed severe flooding in the current development state scenario towards the bottom downstream part of the study area. This is the area where the secondary channel joins with the primary channel along the Nabweru Road and also where most of the commercial activities are taking place. However the hypothetical greenfield state and the urban design with SuDS scenarios showed no indication of severe flooding in this area at all. Again, this implies that the SuDS principle has carefully avoided any flooding from occurring in this part of the study area.

Figure 44: Maximum Flood Depth in Meters

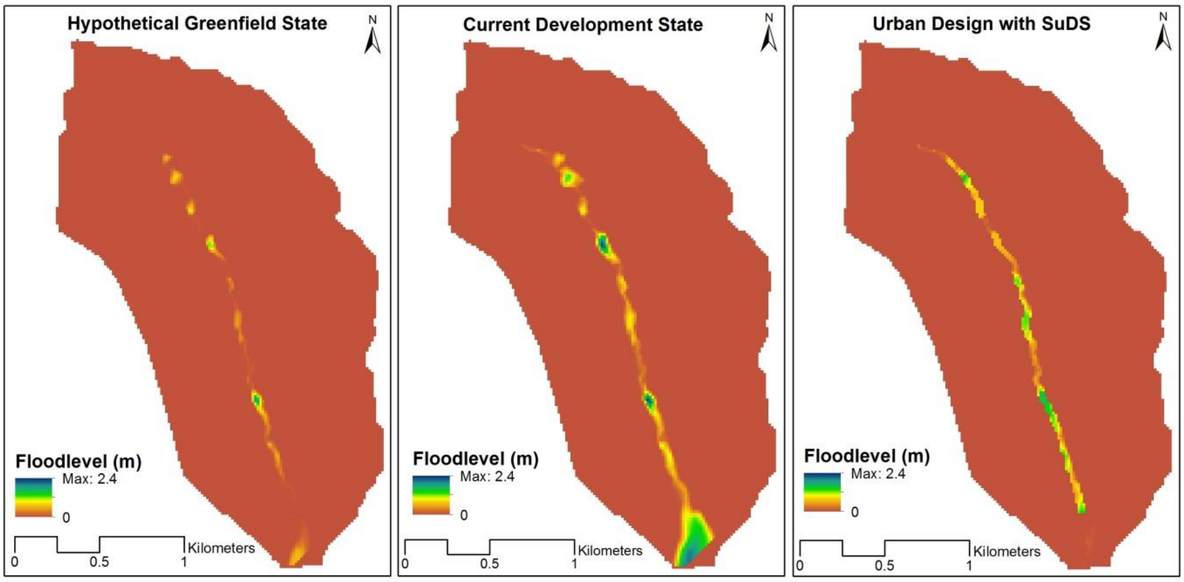
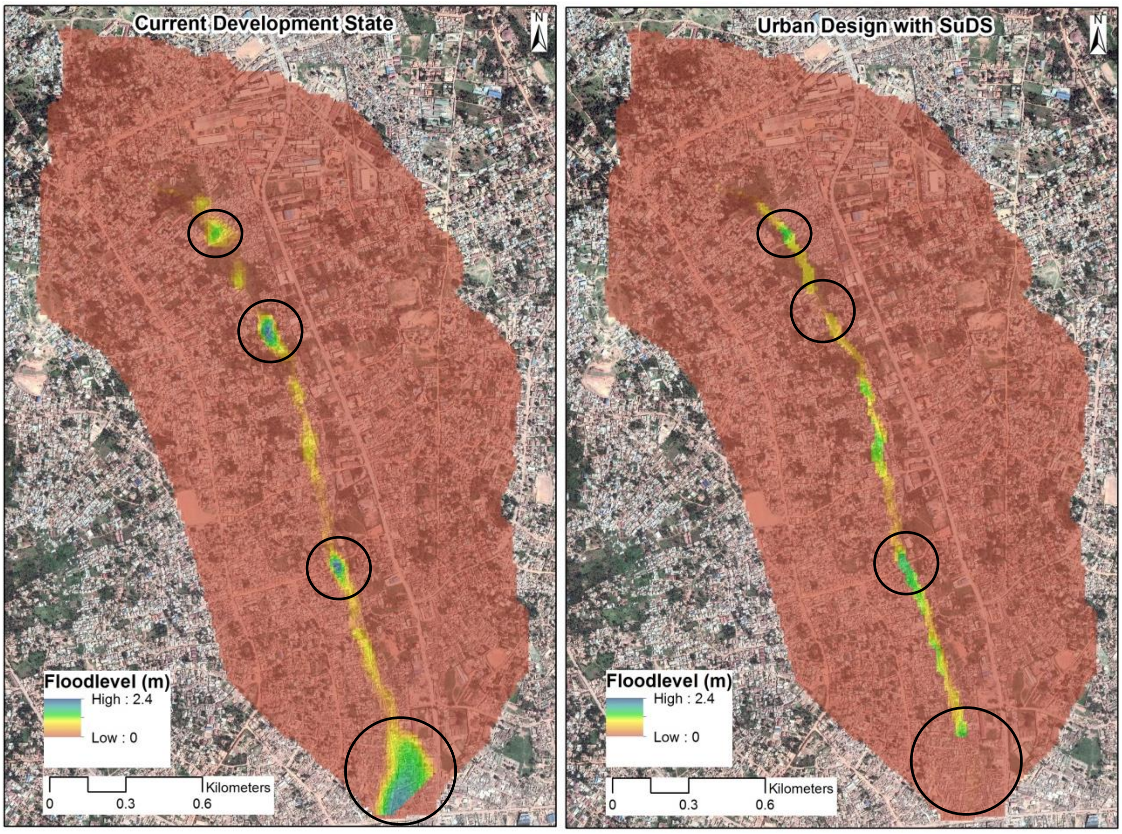


Figure 45 has idenfied (in black circle) some of the potential hot spots for flooding within the study area. It compares the spatial analysis result between the current development state and the urban design with SuDS scenario. It is quite interesting to note that the areas which are considered as hot spots in the current development state scenario may no longer be a hot spot in the urban design with SuDS case. For instance, the area marked with a big circle on the botoom of the study area is considered as one of the vulnerable areas where the maximum flood level could rise upto 2.4 meters. The destruction that the flood waters could cause in this area alone could be quite devastating as most of the study area's economic activities are taking place on this spot. Thus the cost of damage caused by flooding could even double or tripple on this area alone as compared to the floding damage on other residential settlement. Despte it being a hot spot for the current development state, the urban design with SuDS scenario showed that it could no longer be a hot spot if the relevant SuDS principles are well intergrated into the study area urban design. Likewise, other potential hotspot areas for the current development state scenario is showing no sign of threat at all in the urban design with SuDS situation. Therefore the SuDS approach seems to be highly favorable and can be considered as the best alternative method in addressing the runoff and flooding problems in the study area.

Figure 45: Potential Hot Spots Areas

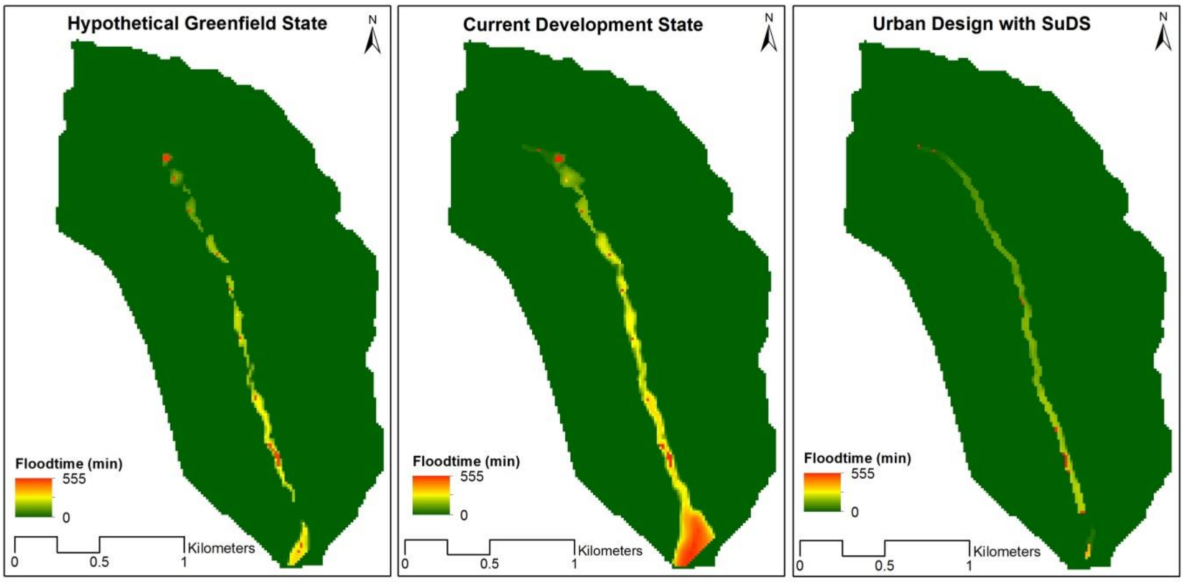


5.4.5. Flood Duration

The flood duration map in Figure 46 showed the different flood time in minutes amongst the three scenarios. The most affected areas which will remain submerged for quite a longer period of time, that is 9 hours, are clearly shown in red. Even though the hypothetical greenfield state and the urban design with SuDS scenario showed some small red spot, they are still located along the channel which could be indeed harmless as flood waters remains where it should be. However, the current development state scenario showed severe widespread red areas towards the bottom of the study area which will remain flooded for hours. This is the same spot where most of the study area's commercial businesses are situated, that is along Nabweru and Bombo Road.

When the SuDS techniques are well incorporated into the urban design of the study area, it could either reduces the flood time or totally avoid any flooding from occuring. For instance, the bottom part of the current development state scenario showed severe flooding which could last for more than 9 hours. However, the urban design with SuDS case showed no indication of severe flood at all. In fact, the overall flood duration result depicts that the urban design with SuDS scenario is far better off than current development state and even the hypothetical greenfield state.

Figure 46: Flood Time in Minutes (Duration)



5.4.6. Flood Summary Result

Table 26 clearly summarised the flood data for the four scenarios. The urban design with SuDS scenario seems to be a "better off" option (apart from the hypothetical greenfield state) since it has a lower flood volume, flood level, and even a small flooded area as compared to the current development state situation.

Table 26: Maximum Level of Key indicators Per Scenario

Scenario	Max Flood volume (m^3)	Flood volume (%)	Max Flood area (m^2)	Flood area (%)	Max Flood level (m)
Hypothetical Greenfield	31,505	10.5	99,450	22.20	2
Current Development	135,168	44.9	207,900	46.41	2.43
Urban Design without SuDS	69,243	23.0	70,425	15.72	1.77
Urban Design with SuDS	65,137	21.6	70,200	15.67	1.62

6. CONCLUSION & RECOMMENDATIONS

This research was undertaken to assess the impact that urban development based upon SuDS principles could have on urban drainage issues and flooding in Kampala. The main finidings of the research are summarised in this section followed by general concluding remarks and recommendations.

6.1. Summary of Findings

The summary of findings is structured in accordance with the sub objectives where the applicability of SuDS principles for the case of Kampala were explored in order to establish an evidence base that can contribute to informed policy making in addressing flooding issues when considering future urban development projects.

6.1.1. To determine the key relationships between urban design, urban drainage, and urban flooding

Urban design is defined as the art and process of designing, creating, making and managing spaces and places for people (Commissioner for Architecture and the Built Environment, 2001; Rowley, 1994). It is the process of giving physical design direction to urban growth, conservation and change (Barnett, 1982a). It sits at the interface between architecture and planning (and related professions), and its emphasis on physical attributes usually restricts its scale of operation to arrangements of streets, buildings, and landscapes (Batty et al., 1998).

There is indeed a high correlation between urban design, urban drainage and urban flooding. Since the urban design process is the first step for any development activity, embedded in it is the future development of any urban area in terms of the type of development that needs to be carried out on the ground (according to the various types of land uses), how the development is to be carried out (based on regulatory requirements), and where is the actual development needs to take place (site location). Likewise, the urban design also contains the necessary infrastructural plans such as roads, drainage, utilities, etc. that needs to be developed by the developer as well. Thus in terms of the urban drainage, the urban design clearly clarifies the type and size of the drainage system that needs to be developed which should be based on some future calculation of the surface water runoff that will be generated from the site, etc. However, when the problem of urban flooding arises, it relates back to the overall urban design of that area which is the initial stage of the development process.

Nowadays as we continue to expand our urban environment, the risk of flooding also increases, which is also partly due to our changing climate. The question as to what strategies can designers, planners and engineers must put in place in order to mitigate its impact has been the subject of discussion in the past and even today. Thus urban design still plays a vital role in coming fourth with potential solutions to reducing urban flooding problems in our modern world.

6.1.2. To compare the current development and runoff with a hypothetical greenfield state in the study area

Surface water runoff as defined by Beven (2004) is "the water flow that occurs over the land when the soil is infiltrated to full capacity". Vinogradov (2009) defines it as "a natural phenomenon of free water movement within land under the influence of gravitational forces". Vinogradov (2009) further mentioned that the term "surface runoff" is unfortunately unequivocal. Simply in a narrow sense, it is a kind of runoff that is determine by the condition of its formation; and in a wider sense, it is all the remaining water running on land surfaces which are not taken into account by the hydrological cycle.

The current development runoff in this case is referring to the total amount of runoff that is produced in the study area which is based on the current development situation whereas the hypothetical greenfield state is the runoff generated from the same study area with an assumption that it is still in its greenfield state with no physical development except for existence of a natural channel.

The model shows some substantial variation between the current development state and the hypothetical greenfield state in terms of the runoff fraction (%), peak discharge (l/s), and total discharge (m^3). According to the model, there is a 43% difference in runoff fraction; 5,854 (l/s) differences in peak discharge; and 107,629 m^3 difference in total discharge, in which the data from the current development state is far more than the hypothetical greenfield state. This is quite logical in the sense that there is more imperviousness in the current development state due to the extent of physical development activity that is present on the site, which is linked to the generation of more runoff in the study area.

6.1.3. To assess the possible impact of a hypothetical urban design based upon SuDS principles on runoff and flooding

SuDS principles are not a new concept. It is simply nature's way of dealing with rainfall. They have been around in the past but was later forgotten and replaced by the conventional drainage systems. The hypothetical urban design based upon SuDS principles in this case is referring to ways in which the study area is designed by taking into account the various SuDS techniques in order to help address the runoff and flooding problems.

There are many SuDS components which are considered relevant within the study area which can be categorised as source control measures, site control measures, and regional control measures. However, this research mainly focussed on the regional control aspect which has to do with the basins, ponds, and buffers that helps to reduce and attenuate the flow of runoff at the regional scale.

The simulation data for this urban design with SuDS scenario seems to be lesser than the current development situation even though it has a high impermeable surface which is indeed a positive indication of a good urban design. For instance the runoff fraction is 34%, which is 29% lesser than the current development state; the peak discharge is 7,865 (l/s) which is 743 (l/s) lesser than the peak discharge for the current development state; and the total discharge is 86,484m^3 which is 71,650m^3 lesser than the current development state. The data really portrays a positive result for the urban design with SuDS scenarios as it reduces all the main key runoff indicators when compared to the current development situation.

Moreover in terms of the flooding data, the maximum flood volume for the urban design with SuDS is 65,137m^3 which is 70,031m^3 lesser than the current development state; the maximum flood area is 70,200m^2 which is 137,700m^2 lesser than the current development state; and also the maximum flood level is 1.62 which is 0.81 meters lower than the current development state. These flooding results together with the runoff discharge and the spatial analysis comparison maps have all shown the positive implications of the urban design with SuDS principles. Thus it can be concluded that the urban design with SuDS scenario really has the potential to address the runoff and flooding problems in the study area and in doing so, it can totally avoid any disruption to the lives of the people of Kampala and also to their daily socio-economic activities.

6.1.4. To perform a qualitative evaluation of the implications of adopting SuDS principles in urban expansion policies

Basically the runoff and flood model which incorporated the SuDS principles into the urban design has proven that it is possible to plan and design the study area in such a way where the surface water runoff is reduced and the impact of flooding is minimised. The model shows that there are indeed some significant differences between the current development situation where the SuDS principles are not part of the existing development and the urban design with SuDS case where the SuDS principles are carefully incorporated into the study area. Overall, the spatial analysis map reveals that the urban design with SuDS situation is far better off than the current development scenario and even the hypothetical greenfield state (to some extent) in terms of the flood depth and flood duration.

The concept of SuDS principles in urban development could be considered as a totally new initiative, in particular to many developing countries such as Uganda. Thus introducing this concept will require a major transition to the existing urban expansion policies of a town or city in order to accommodate them. For instance, not all SuDS techniques are suitable for all sites since each site have unique characteristics which can accommodate different SuDS components. Thus a thorough assessment of the site itself needs to be carried out first in order to ascertain the suitability of different SuDS components on various sites.

In terms of the land use characteristics, the SuDS techniques used are determine by the types of land use which are been proposed or are currently existing in an area. For instance, infiltration basins are restricted on industrial sites because the runoffs on these sites are considered as highly polluted which could pose greater threat to the environment.

Moreover, some of the site characteristics itself could restrict or preclude the use of a particular SuDS technique. For instance, all infiltration SuDs technique can only be applied in areas where the soil is permeable, but wet ponds and wetlands rely on impermeable soils. Secondly, the site slopes also played an important role because steeper slopes can eliminate the use of some SuDS practice such as ponds and basins, but it may have little impacts on others such as swales. Thirdly, the availability of space which is considered as highly crucial also determine the type of SuDS used as some techniques may require more land than others. For example, pond, wetland, basin, and swale do require high spaces for implementation.

Furthermore, it is important as well to determine whether the proposed SuDS components do meet all the community and environmental requirements at the site. For instance, maintenance work is required on every SuDS technique on a weekly, monthly, and yearly basis depending on the various SuDS components. Likewise, some SuDS techniques may not be acceptable in close proximity to properties such as swales and some ponds may only be acceptable if there will be an on-going maintenance and operation work. In addition, the construction and maintenance costs for various SuDS techniques can vary widely and should be considered first at an early stage. For instance, the costs for developing wetlands are quite high whereas for retention pond and detention basin has a medium and low cost.

6.2. Urban Policy Recommendations

The following recommendations are proposed when considering the application of SuDS principles into the city's urban design policies.

- The SuDS techniques that were incorporated into the urban design of the study area were mainly focussing on controlling runoff at the regional level whereas the source and site control measures were not necessarily taken into account in this study. In an actual situation, it is highly recommended that the source and site control measures to be considered and to work in cooperation with the regional control measures in order to drastically reduce the total amount of runoff that is produced on the site.

- Apart from using the SuDS selection criteria only for selecting the various SuDS options that is appropriate for a site, a geotechnical evaluation is also recommended and needs to be undertaken as well in order to determine the suitability of the site for infiltration drainage and other SuDS techniques, which is particularly important on sites where there is filled ground, as the frequent discharge of additional waters could change the soil characteristics, either chemically or structurally.
- A cost benefit analysis needs also to be carried out prior to any SuDS development. Benefits could include water quality, amenity and ecology improvements.
- Climate change projections data must be taken into account when computing the storage volumes. It is recommended that a high factor is applied only when there is a strong recommendation to do so.
- Development of the SuDS components itself must be carried out by a certified structural engineer only when all SuDS requirements are met and the detail SuDS design is approved. This is to avoid any unforeseen problem in the operation and maintenance of the SuDS itself.
- Regular inspection and maintenance is important for the overall effective operation of the various SuDS techniques. Thus, the responsible authority must ensure maintenance works are consistently carried out and all problems or failures are rectified in order to ensure daily effective operation of the SuDS. Maintenance work could range from litter/debris removal, grass cutting, weed/invasive plant control, shrub and green waste management, to sediment removal, vegetation/plant replacement, structure rehabilitation/repair, and infiltration surface rehabilitation.
- For the pond and basin, its design must take into account the local landscaping and the environmental community requirements. Its appearance should be as natural as possible and it must introduce native vegetation in the area.

6.3. Recommendations for Further Studies

The following recommendations relate to the possible directions of any further studies in the field of urban design with sustainable drainage systems:

- Since this research mainly focused on the regional control (management of runoff from a site or several sites) aspect of the SuDS management train, it is recommended that a detail study should be carried out where the source control and site control measures are also taken into account.
- In order to create a model for newly developing greenfield elsewhere in the greater Kampala region where the SuDS principles are incorporated into the city's urban design, it is recommended that a detail study of this nature should be carried out where the total land size of the study area is reduced to less than 80 hectares to allow simplicity and practicality of the research.
- The research does not take into account all the urban design process. Thus the urban design needs to be modified where it should be realistic as possible and also where the urban design process is considered. Likewise, the location of ponds and basin should be determined hydrologically rather than following the SuDS selection criteria.
- It would be enlightening and helpful to use similar data and study area for different runoff/flood modelling software and to make a direct and clarificatory comparison of the result. This will help our ability to decide on the best solution in addressing the flooding problems and to ensure that the modelling results are precise and accurate as possible.

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7. APPENDIX

7.1. Appendix 1: PCRaster Database Script

```
#! --matrixtable --lddin
##########################################################################
# PCRASTER script for the generation of an openLISEM input database      #
# 1 dec 2013, Victor Jetten                                              #
##########################################################################

binding
####################
### input maps   ###
####################

    Dem =  demavg50.map; # digital elevation mdoel
    fields =  landunitn50.map; # land use based units
    texture =  soil50.map; # soil based units, usualyy texture classes
    chanmask =  chanmask50.map;  # mask for channel maps
    mainout = mainoutlet.map;  # user defined true outlet (1 =voutlet, 0 is rest)

    # tables with soil physical properties and land use properties
    lutbl = landuse.tbl;
    soiltbl = soil.tbl;

#######################
### input constants ###
#######################

    Soildepth = 1000;
    Chancoh = 8;
    Chanman = 0.05;
    Chanside = 0;
    Chanksat = 1;

#####################
### output maps   ###
#####################

  # basic topography related maps
    Ldd =  ldd.map;         # Local Drain Direction
    grad =  grad.map;       # sine of slope (not tangent)
    id =  id.map;           # pluviograph influence zones (1,2, ...n)
                            # if there are more classes the rainfall file needs more
columns
    outlet =  outlet.map;   # location of main outlet
    outpoint = outpoint.map;  # location of additional information points, 1
(outlet) 2-n

  # vegetation/crop maps
    lu = landunit.map;   # for output stats
    coverc= per.map;     # vegetation cover fraction
    lai= lai.map;        # leaf area index (m2/m2) for interception storage
    cropheight= ch.map;  # vegetation/crop height for splash detachment energy

    grass = grasswid.map; # grass strip width (m)

  # soil maps, "1" stands for layer 1
    ksat= ksat1.map;       # Saturated hydraulic conductivity (mm/s)
    psi= psi1.map;         # matrix suction at the wetting front (cm)
    pore= thetas1.map;     # porosity (-)
    thetai= thetai1.map;   # initial moisture content (-)
    soildep= soildep1.map; # soil depth in mm
```

```
  # surface maps
    rr= rr.map;  # random roughness (cm) for surface storge and witdh of flow
    mann= n.map; # mannings n, overland flow resistance
    stone= stonefrc.map;  # stoniness, crusting and compaction fractions
    crust= crustfrc.map;
    comp= compfrc.map;

  # erosion maps
    cohsoil =  coh.map;      # soil shear strength (kPa)
    cohplant =  cohadd.map;  # additional root shear strength (kPa)
    D50 =  d50.map;          # median of texture in micrometers (mu)
    aggrstab =  aggrstab.map;# aggergate stability, lowe drop test (number of drops)

  # channel maps
    lddchan =  lddchan.map;    # channel network
    chanwidth =  chanwidt.map; # width (m)
    changrad =  changrad.map;  # sine gradient of channel/river bed
    chanman =  chanman.map;    # flow resistance
    chanside = chanside.map;   # tangent side wall angle, 0 = rechtangular, 1 is 45
degrees
    chancoh =  chancoh.map;    # cohesion (kPa)
    chanksat =  chanksat.map;  # Ksat of channel (mm/h)
    chandepth = chandepth.map; # depth (m) only for flooding
    chanlevee = chanlevee.map; # height of levees in m
    chanmaxq = chanmaxq.map;   # maximum discharge of at culvert location in m3/s, 0
means no culverts
    barriers = barriers.map;   # additional elemants, elevations, dikes, taluts to
be added to the DEM (m)

  # housing maps
    house = housecover.map;    # structure cover fraction
    drum = drumstore.map;      # storage in m3 of water drums
    roof = roofstore.map;      # roof interception storage in mm

areamap

  # MASK
    Dem;

initial

  ######################
  ### BASE MAPS      ###
  ######################

  mask=scalar(Dem/Dem); #make a mask

  # make ldd and ensure it flows to channel and to the main outlet
  report ldd.map = lddcreate(Dem-chanmask*2-mainout*2,1e20,1e20,1e20,1e20);
  report outlet = pit(ldd.map);

  # sine gradient (-), make sure slope > 0.001
  report grad = max(sin(atan(slope(Dem))),0.005);

  ########################################
  ### MAPS WITH RAINFALL INFLUENCE ZONE ###
  ########################################

  report id = nominal(mask);

  #######################
  ### CROP MAPS       ###
  #######################

  report lu = fields; # copy the landuse to a landunit.map for stats output

  # fraction soil cover (including residue), from col 5 of land use table
```

```
report coverc = lookupscalar(lutbl, 5, fields);

# crop height (m) from col 7 of land use table
report cropheight = lookupscalar(lutbl, 7, fields)* mask;#coverc;

# LAI (m2/m2) from cover fraction
report lai = ln(1-coverc)/-0.4;


###########################################################
### INFILTRATION MAPS for option one layer GREEN & AMPT ###
###########################################################

 report ksat = lookupscalar(lutbl, 10, fields);
 report pore = lookupscalar(lutbl, 11, fields);
 report psi =  lookupscalar(soiltbl, 5, texture)* mask;
 report thetai = lookupscalar(lutbl, 12, fields);
 report soildep = scalar(Soildepth);

#############################
### SOIL SURFACE MAPS     ###
#############################

 # micro relief, random roughness (=std dev in cm)
 report rr = lookupscalar(lutbl, 8, fields);
 # Manning's n (-)
 report mann = lookupscalar(lutbl, 9, fields);
 # profile definition in PROFILE.INP and PROFILE.MAP
 report crust = 0 * mask;
 # stone fraction
 report stone = 0 * mask;
 #fraction compacted
 report comp = 0 * mask;

######################
### EROSION MAPS   ###
######################

 #report D50 = 30*mask;
 report D50 = lookupscalar(soiltbl, 8, texture) *2* mask;
 report cohsoil = lookupscalar(soiltbl, 6, texture);
 report cohplant = 0*cohsoil;
 report aggrstab = (1 -lookupscalar(soiltbl, 2, texture))*100 * mask;

######################
### CHANNEL MAPS   ###
######################

 chanmask = chanmask/chanmask;
 # channel is 1 and rest missing value

 report lddchan = lddcreate(Dem*chanmask,1e20,1e20,1e20,1e20);

 report changrad = max(0.005,sin(atan(slope(chanmask*Dem))));
 report chancoh = chanmask*scalar(Chancoh);
 report chanman = chanmask*scalar(Chanman);
 report chanside = chanmask*scalar(Chanside);
 # width empirical scaled up from 1 to 15 meter
 report chanwidth = min(15,max(1,accuflux(lddchan,1)/200));
 report chanksat = chanmask*scalar(Chanksat);

 # flood maps
 report chandepth = chanmask*1; #depth set to 1 m everywhere
 report chanlevee = mask*0; # small levee along channel in m
 report chanmaxq = mask*0;  # culvert max dlow, 0 for all the rest, if no culverts
set to 0
 report barriers = mask*0;  # added to dem is needed, like dikes
```

```
######################
### house MAPS   ###
######################

  report house = if(fields eq 9, uniform(1), 0) * mask;
  # random housecover from 0 to 1 in unit 9 settlement.
  # Note that 9 has compacted soil physical values
  report drum = mask*0;
  report roof = 1*mask;
```

7.2. Appendix 2: Script for Generating Scenario Maps

```
asc2map --clone maskbwaise.map -D -a drainage2.txt drainage2.map
pcrcalc drainage4B.map = scalar(drainage2.map)
asc2map --clone maskbwaise.map -D -a roads2.txt road2.map
pcrcalc road4B.map = scalar(road2.map)
asc2map --clone maskbwaise.map -D -a suds2.txt suds2.map
pcrcalc suds4B.map = scalar(suds2.map)
asc2map --clone maskbwaise.map -D -a landuse2.txt landuse2.map
pcrcalc landuse4B.map = scalar(landuse2.map)
pcrcalc landuse4B.map = scalar(landuse2.map)
pcrcalc landuse4B.map = landuse4B.map/100
pcrcalc landuse1.map = landuse1.map/100
pcrcalc housecover.map = cover(housecover.map,0*maskbwaise.map)
asc2map --clone maskbwaise.map -D -a landuse.txt landuse.map
pcrcalc housecover.map = scalar(landuse.map)
pcrcalc housecover.map = housecover.map/100
pcrcalc housecover.map = cover(housecover.map,0*maskbwaise.map)
pcrcalc roadwidt.map = cover(roadwidt.map,0*maskbwaise.map)
pcrcalc bufferid.map = cover(bufferid.map,0*maskbwaise.map)
pcrcalc roadwidt.map = cover(roadwidt.map,0*maskbwaise.map)
pcrcalc roadwidt2.map = cover(roadwidt2.map,0*roadwidt.map)
pcrcalc bufferid.map = cover(bufferid.map,0*grasswid.map)
pcrcalc bufferid.map = cover(bufferid.map,0*grasswid.map)
pcrcalc buffervol.map = scalar(if(bufferid.map eq 2, 228000, 0))
pcrcalc ksat1.map=if( bufferid.map eq 1, 1e6, ksat1.map)
pcrcalc thetas1.map=if( bufferid.map eq 1, 1.0, thetas1.map)
pcrcalc thetai1.map=if( bufferid.map eq 1, 0.0, thetai1.map)
pcrcalc soildep1.map=if( bufferid.map eq 1, 1000, soildep1.map)
pcrcalc psi1.map=if( bufferid.map eq 1, 100, psi1.map)
asc2map --clone maskbwaise.map -D -a drainage2.txt drainage2.map
pcrcalc drainage4B.map = scalar(drainage2.map)
asc2map --clone maskbwaise.map -D -a roads2.txt road2.map
pcrcalc road4B.map = scalar(road2.map)
asc2map --clone maskbwaise.map -D -a suds2.txt suds2.map
pcrcalc suds4B.map = scalar(suds2.map)
asc2map --clone maskbwaise.map -D -a landuse2.txt landuse2.map
pcrcalc landuse4B.map = scalar(landuse2.map)
pcrcalc landuse4B.map = scalar(landuse2.map)
pcrcalc landuse4B.map = landuse4B.map/100
pcrcalc landuse1.map = landuse1.map/100
pcrcalc -f lubigi_lisem.mod 15m 2
pcrcalc veg.map=1-housecover.map
pcrcalc veg.map=1-housecover.map-roadwidt.map/15
pcrcalc veg.map=1-housecover.map
pcrcalc veg.map=if(roADwidt.map eq 15,0,veg.map)
pcrcalc veg.map*=0.5
pcrcalc -f lubigi_lisem.mod 15m 2
```

7.3. Appendix 3: Detail Steps from ArcMap to PCRaster & openLISEM

1. Create individual layers in ArcMap for the following:
    a. House cover
    b. Road cover
    c. Drainage Channel map
    d. Buffers areas
    e. Grass width

2. Convert polygon shapefile to raster
    a. For roads and drainage channel, first run a buffer in accordance to various roads and channel width, then merge all the roads and channel buffer together before converting to raster
    b. Change the cell size to 15m

3. Reclassify the newly converted raster layer by adding in new values. For instance, for roads, drainage, and SuDS buffers areas put 1 as the new value and 0 for no data. However for landuse (house cover), assign the maximum plot coverage (%) to the various uses (residential, commercial, industrial, education).
    a. In the environment settings, change the processing extent to be similar as the study area and also under raster analysis, the mask should also be similar to the study area.

4. Project the reclassified raster map so that the spatial reference is similar with all other maps that will be used in PCRaster and openLISEM. This step is only necessary when there are different map projections.
    a. In the environment settings, change the processing extent and snap raster accordingly. Likewise the mask in raster analysis.

5. Convert the newly reclassified raster layer into ASCII

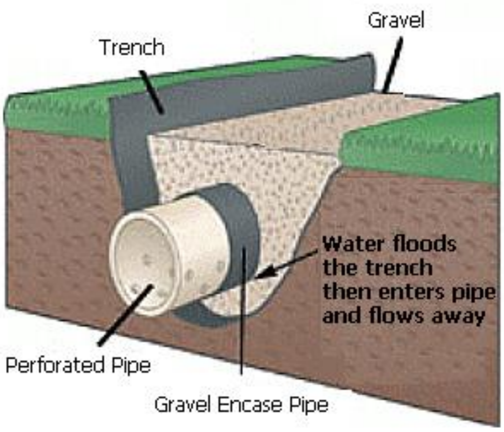
6. Open the ASCII txt file in PC Raster and type in the relevant command in order to generate maps to be used in openLISEM. E.g. asc2map --clone maskbwaise.map -D -a roads.txt road.map
    - Maskbwaise is the study area map
    - Road map is the output map (new map that will be generated)

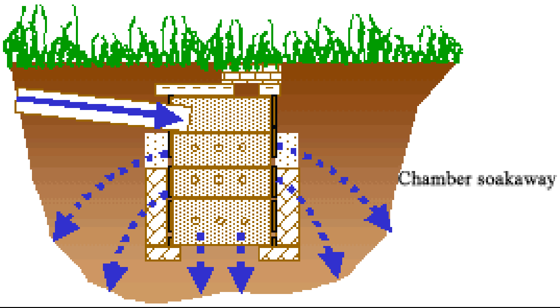
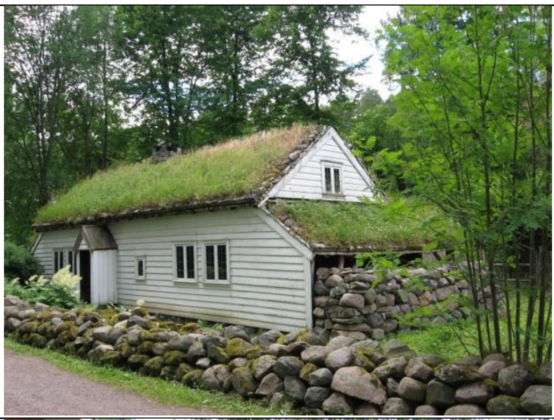
7. Change the map format to scarlar by typing another script E.g. pcrcalc road1.map = scalar(road.map)
    - Road1.map is the output map
    - Scalar(road.map) is format that you want

8. Use the maps in openLISEM to run the model

7.4. Appendix 4: Typical SuDS Components

Component/ Device	Description	Example
Filter strips	These are wide, gently sloping areas of grass or other dense vegetation that treat runoff from adjacent impermeable areas	
Swales	Swales are broad, shallow channels covered by grass or other suitable vegetation. They are designed to convey and/or store runoff, and can infiltrate the water into the ground (if ground conditions allow)	
Infiltration basins	Infiltration basins are depressions in the surface that are designed to store runoff and infiltrate the water to the ground. It has an underground structure which helps to soak water. They may also be landscaped to provide aesthetic and amenity value	

Component/ Device	Description	Example
Wet ponds	Wet ponds are basins that have a permanent pool of water for water quality treatment. They provide temporary storage for additional storm runoff above the permanent water level. Wet ponds may provide amenity and wildlife benefits	
Extended detention basins	Extended detention basins are normally dry, though they may have small permanent pools at the inlet and outlet. They are designed to detain a certain volume of runoff as well as providing water quality treatment	
Constructed wetlands	Constructed wetlands are ponds with shallow areas and wetland vegetation to improve pollutant removal and enhance wildlife habitat	
Filter drains and perforated pipes	Filter drains are trenched that are filled with permeable material. Surface water from the edge of paved areas flows into the trenches, is filtered and conveyed to other parts of the site. A slotted or perforated pipe may be built into the base of the trench to collect and convey the water	

Component/ Device	Description	Example
Infiltration devices	Infiltration devices temporarily store runoff from a development and allow it to percolate into the ground	
Pervious surfaces	Pervious surfaces allow rainwater to infiltrate through the surface into an underlying storage layer, where water is stored before infiltration to the ground, reuse, or release to surface water	
Green roofs	Green roofs are systems which cover a building's roof with vegetation. They are laid over a drainage layer, with other layers providing protection, waterproofing and insulation	
Water harvesting	Direct capture and use of runoff on site. Rainfall runoff can be extracted for domestic use (e.g. for toilets) etc.	

7.5. Appendix 5: SPSS Analysis – Interview Results

1. 53.8% of interviewees are tenants, 36.7% are lessees, while the remaining 5% are tenants.

2. A total of 83.3% of inhabitants who were interviewed are residing in Mailo land, 8.3% are residing in freehold land, and 3.3% on leasehold land.

3. Majority of the people interviewed (91.7%) are residing on land area below 1000m². While only a few people (6.7% and 1.7%) are residing on land above 1001 and 2501m².

4. 66.7% of the properties interviewed are residential, 18.3% are mixed use, while 8.3% are commercial and 6.7% are industrial.

5. Majority of the respondents (43.3%) are living in the same house for less than five years, 15% stayed in the same house between six to ten years, while more than 41.7% have stayed there for more than eleven years.

6. In terms of flood experience, 56.7% of the residents have experience flooding in the past while the remainder of the interviewees have no flood experience at all.

7. 28.3% of the residents are planning to relocate in the future due to the problems of flooding, 25% have no relocation plans at all, 18.3% are undecided and 28.3% have no comments to make regarding this matter.

8. Only 35% of respondents have some sought of rainwater harvesting during rainy days and the rainwater drains to some form of drainage system near their residents, whereas 65% of residents have no form of drainage system and the rainwater just drains freely along the ground.

9. In terms of rating the nearby drainage system that is close to the respondent's property, 70% rated that the drainage system is poor while 26.7% says that it is fairly good, the remaining 3.3% have no comments to make on this regard.

10. In terms of the SuDS concept, 61.7% has already have some understanding about the various SuDS concept while the remaining 38.3% have no SuDS understanding at all.

11. 53.3% of the residents responded that they are prepared to make alterations to their property for the purpose of accommodating the natural method of draining water. However, 41.7% of the respondents are not willing to make changes to their property and 5% have no comments to make regarding this matter.

12. In terms of willingness to cooperate with the City Authority to address the flooding problems, 98.3% are willing to do so whereas 1.7% has no comments about it.

13. In terms of their willingness to install SuDS techniques, 73.3% of interviewees responded positively about it where the rest are a bit sceptical about it.

14. When asked about some of the reasons for installing SuDS, 48.3% responded that SuDS helps to prevent flooding in their property, 21.7 responded that it helps to improve their community's standard of

living, 20% responded that it helps to reduce the volume and speed of runoff, and 10% responded that it is a method used to save money.

15. In terms of their willingness to sell part or all of their property for the purpose of accommodating SuDS, only 13.3% of the respondents are willing to do so while the majority (86.7%) of the respondents are still not willing to cooperate or are still undecided about the matter

Other issues raised by the respondents in the study area

Issues Raised by the Interviewees	Percentage
The drainage channel is very narrow and needs to be widened	28.0
Regular cleaning and maintenance of the drainage channel is required	20.4
Rubbish should not be disposed in the channel so rubbish collection needs to be improved	17.2
More and better drainage channels needs to be constructed	11.8
Tertiary drain that connects to the secondary channel needs to be well constructed	10.8
Proper planning is required for houses to be constructed in accordance with the plan	3.2
Culverts and drainage to be installed on roads to prevent flooding	3.2
Houses to be constructed on higher ground to prevent flooding	2.2
Mosquito spraying along the channel should be carried out regularly	1.1
More awareness is needed about the importance of SuDS techniques	1.1
Experienced engineers in the field of runoff and drainage needs to be consulted	1.1

7.6. Appendix 6: Household Interview Questionnaire

This interview is mainly about Sustainable Drainage Systems which is an alternative solution when dealing with surface water runoff for the purpose of flood management and it has become an increasing important concept nowadays. This approach tries to manage water as closely as possible to what nature has intended (simply nature's way of dealing with rainfall), before it enters the watercourses (any flowing body of water, e.g. rivers, streams and lakes), therefore removing the water quickly and efficiently in a sustainable manner.

Your participation in this questionnaire based interview will assist me in the completion of my MSc. thesis. I do appreciate your willingness to participate in this interview and be rest assured that your contribution will be kept as confidential.

Optional

Name: ____

Gender: _______________________________________

Occupation: ____________________________________

---

1. Interest on Site

1. Owner	
2. Lessee	
3. Tenant	
4. Others (Specify)	

2. Type of land ownership/Tenure Systems

1. Mailo Land	
2. Leasehold land	
3. Freehold Land	
4. Customary land	

3. Area of Site

1. Below 1000m^2	
2. Between 1001 to 2500m^2	
3. Above 2501m^2	

4. Type of Property

1. Residential	
2. Commercial	
3. Industrial	
4. Other (Specify)	

5. How long have you been staying in this house?

1. Less than 5 years	
2. Between 6 – 10 years	
3. More than 11 years	

6. Have you ever experience any flood event while staying in this house?

1. Yes	
2. No	

7. Was the interior of your house flooded?

1. Yes	
2. No	

7b. If Yes, Are you planning to relocate in the future?

1. Yes	
2. No	
3. Undecided	

8. Where does the rainwater from your roof drain? Also make observation whether the property has a roof rainwater gutter to convey water!

____
____
____
____
____

9. How do you rate the current drainage framework that is close to your property?

1. Poor	
2. Fairly Good	
3. Good	
4. Great	

10. Are you aware that the existing drainage may not cope with the changing climate in the future?

1. Yes	
2. No	

11. Do you have any understanding regarding Sustainable Drainage Systems (SuDS)?

1. Yes	
2. No	

***Discuss with him/her about some of the relevant typical SuDS components**

12. Would you consider draining your rainwater naturally to save money in the long term?

1. Yes, I would be prepared to make alterations to my property to save money	
2. No, I would not be prepared to make alterations to my property	

13. Do you understand that any development that is carried out upstream will have flooding consequences downstream?

1. Yes	
2. No	

14. Are you willing to cooperate with the City Council and the National Government to address the flooding problems downstream?

1. Yes	
2. No	

15a. Would you be interested in installing some SuDS techniques on your property (e.g. rainwater harvesting, permeable surface, filter drains, filter strips, swales)

1. Yes	
2. No	
3. Undecided	

15b. if Yes, Why do you think it's important to install some of the SuDS techniques on your property?

____
____
____

16. Should there be a need, are you willing to sell part or all of your land for the purpose of accommodating any SuDS Techniques?

1. Yes, I am willing to sell part or all of my land in order to accommodate SuDS techniques	
2. No, I am not willing to sell part of my land	
3. Undecided	

17. Any additional comments you want to make about flooding or other issues in general regarding this neighbourhood.

____
____
____
____
____
____

THANK YOU FOR YOUR TIME AND COOPERATION