UNIVERSITY OF CAPE COAST

APPLICATION OF NATURE BASED INTERVENTIONS FOR FLOOD CONTROL WITHIN GREATER ACCRA METROPOLITAN AREA, GHANA

JOEL BERNARD ASIEDU

2020

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APPLICATION OF NATURE BASED INTERVENTIONS FOR FLOOD CONTROL WITHIN GREATER ACCRA METROPOLITAN AREA, GHANA

BY

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Thesis submited to the Department of Crop Science, College of Agriculture and Natural Sciences (CANS), University of Cape Coast in Partial Fulfilment of the Requirements for the Award of Doctor of Philosophy Degree (Crop Science)

OCTOBER, 2020

DECLARATION

Candidates Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this universitz or elsewhere.

Candidates Signature ………………….. …………Date……………….……

Name……………………………………………….…………..……………..

Supervisors Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature…………..…………… Date…..……….

Name………………………………………………………..…………………

Co-Supervisor's Signature ………………..…..……… Date………………

Name……………………………………………………….………………

ABSTRACT

Conventional engineering approaches have been used for stormwater management to control floods within the Greater Accra Metropolitan Area (GAMA) but recently, the concept of "nature based" approaches have emerged as good alternative or compliment to the conventional approach. This research seeks to address the question "why the existing conventional system of stormwater management has failed to control floods and how the problem can be addressed." The main objective was to develop and design a stormwater management system that could complement the existing conveyance based system within GAMA. The specific objectives were: (1) to assess the existing stormwater management system to determine the causes of its failure, (2) to develop a strategy or strategies to manage stormwater to complement existing systems and (3) to design action strategies that integrate identified stormwater management interventions. Research for Design was the research strategy used to generate and integrate ideas in the process of generating form_through using a combination of research methods and design methods. The first objective was addressed through the systematic review of relevant literature sources on the causes of floods. The results of the review identified two major challenges; the need to separate critical from non critical causes of floods and the absence of policy on stormwater management which is grounded on local content. The second objective was met using the Soil Conservation Service Curve Number approach to model direct runoff which showed that between 14.7% and 32.6% of stormwater runoff which accumulate in communities originate from the roofs of buildings. This was used to develop a strategy which targets stormwater management at the plot level. To meet the third objective, the developed strategy was implemented by integrating three nature based interventions (Infiltration well, infiltration trench and rainwater harvesting) at the plot level to retain up to 95% of stormwater generated from the roofs of buildings. In conclusion, the research showed the significant contribution of roofs to runoff generation and contributes to existing knowledge by providing the basis for a strategy for stormwater management at the plot level, which could form the foundation for the development of a policy on stormwater management to control floods.

KEYWORDS

Research for design,

Causes of floods,

Stormwater management,

Curve Number,

Green infrastructure,

Schema

ACKNOWLEDGEMENTS

I wish to express my deepest appreciation to my supervisors (Doktor vater) Prof Dr Ing Soeren Schoebel-Ruschmann and Dr Kofi Nyarko for their patience in guiding me through this work. My appreciation also goes to my family for their support, the School of Agriculture for taking the risk to finance aspects of my field data collection, and the University of Cape Coast for offering me the opportunity to pursue a higher degree. I cannot complete this list without acknowledging Prof Stephan Pauleit, Prof Karl Auerswald, Prof Peter Latz, Dr Bernhard Foester, Dr Mengistie Kundu all of the Technical University of Munich who at critical stages in my research were my compass, guiding me through a maze.

DEDICATION

This work is dedicated to my parents Edwin Asah Asiedu and Joana Cordillia Asiedu and my sweet and hard working wife, Ellen.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF PLATES

Plate Page

APPENDIX FIGURES, TABLE AND MAPS

Appendix Figure Page

LIST OF ACRONYMS

FDD	–	Focus Design Discussion
LID	–	Low Impact Development
LLSite	–	Living Lab Site
UNEP	–	United Nations Environment Programme
CRED	–	Centre for Research on the Epidemiology of Disasters
UNISRD	–	United Nations Office for Disaster Risk Reduction
UN	–	United Nations
IED	–	Imperviousness Elevation Distribution
IMP	–	Integrated Management Practice
LID	–	Low Impact Development
GI	–	Green Infrastructure
AASHTO	–	American Association of State Highway and Trnsportation Officials

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

The incidence of flooding in urban areas is increasing in extent, intensity and cost of damage across the globe. Jha (2012) in Cities and Flooding states that flooding events are becoming more costly in terms of damage to property and infrastructure, human life, and effect on socio-economic activities. The year 2018 produced the highest number of flood related disasters making up about 35% of the recorded disasters with 3640 fatalities worldwide (Löw 2019).

Taubenböck (2011) has made the case that flooding across the globe is likely the number one “natural disaster” “event” with the most adverse effect on life and that data supports a clear trend in increasing incidence of “hydrological disasters” dating back to the 1980s. Similar conclusions have been drawn by (CRED/UNISDR 2016, Wallemacq 2018) showing floods as a global threat. EA (2011), Asumadu-Sarkodie (2015) have also shown that the incidence of flooding is increasing worldwide in extent of damage and cost.

In continental Africa "flooding" is the number one natural hazard event that is negatively impacting on development in urban areas, where the incidence have "sharply" "increased" over the past decades. This is supported by statistics which shows that from 1900-2010 a total of 754 major flood events occurred in Africa with the most heavily affected countries being Ethiopia (49 disasters) and Algeria (45 disasters). This off-course likely ignored minor ones which were not reported (Bhattacharya-Mis 2011). Yaghmaei (2019) Reviewed data from 2000 to 2019 on Natural disasters in Africa and drew similar conclusions. Ouikotan, van der Kwast, Mynett and Afouda (2017) confirms this trend by showing that the frequency of "flood" related "disaster" "events" have increased during the past four decades from only 4 to 19 through to 105 with corresponding fatalities of 0 to 252 through to 1155 respectively in the West Africa sub-region alone. They also reported that between 2010 and 2015, there were 57 flood related disaster events with 1169 fatalities.

In Ghana, as in other countries in Sub-Saharan Africa, similar trends have been reported, where urban areas experience perennial floods during the rainy season. In fact the situation has become so bad that Tengan (2016) describes it as an "annual tragedy". Asumadu-Sarkodie (2015) reviewed flood incidence in Ghana and found that Floods constitute the number two national hazard and that between 1964 and 2014, 409 casualties resulted directly from flood related events.

Amoako and Boamah (2015) researched on the causes of floods in Accra, Ghana and found significant flood events in 1955, 1960, 1963, 1973, 1986, 1991, 1995, 1999, 2000-2005, 2007-2012. They found an increasing trend in flooding both in frequency, extent and damage to property. They estimate that the total economic loss between 2000 and 2012 was US$43.7 million with a corresponding casualty of 83, affecting 633 communities. In 2015, Ghana experienced a major flood disaster which resulted in about 200 fatalities for which the reconstruction cost in restoring transportation, the water sector, and housing alone is estimated at US$105 million (Dogbevi 2017).

The observed pattern of flooding resulting in extensive damage and loss of life is attributed to a number of factors the most critical of which is rainfall variability and urbanization. In recent years the pattern of rainfall has tended to extremes, with the severity and frequency of attendant flood events increasing(UNEP 2006).

Jha (2012) also identified increasing urbanization with attendant extensive imperviousness as the number one culprit together with intense precipitation as the cause of the floods.

Worldwide there is increasing trend towards urbanization and present projections show the trend will continue into the future where up to 75% of the worlds population could be urbanized by 2050 (Orum 2005, Parkinson 2005, McDonald, Forman, Kareiva, Neugarten, Salzer and Fisher 2009, Mcdonald 2009, Report 2011, ATKINS 2012). At the same time the projections are that by 2025 Africa's level of urbanization will reach 45% from the current 44.6% (Habitat 2013). In fact the projection is that Africa's urban population will triple by 2050 (Niang, Rupel, Abdrabo, Essel, Lennard, Padgham and Urquhart 2014). But continued urbanization has consequences.

Literature agrees that urbanization has led to fragmentation of landscapes (Benedict 2001, Ahern 2007, Benza 2016) which basically is the loss of natural pervious vegetated areas. The result is that stormwater runoff which could have been stored in natural places and slowly infiltrated, or trapped by vegetation and transpired or evaporated, mostly "flows" quickly across the urban landscape arriving at discharge points such as streams, storm drains in large volumes with high energy (Wibben 1976, National-Research-Council 2009, Allen 2013). The high discharge of stormwater is quickly conveyed by hydrologically efficient drainage systems which are not designed for that volume, causing the drainage system to overflow to flood surrounding settlements (National-Research-Council 2009).

The argument has been made that the increased frequency in flood events could be because of the possible impact of climate change (Jha 2012, Amoako and Boamah 2015, Frick-Trzebitzky 2018) but according to (IPCC 2012, Kundzewicz, Kanae, Seneviratne, Handmer, Nicholls, Muir-Wood, Peduzzi, Mechler, Bouwer, Arnell, Mach, Brakenridge, Kron, Benito, Honda, Takahashi and Sherstyukov 2012) there is currently not enough data to support this claim. But climate change projections show that in some parts of the world increased variability will lead to more serious floods which will increase in intensity, affecting new areas which previously were flood-free(Niang, Rupel et al. 2014). At the same time in other places the increased variability will result in less rainfall and also less surface water flow. The same projection show that increased variability could result in more erratic rainfall which may produce flash floods in urban areas (Kundzewicz 2004, Kundzewicz, Mata, Arnell, Doll, Kabat, Jimenez, Miller, Oki, Sen and Shiklomanov 2007, Bank 2012, Jha 2012, Miller 2017).

It is estimated that by 2030, about 40% of global urban land will be located in high-frequency flood zones compared to 30% in 2000 (Güneralp 2015) cited in (Itsukushima 2018) putting development, life and property in those areas at risk of floods. This is against a current situation where in Sub-Saharan Africa for instance, about 70% of the urban population live in areas exposed to floods (UN-Habitat 2012). Needless to say, the causes of floods is multi-dimensional(Okyere 2013) and in an urban area in a developing country it is fittingly described as a wicked problem. But it is clear that urbanization is not going away and in an urbanized age its impact will continue(UN-Habitat 2009) to produce more runoff than the current drainage efficient systems can accommodate, creating the environment for floods in communities and settlements.

The problem of floods has also been attributed, especially in developing countries, to the absence of a systematic approach to stormwater management (Bhattacharya-Mis 2011) seen in peacemeal treatment of the problem (National-Research-Council 2009) and the absence of established institutions to address the problem(Parkinson 2005). Ouikotan, van der Kwast et al. (2017) and Tengan (2016) explain that in most developing countries drainage systems designed to combact runoff generation from the impact of urbanization is not based on science but just adhoc measures. This is suggestive of an absence of a comprehensive policy to direct action as was found by (Frick-Trzebitzky 2018) who identified a gap between policy documents developed to address stormwater management in urbanized areas and what is actualy implemented on the ground, resulting in solutions which do not work.

Ghana, a country in sub-Sahara Africa is the focus of this research. Ghana is fast becoming urbanized (Stiftung 2012, Gyekye 2013, Bank 2015) with the recently publicised population census showing a national average of 51.5%, slightly higher than the continents average of 44.6% (Report 2011). This has unfortunately put extra burden on local authorities, undermining their ability to provide critical infrastructure like stormwater management, which is effective and holistic in its output to control floods (Habitat 2013).

The research was undertaken within the Greater Accra Metropolis, the most densely populated area in Ghana, where the threat of floods creates a near panic situation for both authorities who have to prepare to meet the consequences of the flood event and the population who have to suffer through the period of the inundation, any time clouds form and it rains (Karley 2009, Studies 2012). Although the incidence of flooding has become so frequent as to be considered normal (Bhattacharya-Mis 2011) its impact and effect is well understood and appreciated by the population.

Existing Interventions - To address the challenge of perennial floods most governments favour the use of engineering methods (Afeku 2005, Zahran 2008, Karley 2009, National-Research-Council 2009, Girot 2012). This engineering method described as a “narrow” approach to stormwater management(Brown 2007) is based on a "conveyance" system premised on "quickly and safely discharging" stormwater generated run-off from impervious surfaces in built-up areas to prevent "flooding" (Chouli 2007, Echols 2008).

To improve the capacity of the conveyance system, drains are periodically dredged, desilted and the length of concrete extended (Studies 2012).

The Failure of Exisiting Interventions – Consistently the literature has shown that reliance on conventional means for stormwater management alone to control floods is not sustainable, effective or efficient (Brown 2007, Warren, Younos and Randolph 2009, Reed 2013). This is because the method fails to emulate nature which relies on retention, detention and infiltration for stormwater management (Echols 2008) causing stormwater runoff to be dispersed quicker than the natural environment can accommodate resulting in floods (Zahran 2008, Gogate 2012).

The failure of the system is also attributed to its fixed capacity, requiring periodic expansion to accommodate increases in volume due to increasing urbanization (Chouli 2007), a condition authorities in developing countries are not able to meet(Habitat 2013). The situation is made worse by the heavy cost of frequent desilting and cleaning drains of solid waste, deterring city authorities and leaving most drains silted-up and filled with urban waste, thereby reducing their capacity to accommodate increasing stormwater runoff volume (AMA 2006, Karley 2009).

The conventional system only addresses problems as they arise and in piece meal, but does not consider long term mitigating measures(Parkinson 2005, Bahri 2012). The failure of the system is also attributed to increasing extent, frequency, duration and cost of flood events (Karley 2009, Jha 2012).

The approach is also depriving both underground and surface water resources of a vital form of life; rainwater, making the whole enterprise unsustainable, especially in the light of the possible effects of climate change (European-Commission 2008, Odefey 2012).

The above failures also suggest that the urban landscape, especially in developing countries is not being adequately adapted to be resilient to meet possible threats and challenges of climate change (Institute 2008, Report 2011, Gogate 2012).

1.1.3 Proposed new approach – This is an alternative approach which addresses stormwater management to control floods and also adapt the urban landscape against the possible effects of climate change through “re-uniting engineering with the natural”(Stockman 2010, Odefey, Detwier, Rousseau, Trice, Blackwell, O'Hara, Backley, Souhlas, Brown and Raviprakash 2012, Zhang, Yang, Voinov and Gao 2016). This alternative approach is based on the use of “nature based interventions” to complement the conventional approach to stormwater management to control floods. Nature based interventions involves using Green Infrastructure or Low Impact Development (LID) techniques for stormwater management by applying ecological engineering principles to design a system that mimics the “natural process” of stormwater management to control runoff at source (CNT 2010, Odefey, Detwier et al. 2012, Yang 2013, Liu 2014, LSRCA 2016, Saraswat, Kuma and Mishra 2016, Shafique 2016, Zhang, Yang et al. 2016, Itsukushima 2018).

The technique has been successfully used to reduce stormwater volume to avert floods, including storage and reuse in the USA (PWUD 2000, National-Research-Council 2009), Australia (Brown 2007), Europe(Chouli 2007) and parts of Asia(Lim 2016). The premise is that urbanization and various human activities have severely affected (Zahran 2008) the “processing capacity” of the urban landscape (Lidy 2006) and to store run-off generated from rainfall, resulting in perennial flooding (Zahran 2008).

A nature based approach seeks to restore the processing capacity of the urban landscape through a systematic design of the urban space in which the entire urban landscape becomes the resource (McHarg 1992, Motloch 2001, Halprin 2002, Rouse 2013).

1.2 Structure of the Research

Problem Statement/Definition - Flooding in urban areas in developing countries has become a perennial problem (Tengan 2016) which the conventional engineering method of stormwater management has not been effective in addressing (Echols 2007, Ouikotan, van der Kwast et al. 2017). This has arisen primarily because of fast urbanization in developing countries, creating extensive impervious surfaces which generate large volumes of stormwater runoff from rain events which the existing drainage infrastructure is not able to accommodate, resulting in floods. The situation is worsened with a hydrologically efficient drainage system which is designed to quickly carry fast accumulating stormwater runoff from built up areas through silted up and debris chocked storm-drains, to disperse into estuaries and lagoons.

The large quantities of stormwater generated from increased urbanization and carried away by the drainage efficient system leaves little room for biodiversity to thrive and for stormwater infiltration into the ground, leading to decreased ground water recharge, and making the entire system unsustainable nor efficient (Peters and Rose 2001, Hatt 2004, Greco 2014).

Work by Frick-Trzebitzky and Bruns (2017) identified a gap between policies developed for stormwater management to control floods and what is actually implemented on the ground. The findings that such policies seem to be ad hoc extractions from foreign reports and conventions, which ends up not addressing the problems on the ground has become a familiar theme in most writings (Rain 2011, Tengan 2016, Ouikotan, van der Kwast et al. 2017).

There is a challenge in identifying the critical factors causing floods and linking them up with specific interventions to address the problem. A number of factors have been put forward in the literature as the cause of floods, and these include intense rainfall, increased urbanization, lack of development control, climate change, among others. Although there may not be sufficient data to support climate change as a direct cause of the floods (IPCC 2012, Kundzewicz, Kanae et al. 2012), the possible impact of climate change based on projections may be worsening the flooding situation. These may explain why the situation continues to worsen in a yearly cycle of floods(Tiepolo 2014).

A case in point is the Greater Accra Metropolitan Area, Ghana which was the case study for this research. The area covers a land mass of about 891 km^2 and is the most densely populated area in Ghana with a population of over 4 million people (Anonymous 2018). The area enjoys a bimodal rainfall and experiences perennial floods anytime it rains within and/or outside the metropolis. Governments over the years have tried to address the challenge using the conventional engineering approach where surface drains are constructed to quickly disperse flood waters from communities, in combination with risk management. Frick-Trzebitzky (2018) has recently observed a "shifted" in govenment approach to risk management - from relief to prevention with more emphasis on providing flood alarms to residents, desilting of drains prior to the unset of the rainy season and providing during and after flood services to affected residents. But despite these government efforts, the problem of perennial floods in urban areas has continued to worsen (Amoako and Boamah 2015, Tengan 2016).

Research Questions - The research seeks to address these questions;

a. Why has the current approach to stormwater management to control floods failed in the study area? And

b. How can the challenge of stormwater management be addressed to control floods?

Objectives - The primary objective of the research was to develop and design a system of stormwater management to control floods in an urban area to complement the existing system. The specific objectives were to;

a. assess the existing stormwater management system to determine the cause of its failure

b. develop interventions that target the management of stormwater runoff

c. determine how to integrate the interventions into a developed urban area

Significance of Research – The research is developed to address a developmental problem of flooding in an urban area in a developing country using the Research for Design model (Frayling 1993, Lenzholzer 2013, Lenzholzer 2017). The Research for Design model was used to provide the basis for the formulation of guidelines for an urban landscape and for the production of a designed structure to control floods.

The holistic approach was chosen for the research to test the theory that the urban landscape can be modelled to generate run-off close to pre-development levels to control flooding; a position supported by recent theories on design and sustainable development in landscape architecture practice (McHarg 1992, Motloch 2001, Halprin 2002, Rouse 2013). The holistic approach first promoted by Ian McHarg is a concept which embraces nature as a critical partner in addressing the challenge of flooding in an urban landscape with an end that provides both amenity and functional values in the urban setting (Herrington 2010, Armitage 2013, Yang 2016).

The research provided a platform to reinforce the position of landscape architecture in holistically addressing the issue of stormwater management to control floods in a world threatened with climate change. Finally the research was used to demonstrate how integrated use of scientific research could be a means to address complex challenges like flooding in an urban environment.

Assumptions and Limitations –

a. the research concentrate on evaluating the use of only a structural approach as a primary means for flood control.

b. Due to the extensive size of the study area, design of interventions was limited to only parts of the study but the concepts built could be replicated throughout the study area and beyond.

c. The research was limited to only quantity control of stormwater runoff because this was the most pressing need to address.

d. The research relied on secondary data most of which was spatial, and was used with limited validation. This approach was faster and more cost effective due to the limitation of time, the extensive nature of the research area and the complexity of the problem of stormwater management to control floods.

e. The primary data used in the research had limited coverage and had to be interpolated over the study area, which assumes limited variability between locations.

f. Evaluation of the design could only be after the structural design has been implemented which the limited time of the research period will not allow.

Definition of Terms

Design process: the "activities" and "operations" used in "finding out" to "address a problem" as part of a design operation(Deming 2011)

Flooding: the inundation of an area by unexpected rise of water by either dam failure or extreme rainfall duration and intensity in which life and properties in the affected area are under risk (Nyarko 2000)

Land Use: A land classification such as row of crops or pasture, that indicates a type of land use(USDA 2012).

Land cover: the biophysical state of the earth's surface and its upper subsurface(Awotwi 2014)

Landscape: a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form through-out (Hellmund 2006).The term will be used to signify both built-up and non-built up areas(Licka 2006) in this study

Landscape architecture: a profession that integrates art and science for the management, planning and design of the entirety of the physical and cultural landscape, including its vestal wilderness and its growing urbanness (Hill 1995).

Landscape elements: The "smallest structural units" such as "forests, pasture, streams, farmlands" "that can be defined using current land use, structural characteristics and social effects"(Kronert 2001, Ho 2007)

Rain Garden: a planted topographic depression that is designed to absorb rainwater that drains from impervious surfaces such as roofs, parking areas, walkways, and areas of compacted soil(Johnson 2013)

Rainwater harvesting: the redirection and productive use of rainwater by capturing and storing it onsite for irrigation, toilet flushing, and other potential uses(CNT 2010)

Research: the process of "addressing an acknowledged problem" by "building upon existing literature and making an original contribution to the body of knowledge"(Ellis 2010)

Storm water runoff: a natural component of the water cycle created by excess rain or snow-melt that runs overland and eventually reaches a river, stream, lake, ditch or pipe(Warren, Younos et al. 2009)

Watershed or Catchment of Drainage Basin: An area of land where surface water will converge or drain to the same point(ATKINS 2012).

Organization of the Research - The work was organized in seven chapters; Chapter1, Chapter 2, Chapter 3, Chapter 4, Chapter 5, Chapter 6 and Chapter 7. Fig. 1-1 summarizes and illustrates the relationship between the chapters.

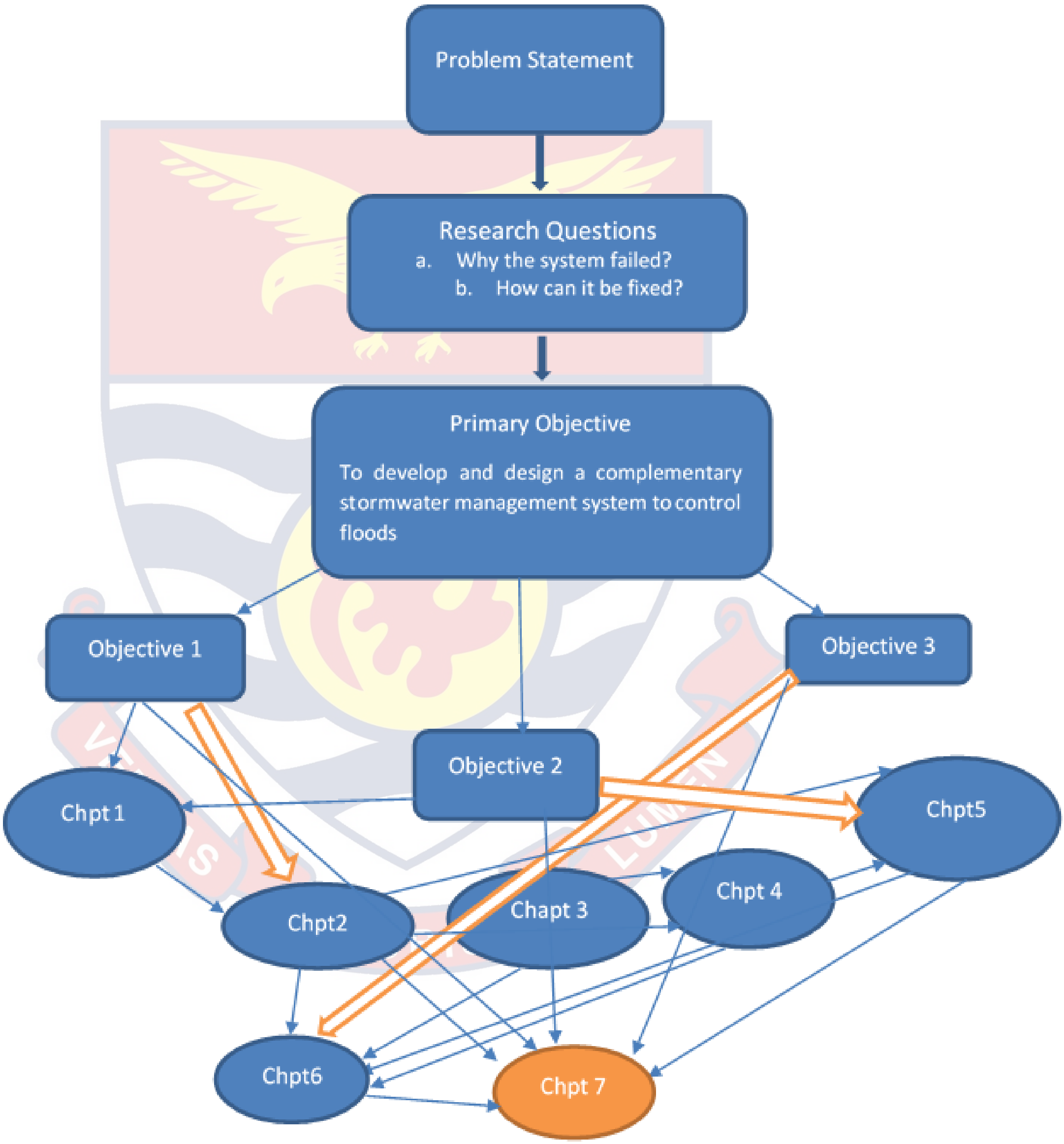


Fig.1. 1: Summary of Structure of the Research showing relationship between chapters

CHAPTER TWO

NATURE-BASED INTERVENTIONS FOR STORMWATER MANAGEMENT TO CONTROL FLOODS – A LITERATURE REVIEW

This part of the research was used to address Specific Research Objective 1- To assess the existing stormwater management system to determine the cause of its failure.

2.0 Introduction Review

The review provided a critical analysis of contemporary academic and expert literature and prevailing debates on urbanization, ecological living systems, stormwater management systems, sustainable flood management, and use of Spatial data and GIS to improve design decisions for flood management, all being themes relevant to the research. They were used to determine the relation between urbanization and flooding and how they will be intensified by climate change and various approaches being currently used to address the challenge. It established links between the causes of floods and floods and how these can be used as a guide to adapt an urbanized area against floods. It reviewed literature on the concept of the urban space as a living ecological system and how this can be used to address flooding in urbanized areas. It critically reviewed cases on the use of various interventions to address the specific challenge of flooding in urban areas. The review relied on published literature (books, journals, expert publications, etc), policy documents, legislation and appropriate web resources as its sources.

2.1 Review Methodology

To ensure a "thorough and comprehensive search" through the various sources of literature, the study adopted the "systematic review approach" (Executive 2006, Kamwamba-Mtethiwa 2016). The systematic review process is an established system of Literature review used to synthesize published and grey evidence material to identify key factors and use the evidence to inform policy (Kamwamba-Mtethiwa 2016). The approach involved the definition of the research question, drafting a protocol to define methodology and screening of the literature. Screening of the literature was done by first considering the titles and then the abstracts for keywords and phrases like 'flood', 'causes of floods', 'floods in urban areas', urbanization, stormwater management, etc. Research Methology - Landscape Architecture as a discipline does not have its own tailor- made "body of research methods" which are tools for carrying out a systematic research in the descipline, but has been building on what has been developed in other disciplines (Deming 2011, Chen 2013).

2.1 Floods and Flooding

This section is based on a publication by the researcher titled "Reviewing the Arguments on floods in Urban areas: A look at the Causes" published in Theoretical and Emprirical Researches in Urban Management (TERUM), Vol 15, 1, 2020

Several definitions of the term "Flooding" exists in the literature but for the purposes of this research flooding is defined as *the accumulation of stormwater runoff in areas which does not normally submerge and the overflow of the normal confines of a river or water body as a direct result of stormwater accumulation, possing risk to life and property* (Nyarko 2000, Kundzewicz, Kanae et al. 2012). Floods are natural phenomena but become a risk especially in urban areas because of its extent and damaging impact on life and property (Douglas 2008, OPW 2009).

Types of Floods – Two main types of flooding are recorded in the literature. These are coastal flooding and inland flooding. Coastal flooding is caused by higher than normal sea level rise as a result of storm surges, resulting in the sea overflowing the land. It is thus a direct result of high tide, storm surges, or wave action. Inland flooding is caused by prolonged and or intense rainfall which can result in overland flow, river flooding, flooding from artificial drainage systems, ground water flooding, and estuarial flooding (OPW 2009). Other forms of inland floods include "river floods, flash floods or torrential floods, storm surges", urban floods (Taubenböck 2011, Ristic 2012), surface water flooding such as pluvial flooding and sewer flooding (Kazmierczak 2011).

Any of these types of flooding can be deep or shallow resulting in slow and gradual flooding which takes hours to accumulate or flash floods which are sudden flashy, occuring with no warning signals. Where "ephemeral" rivers or "streams" which flow only during rainy periods are common as opposed to "perennial rivers" which flow throughout the year, flash floods are more common (ISWM 2006, Ortega 2014).

These types of floods considered as part of the natural hydrological cycle can happen at any "time", "place" or "location" but "presents a risk" only where life and property are at risk (OPW 2009, Watson and Adams 2011). Especially deadly are flash floods, or "surface water flooding" which is caused by "abrupt", short duration "intense rainfall" which leads to sudden rise in stream flow, resulting in death and destruction (Zahran 2008, Kazmierczak 2011, Watson and Adams 2011, Ortega 2014). Most flood-related deaths are as a result of flash floods(Zahran, Brody, Peacock, Vedlitz and Grover 2008).

In general flood events in developing countries can be “categorized” based on the extensiveness of the flood event. These categories are flooding based on “inadequate drains”, flooding due to low elevation nature of area, flooding caused by high water levels in rivers, “backup due to elevated downstream water levels” and flooding due to “blockage of the drainage system” (Parkinson 2005).

2.2 Causes of Floods

Flooding in urban areas is caused by a number of factors which may be “topological, meteorological, climatic, and biological or hydrological”(Zhang 2008). Hydrological factors relate to increased runoff generation from impervious surfaces which lead to reduced infiltration and percolation to underground water resources as both pervious land and natural dispersion structures like wetlands are urbanized (Webster 2009). “Increased” imperviousness due to “urbanization” especially “close” to water bodies or natural drainage systems is considered the most important factor which affects the hydrology of a watershed and also contributes immensely to increased volume of stormwater runoff within a catchment, turning the urban area into a “flood driver”(Warren, Younos et al. 2009, Llasat 2010, Okyere 2013). This concept of a flood driver stems from a condition where an entire community of urbanized surfaces is made to behave like a channel through which large volumes of high speed floodwaters generated from impervious surfaces flow through during a rain event(Ortega 2014).

There are factors which go to reinforce the hydrologic situation, like "human factors" or "human activity", such as dumping of waste in drainage ways; "poor development planning" which affect the drainage capacity of an urban area; and removal of "riparian vegetation" in water "channels", weak enforcement of development control laws, development in low laying areas, etc. These may not directly cause floods but the flooding situation may be worsened, resulting in many disasters (Ristic 2012, Okyere 2013, Abeka 2014, Ortega 2014).

Zhang et al classify causes of floods as "large scale" "natural factors" and "local scale" factors. "Large scale natural" causes of floods result from "extreme rainfall" which is influenced by "storm size". These extreme rainfall events are usually "unexpected" and stormy, generating large volumes of sediment ladended runoff that overflow rivers and streams which have been heavily urbanized. Where urbanization has destroyed hydrological factors which control surface flow such as interception, storage, infiltration and evapotranspiration, the result is floods over large areas due to the large volume of runoff (Oguntala 1982, Zhang 2008, Ortega 2014).

The "local scale" factor results from "rapid urban sprawl", which creates impervious surfaces spread over a large area with no attenuating factors to control surface runoff generation. The least amount of rainfall thus generates runoff which quickly accumulates to cause floods (Zhang 2008). It is worth nothing that not all impervious surfaces have the same effect on run-off production, thus different "impervious cover" will produce different volumes of run-off and by extension different extent in flooding(Wibben 1976). Other factors which can also induce changes in the extent of a flood event are accumulation of sediments in the drainage system and constriction of channel width due to urbanization, both of which reduce channel capacity from the destruction of vegetation, especially along water courses. Where natural drainage channels have been urbanized, forward slopes made steeper, the edges straightened and all impediments to smooth and quick flow removed, stormwater is able to flow swiftly, eventually causing floods (Ortega 2014).

Soil type and the presence of vegetation play crucial roles in averting floods by slowing down the flow rate of stormwater generated runoff, "creating losses" through evapotranspiration, infiltration and storage in shallow depressions, interception by vegetation. Where the vegetation has been removed due to urbanization, the soils become exposed and compacted over time resulting in increased "overland flow" culminating in floods (Ristic 2012).

2.1.1The link between Causes of floods and Floods

Major sources of literature were reviewed in order to establish the link between the causes of floods and floods. The distribution of the case sources which formed the bulk of the literature is shown in Fig.2-1. Only 45 cases were found to contain relevant material.

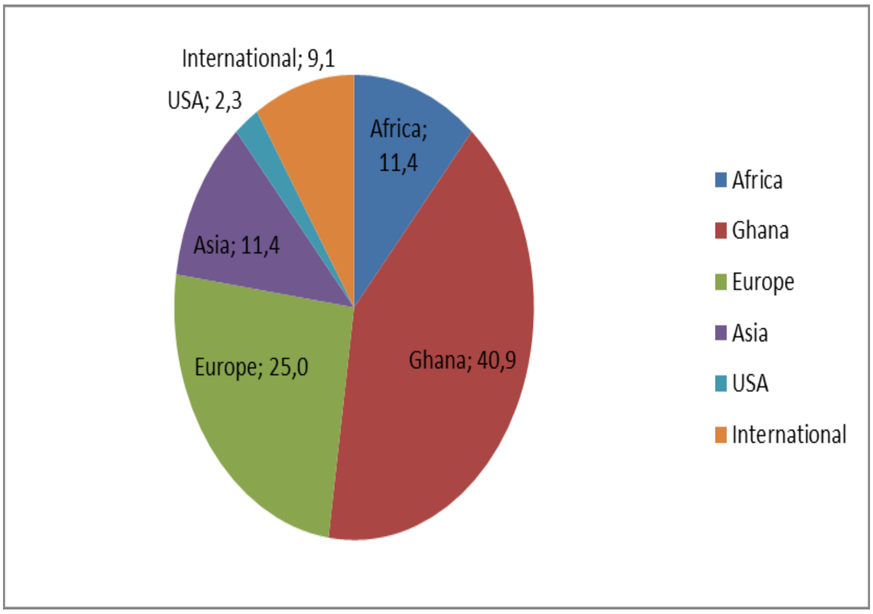


Fig.2. 1: Geographical distribution of cases identified in the literature review (Source: Author, 2020)

A large proportion of the literature reviewed (64%) were from developing countries in Africa and Asia (Fig.2.1) where a wave of urbanization has resulted in fast land cover change and attendant challenges (Rain 2011, UN-Habitat 2012).

The literature from developing countries seems to focus more on the causes of floods because those were seen as the most foundational analysis to a possible solution to the perennial floods challenge. This contrast with developed countries where the literature on floods looks more at the secondary effects of floods(Kundzewicz, Kanae et al. 2012).

There was no uniform vocabulary for describing the causes of floods across the literature, creating a number of ambiguities and in some cases the link between the cause and incidence were not clear. Also most of the literature sources only listed the causes of floods but did not follow it up with any extensive discussions to show the actual link to floods. Some of the causes were conflicting and did not seem to have any direct bearing on floods, others though were clear. For instance inadequate spatial information on flood-prome areas was cited by (Tengan 2016) as a cause of floods but no further explanations were given. Others listed population dynamics as one of the causes of floods(Frick-Trzebitzky 2018, Cirella 2019) but its link to floods was made by (Ahadzie 2011) who explained that rapid population growth especially in urban areas has resulted in haphazard development which has destroyed the integrity of the landscape to accommodate large volumes of runoff to avert floods.

The 45 literature sources identified 24 causes of floods out of which twelve scored more than 10% (Fig. 2-2).

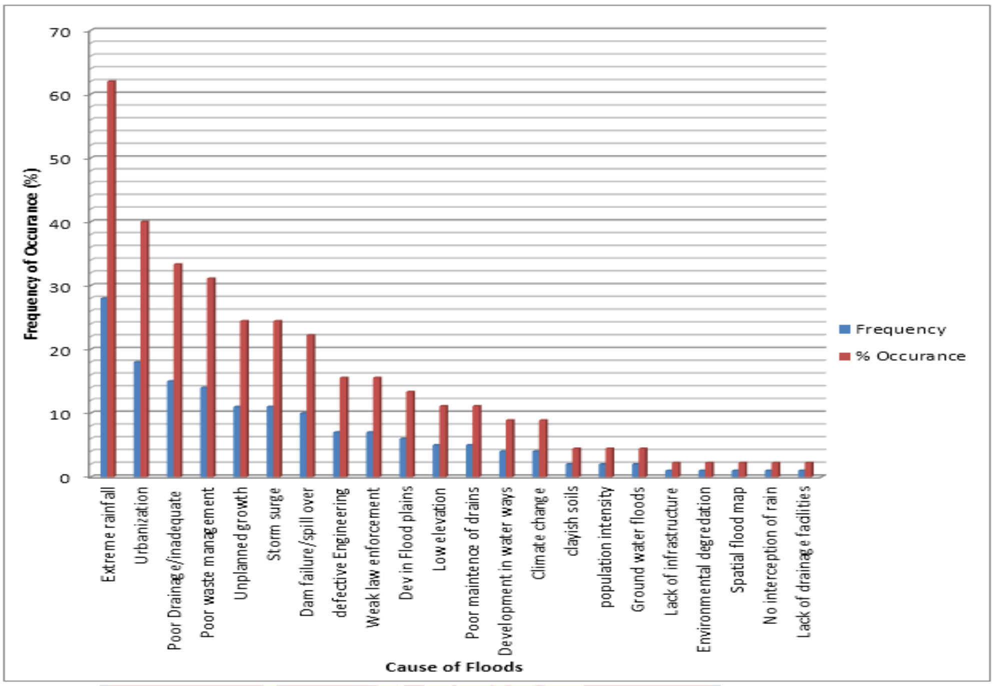


Fig.2. 2: Summary of main causes of floods (Source. Author, 2020)

Exteme rainfall- this was the most cited cause of floods (62%) and different expressions were used to express this such as short extreme rainfall, extreme rainfall, heavy rainfall, heavy and intense rainfall, and heavy storms (Twumasi 2002, Atuguba 2006, Bhattacharya-Mis 2011, Gyekye 2011, Jha 2012, Tiepolo 2014, Amoako and Boamah 2015, Asumadu-Sarkodie 2015, Hilly 2018), heavy downpour, torrential rains(Ahadzie 2011). Tapia et al., (2017) cited in (Kaendler 2018) and (OPW 2009) linked intense rainfall to floods through surcharge of urban drainage systems, or high antecedent moisture conditions(de Bruijn 2019). These phrases were used in the literature to express rainfall and duration in a qualitative form with no quantitative evaluation. The only exception was (Itsukushima 2018) who reported an intense rainfall exceeding 100mm in 1 hour as the cause of floods in an urban area. Others though make the argument that under current urban conditions, especially in Africa, the duration of rain event does not matter, as it could be short, intense, moderate or above an hour, yet produce enough runoff from impervious surfaces and drains to trigger floods(Andjelkovic 2001, Douglas 2008, Amoako and Boamah 2015).

Indeed, this is characteristic of rainstorms common in Africa and other tropical climates where short intense rain events results in flash floods that generate fast moving runoff which carry debris and with increased volume is usally violent, causing destruction to life and property as it moves through urban centers (Twumasi 2002, Douglas 2008). Douglas et al., (2008) further explain that unlike other forms of climatic events, flash floods which result from localized storms are caused by events which are hard to detect and predict using technology. This is because it is usally influenced by "urban heat island effect" which is directly related to increased imperviousness from urbanization.

Urbanization- this was the second most cited cause of floods. Kaendler et al., (2018) considered urbanization as the cause of floods and linked it to intense rainfall. Bhattacharya and Lamond (2011) discussed massive urbanization and its impact on flooding in urban areas, Itsukushima et al., (2018) implicates urbanization by referencing 20% increase in urbanized surfaces in an urban area within a 20year period and how this has affected infiltration leading to floods whilst, Oguntala and Oguntoyinbo (1982) link urbanization to lower infiltration resulting in floods. Other researchers like Hilly et al., (2018) link urbanization to high discharge of stormwater runoff resulting in floods, OPW (2009) expansion of urbanized surfaces which reduces permeability and Kundzewicz et al., (2012b) who directly links urbanization to floods.

Urbanization is defined as "the percentage of a basin which has been developed and improved with channelization and a stormwater collection nexwork" (ISWM 2010) or the land area occupied by man-made structures such as roads, roofs, towns etc., (Scholz 2004), rock outcrops and compacted soil (Rain 2011). The aspect of compacted soil is interesting but compared with developed countries, there is less imperviousnesss per unit area in developing countries (Parkinson 2005), yet the problem of floods continues to worsen.

A number of writers (Oguntala 1982, Douglas 2008, Bhattacharya 2010) have written about the role of compacted soils in runoff generation in developing countries. The explaination is that bare soils become compacted due to urban activities, affecting the structure of the top 150-200 mm of the soil. This goes on to affect the infiltration capacity of the soil, altering the flow path of surface runoff towards receiving natural storage structures, leading to higher runoff generation. Where urbanization has been rapid, the impervious surfaces limits infiltration and storage of stormwater generated runoff in the landscape even more (Oguntala 1982, Douglas 2008).

Liu et al., (2015) adds that urbanization results in the displacement of pervious surfaces with impervious surfaces and progresses with the "extent of impervious surfaces" (Rain 2011). Thus rainwater that once soaked into fields and forests now runs off "hard" and "impervious surfaces" as run-off (Odefey, Detwier et al. 2012) and as these surfaces increase in extent due to urbanization, the volume and velocity of run-off also increases, giving soils little time to absorb stormwater and infiltrate. This way rain falling on impervious surfaces takes a short time to produce runoff ["time to peak"] because there is little infiltration, with an equally short time to travel across a watershed [reduced lag time] (EPA 2001, NEMO 2005, Warren, Younos et al. 2009, Garrison 2011, Okyere 2013, Shafique 2016).

Urbanization also results in channelization of drainage systems where previously natural courses are made drainage efficient by concrete lining, forward "slopes made more uniform", curves and other obstructions removed to ensure a smooth and quick discharge of stormwater runoff (Raghunath 2006, Liu 2015). "These changes" results in large volumes of stormwater runoff being generated (Raghunath 2006), which the urban landscape is not able to contain, resulting in floods. The situation is worsened when a fast growing urban population is forced to seek shelter, creating unregulated, unstructured and uncontrolled development in areas prone to floods. Such developments has the added effect of reducing infiltration of stormwater runoff leading to runoffs six time higher than that which occurred prior to the invasion (ActionAid 2006, Bhattacharya-Mis 2011).

The result is an urban area which generates large volumes of runoff from impervious surfaces that overwhelms existing poor drainage facilities, resulting in floods.

Inadequate drains – Lack of drainage facilities, the least cited cause of floods (2%) and inadequate or poor drainage, the third most cited (33%) are ambiguous expressions which seem to express the same idea. In some of the literature, inadequate drainage system was mixed up with poor maintenance and sedimentation from massive soil erosion causing blockage(Karley 2009), or under sized drains which cause floods when they are silted up or blocked with solid waste (Twumasi 2002). Inadequate drains as a cause of floods is also listed by (UNCT-Ghana 2015), but its exact meaning is not given. Amoako (2015) uses the expression "insufficient drainage next-work" and implies that this becomes a cause of floods when it is clogged by solid waste.

Frimpong (2014) used inadequate drainage system to refer to absence or insufficient number of conduits and channels. ILGS/IWMI (2012), Bhattacharya and Lamond (2011), WAVIN (2017) all list inadequate drains as a cause of floods but they relate it to drains not being sufficient in extent and carrying capacity. Abraham et al., (2006) associate drainage systems as a cause of floods with "missing or obstructed" drains, "insufficiency of stormwater drains" or "under capacity drains". Poor or inadequate drainage is also listed as a cause of floods by (Xeflide 2007, Kundzewicz, Kanae et al. 2012, Okyere 2013, Tengan 2016, Miller 2017) but no explaination is given on its actual link to floods.

Poor waste management and Siltation of drains – Poor waste management was identified by 31.1% of the literature as the cause of floods. The argument is that urban areas generate a lot of waste, especially solid waste, most of which is not properly disposed off, resulting in blockage of drains(Frick-Trzebitzky 2018) and eventually floods. A similar view is shared by (Oguntala 1982) that solid waste combines with silt, wash into drains to reduce the capacity of the drains, resulting in floods.

The above suggests that the waste generated and left uncollected at homes, market places, industrial areas, along streets and those haphazardly dumped at dump sites is one of the causes of floods. Afeku (2005) and Rain et al., (2011) asked a rhetorical question, "How do waste management practices contribute to floods?" A number of scholars and reports(Afeku 2005, UNEP/OCHA 2011, Nartey 2012) have explained that only 60-70% of the solid waste generated within urban areas of Accra is properly disposed off, the rest is left along the streets, illegally dumped into drains, along waterways, left in community dump sites or dumped on vacant lots. These are washed into the drains during heavy downpour resulting in blockage of the drains and eventually causing floods.

It is also interesting to note that flood waters sometimes enter homes and carry away personal belongings which get dumped into drains to compound the problem. The effect of these sources of waste is better appreciated when at the end of a flood event authorities have to mobilize labour and equipment to clear urban centers of after-flood waste (UNEP/OCHA 2011). So far no research has tried to quantify the actual contribution of these sources of waste to the incidence of floods but (Cirella 2019), considers blockage of drains from waste the second "highest cause" of floods, adding that this actually makes worse the problem.

The connection between waste and floods is compounded by siltation or sedimentation which is recognized by 11% of the literature as a cause of floods. Nartey et al., (2012) explain that sedimentation of watercourses occurs when vegetation along the watercourses is cleared for farming, exposing the banks and litered with illegally dumped waste which get washed into watercourses and drains during heavy rainfall.

The link with sedimentation is seen where sediment ladenned stormwater runoff which is slow to disperse settles in stormwater drains, leaving large quantities of fine sand. Subsequent rain events adds to this, drastically reducing the carrying capacity of the drains and because the city authorities are already overwhelmed with other challenges of urbanization (Nartey 2012), regular desilting of drains is not made a priority. The drains become incapacitated, resulting in floods from the least amount of rainfall

Storm surge, Low elevation and Clayey soils - Storm surge was attributed as a cause of floods by 24.4% of the literature. Storm surge occurs when heavy rain events cause sea level rise, where the sea flows back unto land to cause floods inland (OPW 2009, Amoako and Boamah 2015, WAVIN 2017). This could happen in higher elevation areas but is more serious in low laying areas. The low laying nature of the land in the research area was indeed identified by 11.1% of the literature as the cause of floods.

A number of writers have suggested that floods results where urban dwellers are allowed to build in low lying areas which incidentally are usually flood prone(Abeka 2014, Amoako and Boamah 2015). The situation is worse for communities with surface water bodies which bring in large volumes of stormwater runoff during rain events. The soil characteristics of low-lying areas, was also considered as a cause of floods by 4.4% of the literature. Soils in low lying areas with high clay content reduce infiltration (Twumasi 2002, Bhattacharya 2010), and this combines with the low elevation to create a natural drainage system for stormwater runoff from impervious surfaces within the catchment to quickly accumulate to flood communities. Thus these three factors combine to cause floods but each cannot be considered in isolation as a cause of floods.

Development in low lying areas can be tied in with development in flood plains which was also cited as a cause of floods by 13.3% of the literature. Development in flood plains creates a situation where it is not possible for city authorities to provide surface drainage systems, because development in such areas is considered illegal (Amoako and Boamah 2015). There are also serious engineering challenges due to the low elevation of such areas some of which are known to be below sea level. In similar situations, areas which lie within flood plains but have been recognized by city authorities may also lack surface drains creating flooding situations.

Unplanned growth and Failure of Infrastructure - Unplanned growth was cited by 24.4% of the literature as the cause of floods. Unplanned growth or development was linked to the cause of floods through various expressions such as unplanned development in flood plains (Jha 2012), construction along water courses (Tengan 2016), inappropriate urbanization of flood plains and unwise land use policies(Andjelkovic 2001), or unplanned development combined with inadequate drainage and poor waste management (Frick-Trzebitzky 2018), uncontrolled physical development (Ahadzie 2011), poor physical planning(ILGS/IWMI 2012), poor planning and land use(Cirella 2019).

Some argue that unplanned development does not cause floods but worsens it (Okyere 2013), and others asset, it both causes and worsens the incidence of floods (Abeka 2014). However, none of the literature gave any further detail on the processes by which poor planning cause's floods.

Defective engineering - Defective engineering has been cited as a course of the floods in most developing countries and the literature produced 15.4% in support of this view. Atuguba (2006) cites poor engineering or construction of drains as the cause of floods, in terms of narrow bridges which is not able to accommodate stormwater runoff during excessive rainfall(Oguntala 1982), or poorly designed and poorly maintained drainage systems(Frick-Trzebitzky 2018), under sized drains(Abeka 2014), poor engineering works where secondary drains are designed to connect primary drains at right angles resulting in quick build-up and overflow (Karley 2009).

Climate change - Only 8.9% of the literature reviewed considered climate change as a cause of floods in urban areas. Vogel (2011) explained that urbanized areas can experience dramatic increases in the frequency of extreme weather events, such as floods, where a 100 year event could become 2-3 times more frequent. They further argue that although climate models may predict increases in some future flood events, it is possible that this could be due to increased urbanization. A similar view is expressed by (Douglas 2008) who noted that recent extreme variability in rainfall could be due to the impact of rapid urbanization and not necessarily as a result of climate change. There has been a lot of debate on the effect of climate change on floods. Generally, the trend is that there are not enough grounds to support the assertion that there is climate change based on past record of climate data (Kundzewicz, Mata et al. 2007, IPCC 2012, Kundzewicz, Kanae et al. 2012), however there is also a growing volume of research which takes the position that climate change could lead to variation in rainfall. Where the variation results in intense rainfall, the incidence of floods will increase both in frequency and extent, and with devastating effect (Jha 2012, Kundzewicz, Kanae et al. 2012). The implication is increased frequency of extreme rainfall events, where for instance 100year events could become 2-3 times more frequent (Kundzewicz, Kanae et al. 2012). This means that extreme rainfall which may result in extreme incidence of floods may be more frequent under a future climate change scenario. Various writers however maintain that climate change has already begun, citing instances like increased variability in rainfall and increase in global temperatures (Afeku 2005, Zahran 2008, Karley 2009, Rain 2011).

Direct and Indirect Causes - From the foregoing discussions the cause of floods in urban areas can be traced to three primary or direct causes; excessive rainfall, increased imperviousness, and iadequate or absence of drainage systems.

The other factors are secondary or indirect causes which include poor waste management, poor engineering of drains, development in flood plains or along waterways, the possible effect of climate change, lack of enforcement, haphazard or unplanned development, low lying nature of land, etc. In my opinion, the indirect causes actually reinforce in one way or the other the direct causes to exacerbate the flooding problem while direct causes actually cause floods.

Intense rainfall is considered a direct cause of floods. Thus floods results because the intensity of the rainfall is such as to exceed the infiltration, detention, retention and storage capacity of the urban landscape resulting in large volumes of runoff which existing highly urbanized drainage facilities do not have the capacity to accommodate(Jha 2012).

Poor or inadequate drains explained in terms of undersized drains, absence of drains or blocked drains, conduits, channels, bridges (Abraham 2006, ActionAid 2006, Amoako and Boamah 2015) is considered a direct cause of floods where large volumes of stormwater generated runoff easily overwhelms existing drainage systems to flood surrounding communities. This is an important factor since according to (Ouikotan, van der Kwast et al. 2017) drains for stormwater management are designed and built in most developing countries without any empirical basis. This way urbanization is not a direct cause of floods but creates the environment for floods to occur, acting more like a floods driver (Okyere 2013) whilst the presence of impervious surfaces and concrete channelized drains actually cause the floods(Raghunath 2006). Amoako and Boamah did an extensive work by categorizing different types of factors causing floods in the city of Accra (Amoako and Boamah 2015). Their categorization affirms that extensive imperviousness is the primary cause of floods in the urban area. This conforms with Frick, who argue that "urbanization" does not directly cause floods (Frick-Trzebitzky 2018) but rather affect the intensity and location of flood events.

2.1.2 Policy on Stormwater management - Frick-Trzebitzky and Bruns (2017) had done a comprehensive review of the literature on flood risk management on Ghana and made the discovery that there is disconnect between the policy developed by government to address the problem of flooding and what is being implemented on the ground. Similar but related observations have been made by several writers including (Tengan 2016, Ouikotan, van der Kwast et al. 2017) who noted the development of drainage systems without any sound scientific basis in Dakar and Accra, absence of a systematic approach to stormwater management in developing countries (Bhattacharya-Mis 2011) seen in peacemeal treatment of the problem (National-Research-Council 2009) and the absence of established institutions to address the problem of stormwater management to control floods (Parkinson 2005).

2.3 Imperviousness, Urban Hydrology and Flooding

2.2.0 Imperviousness - Rain (2011, p. 13) has defined impervious surfaces as "materials that prevent infiltration of water into the soil". Another definition given by Odefey et al (2012, p. 2) is any surface that cannot be effectively or easily penetrated by water, thereby resulting in run-off. These impervious surfaces include road pavement, rooftops, buildings, sidewalks, asphalted surfaces, bedrock outcrops, compacted soil, and even dams (Rain 2011, Odefey, Detwier et al. 2012, Okyere 2013). Impervious surfaces are hydrologically active surfaces and generate 100% runoff, thus the more impervious cover there is the higher the runoff generation capacity of the surface(Barnes 2002).

2.2.1 Imperviousness and spatial location**:** Within the urban landscape there is spatial variation of imperviousness otherwise called "imperviousness pattern" which is defined in "terms" of the location of impervious surfaces in a catchment area; whether upstream or downstream location, the distance of impervious surfaces from a receiving drainage system, or clustered and dispersed pattern of the impervious surface (Su 2014).

An impervious surface may be described as directly connected when it is connected to the drainage system through pipes and lined channels(Hatt 2004). It can also be by direct flow of surface runoff into the drainage system or as concentrated shallow flow (ODOT 2014). This variation within a catchment affects "hydrologic function" by influencing the "speed" and the "volume" of run-off generation(Su 2014).

Although Su (2014) found no clear effect on runoff volume generation for either clustered or dispersed impervious surface distribution within a catchment, in a simulation run between urbanized areas and forested areas, Corbett (1997) found an "independent" relationship between "run-off volume" and the relative distribution of impervious surfaces within an urbanized watershed. They also found that “increased” total “imperviousness” in a catchment affects the hydrological system by increasing the “volume” of stormwater runoff generated from an area as well as the “flow rate”.

The “distance between impervious” surface and a drainage system is one of the “most important factors regarding” the speed and volume of run-off generated in a catchment, “particularly” where stormwater run-off is not “piped directly” into a drainage channel. Where impervious surfaces in a catchment are located close to the outlet of the catchment, the impact is greater than where it is located further away. Also impervious surfaces located “upstream” of a catchment generated “disturbances” which stretched over longer distances compared with location “downstream”(Su 2014). Location downstream creates localized impact resulting in greater impact on life and property.The implication is that the “effect of urbanization” on floods in a catchment will vary from one catchment to the other even if the extent of urbanization is the same (Wibben 1976). But where impervious surfaces in an urban area is networked, the network can serve as a “stormwater superhighway” that “quickly conveys stormwater” to overwhelm drainage systems, resulting in floods (Hunt 2006).

2.2.2 Reduced time to peak: A reduction in the time to peak due to extensive “impervious surfaces” in urbanized areas results in drastic reduction in the “lag-time” between “centres of precipitation” and stormwater runoff accumulation. This allow faster run-off accumulation which leads to increased peak discharges and eventually, flooding (Zahran 2008, Okyere 2013). The implication of “reduced lag time" is that run-off will reach streams and other other drainage systems "more quickly" and in large volumes because of increased flow velocity and hydraulic efficiency due to imperviousness(UNHSC 2010). This allow stormwater runoff to leave a basin within a "short period of time", because the natural attenuating ability of the hydrological system has been destroyed through displacement with impervious surfaces (Wibben 1976, Zahran, Brody et al. 2008, Biggs 2010, Barbosa 2012).

2.2.3 Increased Flow rate: As the flow rate of the stormwater increases due to extent of impervious surfaces, other factors come into play to reinforce the flow rate. One such fact is the "energy balance" in "active" water channels which due to "constriction and modification" of the "active channel" (as a result of urbanization) creates a different form of flow so that the accumulated stormwater runoff behaves differently from normal overbank flow. In this way an entire community, a river basin, a street, a lane or alluvial flood plain is turned into a "high velocity flow channel in a semi confined environment"(Ortega 2014), with devastating impact on life and property. The effect is however made worse where energy from falling roofwater join runoff over other impervious surfaces. These combine with "drainage efficient" active channels, leading to floods (Burns 2012).

2.2.4 Vegetation: The relationship between vegetation and the water storage capacity of the earth surface may be more complicated (Viles 1990) and "not clearly understood". This makes it "difficult to generalize" (Oguntala 1982, Hamel 2013) but significantly, depending on permeability of the soils which may influence "infiltration" their primary effect is "increased interception" of rainfall.

Thus, an acre of vegetated land surface replaced with an impervious surface results in the production of "runoff volume almost 16 times" as large as the runoff volume produced prior to the replacement of the vegetation cover (Oguntala 1982, EPA 2001, Hamel 2013). A lesser ratio is suggested by Zahran et al., who states that the "proportion" of "flood" water discharged from urbanized impervious surfaces is 250% more than that in non-urbanized vegetated areas (Zahran 2008). Generally where there is a lot of vegetation dispersed within the urbanized area, the impact of floods is minimized compared to where there is less vegetation (Su 2014), although the critical mass has not been determined.

2.2.5 Effect on water resources: Where impervious cover extends is more than 10% of the upper reaches of the catchment area of a water feature, the level of deterioration of water quality increases sharply (NEMO 2005, Cacciatore 2010, Yang 2013). The continued effect is seen in decreased water "percolating capacity" which affects "watershed hydrology" leading eventually to reduction in ground water recharge potential in quantity and quality (EPA 2001, Zhang and Guanghe 2008, Zhang and Wang 2008, Cacciatore 2010).

Haase (2007) directly related increased "surface run-off" generation to reduction in "groundwater recharging rates" adding that this "subsequently" results in "low water flow". The end result is a "reduction in the base flow" of "receiving" surface water bodies and a reduction in the infiltration and storage capacity of soils (Haase 2007, Burns 2012). This has turned most of the receiving water bodies in urban areas into ephemeral water features having little to no aquatic life as there is no ground water recharge to provide base flow to keep the water bodies flowing during dry weather (Warren, Younos et al. 2009).

This trend is seriously affecting agricultural activities in urbanized areas too, especially in Sub-Sahara Africa where small scale farming is popular in urban areas. These small scale farmers depend on surface water and underground water for horticultural crops production especially during the dry seasons of the year (McCartney, Boelee, Cofie and Mutero 2007). Kundzewicz, Kanae et al. (2012) notes that as the volume and velocity of run-off increases, a greater percentage of the run-off enters directly into streams, rivers and lakes, "reducing the storage capacity" of features like wetlands, flood plains, forested land, and soils which also serve for flood dispersal. The "loss of wetlands" in most urban areas as a major flood dispersal feature has also "decreased the overall natural water absorption function" of the landscape and "increased the vulnerability of the surrounding areas to flooding" (Webster 2009).

2.2.6 Climate change: It is worth noting, that there is not much literature on the "magnitude and frequency" projected for floods in urban areas due to climate change (IPCC 2012). The situation is even worse for developing countries where there has not been any "consistent and appropriate research on flooding" until recently (Afeku 2005). However, studies in Maryland, USA suggest that climate change has a direct relationship with urbanization induced flooding. The research supported this assertion by showing that flood events with a 100year return period were found to increase in frequency to 5 years when impervious cover due to urbanization increased by 25% in a watershed(Odefey 2012). This could become worse with the possible impact of climate change.

2.4 Measuring the impact of Urbanization on Flooding

A lot of research is ongoing to quantify the "impact" of "urbanization" on the generation of stormwater runoff (Grizans 2009). This support McIntyre (2011) position that any effort to measure the impact of urbanization must go with a "quantitative description".

Early research in this area centred on "local hydraulic representations" and was later extended to "impervious thresholds" as a means to "quantify" the "impact" of urbanization on "hydrological processes" (Grizans 2009). This early research used a collection of measures such as "effective impervious surface", "measured impervious area", "extent of impervious cover", and "percentage impervious cover" or "total imperviousness" and "catchment imperviousness" (Wibben 1976, Hamel 2013).

"Percentage impervious cover" which is also expressed as "catchment imperviousness" or "total imperviousness" has been a popular means of characterizing the extent of urbanization, especially in relation to impact on hydrological processes like stormwater generated runoff (Hamel 2013). Developed in the 1970s it was used to subdivide a catchment area into low, medium, high density residential, manufacturing and commercial areas (Wibben 1976, Su 2014). It has also been used to define four categories of urban streams using the "imperviousness ratio" (IR) value and adopts other forms of quantification such as "imperviousness pattern" and "imperviousness elevation distribution" (IED)(Su 2014).

Impervious cover in an urban area is used to measure the "amount of imperviousness" and the "location" while imperviousness elevation distribution determines the direction imperviousness is likely to move towards. Accordingly elevation in each "catchment" is categorized to fall into one of three zones such as "4m, 13m, and 22m" above sea level. Surfaces with less than 13 m elevation are classified as lowlands while those greater than 13 m are hillsides. Imperviousness elevation distribution is calculated by subtracting the actual ratio of imperviousness in a catchment area from lowland area ratio (Su 2014).

Imperviousness ratio can also be used to categorize a catchment into high density areas with imperviousness ratio exceeding 40%; middle catchment with values between 30-40% and low density areas with values of 20-25%. While high density catchment areas are mostly residential areas, Middle catchment areas are usually industrial and residential land while low density catchment areas are considered as “land under construction” (Su 2014).

Wibben (1976), Hamel (2013) have related urbanization to runoff generation and argued in support of the fact that the location of impervious areas relative to a drainage channel matters in its contribution to floods. But this position is negated by the fact that pervious areas in urbanized landscapes have become sufficiently compacted to behave like impervious surfaces(National-Research-Council 2009).

Hamel (2013, p. 202) distinguished between “effective imperviousness” and “total imperviousness” and explained that the former includes impervious areas that are hydraulically connected to a drainage system and is a preferred means to estimate stormwater generated runoff while the latter (total imperviousness) will be for the general impact of imperviousness on infiltration within a catchment.

Although no exact values have been provided, some research have come up with a host of values and comparisons to give an indication of extent of urbanization based for instance on thresholds where “20% impervious cover” is quoted as level of urbanization beyond which increase in “run-off” is "dramatic"(Scalenghe 2009). Percentage vegetation or impervious cover associated with run-off is also used. Low density residential areas with 66% vegetation or "25% impervious cover" are characterized with 32% run-off compared with a high density urban centre with 20% vegetation yielding 74% run-off (Kazmierczak 2011, Burns 2012).

The impact of urbanization can also be measured in terms of the volume of runoff and sediment generation using the "run-off control factor", but this depend on the levels of imperviousness, bare soil surface and extent of vegetation within a catchment. Thus as part of the process of describing the impact of urbanization it is necessary to delineate "impervious surfaces" which are linked to less "sediment" generation but faster run-off accumulation from "bare soil" surfaces which although generate less run-off, produce a lot of sediments (Biggs 2010). The "run-off control factor" as a measure of the extent of urbanization is determined in relation with the respective "field capacity" of soils. Areas with high imperviousness usually have low run-off control factors while areas with low imperviousness have high values. The run-off control factor starts to deteriorate when imperviousness exceeds 20% and where imperviousness increases to 40-60%, surface run-off increases by 200mm/acr. In areas where imperviousness has exceeded 60%, the run-off control factor drops by 3-4 levels; at greater than 80% it drops by 5-6 levels (Haase 2007).

Measuring the impact of urbanization can be done using a catchment or neighbourhood as a development unit, although some professions like the Planners prefer the former(Su 2014). However, most research seems to rely on the catchment as a development unit. Su (2014, p.6393) used the catchment as a development unit to create divisions along a main river channel as;

downstream, middle stream, and upstream. According to this categorization, the degree of imperviousness lies parallel to the main stem of the water channel. Veenhuis also developed a number of characteristics by which the impact of urbanization can be quantified using the catchment as a development unit (Veenhuis 1986). These included the contributing drainage area and the total percentage of impervious cover which is the percentage of the total contributing drainage area that is impervious.

The total impervious drainage area is expressed as total % of impervious cover multiplied by the contributing drainage area. Coefficient of imperviousness is defined by (Veenhuis 1986) using the relation;

$$1 + \frac{total\ \%\ impervious\ cover}{100} \qquad \text{Eq1}$$

The impact of urbanization was measured using the “vulnerability” assessment by Chang (2015) to determine how vulnerable an urban area is to the threat of flooding. Vulnerability is explained in terms of the entent to which a system is affected by the adverse impact of climate variability, resulting in floods.

2.5 The Flooding Process

Most floods begin with rainfall. In every rainfall event some portion of the rain eventually becomes runoff (Chang 2015), but how much will depend on the extent of the paved surfaces; generally the greater the extent of paved surface the more run-off will be generated. For any rainfall event vegetation may intercept raindrops and store on the leaves and other parts of the plant (Critchley 1991), impervious surfaces like buildings, and water bodies may also receive and store some amount, from where the rest continue down to the ground. On reaching the ground, influenced by the nature of the “land cover”, the characteristics of the rainfall in terms of "duration of the rainfall, intensity and distribution", and soil properties, some percentage of the rainfall will be absorbed and "infiltrate into the soil". This process continues as the rainfalls until a time when the rate of rainfall (rainfall intensity) does not much the rate at which water is infiltrating into the soil. At this point the rainfall intensity has exceeded the infiltration capacity of the soil, and the rest of the rainwater them moves over the surface of the soil to fill shallow depressions, crevices or run over the surface of the ground as runoff (Critchley 1991, Chang 2015). Thus from the rainfall until the run-off, there are "losses"(Burns 2012) due to rainfall intercepted by leaves and branches called the "interception storage"(Critchley 1991), followed by "water stored" in the "soil matrix" through infiltration (Critchley 1991, Burns 2012), evapo-transpirational losses (Burns 2012) "ground water" storage and then storage in surface puddles, ditches and other depressions called "depression storage" (Critchley 1991, Burns 2012).

How much rainwater will infiltrate into the soil will depend on porosity; structure and texture, and resistance of water flow to deeper layers which is influenced by the antecedent soil moisture content, that is previous rainfall or length of dry season(Critchley 1991). Stormwater runoff will continue to be generated after the rate of rainfall (rainfall intensity) has exceeded the infiltration capacity of the soils but will stop when the rate of rainfall falls below the soil infiltration capacity. Other parameters like the soil structure may also affect infiltration.

As rainfall intensity increases "soil aggregate" may "breakdown" due to increasing size of "raindrops" and soil dispersion will result, producing fine soil particles which fill the upper pores to clog the pores in the soil. This is what forms the thin, dense and compact layer on the soil surface called “capping”, or “crusting” or “sealing”, a layer which limits the infiltration of stormwater runoff into the soil. Soils with “high clay or loam content” are the “most sensitive” to this capping effect with sandy soils being the least (Critchley 1991).

There are two types of sealing or cupping in the urban landscape; the natural and the artificial. “Natural sealing” is the loss of soil structure due mainly to soil compaction which may be from a combination of impact of direct raindrops and human activity in pervious areas (Scalenghe 2009). Artificial sealing involves covering of the soil surface with “impervious materials”. Both types of sealing results in increased runoff generation but natural sealing generates more sediment ladened runoff compared with artificial sealing. The resulting effect is not only on ecological systems in the urban environment but the sediment ladened runoff are deposited in drainage ways to reduce their capacity or are carried in flood waters (Scalenghe 2009).

Where an area is covered by “dense vegetation” the “soil surface” will be shielded from the direct “impact” of “rain drops” which reduces capping effect to encourage infiltration. Also the roots of plants and high humus content of soils increase porosity, retards surface flow especially on gentle slopes giving the water time to infiltrate (Critchley 1991). Steep sloping land yields more run-off than gentle sloping areas, also run-off volumes increase with decreasing slope length. This is because run-off has more time on gentle slopes which are long, to infiltrate and evaporate, before joining the conveyance system (Critchley 1991).

In areas where vegetation has been replaced with extensive impervious surfaces or compacted soil, and riparian areas have been urbanized, none of these protection is available leading to increased speed and volume of run-off generation and eventually flooding (Scalenghe 2009, Palanisamy 2015).

Two factors are used to describe runoff movement at this stage, "peak flow" and "lag time"(Center 2010). "Lag time is a measure of how long run-off remains within the system". Highly impervious areas have shorter lag time as run-off have no means to infiltrate the soil and will move quickly over the surface of the soil (Zahran, Brody et al. 2008, Center 2010). Areas with pervious but compacted surfaces behave like impervious surfaces and may have similarly short lag time. Peak flow is not finely defined in the literature but is the maximum amount by volume of runoff generated per rain event(Center 2010).

2.6 Approaches to Flood Control: Theories and Principles

2.5.1. Approaches to Flood Control: There are several approaches to stormwater management such as the minor and major drainage systems which are defined by their carrying capacity (Parkinson 2015) and the conventional and non-conventional systems (Burns 2010).

Minor drains are developed for frequently occurring rainfall events of 2-year to 10-year return periods while the major drains are designed for less frequently occurring rainfall events of up to 100 year return period(PWUD 2000). The major drainage system is built from natural channels and surface flow pathways (Parkinson 2015). The minor drainage system is composed of pipes and open drains and other forms of engineered flood protection including underground piping and natural waterways (CDOT 2004, Parkinson 2015). It forms the “structural control” system which uses the “drainage efficient approach” to "convey” run-off from impervious urbanized areas quickly and "directly" to receiving drainage systems with little reduction or "treatment" (Warren, Younos et al. 2009, Barbosa 2012, Burns 2012).

Extensive work has been done on the conventional and non-conventional systems of stormwater management (PWUD 2000, Andjelkovic 2001, Warren, Younos et al. 2009, Barbosa 2012, Jha 2012). While conventional approach relies on a system of conveyance, detention and retention to quickly remove stormwater runoff from built up areas to avert floods, the non-conventional system depends on a system of infiltration, retention and detention to manage stormwater runoff to control floods (Burns 2010). Both conventional and non-conventional systems have structural and non-structural components.

2.5.2 Structural and Non-Structural measures for Conventional systems - Structural control measures for the conventional drainage system are built systems used in stormwater management (Barbosa 2012) and include underground, surface drainage systems; combined and separate drainage systems, raising of foundations, use of sand bars, kerbs, gutters, pipes, detention systems, widened rainforced waterways, etc., (Parkinson 2005, Organization 2006, Warren, Younos et al. 2009, Cirella 2019).

Non-structural systems (Warren, Younos et al. 2009) are a set of activities aimed at changing public attitudes through education (early warning and evacuation, preparedness plans, emrgencz response), "governance and legislature", "financing" (Insurance, incentives system) (Urbonas 2000, Andjelkovic 2001, Warren, Younos et al. 2009, Barbosa 2012, Jha 2012, Lynn 2014)

2.5.2. Criticisms of the Minor Drainage system (Conventional stormwater management) – The system is criticized because its design is based on a "return period"(Scholz 2004) and aims at preventing flooding by quickly removing stormwater from built-up areas, a situation which is increasingly considered unsustainable and rather leads to worsening situations downstream, where previously flood free areas become flooded (Warren, Younos et al. 2009, Barbosa 2012, Burns 2012). Vietz (2016) explained that the minor drainage system concept is completely flawed, as it attempts to confine a watershed-wide problem into a small "channel".

The system is criticised because it aims at just removal of stormwater but does nothing to reduce the quantity, improve the quality nor its aesthetic value(Echols 2007). It is seen as a means to orphan underground water resources as it provides little room for infiltration and percolation of run-off to recharge ground water resources (Garrison 2011). Another criticism is that in tropical climates where run-off is usually greater than the capacity of the minor drainage infrastructure, a significant proportion of run-off occurs as overland flow, making the minor drainage system ineffective and creating flooding situations most of the time (Parkinson 2005).

Another criticism is that the system is not friendly to tropical environments. It is noted that stormwater runoff flow through a "path of least resistance" and is thus forced to conform to the rigid structural systems in an area (Watson and Adams 2011), thus a flood control system based on the minor drainage system which is designed to define the flow path of water that does not necessarily follow a path of least resistance is destined to fail in a tropical environment.

Again the conventional engineering system provides no room for biodiversity as drainage channels are concretized to facilitate swift movement of water, a process which also ensures the removal of all forms of "meanders" to shorten flow distance and also remove any form of debris in the channel (Prominski 2012). This is especially significant in developing countries where rivers and streams close to urbanized areas are channellized and used as part of the stormwater management system to control floods, destroying their ecological value (Greco 2014). Others consider this a narrow or single objective nature of the conventional drainage system(Leitao and Ahern 2002), which is focused on the most convenient solution to stormwater management problems instead of multi-functional solutions (Echols 2007). In short the conventional system does not protect ecological systems and their functions from the impact of urbanization and thus not sustainable(Burns 2010).

2.7 Alternatives to the Conventional System

Over time as these challenges associated with the conventional stormwater management and flood control system became clearer, new alternatives which sought to reduce the impact of stormwater generated runoff and its damaging effect on the environment were considered (Burns 2012), and these formed the alternative system of stormwater management. It also signalled a shift in view from a mainly exploitatory position to a conservatory position(Roorder 2012) leading to the development of "different approaches", "strategies" "collectively" called "low impact development" (LID).

This system of stormwater management has been given various names such as "Water sensitive urban design (WSUD) in Australia", "Low impact design (LID) in the USA"; or "Sustainable urban drainage system (SUDS) in the UK" and also "Load-reduction approach to stormwater management", "Best management practices" (BMPs), "Innovative stormwater management'' in Canada, "Techniques alternatives'' in France, "Low impact urban design and development (LIUDD)" (Kazemi 2011, Verbeeck 2011, Barbosa 2012, Burns 2012, Vranayova 2015).

Other researchers also associate this new approach with such concepts as Green Technology Best Management Practices (GTBMP) which are designed to resemble natural processes similar to LID (NEMO 2005) or Green stormwater infrastructure (GSI) which is also called LID(Shrestha 2018). The LID system of stormwater management can be divided into "two major categories": "source control" and "treatment"-based systems (ASCE 1998)cited in (NRMRL 2002). 2.6.1 Source control systems - Source control systems manage stormwater runoff at the point of generation before it travels any distance or pick up pollutants through the use of "non-structural measures" or "structural techniques"(Urbonas 2000, NRMRL 2002, Chouli 2007).

Structural control systems for non-conventional drainage systems are usually made from concrete or earthen material (Lynch 1971, NRMRL 2002, Chouli 2007), manufactured and/or designed and integratively installed in urban settings (Lynn 2014) either at the plot level, neighbourhood level or within an entire watershed (Chouli 2007). Thus a structural source control technique can be applied i) *insitu*, at the plot level, or ii) at the scale of a neighbourhood or, iii) end of pipe, where stormwater is treated at the end of a drainage system (Chouli 2007).

Insitu structural source control techniques at the plot level (Vranayova 2015) may include infiltration basins, infiltration trench, rain gardens, reuse/roofwater harvesting, porous pavings, etc. At the neighbourood level it may involve "Land use planning" applied through the imposition of "limits" on "flow volume" or flow rate (ASCE 1992), constructed wetlands, porous asphalt, swales, filter strips, soak aways, filter drains, local ponds, permeable pavings, rainwater harvesting (NRMRL 2002, Chouli 2007, Vranayova 2015).

Non-structural source control measures include education, street cleaning, desilting of drains, reducing levels of imperviousness, reduction of street size, limiting the degree of clearing and grading on a site prior to development(Chouli 2007, National-Research-Council 2009). At the regional level detention basins, extended detention basins, lagoons, wetland are used(Chouli 2007).

Another form of source control is "source disposal and treatment" which is targeted at reducing the "volume" of stormwater run-off and speed of flow in order to reduce pollutant loads at both plot level and neighbourhood level (Urbonas 2000). At its core, source control aims at reducing "excessive runoff"(Barbosa 2012), as well as according to (Burn et al. 2012, p.231) addressing general “hydrological changes” introduced into the urban landscape as a direct result of the stormwater runoff generation from impervious surfaces.

2.6.2 Treatment-based systems – Treatment-based systems are stormwater management strategies which treats and removes pollutants outside the confines of a plot (NRMRL 2002) relying mostly on "structural source control techniques" (Chouli 2007). This include “follow-up treatment”, a structural

BMP which is installed outside a plot at the neighbourhood level and is used to trap and treat stormwater generated runoff (Urbonas 2000).

2.6.3 State-of-the-Art LID and challenges of the system– The LID system which relies on a combination of structural control features and non-structural control features (Barbosa 2012) for stormwater management to control floods is now in vogue. Indeed the "current trend" is towards the use of a combination of "source control", "treatment" and other approaches to address the problem of stormwater management to control floods in urban areas (Urbonas 2000, NRMRL 2002).

2.6.5 The Catchment-wide approach: One school of thought that has gained currency in recent times is the concept of stormwater management across an entire catchment to control floods (OPW 2009, Hamel 2013). This approach allows for an integrated stormwater management to control floods which combines both structural and non/structural approaches as well as the proper sitting of interventions at critical points for runoff reduction and sediment control (Mar 1981, Andjelkovic 2001, NRMRL 2002, Warren, Younos et al. 2009).

Although “natural hazards” like floods canot be completely prevented, the frequency and extent could be greatly reduced by harnessing and maximizing elements and natural processes in the urban landscape using state of the art technologies (Ristic 2012).

Over the years the changing phase of stormwater management has been continuously shifting from the use of hydrologically efficient structures to reduction in stormwater runoff volumes, reduction in pollution levels and runoff volumes to the current emphasis on a more environmentally friendly approach

(Burns 2012, Su 2014). This has helped explain the connection between run-off generation, spatial location of imperviousness and drainage systems in flood control at the watershed basin level.

The premise is that the “natural landscape” has some unique built-in qualities that allow different parts to perform critical roles in stormwater management to control floods which can only be realized at the watershed level (Burns 2012, Su 2014) by combining patterns of imperviousness and drainage systems.

The new paradigm emphasises that flood management approaches should be based on measures to ensure the “flow regime” in a watershed or catchment is reversed close to the state it was before it was urbanized. The philosophy holds that addressing the challenge on a catchment-wide scale provides a means to also protect and”restore” the nature and form of surface water bodies which are key in stormwater management to control floods in urban areas (Hamel 2013, Vietz 2016). This shift is encouraging a deeper understanding of the relationship between components of the “urban” environment like “physical”,” socioeconomic”, and the “biotic” and how they “interact” to form a living “system” that can be integratively developed to achieve a more holistic stormwater management to control floods across an entire watershed (Douglas 2011).

2.8 Green Infrastructure - Holistic Approach to Flood Control

An Overview

This is a collection of artificial, semi-artificial and natural systems consciously introduced and designed into an evolving landscape to provide stormwater management as well as functional and aesthetic values. These values can be provided at the local and regional level for stormwater management and involves using a combination of interventions. The section explore the link between Green infrastructure (GI) and Low Impact Development (LID) and other technologies for stormwater management.

2.7.1 Green infrastructure, LID, SUDS and BPMs: Green infrastructure is a suite of development interventions which include the use of landscape elements and technologies variously called, rain gardens, retention basins, detention ponds, wet ponds, dry ponds, green ways, open space, bioswales, bioretention basins, constructed wet lands, infiltration wells, percolation trench, dry wells, green roofs, decentralized water management systems like "rainwater harvesting", surface water bodies and the vegetation they support, underground water tanks; all aimed at stormwater management to control floods (Urbonas 2000, Institute 2009, Dehais 2011, Odefey 2012, Yang 2013, US-EPA 2014).

Various definitions are found in the literature for green infrastructure but these definitions seem to reflect different aspects of green infrastructure, which may be biased by a particular research context, with some common threads running through like; natural, semi-artificial or artificial systems, mimic natural processes of hydrology, restore ecological systems, provide ecological functions or services to man.

Benedict (2001) define green infrastructure as "an interconnected network of green spaces that conserve natural ecosystem values and functions and provide associated benefits to human populations".

Odefey (2012) defined green infrastructure as "an approach to wet weather management that uses natural systems or engineering systems that mimic natural processes to enhance overall environmental quality and provide utility services". The Center for Neighbourhood Technology (CTN) defined green infrastructure as "a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens, and permeable pavements, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways" (CNT 2010).

Rottle (2010) consider green infrastructure as "comprised of the natural, semi-natural and artificial networks of multifunctional, ecological and low impact systems that provide ecological services while promoting the health of humans". US-EPA (2014) define green infrastructure "as structural or nonstructural practices that mimic or restore natural hydrologic processes within the built environment". Other definitions include “systems and practices that use or mimic natural processes to infiltrate, evapo-transpirate, or reuse stormwater run-off on the site where it is generated” (Rouse 2013); or “open space and infiltrating-promoting stormwater management practices which in turn can reduce peak flows and pollutant loads in surface waters”(Warren, Younos et al. 2009). From the above definitions, an operational definition for Green Infrstructure was coined to suit the context of this research as follows;

Natural, semi-natural or artificial systems designed to mimic and restore natural hydrological processes for the conservation of natural resources, ecosystem functions and to provide associated benefits to man.

The green infrastructure concept is based on the “creative” and “skilful” “design” of various elements in the landscape to address stormwater threats, providing other benefits which go to “enhance property value” and improve “quality of life”(Echols 2007). This is achieved through the use of "the natural environment" to store, filtrate, infiltrate, evaporate and evapo-transpirate stormwater in the management of stormwater runoff (Institute 2009, Odefey 2012).

Green infrastructure (GI) is considered together with LID and Sustainable Urban Drainage Systems (SUDS) and Best Management Practices (BMP) as technologies that can be used to reduce stormwater runoff volumes in urbanized landscapes (Burns 2012, Itsukushima 2018, Kaendler 2018).

Low Impact Development (LID) is defined as a comprehensive land planning and engineering design approach to managing stormwater runoff with a goal of replicating the predevelopment hydrologic regime of urban and developing watersheds(UDFCD 2010). The LID approach is composed of a number of stormwater management interventions each of which is called an Integrated Management Practice (IMP) (NRMRL 2002).

While LID is considered a structural method, BPMs are for Non-structural interventions(Kaendler 2018). But Lynn (2014) considers LID to be one category of BMP which is used within or as part of an infrastructure for stormwater management to control floods. UDFCD (2010) considered the planning dimensions to LID in which a number of BPMs may be adopted to meet targets, essentially making BMPs a subset of LID.

GI at the local and plot level is introduced to mimic natural hydrological processes in the management of stormwater but at the regional level it is used as a “multifunctional open space network”(Rouse 2013).

Rouse & Bunster-Ossa (2013) further explain that GI in modern terms has become part of the “infrastructure” for stormwater management in urban areas which is “nature-based”; a vast contrast from the conventional concrete based systems for stormwater management. This makes LIDs a sub-set of green infrastructure where LID has all the features of GI but without open spaces, parks, river side greenery, road side greenery, agricultural lands, cultivated alluvial lands, historic sites(Uy 2008, Yang 2016).

2.7.2 The Science of Green Infrastructure: The management of stormwater using green infrastructure is a science defined as “the science of managing stormwater run-off to prevent adverse impact on the environment”(NEMO 2005), and a lot of research has been published on it (Benedict 2001, Warren, Younos et al. 2009, CNT 2010, Odefey 2012, Yang 2013).

So far what has been lacking is the quantification of these variables in terms of location, extent, capacity and their integrative use to holistically perform the function of stormwater management which offer other environmental services as well (Echols 2007). This could explain why despite the much published values of the system, there is still a wide-spread lack of interest, and knowledge about the importance of the concept and the standards required to determine a good design (Echols 2007, Institute 2009).

This not-with-standing, where the concept has been adopted as an integral part of stormwater management to control floods, it has led to sustainable environments where flooding is controlled. A sustainable environment, in this sense, is defined by Leitao and Ahern (2002) as an environment in which ecological integrity and basic human needs are concurrently maintained.

The concept of green infrastructure is expressed through designs which protect and conserve the natural landscape by avoiding site preparation processes which will remove any remnants of the natural to allow the imposition of compeltely foreign objects on the site (NEMO 2005). Its implementation requires integrating interventions on a catchment-wide basis (Davis 2009, Palanisamy 2015) or in combining several interventions to form a chain of interventions (Urbonas 2000, Barbosa 2012). Of the suite of interventions classified as green infrastructure, NRMRL (2002) considers the three most important to be retention basins, detention basins and vegetative biofilters which include swales, filters/buffer strips, bioretention cells and constructed wetlands. Other green infrastructure techniques which also very relevant to stormwater management to control floods is rainwater harvesting and other infiltration based interventions. This research will be focused on aspects of these three categories; retention basins, detention basins, bioretention cells, as well as percolation trench, infiltration well, and rainwater harvesting.

The green infrastructure concept which uses either LID or other nature based approaches to manage stormwater to control floods has been developed and popularized based on research findings from mostly developed and cold countries(Gogate 2012, Shafique 2016). Shafique (2016) in a comprehensive review of bioretention systems, emphasized the need to adopt these nature based interventions in "hot regions"to determine their all weather suitability.

2.7.2.1 Biofiltration systems: Within the GI technology is a "suite of techniques"; the "Biofiltration systems, also called Bioretention systems, Biofilters", "rain gardens" "bio-infiltration" (Le Coustumer 2008, Davis 2009); "retention systems"(Industries 1993, PWUD 2000, PWUD 2000) and "Bioretention swales"(Kazemi 2011).

Le Coustumer (2008) consider biofiltration systems as "one technique in a suite of tools" for stormwater management. This is a popular “source control” intervention to manage stormwater generated runoff to control floods in urbanized areas (Le Coustumer 2008, Shafique 2016) through "capture" and storage of a limited quantity of runoff (Industries 1993) using designed structures installed in the soil in higher elevation areas (ESD 2007).

It works by filtering stormwater runoff from these limited impervious areas of about 1acre using an engineered soil mix of sand, soil and organic matter (Government 2015). Its effectiveness is in its versality as a “retrofit” in developed urbanized areas (Le Coustumer 2008) to reduce the amount of runoff generated in a given time, restore surface water flow through increased base flow, recharge of ground water resources (Davis 2009, Liu 2014, Shafique 2016, Shrestha 2018). It also increases infiltration close to generation point, as well as storage and water uptake by plants (ESD 2007).

These effects are best achieved when installation is watershed-wide (Davis 2009, Gogate 2012) and the infiltration capacity of the soils of the bioretention system is very high. This mean that poor selection of soil media will affect performance (Davis 2009, Shafique 2016). Bioretention systems are reported to be effective in total soluble solids (TSS) removal with the literature indicating removal rates of 54-60%(Shafique 2016) or up to 97% (Davis 2009, Shrestha 2018). The trapping mechanism for "TSS" removal is "sedimentation" which occurs as the stormwater is temporarily stored in the bioretention system(Hunt 2006).

Sedimentation is a "physical" process which is used to “remove soil particles, litter, and other debris" from stormwater but when the amount of sediments in a stormwater runoff is high the effectiveness of the "bioretention" system could be destroyed (Hunt 2001, Hunt 2006).

2.7.2.2 Storage systems: This consists of detention, extended detention and retention basins which are designed as storage facilities for stormwater management(ISWM 2006), using the "peak discharge approach" to control floods. This approach uses the storage facilities to contain a volume of stormwater generated runoff based on a "design storm", for a period of time, before it is discharged at an allowable release rate (NRMRL 2002). They can be categorized as "on-site" or "regional", terms relating to "location and size". "On-site" relates to location at the plot level for very large projects while "regional" relates to watershed level.

Another form of categorization is either as "online" or "off line", terms relating the storage facility to location directly within a "conveyance system" (online) or as a "separate storage facility" whose flow is routed away from the conveyance system (off-line)(ISWM 2006).

The system can be developed as a "man-made" structure or formed in an area of "natural” depression within the urban landscape with the base floor graded close to perfect flat. Turf or other permeable surfaces should be established around the system to promote infiltration, stabilization of side slopes and reduce sedimentation (Industries 1993).

Retention basins: "Retention ponds or wet ponds" are stormwater management structures designed to detain stormwater generated runoff for a long time in order to control floods (PWUD 2000, ISWM 2006, NCTCOG 2006, National-Research-Council 2009, Strom 2009, Center 2010). They are designed to store a defined quantity of stormwater runoff as well as infiltrate and percolate to recharge underground water resources (Industries 1993). They are sometimes grouped together as storage based systems and include bioretention, rain gardens, extended detention basins, sand filters, constructed wetlands ponds, and retention ponds (UDFCD 2010).

Detention systems: Another technique which forms part of the green infrastructure is the Detention systems or "Detention structures" which are designed to detain stormwater generated runoff directed to it to allow runoff to be released into the environement at a regulated rate (peak flow) which usually is up to pre-development levels or until it can infiltrate into the soil (Motloch 2001).

The literature confirms "detention basin" as a popular and successful built-in intervention for controlling peak flow in urban areas (USDA 1986) and the removal of sediments through sedimentation (Nix 1988). They are used to contain stormwater runoff for a limited period of time (PWUD 2000, Urbonas 2000, Center 2010). The detention system may consist of wet and dry detention ponds, or just detention ponds(Martin-Mikle 2015), detention basin and the "extended detention basin"(PWUD 2000).

"Wet detention ponds", also called “wet ponds”or retention ponds(Center 2010) are designed to hold stormwater generated runoff for an extended period of 14 days or more to allow for controlled release into the environment through an “outlet” and are suited for areas with high water table (Industries 1993). Where they are used for both peak flow reduction and water quality control, they may be designed to hold stormwater runoff for a longer time - giving it the "coined" name "wet extended detention basins"(Urbonas 2000, ISWM 2006, PWUD 2014).

"Detention basins", "detention ponds", or "dry ponds" on the other hand are designed to reduce the amount of runoff generated from an area per unit time (Urbonas 2000, Center 2010, Yang 2013) by "holding” stormwater generated runoff on site for a limited time and slowly releasing it through an outlet to control floods during "large storm events"(PWUD 2000, Echols 2008, Center 2010).

Detention basins are used in areas where space is not a limitation, within a catchment of at least 5 impervious acres (Water 2013, Martin-Mikle 2015). Their design should dissipate "excessive” erosion through the introduction of structures like “step-pool” or “sand beds” or “riffle pools” which will also help increase infiltration and storage (Palmer 2014) and "check dams” to control the flow of runoff (Yang 2013). The design should also ensure the volume of the basin is large enough and properly configured (Norfolk 2013).

2.7.2.3 Distinction between Retention and Detention basin: The literature clearly distinguishes between retention and detention basins although there are some grey areas. In terms of coverage, Martin-Mikle et al did not make any distinction between detention and retention ponds, stating that both are used for "catchment-scale" stormwater management(Martin-Mikle 2015). Motloch considers both as stormwater management techniques introduced to control runoff generation from urbanized surfaces (Motloch 2001). The "wet detention ponds" described as "permanently wet ponds"(Industries 1993) is also considered a "Retention pond" (PWUD 2000, NEMO 2005).

A clear distinction is made by (PWUD 2000, Urbonas 2000) who states that a "major feature" of the "retention pond" in terms of "design" "includes “a permanent pool” and a larger size to allow it to perform the critical function of removing polluting nutrients from stormwater runoff and are designed to have better aesthetics than detention basins (Urbonas 2000). Never-the-less the two are considered as similar and are described by (PWUD 2000, ISWM 2006, Strom 2009) as "storage structures" because most of their design procedures and "design characteristics" are the same, even with or without the presence of a permanent pool.

2.7.3 Challenges of the Green Infrastructure system: A number of challenges have been identified with the GI system of stormwater management to control floods. These include the large number of interventions needed to effect change, adoption of correct design standards, and maintenance. Along side these is the challenge to determine the right combination of green infrastructure interventions for an effective stormwater management to control floods (Prominski 2012).

As is required for all systems, success depends on a strict regimen of maintenance and this is even more critical for infiltration based systems which has to maintain hydraulic conductivity of between 50 and 200 mm/h to be effective (Lim 2016). Further research show a direct relationship between age of infiltration based system and hydraulic conductivity to the extent that "hydraulic conductivity" decrease by "50% with age" in some systems (Le Coustumer 2008, Lim 2016).

In some places the complaint has been about large retention basins and how poor management has resulted in unsightly developments, bad odour, breeding of mosquitoes and sedimentation which is affecting public perception and acceptance as well as the periodic maintenance of structural components (Ahern 2012). Another criticism of the system is the large number of interventions required to make an impact on a stormwater management system to control floods, especially for on-site source control systems, making it difficult and expensive to evaluate their commulative performance over time (NRMRL 2002, Garrison 2011, UDFCD 2016).

For infiltration based interventions, the problem of sedimentation and clogging could course the system to fail and this is another weakness of the system. Infiltration based interventions could also lead to underground water contamination especially when the interventions are located close to "gasoline stations", or "chemical storage areas"(Urbonas 2000). The various green infrastructure interventions also require a lot of space to be effective and efficient (Griffin 2018).

The suggested remedies have been to introduce a pre-treatment areas, increase the size of the infiltration based systems, introduce plants and use a filter media with a higher percentage of course material (Lim 2016). Using roof water will also drastically reduce the effect of sediments and thus prolong the life of the system.

2.8.5 Rainwater Harvesting for Stormwater management: "Rainwater harvesting" and infiltration are Low Impact techniques for stormwater management(Palanisamy, 2015, p. 310) and are an integral part of the concept of decentralized stormwater management(Dehais 2011). Rainwater harvesting is considered a major part of stormwater management at the local level and in the management of floods in urban areas (ActionAid 2006). It is one of the "improved sources" of water which the teaming urban population can easily access (Osumanu 2010).

Liaw (2007) consider rainwater harvesting as an "environmentally sound solution" to the urban water crisis which avoids the many problems associated with other systems of water management. Rainwater harvesting as a "source control concept" at the plot level, avoid movement over long distances, making it more cost effective than conveying and managing water on a large scale. It is a concept which also "decrease" water "demand in urban areas" and reduces the amount of runoff to receiving water bodies (Ibid. p1-2).

As an "age old practice" its successful integration and development for domestic use will not only affect the economy of Sub-Saharan Africa, whose livelihood depends on reliable water supply but will help in addressing perennial floods (Boelee 2013).

Herrmann (1999) wrote about the concept of rainwater harvesting in Germany. They explain that rainwater harvesting was for mainly non-portable uses such as irrigation, flashing of toilets, washing of clothes and cars. Until recently rainwater harvesting in Germany was only regarded as a means to "save drinking water" and that the "hydraulic effect" of rainwater harvesting on a drainage system was largely "unknown". This is because there hadn't been any effort to quantify its effect on stormwater generated runoff.

Teston (2018) found that although rainwater harvesting has been made mandatory in some parts of Brazil, its aim is to save portable water but not for stormwater management to control floods. Similar findings is made by (Gerolin 2013) in France showed that traditional rainwater harvesting was not intended for stormwater management to control floods.

Petrucci (2012) modeled the effect of rain water harvesting on stormwater generated runoff in a community in France. Data was collected from houses with rainwater tanks and used to run the model. They concluded that the effectiveness of rainwater harvesting depends on the size of the tank, catchment area and the rate of reuse of the stored water, and according to (Lawson, LaBranche-Tucker, Otto-Wack, Hall, Sojka, Crawford and Brand 2009) underground storage is often the best option.

Design Principles: A number of principles to guide the design of rainwater harvesting tanks has been proposed and this include, shared tanks and infiltration of over flow tanks from individual tanks. Over flow from shared tanks and individual tanks can be connected together into a central infiltration basin. In Germany water harvesting tanks are fitted with a porous concrete ring to allow infiltration of overflow around the tank (Ibid 3, 4). Beery looked at collaboration between the public and private home owners in stormwater management to control floods and suggested that collaboration should focus on interventions that benefit both parties, while emphasizing the repercussions on life and property where parties fail to meet their obligations in any collaboration (Beery 2018).

Challenges with the system: Boelee et al have cautioned against unregulated and wide spread use of the concept of rainwater harvesting en masse and how this could become a health hazard(Boelee 2013), but this concern will not be relevant where rain water is harvested and stored in enclosed systems for non-portable use like irrigation, washing of cars, clothes and flashing the toilet. Coombes et al also caution that the concept of on-site detention using roof water storage and infiltration is considered simple but in areas where infiltration is the dominate strategy due to lack of space or funds for storage facilities, uncontrolled and large infiltration volumes over extensive areas could create similar problems encountered with large storm discharges (Coombes 2003). These are challenges which could be addressed through modeling and the development of standards to guide design and construction derived from success stories and best practices.

The whole idea of rainwater harvesting for this research is to design to reduce peak discharge to downstream sewers at the plot level, thus "reducing the downstream flood peak" to prevent accumulation and flooding(Coombes 2000). It is the contention of the researcher that an effective rainwater harvesting system at the plot level will reduce the volume of stormwater generated runoff to the extent as to allow the existing drainage systems to effectively disperse stormwater with less possibility for fast accumulation to cause floods. By this "rainwater harvesting" could become a primary intervention in stormwater management to control floods in urban areas, especially in developing countries(Jha 2012). The effectiveness of such a system in flood control will depend on watershed wide implementation. Just like the other forms of interventions described above, "piecemeal" implementation will make it only "partially effective" in achieving its stated objective of stormwater management to control floods (National-Research-Council 2009).

2.9 Design Parameters for Interventions

The results of the literature search identified seven critical interventions; Detention/Retention basin or storage basins, rainwater harvesting, Rain Garden/Bioretention, Bioswale, Infiltration well, Percolation trench and grass swale. The following discussions will cover design considerations for each of the interventions in terms of appropriateness of selection, location, and detailed design considerations. An impermeable membrane as used in this section represents sheetings of synthetic black polyethylene and plastic sheeting with minimum thickness of 0.1524 mm, or a 30 mil vinyl sheet or geomembrane liner or roofing felt as described in (Frasier 1983, PWUD 2000).

2.9.1 Storage Systems Design: The research adopted a "hydrologic concept" for storage systems which focuses on reduction of runoff volume and recharge of ground water resources through the capture of both small and large storms of 50 mm to 250 mm of “daily rainfall" (NRMRL 2002) using retention basins and detention basins.

Depth: Retention basins should be designed to a depth of 1.5m - 3m (5-10ft) with a "bottom slope" of 2% minimum (on unpaved areas), except fishery requirements dictate otherwise and sufficiently aerated to prevent anaerobic conditions in permanent pools (PWUD 2000). Retention basins should be designed to permanently hold water with a minimum depth of 0.9 m (NEMO 2005), preferably between 1.2 m and 2.4 m deep (Strom 2009) and should be installed within a watershed with at least 5 impervious acres (PWUD 2014).

Side Slopes, Shape and Safety: Side slopes to the basin should not be steeper than 3:1 (Strom 2009) or 4:1 or flatter and the shape of the retention basin should be defined by a "basin length" to "width ratio of at least 3:1" (Strom 2009, PWUD 2014) or "2:1" with "average” ponding time of 14days or more for wet ponds (Industries 1993).

Although flatter side slopes are preferred, mainly for safety reasons (Strom 2009), the space implication could be huge. Storage systems located in residential areas should be installed with "fencing" "as a safety measure" (Strom 2009, Dziopak 2015).

Filter bed: Where a storage facility is installed in an area with high levels of surface pollution, it should be designed with a filter bed to filter off pollutants before the stormwater is released into the environment (Dziopak 2015). The filter bed should have topsoil to support plants laid to a depth of at least 0.30 m, followed by a bed of sand described as "clean medium aggregate concrete sand" to minimum depth of 46 cm (18 inches) in accordance with AASHTO M-6 or ASTM C-33 standards. This should however contain some amount of clay if it will be effective in adsorbing heavy metal pollutants (NJSBMPM 2004, Dziopak 2015, Hlavinek 2015).

Vegetation: the presence of vegetation in a retention basin serves to encourage sedimentation, filtration and infiltration of stormwater runoff into the growing media through the roots of the plants. The choice of plants is important because native plants species are known to be better as they are adapted to the environment and soil (Lim 2016)

Pre-treatment: All storage structures should be designed with a pre-treatment area which will "provide" space for large particles in a sediment-laden stormwater runoff to settle-out for periodic maintainance (Hunt 2006, Design 2014, PWUD 2014).

Other forms of pre-treatment could be a "thin strip of gravel verge" of between 200mm to 900 mm or as wide as 6 m width installed to "disperse flow" prior to entering a filtering area constructed from turf grass which should cover the perimeter of the storage system (Hunt 2006, Davis 2009).

Where space is a limitation, a forebay is recommended, but in all situations retention systems should be so designed as to avoid it being used as a "sediment trap"(Liu 2014) with “designated overflow” points designed to avoid erosion (Hunt 2001).

Return Period: Detention basins should be designed for major storm events with a return period of 2, 10 and 100 years to provide "peak flow reduction" with a "drain time" of "24-40 hours"(PWUD 2000, PWUD 2014) but maximum of 72 hrs for large storms and to prevent mosquitoes from breeding (PWUD 2014, Blansett 2016).

2.9.2 Percolation Trench: Percolation trench, also called Infiltration trench is part of the suite of infiltration based stormwater management systems which includes infiltration basins, bioretention basins, porous pavements, infiltration wells (CDOT 2004, Strom 2009). It is described by (Urbonas 2000, Strom 2009, RWRA 2011) as a "shallow" rock filled trench which is used to temporarily hold stormwater generated runoff from a catchment area of up to 5acres, to infiltrate into the "ground".

It can be installed as a stand-alone facility or in series with a detention basin or under a swale to improve storage capacity and infiltration efficiency of the swale (Abida 2006, RWRA 2011). It can be constructed sub-surface or surface and in various shapes with the popular shapes being trapezoids and rectangular (Young, Younos, Dymond and Kibler 2009, Chachar 2012).

It should be installed in areas with infiltration rate of at least 12.7 mm per hour (0.5 inch/h) and maximum allowable infiltration rate of 305 mm per hour (12inc/h), in which case a soil with hydrologic group D is not suitable (Young, Younos et al. 2009). The storage period can be extended where the trench is lined with an (impermeable) geotextile membrane. The bottom of the the trench lined membrane is then overlaid with a bed of sand to prevent the the rocks from puncturing the membrane(Frasier 1983).

Depth and Construction: An infiltration trench can be dug to 0.9 m -3 m (3-10 feet) deep and 2.4 m (8 feet) wide, "backfilled with aggregate course stone" of 38 mm - 75 mmØ before being "covered" with topsoil (min depth of 300 mm) and grassed. Alternatively it can also be "covered with sand, gravel or stone". Where the sides of the chamber are sealed, the bottom can be under-laid with a sand filter bed 150-300 mm deep to interface the infiltration chamber and the insitu subsoil for smooth infiltration of stormwater into the subsoil (PWUD 2006, Strom 2009, Young, Younos et al. 2009, RWRA 2011). Where the sides of the chamber are not sealed, the trench can be lined with a semi permeable "filter fabric" to filter off pollutants before the stormwater is released into surrounding soil(PWUD 2006).

Filter strip installation: PWUD suggest that stormwater runoff should be directed into the trench as "sheet flow" through a vegetated filter strip of at least 6 m (20 feet) wide, installed "up slope from the trench" to "capture" sediments to protect the system from "clogging". Where runoff carry a lot of sediments, a 50 ft (15m) filter strip may be installed over a slope of 1-5% along the "entire length" of the infiltration trench (CDOT 2004, RWRA 2011). Also installation should be limited to areas with slope of less than 12-15% (PWUD 2006) with the trench laid to a forward slope of 3% or flatter (Arkansas 2014).

Filter fabric: A geotextile filter fabric may be installed in areas where infiltration could affect foundations due to proximity. It can also be installed in areas with high water table or impermeability. Where infiltration rate is low, marshy conditions could develop with the continued use of the infiltration based facility. In such cases an underdrain should be installed to curt away excess runoff. Installation of a "semi permeable" "filter fabric" between the "drainage layer" and the soil media for plant growth is very important to prevent the "media from migrating” down into the “drainage layer" to cause "clogging"(RWRA 2011).

Off and On-Line Installation: An infiltration trench may be installed "off-line" and in "combination" with a "detention" system for stormwater management and flood control and will require under drains when installed in areas with infiltration rates of less than 12.7 mm per hour (0.5 inc/hr) or in areas with seasonally high water table (Arkansas 2014).

Off line installation treats runoff from isolated areas not directly connected to a drainage system. It can also be installed as part of an existing drainage system with under-drains to increase the storage volume to reduce the volume of stormwater generated runoff from an impervious area per given time for a storm with 1 or 2 year return frequency (Young, Younos et al. 2009).

Depth to Water table: An infiltration trench should not be located where seasonally high water table is less than 1.5 m (5 ft) between the bottom of the facility and the water table or where a "shallow" "bedrock" is present (CDOT 2004, Young, Younos et al. 2009). Where seasonally high water table is a problem, the facility can be underlain with an impermeable membrane with an under drain to drain away stormwater.

Proximity to Foundations and Fuel Damps: Installation must be clear of any foundation with a distance of at least 6 m (20 feet) down slope of the foundation or 30m (100 ft) up slope and not closer than 30 m (100 ft) clear from a “water supply well” or borehole (Young, Younos et al. 2009, RWRA 2011). Installation in areas close to fuel dumps/"gasoline stations", mechanic shops and car washing bays, "industrial and commercial sites" should be avoided to prevent possible contamination of underground water resources (Urbonas

2000), unless of-course, a "pre-treatment facility" can be installed (RWRA 2011).

Challenges: Challenges of these systems of stormwater management and flood control includes high failure rate due to clogging from sediments (Urbonas 2000, Strom 2009, RWRA 2011), deteriorating visual effect due to poor maintenance, development of marshy conditions (Young, Younos et al. 2009).

2.9.3 Infiltration wells or Dry Wells: Infiltration wells are small wells fitted with a leaf debris separator to receive water directly from the roof(Parkinson 2015). They are part of the suite of infiltration based stormwater management practices as explained under infiltration trenches.

Infiltration well is similar in operation to a "dry well" which is described as a "vertical well" "filled" with rocks to "temporarily" store stormwater generated runoff long enough to infiltrate into the ground (Urbonas 2000). Urbonas also considers the dry well as "similar in operation to a percolation trench", which can be installed to drain discrete impervious areas of 2 ha or less (Urbonas 2000) and could be installed to break an impermeable rock barrier to allow stormwater generated runoff to drained into more permeable layers underground (Ibid 7-8).

Similar descriptors have been used for other structures such as "underground injection control wells" and "stormwater drainage wells" (Edwards 2016). However for this research the term “dry well” is used in the strictest term as described by (Blick, Kelly and Skupien 2004, Government 2015, Blansett 2016) who describes a dry well as an "excavated pit or structural chamber filled with gravel or stone that provides temporal storage of stormwater from rooftops". A dry well can be used to drain areas with poor infiltration into deeper layers where infiltration is "possible"(Edwards 2016).

Both infiltration trenches and dry wells should be installed to receive stormwater directly from roofs, which is temporarily stored in the gravel (38 mm - 75 mm) layer (1.5inc - 3 inc diameter) before slowly percolating downward to recharge groundwater reserves (Un 2010, Blansett 2016, Edwards 2017). This way the problem of sedimentation is completely taken care of, making them an invaluable source control system for stormwater management to comtrol floods (Government 2015).

Size and Depth - They are "deeper" than they are wide with depth ranging between 0.6m to 26m and width or diameter between 0.9m and 2.0m(Bouwer 2002, Edwards 2016, Edwards 2017) or 10-50m deep (Bouwer 2002). A dry well in a residential home typically will be no more than 1.2m deep (Blansett 2016). Deep wells encourage drainage by gravitational force (Vertical Drainage) where the water table is deep but shallow wells will encourage lateral drainage especially where the ground water level is high(Bouwer 2002).

Distance from structures and Water table - The location of dry wells in relation to buildings require a set-off distance from buildings and other foundations of not less than 3m and where space is a limitation, an "impermeable liner must be installed" to prevent any negative effects(Blansett 2016) and a "separation distance" of at least 60 cm (2ft) or typically 3 m (10 feet) above the seasonal high water table(Blansett 2016, Edwards 2017). It should be located at least 7.6 m (25ft) from septic tanks, 15.2 m (50 feet) from confined water supply wells and 30.5 m (100 feet) from unconfined water supply wells(Government 2015).

Drain time - It should be designed to drain completely within 48-72hrs with a minimum design permeability rate of 5.1-12.7 mm/h (NJSBMPM 2004, Government 2015).

These standards may however be best determined from site to site as successful applications of the technique depends on "permeability of underlying soil" and the distance between the bottom of the well and the “seasonally high watertable” (Government 2015, Caldarelli 2016).

2.9.4 Grass Swale: This is also called bioretention swales; "shallow impoundments" designed to “infiltrate runoff" to "recharge ground water" (NEMO 2005). They are a type of the bioretention system designed to treat and rapidly infiltrate stormwater generated runoff through an *institu* or engineered soil. They can thus exists as a "natural system" or constructed with an engineered "filter media" laid to longitudinal "channel” "600-2000 mm wide" with a flow velocity of between "0.5 m/s for minor flood flows" to "2.0 m/s for major flood flows" (Industries 1993, Young, Younos et al. 2009, Arkansas 2014, Design 2014, Public-Utilities-Board 2014).

Slope and Construction - Longitudinal slopes should not be less than 1%, to avoid stagnation and water logging conditions. Areas with slopes of 3% - 6% are considered the optimim but should have check dams installed to prevent erosion (Urbonas 2000, Public-Utilities-Board 2014). Side slopes should be 1:4 - 1:10 (Public-Utilities-Board 2014). It should be constructed to prevent concentrated flow, typically with a "trapezoidal cross sectional channel" where the bottom is greater than 60 cm (2 feet) but not wider than 240 cm (8 feet). This will ensure a low flow speed for infiltration and removal of pollutants. The design should allow a maximum ponding depth of 450 mm (18 inch) for a 10-year design storm (Young, Younos et al. 2009).

A vegetated or grassed swale may be installed over an infiltration trench to increase the storage volume (RWRA 2011). Grass swales are usually designed for a catchment area of < 2ha (Design 2014) and in places with seasonally high ground water it should be located at least 1 m above the ground water (Lim 2016).

Rain Gardens – Rain gardens, also called Bio-filtration, Bio-filter systems, infiltration basin and are designed for small catchment areas of 1-4acres or large catchment areas with lower water table(Davis 2009). It is installed as a retrofit in built up areas to control stormwater (Dehais, 2011, p. 24; Le Coustumer, 2008, p. 6). The larger the catchment area though, the greater the challenge with watertable levels.

Size – The size of raingardens in relation to size of catchment area (ratio of size of bio-filter over size of catchment area) help determine effectiveness of the system over time (Le Coustumer, 2008, pp. 15-24) as well as control infiltration rate (Dehais, 2011, p. 29). Another important consideration is the media depth to drainage area ratio as relates to effectiveness in moderating runoff control. Larger soil media depth/drainage area ratio is considered effective in reducing runoff volume (Davis 2009).

Ponding depth - The ponding depth for a rain garden could range between 150 mm – 450 mm with a minimum subsoil infiltration rate of 1.3 cm/h. This should allow the storage bowl to be emptied at a rate of 2.5 cm/h minimum and within 40 – 72 hrs. But the deeper the ponding depth, the greater the risk of clogging, especially where the system is exposed to sediment-ladened runoff. Where sub soil infiltration rate is less such as in heavy clay soils, an under drain should be installed (Davis 2009, Dehais 2011).

Media, depth and pretreatment - The infiltrating media for a rain garden could be *insitu* soil of high infiltration rate. “Percolation tests” could be conducted at depth equal to the bottom of the raingarden to determine rate of infiltration. Infiltration rates should allow for complete draw down in 40hrs – 72hrs but where this cannot be achieved due to poor infiltration, an under drain shld be provided (PWUD 2000, Davis 2009, Dehais 2011). Alternatively an engineered soil consisting of 85-88% sand, 8-12% silt+clay, and 3-5% organic matter could be introduced in areas with very poor infiltration (Davis 2009). Deeper media depth improve water quality (but at a cost), and could be used to capture stormwater runoff directly from impervious areas. However a depth of between 450 mm – 1200 mm is adequate for a system designed to drain in 40-72 hours to prevent mosquito breeding, and to allow vegetation to establish (PWUD 2000, Davis 2009). Where the system drains impervious areas, a pretreatment area of 1 m - 1.5 m (or 3 - 6 m for extensive areas) wide lawn filter strip should be installed around the raingarden to capture sediments (Davis 2009).

Vegetation - Rain gardens should be planted with vegetation. Covering with rocks or other decorative surfacing is not ideal because sediments tend to settle quickly on the rock mulch causing clogging. Alternatively a surface covering of “wood mulch” made from a “double shredded hardwood” could be used (PWUD 2000, Davis 2009).

Slope and Distance to Foundations - Rain gardens should not be located close to foundations. A minimum distance of 3 m downhill of foundations at a slope of 5-10% from pervious areas and 2% for paved areas is recommended (PWUD

2000). This will “avoid adverse impact” on foundations which can result from “oversaturation of subgrade soil underlying a structure”. This may also result in “wetting” of soil which could cause heaving and “expansion” in some soils leading to “structural movements” and failure. Two options exists where rain garden is located close to foundations; provision of an under drain to quickly drain away soil or installation of an impermeable membrane adjacent to the foundation to prevent “seepage” to affect the foundation (Ibid p8-10, 8-37).

Bottom geometry - The bottom should be graded flat and the bottom surface area made large to prevent frequent clogging and maintenance with side slopes not steeper than 4:1 (vertical: horizontal). Where the bottom surface area is small there could be “premature failure” due to clogging (PWUD 2000).

2.10 Spatial Approaches to Flood Control

For the effective implementation of the increasingly "popular" concepts of LID, WSUD, SUDS for stormwater management to control floods in urban areas at the watershed-wide scale, a number of factors like location and placement, and the right combination of interventions must be considered. Of these factors "location" and "placement" are the most critical in determining the success of any set of interventions(UDFCD 2010), which also ensure cost effectice use of available resources (Passeport 2013, Martin-Mikle 2015).

2.10.1 Flood Risk mapping: The main approach used for this non-structural measure to flood control/stormwater management is to identify and map out flood risk zones (Nyarko 2002, Twumasi 2002). The availability and versatility of remote sensed technology has greatly increased the ability to capture and “accurately map” flooding events which have become more frequent in urban areas (Lennartz 2004).

The flood map is used in combination with “GIS information” and “hydrological modelling” tools to assess “flood risk and flood hazard” for a given return period indicating depth, and the extent of flooding for a particular place(Jha 2012). In this approach, GIS is used as a mapping tool to capture, collate, store, analyse and display spatial data on floods which can be linked to a geographic location in space and time.

This allows large volumes of data to be displayed as spatial data which can be querried simultaneously, visualized or overlaid in the form of “maps, charts and reports” to reveal “relationships, patterns, and trends” (Jha 2012).

Models may be run using different scenario with a time dimension to project the extent of effectiveness and coverage of proposed interventions, indicating which areas could be affected in a future flood event and how much damage to expect (Jha 2012). The information presented this way allows areas such as flood plains, locations below sea level, and areas with known flooding problems to be identified and demarcated as a basis to inform the public and prepare for imergency (Twumasi 2002) which can also be updated periodically with little effort .

For better risk assessment, areas exposed to flooding are usually zoned, based on the probability of a flood event occurring there within a year (OPW 2009). A flood zone designated as Zone A may have 1% chance of flooding within a given period and thus considered a high risk area; another place may be designated as zone B with a 0.1% risk of flooding, a medium risk zone; and a zone C with less than 0.1% probability of flooding designated a low risk zone. The risk level for each zone though increases with increasing imperviousness. Putting this in perspective, for an area designated as ‘Zone A’, “floods that have

1%" probability of occurring in a given year may double in extent of coverage if the imperviousness increases to more than 20% (NEMO 2005).

A key takeway in the foregoing is not just the ability to analyse large volumes of spatial data on flood events but the posibility to update the data on short notice and with little effort, a critical point in a fast urbanizing world(Fedeski 2007).

2.10.2 The Multicriteria Suitability Overlay Approach: This is an approach first proposed by Ian McHarg in which information is organized in a spatial form and layered and used to bridge the gap between scientific knowledge and a design solution to an environmental problem (Turner 2017). It is a method of spatial analysis used to "define" an ideal location for a "potential land use" such as an intervention for stormwater management to control floods, after all the necessary information for the intervention has been gathered, analysed and synthesized (Steiner 1983).

2.11 Summary of Chapter

Literature was reviewed using the systematic literature review approach. The review traced the causes of floods to three primary causes, increased and erratic rainfall, urbanization and inadequate drainage. The secondary causes work to worsen the problem and included poor planning resulting in sprawl development, development in low lying areas, problems with waste disposal leading to blockage of drains, poor development control, deffective engineering, failure of infrastructure, environmental degredation, climate change, etc.

The review looked at the different types of floods - fluvial, pluvial, urban, river, storm surges, ground water, estuarial and flush flooding and identified flash floods as the most common form of flood in urban areas which results in destruction to life and property.

The literature identified two main systems of stormwater management as the minor and major drainage systems, and the conventional and non conventional systems. The features and associated challenges of the systems were examined. The conventional system is described as hydrologically efficient and is based on the use of conveyance, detention and detention systems for stormwater management.

The challenges associated with the conventional system lead to the development of the non-conventional system. The Non-conventional system uses infiltration, retention and detention for stormwater management to control floods and is categorized as either source control or treatment based and can be structural or non-structural. The non-conventional system has been developed into a state-of-the-art technique for stormwater management to control floods and is collectively called LID, Green Infrastructure, SUDS, Water Sensitive Urban Design (WSUD) or BMP with a good track record in stormwater management to control floods.

The challenges associated with the state of the art system were also reviewed and possible solutions suggested. Some of the interventions for the state of the art techniques - infiltration based systems, retention and detention based systems and rainwater harvesting, and their challenges were also reviewed together with suggestions to overcome the challenges.

The main weakness of the non-conventional system was that to be effective in flood control large number of structures would have to be installed watershed wide making it difficult to monitor and measure effectiveness. This could be addressed by proper location of interventions.

The review then looked at the best methods for locating identified interventions for maximum effect in stormwater management to control floods.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter provides an overview of the types of data collected and the processes used in the collection, analysis and synthesis of the data. The Research Model used was the Research for Design where research is used to provide information and insights to "support" the activities (design process) which will lead to the design of a product (Lenzholzer 2017). Research for design is a highly knowledge intensive model which requires the researcher to acquire a wide range of knowledge in order to meet the trendy demand to be clear and explicit on how a design product is arrived at, and so fulfil the need to "support" every initiative in the design process with reasonable explanations (Linden 2001, Lenzholzer 2017).

Research Methods: I combined complex descriptive strategies, descriptive case study and descriptive observational strategies as explained by (Deming 2011) to gather and analyse the data. The complex descriptive strategy allowed me to use multiple sources of information (interviews, Field survey report, and field tests) which helped to provide "greater certainty" to the data collected. The descriptive case study was used to analysis various cases relevant to the research from which principles were adapted for the research. I used the descriptive observational strategy (Parametric layered approach) to develop several layers of information which were prepared as discrete sets of data.

Data was analsyed using simple statistical analysis, central tendency, ANOVA, Linear Mix Model Test (REML) accuracy assessment and multicriteria suitability overlay analysis to explain observed trends and determine the level of usefulness of spatial forms.

3.1 Data Gathering

This phase of the research included library/internet/site research, feasibility/reconnaissance study, and a field survey which formed part of the "before design" phase of the design process. The library/internet research part has been delt with in chapter 2.

Development of Brief: I developed the brief in two stages; the strategic design brief and the final design brief(Cross 1982). The brief is a statement of intent by the 'client' which for this research was the public (or user community). I developed the initial brief based on the research questions and the set objectives. This was refined into the final design brief during a public seminar at the Accra Metropolitan Assembly, Accra-Ghana in Feb 2018.

Reconnaissance - This was an almost unplanned, disorderly attempt I used to begin the process for a thorough "understanding" of the research area (Lynch 1971). This stage was confined to gathering data on "bare essentials" for the research (Ibid p13).

I begun by walking through the site, spending between 4-7 hours a day, looking and searching but with no particular focus in mind, just observing and noting the various activities and processes in the study area (Lynch 1971) and recording in a field note book and with a digital camera, the images later georeferenced to the respective locations.

Site Documentation and Research - Alongside the Reconnaissance, I sent introductory letters to government establishments about my research, including request for data on past and on-going project reports on stormwater management and flood control, soil data, land cover/ land use data, geology, etc,. Private discussions were held with experts (classified as enablers) to gauge extent of work and to gain a better understanding of the problem vis a vis the study area.

I attended a few Municipal/Metropolitan Assembly meetings involving various stake holders during which I had the opportunity to introduce my research to participants. This phase lasted for 6 weeks.

3.2 Field and Site Survey

This section was used to gather information about the site (site survey) and to determine from the users of the site why interventions to address stormwater management to control floods have failed and what can be done to solve the problem (field survey). The section begins with the methods used to collect data from users of the site on why the interventions failed and continues with site survey.

3.2.1 Field Survey and Survey Instruments

I combined the formal survey instruments, "interviews" and rapid rural appraisal approach with personal "observations" and "photography" to provide a detailed account of the research area.

Interviews**:** I combined "opportunistic" and "key informants" approaches as recommended by (Griffee 2005) and (Deming 2011) to determine the category of people to interview; community members and experts on stormwater management to control floods.

I interviewed these two categories of respondents to make simple deductions from experts and gather common knowledge from community members to help draw conclusions on the causes of floods and why interventions for stormwater management to control floods have failed. The key informants were technical officers (experts) in government establishments

(Table 4-1). The experts were in two categories. One category was directly involved with the design and development of stormwater management systems (Hydrological Services Institute and Engineering Council, Ghana) while the other category was collaborating and implementing agencies (Municipal and Metropolitan Assemblies, Survey department, NADMO, Urban Roads department etc).

Rationale for Selecting the Population**:** Technical officers from government establishments were chosen to be interviewed because they provide technical expertise on interventions to address stormwater management to control floods in communities, they are in charge of implementation of government policies on flood management and are familiar with the challenges faced at the community level in addressing flooding issues (ILGS/IWMI 2012).

The community members account for the bulk of those directly affected by flooding, thus their views are very relevant. A number of research have already been published on flooding in the research area (Nyarko 2002, Twumasi 2002, Atuguba 2006, Xeflide 2007, Karley 2009, Rain 2011) similar to other urban areas in Africa (ActionAid 2006, Bhattacharya-Mis 2011) which involved interviewing community members, thus this was to be used as a form of triangulation.

Interview Questions Design**:** Semi-structured open ended interview questions were combined with rapid rural appraisal approach in the data collection. The interviews were built around 12 open ended questions which were used to answer the key question of the research; why the current approach to stormwater management to control floods has failed and how the challenge can be addressed. The public were asked about their views on flooding while experts were interviewed on how they view the performance of the stormwater management system.

Sampling Method and Interviews**:** Technical officers in government establishments who are directly associated with flood management in communities were identified and interviewed. The interviews were "depth interviews" taken "one on one" (Deming 2011) and lasted about 25mins. The respective government establishments were identified earlier during the reconnaissance stage when a few experts were interviewed.

The community members interviewed were categorized as; on-street (on the move respondents), sedentary respondents (those in stores) and resident respondents (those in their homes) with each interview lasting about 10 minutes. Efforts to involve other important players in the communities like opinion leaders and recognised organizations were not very successful mainly because of the elaborate process of booking an appointment, requiring time which I did not have.

Background Data on Respondents: The experts interviewed from government establishments had varied educational background (Table 3-1).

Table 3. 1: Summary of Background of respondents for Interview survey

Institution	Position	Education	Level	Sex
Ga East Municipal Assembly	Planning Officer (Budget)	Planning/Sociology	MSc	M
	Planning officer (Physical plan)	Planning	MSc	F
	Works Dept	Construction Engineering Manag't	MSc	M
	NADMO Administrator	General Certificate	GCE	F
Ga West Municipal Assembly	Dept Planning Offic (budget)	Planning/Development Studies	BSc.	F
	NADMO Administrator	Business Adm.	Diploma	F
	Planning (Physical)	Planning	MSc.	M
	Deputy Works officer	Architecture	MA-GIA	M
Ga Central Municipal Assembly	Planning officer	Planning	MSc	M
	NADMO officer(s)	Economics, Social Science	BSc	M
	Works officer	Draftsman	Cert	M
Ga South Municipal Assem	Planning (budget)	Economic Policy Management	MSc	M
	Deputy Planning (Budget)	Integrated Development Studies	BA	M
	NADMO officer(s)	Social Science	BA	M
	Deputy Planning (physical)	Project Management	BSc	M
	Works	Architecture	Doc.	M
	Deputy Works	Building Technology	BSc.	M
Accra Metropolitan Assembly	Planning (Budget)	Planning	Post Grad Dip	M
	Works Dept	Construction Manag't	MSc	M
	Planning (Physical)	-	-	F
Ghana Engineering Council	Registrar/Drainage Consultant	Water Resources Engineering	MPhl	M
Hydrological Services Institute	Drainage Engineer	Hydrologist	MSc	M
Dept of Urban Roads	Dept D. Maintenance	Civil Engineering	MSc.	M
Survey Dept	Survey and Mapping Sectn	Geomatic Engineering	BSc	M
Community Water and Sanitation	Director (Retrd)	Engineering	PhD	M

Source: Field Survey, Asiedu 2013

3.2.2 Site Survey and Analysis

A site is "a web of things and activities"; a collection of natural and man-made features within which various activities are carried out. These collections of features may impose some "limitations" as well as create opportunities for an intended use, but must be comprehensively studied to understand the site in order to know how these limitations can be overcome or how these opportunities can be optimized (Lynch, 1971, pp. 4-5).

To study to understand the site "demand time and effort" (Lynch 1971) requiring several "visits to the site" (Simonds 1997). It involves understanding the condition of the site from which the designer hopes to introduce change (Lynch 1971) and how existing features and "systems" operate in relation to one another. This way one will avoid introducing interventions to make worse an already bad situation (Ibid. 9) such as an unusually high rise in the water table due to en-masse implementation of infiltration based interventions. It also involves understanding "the essential character" of the site; the critical features of the site which is the combined effect of topography, living communities developed from particular mix of plant and animal species and the way the site has been used by man (Lynch 1971).

A site survey is an effort to understand a site to be able to design interventions to address known challenges. I used the site survey as a "more systematic" way of gathering data on the study area. Thus the "purpose" of the site survey was to gather information to determine the best approach to stormwater management to control floods in the research area. It was also used to gauge the response of the site to any form of modification, to study the delicate balance maintained by the site as an ecological system, and weaknesses in its ability to manage stormwater to control floods (Lynch 1971). It involves the study of the site through observations which is recorded as a photo graphic image, or a GPS handset, spatially displayed as a map, or annotations on a map of the study area describing various activities. A site survey is followed with an analysis.

Site analysis is "a study of the site itself" and the existing structures which govern the place, including know-how, both formal and informal which will influence the outcome of any design intervention (Lynch, 1971, pp. 4-5)."Site analysis has two elements" - "one oriented to human purposes and the other to the site itself as an on-going system"(Ibid. 9). The first is about how the various parts of the site are being used while the later looks at its coherence as an organized ecosystem. This makes site analysis a "prelude to successful revolution" (Ibid. 11) of a design, which will occur "only after repeated analysis and the trial of many plans" (Lynch, 1971, p. 18).

Site analysis is thus not a "self contained step that is completed before design begins" but "continues as long as the design is being created" (Ibid. 21). In this research site analysis was guided by the fact that the design will be set "over ground occupied by many human and physical assets"; "dotted with structures and activities of continuing utility"(Ibid. 22).

3.3. Case Study

The whole idea of a case study is learning from what others have done and using the knowledge to develop insights with which to address particular problems (von Seggern 2008). This allowed the research to be situated within the frame of a collection of popular and established cases showing how things work in the real world (Johansson 2003).

The research adopted the "descriptive case study" method to address the challenge of stormwater management to control floods through a critical and extensive review of existing literature instead of just a common “understanding” of phenomena in a real life situation. The method is well accepted and is considered to be suited for "research" in "Landscape architecture" (Francis 1999a, Levy 2009, Deming 2011).

In determining the selection of a case study, a number of guide lines have been given in the literature. Foremost among the guidelines is that a "case study should have a case" and the choice of the case study should not be based only on the "methods and techniques" used but rather on "the case", which is the "subject of interest" (Johansson 2003). A "case" has been defined by Johansson as "a phenomenon specific to time and space" (Johansson 2003). Thus a major characteristic of a case study is that the subject of research must be "a case" which can be used to build or revise existing theories (Francis 1999a, Levy 2009).

The research adopted a "purposefully" "selected" case study approach, and combined abductive and inductive reasoning in drawing generalizable conclusions (Johansson 2003). The purposeful approach allowed for the selection of cases which were both "critical", and "information rich" as well as "pivotal" to "theory" from which "generalizations" could be made and applied to the research(Johansson 2003). In combining abductive and inductive methods of reasoning the research sought to test existing "theory" on stormwater management to control floods. This was done using nature-based interventions through "emulation" of the "methods and techniques" which were derived from the case in a real life situation (Johansson 2003).

The cases were thus used as a "source of practical information on potential solutions" to the challenge (Francis 1999a) of stormwater management and flood control in a developed urban area where understandably the challenge is complex and involves a close study of the existing relationship between man and the "biophysical" environment (Deming 2011).

Limitations: The case study method has limitations, chief among which is the quality of information about a project. Francis (1999a) has observed that "project designers, owners, managers" and even users may not be willing to “provide” open and honest “information” for a critical evaluation of a case. Furthermore, since the case study method is considered not “effective” on recent projects, selected cases should be at least "2 years" old which is not so easy to find. Information on the selected cases was also a major challenge, and as noted by Francis (1999a) information on cases are often not enough to make value judgment, and they may be in a language which is not even understood by the researcher.

A Case Study research is usually expensive as the researcher will have to visit the case sites to spend time on site to learn, describe, enquire, study, understand and interact to develop the case. Close contact with the case is very critical to avoid the "stratified learning process" effect which results from poor contact with a case (Flyvbjerg 2006).

Challenges in Case Selection: Several cases which were critical to the development of the research were explored. No direct precedents were found but the research adopted a case which was central to the research and an amalgamation of approaches and methods from different projects. These projects included the Green infrastructure plan for La Parguera Puerto Rico (Terrasa-Soler 2012), the water sensitive design project in metropolitan Lima, Peru(Nemcova 2012) and principles abstracted from Steinitz (Steinitz 2010) and (Frick-Trzebitzky 2018). The single case adopted which was central to the research was the Smart interventions to adapt urban areas against floods in some cities in Japan (Yamashita 2015). The critical aspects of the research resulting in the production of designed interventions was inspired by the principles adapted from these cases.

The Case: The case was the “smart adaptation of urban areas to flooding” and is situated in Fukuoka (population 1.52 Million) and two of her suburbs Itoshima (population, 97,000) and Shingu (population 29,000) in Japan. The stormwater management system based on source control was adopted after a long search for a solution to urban flooding. During a 2009 flood event in the city, the city's authorities together with various interest groups decided to try out a different approach to the conventional system of flood management and distributed 0.2 m^3 capacity water harvesting facilities to 106 homes. These were installed for free and after some time the views of those who benefited from this hand out were evaluated.

The survey showed that the views of the citizens who received the handout had changed from supporting conventional methods to address flooding to the use of rainwater harvesting, and they had started sharing their experiences and encouraged neighbors to adopt water harvesting. To further demonstrate the importance of rainwater harvesting in flood control, a rainwater harvesting house was built where a larger volume storage structure (42 m^3) was installed. This proved to be more effective in reducing runoff volumes after a period of monitoring. Similarly a housing complex with over 100 m^3 water harvesting cisterns were built in Itoshima and Shingu, two fast growing suburbs.

The cisterns which were used to harvest and store roof water were constructed from plastic and filled with rocks before being overlaid with top soil and planted (Fig. 3.1). Water was pumped from it, powered by photovoltaic cells to irrigate lawns, flash toilets and for the running of washing machines. Following the success of this project, a school complex was also built.

The school complex was constructed in a place prone to flooding, exposed to noise from nearby rail and road traffic as well as smoke pollution from an industrial setup. The integration of 3800 m^3 cap rain water harvesting system in the design of the school was used to create a sustainable design in which rain water is harvested, stored and reused, Environmental challenges such as noise from rail tracks, smoke from near-by industry were thus addressed. Moreover, poor drainage that leads to floods in the area was also controlled as well as the creation of multiple functional uses in the landscape. The design has become an educational material for the pupils as they use the water from the cisterns to irrigate lawns, plant gardens and flush toilets (Yamashita 2015).

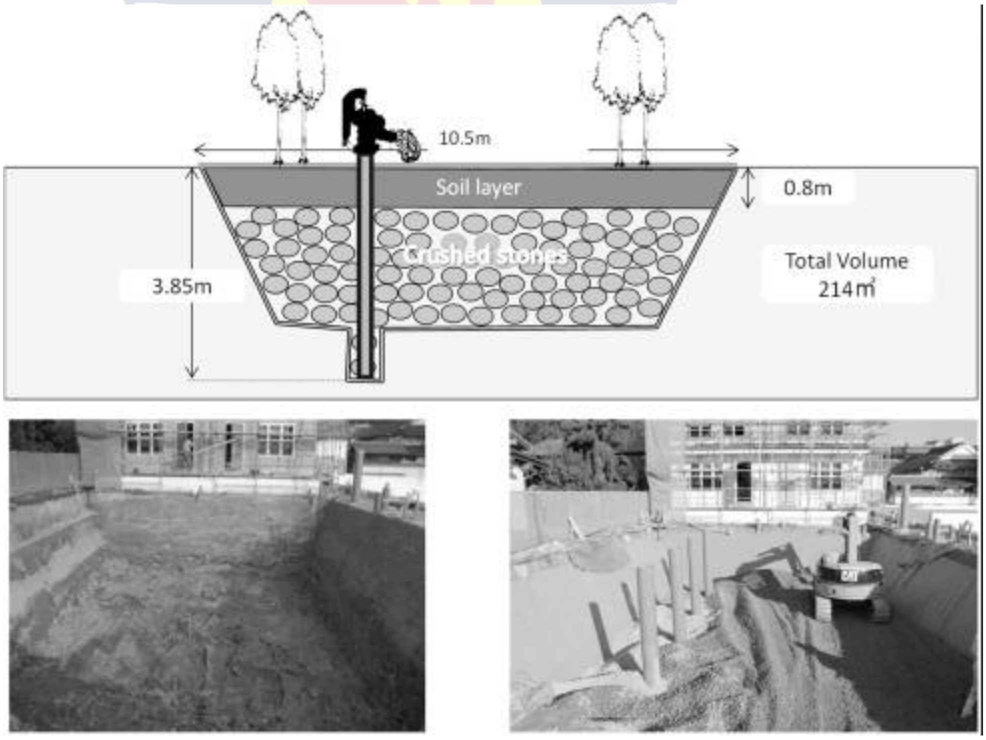


Fig.3. 1: Excavation and construction of water harvesting cistern for a housing estate. Source: (Yamashita, 2015)

3.4 Data Identification and Use

This section looks at both spatial and non-spatial data I prepared by combining the results of the literature review, the review of the case study, documentation obtained from the field and site survey.

I was inspired by the works of Ian McHarg (1992), Jauslin (2012), Marsh (1978), Terrasa-Soler (Terrasa-Soler 2012) in the collection of the spatial data which was used to develop a schema (using the multicriteria Overlay Analysis method) to guide the location of critical interventions for the management of stormwater to control floods.

3.4.1 Data Sources – I obtained both spatial and non spatial data from various sources (Table 3.2). These data were used as inputs for a rainfall - runoff analysis, the design of stormwater interventions and the development of a schema to guide the location of interventions.

Table 3. 2 Spatial and Non-spatial data and their sources

Data	Data Form	Stage	Data Source
Digital Elevation Model DEM	Spatial	Secondary	CERGIS-Legon
Soil map	Spatial	Secondary	Soil Research Institute, Accra
Soil Map	Spatial	Secondary	European Soil Data Center
Landsat 7& 8 images	Spatial	Primary	USGeological Survey (USGS)
Geological map	Spatial	Secondary	Geological Survey Dept, Accra
Hydrogeological Data	Non-Spatial	Secondary	Water Research Institute
Rainfall data	Non- Spatial	Primary	Ghana Meteorological Services
Infiltration	Non-spatial	Primary	Field Survey
Soil Profile	Non-spatial	Primary	Field Survey
Population	Non-spatial	Primary	Ghana Statistical Services
Orthophotos	Spatial	Secondary	Survey Dept. Accra

Flood map	Spatial	Secondary	Royal Haskoning DHV

Source: PhD Research, Asiedu 2020

3.4.2 Accuracy assessment - A "map" is not an actual representation of physical quantities and processes in the landscape and thus has errors(Bogoliubova 2014). Errors in spatial data will affect the reliability of any spatial analysis, so to minimize errors I carried out coordinate system synchronization, coordinate projection, correction applied to remote sensed images (Pabi 2007, Mariwah 2015) (Pabi, 2007, p. 373). I also used georeferencing and improved methods of classification, which were validated to show how close to reality the maps were (Bogoliubova 2014).

3.4.3 Image Classification

Relevance to the Research - Landsat images were classified into Land cover thematic layer maps and used as input to the initial site analysis. The Land cover types were classified based on clear details of objects and features on the ground (Muzein 2006) with the resulting map used as input in a soils loss model and in a schema to guide the location of nature based interventions to manage stormwater runoff (Davis 2009, Panhalkar 2011).

Classification of Landsat Images - Remote sensed Landsat 8 images for 2014, were classified using the maximum likelihood, automated Supervised Classification with the majority filter algorithm. The layer bands 4, 3, and 2 were used to enhance identification. Maximum Automated Supervised classification was used because of the researcher's knowledge of the site (Muzein 2006, Turkar 2008).

3.4.4 Digital Elevation Model (DEM) - These are rastered images produced as a "by-product of an orthophoto mapping program"(O'Callagan 1984, Stuebe 1990). For this research, I used it for watershed delineation with a 30 m x 30 m grid cell size and in the development of a slope map which was an input in modeling erosion and in the Multicriteria Suitability Overlay Analysis. It was also used for the development of a contour map at 2 m interval.

3.4.5 Soil Series Map Preparation - A detailed soil series map of the area based on Accra Plains Soil Map 2 and Ayensu-Densu Basin Soil Map 6 was extracted for the research area using ArcMap software. Soil series map was used as against soil group map because at the "series" level, soils with similar characteristics are grouped together under one name and are more detailed than soil group maps (Lynch 1971).

Physico-Chemical Data on Soil Series Map - Data from published, and unpublished sources were combined with information from the Harmonized World Soil Database (HWSD) to build a physico-chemical database for each of the soils identified in the map.

The soil map was used to build a soil erodibility factor map for the Soil loss model which was an integral part of the multicriteria overlay. A few soil series (like Chuim-Gbegbe association, Songaw consociation, Ayensu-Chichiwere complex, etc) had no information from the literature and unpublished sources, so information at the major soil group level was used.

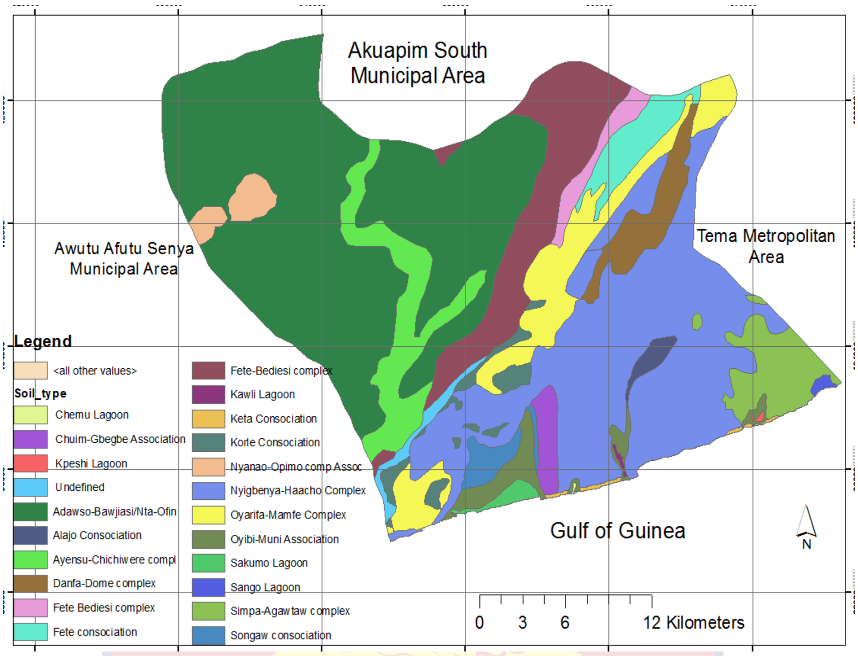


Fig.3. 2: Soil series map. Note: Refer Appendix 1& 2 for details.

3.5 Revised Universal Soil Loss Equation (RUSLE) Model

This section is based on my paper, “Assessing the threat of erosion to nature based interventions for stormwater management and flood control in the Greater Accra Metropolitan Area, Ghana” Journal of Ecologicl Engineering. 19 (1). 2018

The RUSLE model is commonly used to predict soil loss due to sheet and rill erosion (Silva da 2010, Kamaludin 2013, Efthimiou 2014, Kusimi 2015). It is also described as an "empirical model" for determining the “risk” posed by erosion (Kamaludin 2013), as well as the effect of periodic land cover change on soil loss (Jin 2010).

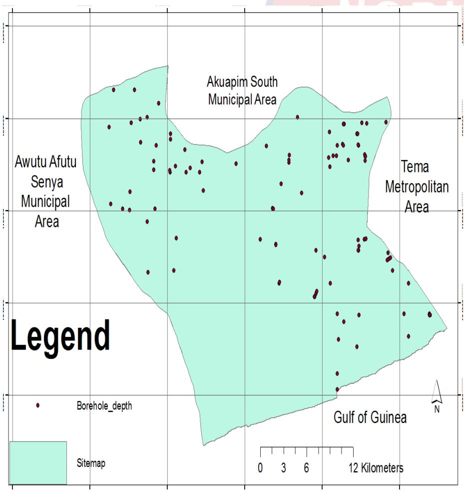
Empirical models of soil loss have become very popular where direct measurements is not possible, too expensive or time consuming and has become quite indispensable for data poor countries where direct measurement is non-exitent (Efthimiou 2014, Kusimi 2015). Its applicability in a "GIS" environment which is used to depict spatial distribution through mapping show soil loss in different locations across a watershed, and this is what has helped to increase its versatility (Kusimi 2015).

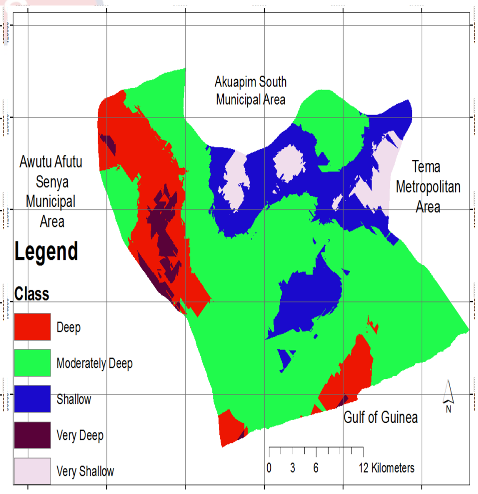
I used the model to estimate soil loss, soil erosion and sediment yield as well as spatial distribution at watershed or regional scale (Efthimiou 2014, Kusimi 2015) and to determine the possible effect of sediment yield on infiltration based interventions to control floods in the research area.

3.6 Non-Spatial Data Processing

Non-spatial data made of population data and hydraulic conductivity were processed as spatial data, ranked and weighted and used as inputy in a Multicriteria Suitability Overlay Analysis.

3.6.1 Hydrogeologic Data and Interpolation: I obtained Hydrogeologic data on 165 boreholes from the Water Research Institute of CSIR, Accra. The data covers about 70% of the study area and was edited to remove extraneous material before being displayed in an arcmap environment. I used the Kriging approach to interpolate the data on borehole depth and yield over the entire study site (Fig.3.3a & Fig.3.3b). The research adopted the "Kriging method" because it is considered ideal for interpolating hydrogeological data (dos Santos 2015, Wang 2016).





(a) (b)

Fig.3. 3: Spatial Distribution of Hydrogeological data sites within study area (a); Kriging extrapolated Hydrogeological map (b)

Hydrogeologic Data Ranked and Weighted: A raster layer generated from the interpolation was reclassified into 5 classes, ranked and weighted in ArcMap. Ranking was guided by (Lynch 1971, Liu 2014, Lim 2016). The ranking took into consideration admonitions by (Lynch 1971, Liu 2014, Lim 2016) on the depth to water table and possible effect of mass implementation of infiltration based interventions within a watershed. Thus in ranking, areas with < 3m depth were given very low ranking while areas with depth of > 7m received the highest ranking (Table 4-11) for locating a detention/retention basin.

3.6.2 Population Data - Population Data for 2014 was combined with boundary data to calculate population density. Ghana Statistical Services provided population data and boundary maps for the 2010 census period and projected population for intervening years between 2010 and 2015(GSS 2013, GSS 2014). This was used to calculate the population growth rate for each of the Administrative Districts, the average of which was used to estimate the 2014 population for the communities within the corresponding Administrative Districts. Population growth rate was calculated using the relation;

$$Dr = \left(\frac{N2-N1}{N1}\right) \text{ x } 100 \qquad \text{Eq. 11}$$

Where D_r is the Population Growth Rate; N_1 is the population of the base year and N_2 is the population of the current year.

Preparation of Population Density Map**:** Population density was calculated following similar works by (Dhorde 2012) and (Chabaeva 2004). Boundary maps (census tract) were obtained from the Ghana Statistical Services (GSS).

The population density for each community was calculated as number of persons per census tract (Number of Persons/km^2).

3.6.3 Hydraulic Conductivity - This section is based on a paper I published "Infiltrating to Control Floods – Suitability of Infiltration-based Systems in Urban Sub-Saharan Africa", American Journal of Earth and Environmental Sciences, 2020, 3 (1)

3.6.3.1 Hydraulic Conductivity (K-value) - Soil hydraulic conductivity, also called permeability (Earle 2006, Earle 2015) is a most critical factor when it comes to "soil hydrology"; water movement and distribution in the soil matrix and "other porous material" which may be used as media for infiltration based systems (Stibinger 2014). It is used to estimate the ease with which different types of soil allow water to pass through them to deeper depth and is an important parameter for infiltration based interventions in stormwater management to control floods (Ingelmo 2011).

Two types of hydraulic conductivity measurements are recorded in literature, "saturated and unsaturated hydraulic conductivity" (Leiveci 2016) and these can be determined through direct or indirect methods, laboratory or field methods. Field methods can be small scale or large scale (Le Coustumer 2008, Stibinger 2014, Leiveci 2016).

For this research I chose the small scale field method to investigate the hydraulic characteristics of soils of the research area. The method allowed for quick testing of many locations within a relatively short period of time(Stibinger 2014).

3.6.3.2 Methods Used - I used four small scale infiltration methods (Plate 3.1a, Plate 3.1b, Plate 3.2a, Plate 3.2b); double ring infiltrometer, Hand- held Soil

Auger (Plump-line method) mini disk infiltrometer and Turf-Tec infiltrometer for field data collection on infiltration and hydraulic conductivity. Details of the set-up and operation of the different instruments used and the theories for deriving hydraulic conductivity are provided in the paper (Asiedu 2020).

(a) **(b)**

Plate 3. 1: A Double Ring Infiltrometer set up in the field (a) Inverse Auger Hole setup (b) Source: Researcher 2015, Field survey

Drain time: The hydraulic conductivity values from all four methods were used to estimate drain time (based on a 25year design storm), using an infiltration well of 1.5 x 1.5 m size, designed to infiltrate a roof runoff volume of 18.9m^3. This allowed for comparism between the methods. The calculation of the drain time is based on Blansett (Blansett 2016).

(a) (b)

Plate 3. 2: Field set up for MiniDisk Infiltrometer (a) and set-up of Turf-Tec Infiltrometer (b) Source: Researcher 2015, Field survey

Hydrological Soil Groupings – Near saturated hydraulic conductivity values derived from the infiltration rate were used to provide a prelimary classification of the soils of the study area into hydrological soil groups based on (United States Department of Agriculture 2009)

Spatial Display of Infiltration Sites**:** Site selection for the infiltration rate tests was randomly done and a GPS handset (Garmin GPS e_Trex 10) used to determine and record the locations as relates to the rest of the study area (Fig 3.4).

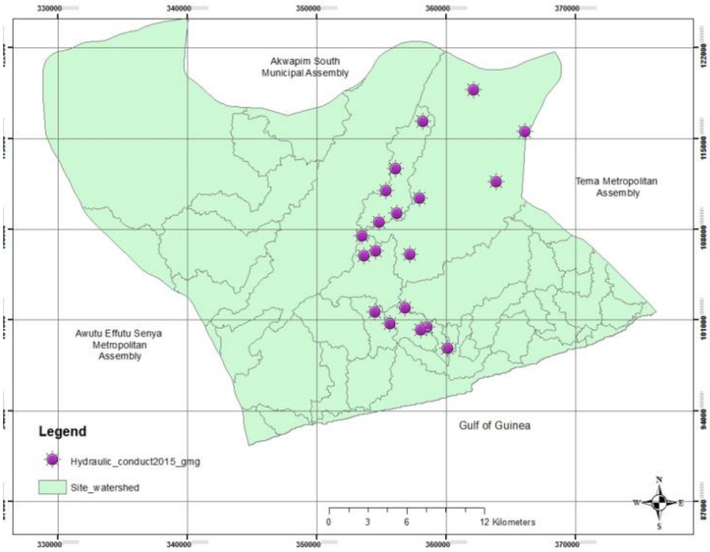


Fig.3. 4: Spatial distribution of Infiltration test sites in study area

3.7 Multicriteria Suitability Overlay Analysis

Multicriteria Suitability Overlay Analysis method was adopted to aid in organizing the large amount of data (Jauslin 2012) and to sift through the volume of data critical to the design process to help "fit" the various variables into a consistent “pattern” in the form of a schema, on which to build the “design” (Lynch 1971). The schema was built using GIS based multicriteria suitability overlay as described in Rottle (2010), Deming (2011), Jauslin (2012) and (Nillesen 2014).

The constructed schema is composed of two sets of maps; a factor map and a constraint map. The elements in these maps were built guided by the results of literature review on causes of floods, literature search on state of the art stormwater management to control floods, expert discussions, personal observations and notes made during the field survey. I used Land cover, population density as proxy to imperviousness, soil, geology, hydrogeology, slope, erosion or soil loss, and infiltration maps to form the factor map. These maps were prepared based on a set of criteria that influence, enhance or detract the suitability of an area for a particular intervention(Lopez-Marrero 2011).

The elements used to build the constraint map; flood risk map (100mm in 1hr flood map), flood prone areas, wetlands, salt ponds, surface water features, areas with special ground conditions map; were the elements which excluded an area as suitable for the location of an intervention (Lopez-Marrero 2011).

Variables within each layer was ranked as defined by (Toms 2010) but "weights" were applied between layers. The final schema was classified into three levels; high, moderate and low suitability according to Marsh (1978). The table below summarizes the weights applied to the layers in the factor map (Table 3.3).

Table 3. 3: Weight for Layers forming the Factor Map for Detention /Retention Basin

	Weighting (W)						
Map type	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
Population Density							0.7
Landcover					0.5		
Slope			0.3				
Soil type						0.6	
Geology						0.6	
Hydrogeology							0.7
Soil loss				0.4			

Source: PhD Research, Asiedu 2020

The layers were run in an ArcMap environment using the following relation;

$$SWM = \sum W_i * R_i \qquad \text{Eq. 8}$$

Where SWM is a Stormwater Management Model, W_i is Map weight; R_i is Ranking for each layer, thus for various layers the expression becomes

$$SWM = \sum(W_a * R_a) + (W_b * R_b) + (W_c * R_c) + \cdots. \qquad \text{Eq. 9}$$

Where a, b, c, ...represent the different layers.

Applied in Raster Calculator, Equ becomes;

Lookup("ImperRast","W") x Lookup("ImpervRast","R") + Lookup("LandcoRast14","W") x Lookup("LandcoRast14","R") + Lookup("SlopeRast","W") x Lookup("SlopeRast","R") + ... Eq.10

Multicriteria Suitability Overlay Analysis Analysis II - A second Multicriteria Suitability Overlay analysis using slightly different factor variables but the same constraint variables was run for suitable locations for Infiltration trenches and Infiltration wells within the study area. In this model, three levels of fitness were used as High Suitability, Moderate and Poor suitability. The different layers used in this model are presented in Table 3.4 below, weighted.

Table 3. 4: Weighted Layers for Infiltration well and infiltration Trench

	WEIGHT					
FACTOR	**0.1**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
Hydrogeology						0.7
Infiltration rate				0.5		
Slope		0.3				
Soil type						0.7
Geology					0.6	
Land cover			0.4			
						0.7
Soil loss	0.1					

Source: PhD Research, Asiedu 2020

3.8 Stormwater Run-off Estimation

In determining interventions for stormwater management to control floods, I run a model to estimate the contribution to stormwater runoff from various landcover types in the study area. The research adopted the Curve number method in running the runoff model.

3.8.1 Run-off Estimation by Curve Number (CN) Method**:** The "USDA Natural Resources Conservation Service (NRCS)" "Curve number method" (TR-55), formerly Soil Conservation Service (SCS) Curve Number method is the most popular hydrological model used to estimate stormwater runoff from a single rain event (Grove 1998, PWUD 2000, Dingman 2002, Manual 2004, NJSBMPM 2004, Arkansas 2014, Dile 2016, Oliveira, Nearing, Hawkins, Stone, Rodrigues, Panachuki and Wendland 2016, Ogden 2017).

A CN value is used to estimate the amount of direct stormwater runoff generated from a surface after antecedent soil moisture (stored in the soil 3-5 days after the last rain), the infiltrating properties of the soil, and the condition of the soil surface have all been considered for a particular rain event (Stuebe 1990, Strom 2009, Oliveira, Nearing et al. 2016). It is called the "runoff factor" and represents the ability of an area to produce runoff; higher values indicative of higher run-off potential for values which range from 0 -100 (Ponce 1996, Arkansas 2014).

The general reliability of this model has been confirmed in different geographic locations (Nearing 1996, Fan 2013, Dile 2016). However, the accuracy of the model reduces when runoff is less than 12.7 mm(USDA 1986). In this research the model was applied over an urbanized area.

Limitations of the model - The method is noted to have a few draw backs as it "underestimate" runoff under "low rainfall-intensity situations"(Dile 2016), and assumes uniform rainfall conditions over a watershed, a situation which may not always be true (Ponce 1996, Singh 2017). Another draw back is that accuracy requires the correct determination of the CN value(Grove 1998) and the method can best be applied to areas with CN values of between 40 and 98; anything beyond this affects accuracy (PWUD 2000).

These limitations not withstanding, I used the method because of its simplicity, popularity, versatility, low data requirement especially for a data poor developing country like Ghana (Dingman 2002) its adaptability, extensive usage over many geographical areas and its high level of sophistication (Ponce 1996, Grove 1998, PWUD 2000, Dingman 2002, Manual 2004, NJSBMPM 2004, ISWM 2010, Arkansas 2014, Dile 2016, Oliveira 2016, Ogden 2017).

I chose the model over other methods like the Rational Method or the Modified Rational method because it allowed the effect of different land cover types on runoff generation to be isolated (Dingman 2002) and also because of their limited coverage of less than 20 acres (NJSBMPM 2004, Strom 2009) as compared with up to 8.09 sq km (2000acres) for the CN model. The model was used with the composited approach to provide a common CN value for the many landcover types identified in the focus areas(ISWM 2006).

3.8.2 Process of Estimating Run-off: Three focus areas (Area1, Area2, and Area2) were selected within the research area to capture variations in Land cover types (Fig 3.5). Area1 is about 10.2 km^2 and extends from the suburbs of Abbosey-Okai, Kaneshie, Bubuashie, Russia and Darkoman.

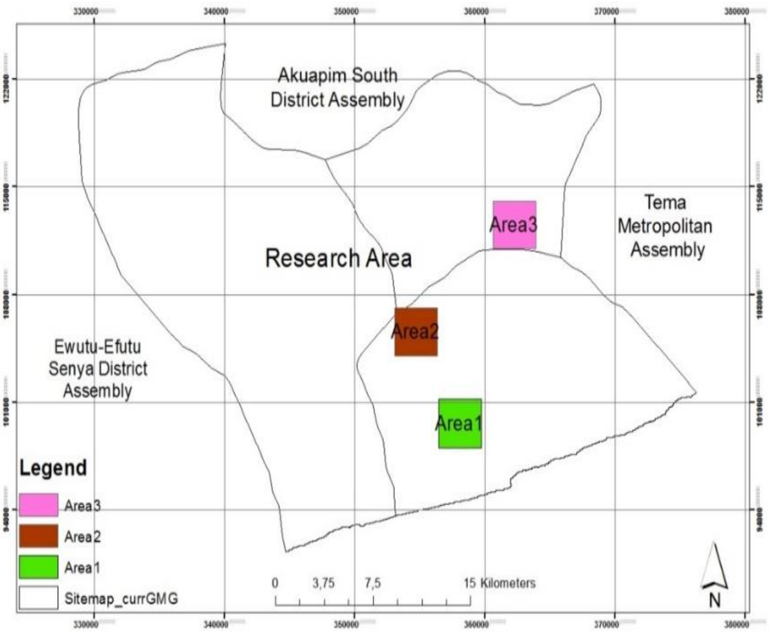
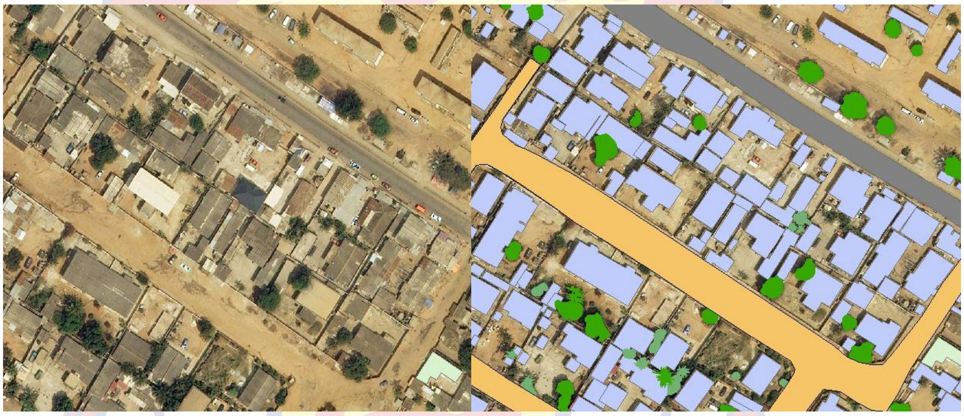


Fig.3. 5: Location of the three focus areas within study area. Note: Map of study area obtained from Internet sources

Area2 is also about 10.2 km^2 and covers the suburbs of Chantan, Tabora, New Achimota, Sowutuom, Lamnava, Trantra Hill and parts of Ablekuma while

Area3 (10.5 km^2) extends over Hatcho, Agbogba and the entire Ashongman community.

Land cover types were extracted from 20 cm pixel size 2014 orthophotos (Plate 3.3a) for the selected focus areas aided by the researchers' knowledge of the study site obtained through field studies as was similarly done by Stuebe (1990), Justice (2002). Extraction was partly automated using the Feature analyst software and partly manual (Plate 3.3b) by on-screen digitization of land cover types using GIS techniques (Chabaeva 2004, Verbeeck 2011).



(a) **(b)**

Plate 3. 3: Orthophoto image (20cm pixel) showing a section of research area (a); Digitized surfaces as Land cover types (roof as blue, concrete surfaces as light green, and vegetation as green) (b). Scale Factor 1:1.2

The coverage of the digitized land cover types was calculated and combined with respective hydrological soil groups to determine the Curve Number for each land cover from tables (USDA 1986, ISWM 2006). I used the Class II antecedent runoff assumption(United States Department of Agriculture 2004a, United States Department of Agriculture 2004b) for deriving the CN values. The CN for each land cover type was composited to obtain a representative or composite CN (CNw) for each focus area. The CNw was used to model direct runoff for each focus area using 7 year rainfall data.

3.8.3 Process Flow – the following summarizes the direct runoff model (Fig 3.6).

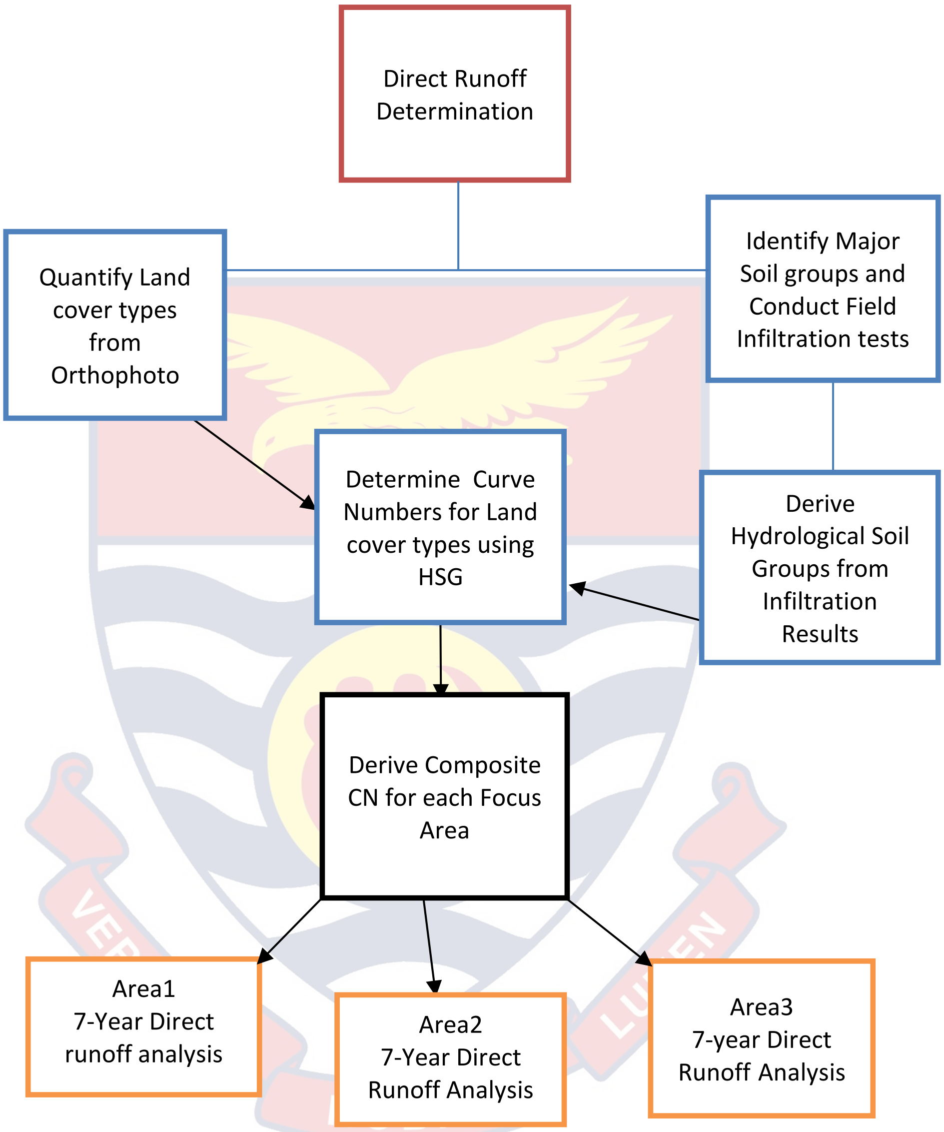


Fig.3. 6. Summary Chart showing process flow for direct runoff estimation

Analysis of Data: The rainfall run-off analysis was based on daily rainfall values ≥ 40 mm for the evaluation years 2006-2015. Direct runoff values ≥ 12.7mm was selected for the runoff analysis to gurantee reliability of the results as suggested by (USDA 1986).

Derivation of composite CN factor value (ISWM 2006)

$$CN_w = \frac{Q_T}{A_T} \quad \text{Eq. 16}$$

Q_T is given as follows;

$$Q_T = \sum_n^i Ai\ x\ CNi + \cdots \ldots \ldots \ldots \ldots An\ x\ CNn. \quad \text{Eq.17}$$

CN_w - Computed Weighted or Composite CN (Table 4-17)

Q_T - Products or Percentage area of individual cover types and CN factor value

A_i - Area of the ith land cover type;

CN_i is the CN value of that ith Land cover type for a particular Soil Hydrologic group;

A_T is size of focus area in Acres.

3.8.4. Runoff Volume: Effective Runoff volume was estimated based on (Juliana 2017) as follows;

$$ER = R\ x\ A\ x\ C \quad \text{Eq. 20}$$

Where ER is Effective Runoff (m^3), R is rainfall (mm), A is catchment area (m^2) and C is runoff coefficient. Effective runoff is defined by(Ponce 1996) as the difference between rainfall and infiltration capacity.

3.8.5 Harvestable Roofwater**:** Roofwater available for harvesting per household per rain event for both roof area ≥81 m^2 (0.02acres) and < 81m^2 was calculated for the three selected focal areas based on (CNT 2010). Water available for harvesting per rain event was calculated based on (Siabi, Van-Ess, Engmann, Mensah and Tagoe 2015, Rahimi 2018).

Quantity of Rainwater Harvested per Rain-event:

$$Q = R_f\ x\ A_r\ x\ C_o \quad \text{Eq. 21}$$

Q - Quantity of roof water collected during rainstorm, R_f - Rainfall in (mm), A_r - Surface area of roof

C_o - Runoff Coefficient

Runoff Coefficient (K) (Marsh 1978)

$$K = \frac{Runoff(mm)}{Rainfall(mm)} \qquad \textbf{Eq. 22}$$

Percentage Harvestable Roof Water: This was calculated as the ratio of harvestable roofwater volume to effective direct runoff per rain event.

3.9. Determination of Return Period

I used rainfall data from 1972 to 2014 from 6 rain gauge locations, to calculate 2, 5, 10, 20, and 25 years return period in Excel. The data was organized using the Plotting Position Method and the derivation of return period done by the Weibull's approach. Weibull's approach is considered to be one of the "most popular" frequency analysis methods for estimating return period(Maity 2018).

3.10 Ideas Generation

In this section I applied concepts in design methods to various aspects of the research to generate innovative ideas to address the challenge of stormwater management. I was influenced by the works of Jones (1992) and Lynch (1971) and the Living labs model. Chris Jones's book is centred on the idea that design and innovation and the processes involved have moved from a 'one-man-show' to a collaborative effort. This idea is expanded on in the Living Labs concept which is used to develop innovative solutions to challenges in the environment through active participation of various actors (Eriksson, Niitmano, Kulkki and Hribernik 2006, Katzy, Pawar and Thoben 2012, Leminen 2013, Capdevila 2014, Schuurman, Ballon, Baccarne, De Marez and Veeckman 2016).

I identified and worked with three main actors; the end "users" (community members), the "enablers" (technocrats) and the mediator (researcher)(Schuurman, Ballon et al. 2016). The main challenge I encountered was learning to oscillate between being the "person responsible for the results", and the "driving actor" or "mediator" who "ensures that the process" adopted to arrive at a good and reliable design is "right"(Lynch 1971, Jones 1992, Leminen 2013).

I endeavoured to achieve this by presenting the results of the literature search, analysis of historic cases approapriate to the set objectives, results of organized and analyzed volumes of spatial and non-spatial data, together with the field survey and site survey to a section of the enablers and end users in a public forum. The event was organized at the Accra Metropolitan Assembly, Accra Ghana in February, 2018.

I presented the results after analysis and synthesis of the data as outline proposals at the seminar for further discussion. The input of the "actors" and "enablers" led to the development of the strategic brief which was further developed for the concept drawing. The concept drawing also called concept plan or sketch drawing was developed based on (Simonds 1997, Koliji 2012, Edmonton 2017). This way I was able to convert the "over-complicated problem" of stormwater management to control floods in urban areas in GAMA into a "simple enough" form (Jones 1992) to allow the generation of innovative ideas.

Actor participation: To motivate the actors to actively participate in the process of ideas generation under the living labs concept (same as Focus Design Group Discussion) I had to convince them of the "long term" implications of their participation (Capdevila 2014); in this case to help address the problem of perennial floods in communities. This was a "bottom up" approach where the active participation of actors helps fulfill the "needs" of a "community" (Capdevila 2014), motivated by "curiousity" and a desire to contribute to find a solution to perennial floods(Schuurman, Ballon et al. 2016).

3.11 Summary of Chapter

The chapter begins with spatial data preparation, organization and classification of Landsat image into Land cover thematic layer map. The Land cover map was combined with soil map, rainfall erosivity map and a slope map generated from a DEM to prepare a soil loss map for the study area.

Population data obtained from the Ghana Statistical Service was used in combination with boundary maps to produce population density maps for the periods 2002 and 2014. This was used as an integral part of the multicritiria overlay suitability analysis and as a proxy to an imperviousness map. Field data on hydraulic conductivity and hydrogeology was analysed and used to classify soils of the three focal areas into hydrological soil groups and to prepare hydraulic conductivity and hydrogeologic maps for the study area. The maps were prepared using the Kriging Interpolation tool and were used as input in the Multicriteria Suitability Overlay Analysis.

The Multicriteria Suitability Overlay Analysis Map (Schema) was prepared by running a model using elements of the landscape to produce a schema made of a factor map and the constraint map. An estimate of direct runoff was done for three focal areas (Area1, Area2, Area3) using the CN method.

Return period was estimated using rainfall data from 6 raingauge locations from 1972 to 2014 by the Weibull's approach which produced 2 year, 5year, 10, and 25 year return periods.

The chapter also covered results of field survey conducted at the study area including focus expert interviews and interview of community members and experts on why current interventions for stormwater management to control floods have failed and what can be done to solve the problem.

The chapter ended by introducing aspects of the design methods adopted for the research, where the contribution of actors was integrated into the design process through a public seminar.

CHAPTER FOUR

GEOPHYSICAL CHARACTERISTICS OF STUDY AREA

4.0 Introduction

The chapter reviews the physical and social features of the research area bringing out the interactions between these features and how they have worked to influence stormwater management.

4.1 Study area

The study area lies along the south-eastern part of Ghana and forms part of a group of Administrative Districts collectively called the Greater Accra Metropolitan Area (GAMA) in the Greater Accra region. GAMA is made of eight Administrative Districts (Kagblor 2012), although a more recent re-demarcation puts it at 15 (ARUP 2016) out of which the research was concentrated in five – Ga East, Ga West, Ga Central, Ga South and Accra Metropolitan Area(Fig 4-1). These five administrative areas are among the most heavily populated areas of the country where perennial floods are also a major challenge.

4.1.1 Location - The study area lies on a "plain facing the Gulf of Guinea" and is divided into four drainage basins as "Korle-Odaw catchment, Densu Catchment, Kpeshie Catchment and Songo-Mokwe drainage basins (UNEP/OCHA 2011). The total land area of the five Administrative Districts is 891 sq km and lies within the Geographical coordinate of Longitude 5.804253 and 5.492637dd West and Latitude-0.527292 and -0.082525dd North. It is bounded to the North by the Akuapem Hills and the south by the Gulf of Guinea (Programme 1991, Nyarko 2002). On the south western side is the Weija Dam while the Tema administrative area lies to the east.

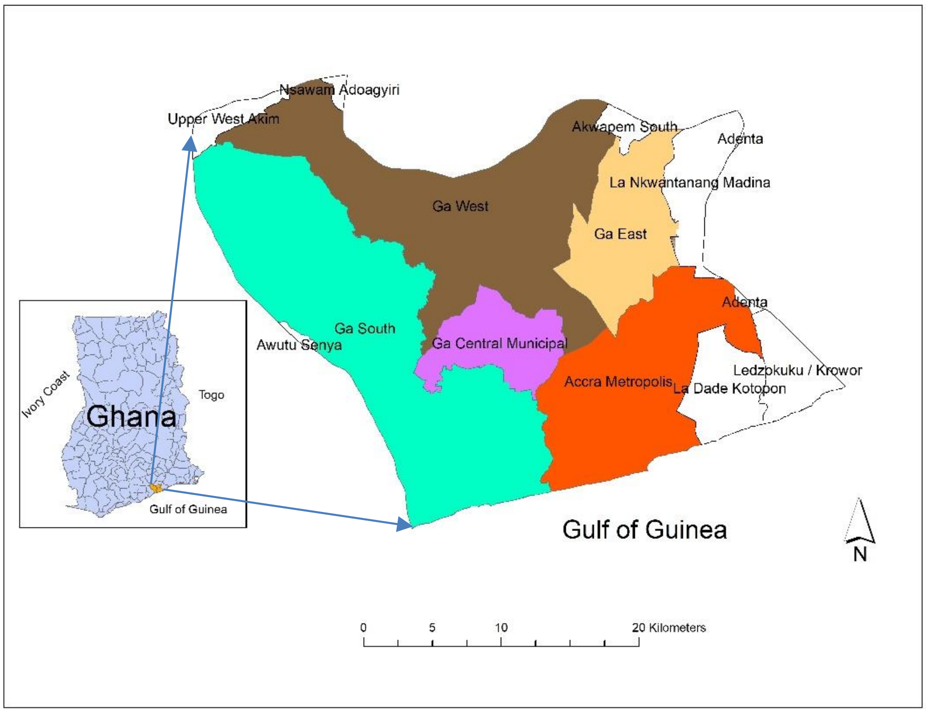


Fig. 4. 1: Study Site in Regional Context

4.1.2 Climate and Microclimate - Ghana lies within the "Tropical Savannah Climate" Zone and has two well defined rainy seasons, the major rainy season and the minor rainy season, saperated by a dry season which lasts for more than "3 months" (UNEP 2006). Greater Accra Metropolitan Area (GAMA) within which lies the capital city of Ghana, Accra is in the "Coastal Savannah Zone" of Ghana and has the same climate as most parts of the country but receives the least amount of rainfall (Darko 1995), ranging from "730mm" to "800mm" per annum (Oppong-Anane 2006, Glover 2013).

The rainy seasons are of unequal magnitude with a minimum and maximum range of between 780 mm and 1200mm per annum(Darko 1995). The main rainy season which starts from March, peaks in June and ends by mid July and is usually stormy and "intense", each event lasting for a short time. The second season (Minor season) begins in September and ends in October. Between mid July and September is a "short dry" "cloudy" "spell", which peaks in August (Oppong-Anane 2006). The dry season which is longer starts from "November to April" (Glover 2013, Coulter 2016).

Daily temperature changes within the year is very small, ranging between "24.7˚ C in August and 28˚C in March" with an "annual average of 26.8˚C" (Programme 1991, Kortatsi 2001). The warmest months of the year is February and March when temperature can rise up to "33˚C in March" just prior to the onset of the "rainy season" while "June-August" is the "coolest" with temperature of "24.7˚C in August" (Nyarko 2000, Services 2014). Relative humidity ranges between 65% in the mid-afternoon to a relatively high 95% at night (Programme 1991).

The research area, like the rest of Ghana experiences almost no changes in "daylight hours" except in August when clear sunlight could be as low as 2-4 hours per day and also in the long dry season between December and April when it could reduce to 8 hours per day (Programme 1991, Oppong-Anane 2006).

Predominant wind direction is WSW to WNW sectors and wind speeds range between 8-16km/hr. The highest wind speed on record is 107.4km/hr (58 knots). Such high wind speeds occur as "high wind gusts" accompanying "thunderstorm activity", which characteristically wreck havoc on vegetation and structures (Programme 1991).

4.1.3 Hydrology - The GAMA is naturally drained in most places (Frimpong 2014) due to the presence of a network of rivers and streams including the Densu river, part of which has been dammed (the Weija dam) to provide portable water for the city. Other major rivers and streams are "Odaw, Sakumo, Mahahuma, Lador, and Dzorwulu", Onyasia and Brenya (Nyarko 2000). This drainage network forms part of the stormwater management system with part cannalized into concrete stormdrains to facilitate drainage from built up areas (Nyarko 2000, UNEP/OCHA 2011).

With the exception of the Densu river, all the other rivers and streams are ephemeral (Darko 1995) with most taking their sources from the Akuapim range of mountains which lies to the North Eastern side of the study area. The area also boasts of the Korle Lagoon and Chemu lagoon among several others. The Korle Lagoon is located in a natural depression and although heavily polluted, receives stormwater runoff from about 400 km^2, approximately 45% of the study area (Aglanu 2014).

Depth to the water table varies between "4.8m and 70m in places like Ofankor, Kantamanso, and Accra Brewery Limited Bottling" factory area (Nyarko 2000) and has developed from secondary porosity in which percolated water is able to reach water bearing layers through weathering or breaks through the water bearing rocks (Kortatsi 2001).

4.1.4 Soils and Geology - "Most" soils in GAMA have formed from the weathering of the parent material with "Alluvial (fluvisols) soils and eroded shallow (Leptosols) soils common to all ecological zones" within the country. The soils generally have inherently low fertility (Oppong-Anane 2006) and have been classified into four groups as drift materials, alluvial and marine clays, residual clays and gravels and lateritic sandy clay soils(Programme 1991). The "drift materials" develop from local parent materials and may have either biotic or abiotic origins. Abiotic origins relates to soils formed from wind blown depositions, or eroded soils from upslope areas (Brammer 1958).

Alluvial and marine clays are derived from underlying shale and are described as loose and undeveloped with no identifiable horizons(Asiamah 2008). Lateritic sandy clay soils are derived from weathered Accraian sandstone bedrock whilst residual clays and gravels are derived from weathered quartzites, gneiss and schist rock “formations” (Programme 1991).

Areas with very low elevation which also have poor drainage have many small amounts of alluvial black cotton. Black cotton or tropical black earth soils are grouped under vertisols which form on “flat alluvial plains” in areas with less than 3˚ slope (Programme 1991, Gidigasu 2013). They have “high organic matter content” and characteristically changes in volume as the moisture content varies; a property which has adverse effect on building “foundations and footings”.

The geology of the area consists of Precambrian Dahomeyan schist, granodiorites, granite gneiss and amphibolites to late Precambrian Togo Series mainly quartzite, phyllitones and quartz breccias. Other formations also found within the area are Palaeozoic Accraian sediments-sandstone, shales and interbedded sandstone shale with gypsum lenses. The most geologically stable areas are those with hard Togo quartzite and schist and hard Dahomeyan schists and gneiss.

Hills in “Mallam”, “Shai Hills”, “Amasaman” and areas near foothills where there are large areas of coalluvial gravels, “rocks” and “ornamental stones” are quarried in an uncontrollable manner for building construction (Plate 4.1), exposing vast tracts of land to erosion and sedimentation of drainage ways, ceating an eye sore (Programme 1991).

Plate 4. 1: Rock and Laterite extraction for construction creates eyesore and generate sediments when it rains. Source: Author 2014, Field Survey

Moderate to severe erosion affects about 70% of the study site (Oppong-Anane 2006). The most common forms of erosion are “Sheet, gully and wind erosion” with “sheet erosion” occurring in hilly areas where the natural vegetation has been replaced with farms (Programme 1991). “Gully erosion occurs along all major drainage channels”, particularly where there are abrupt changes in elevation and in low elevation areas, and this combined with the other forms of erosion have resulted in heavy sedimentation of drainage channels, worsening the flooding problem (Programme 1991).

4.1.4 Topography - The area is “generally flat and undulating”, covered by low lands and dotted with hills or inselbergs that suddenly rise to “70m above sea level”, with altitude averaging “20m above sea level” (Nyarko 2000, Kortatsi 2001).

The slopes are generally gentle with most slopes below 11%, except in a few places like the MaCarhty Hill, the Television Transmission Station near

Abokobi and the Kwabenya Hills, where slopes are above 22% (Adu 1992, Nyarko 2000, Amoako and Boamah 2015).

4.1.5 Vegetation - The vegetation has been drastically modified by crop cultivation activities, "firewood extraction", bush burning and urbanization, changing the tree cover from the forest reminants of "Ceiba, Bombax, Antiaris, the occasional Triplochiton and introduced Azadirachta" (Programme 1991, Oppong-Anane 2006, Coulter 2016). The vegetation is classified into three broad "zones" made of "shrubland, grass and coastal lands" (Programme 1991). Oppong-Anane (2006) describes only two vegetation types as the coastal scrub and grassland, and the mangrove forest most of which has been destroyed by human activity.

The shrubland vegetation is distributed to the western conner and in the north towards the Akuapim range of mountains extending to cover most of the Akuapim hills (Programme 1991). "The coastal scrub and grassland" occur together in "patches" with occasional trees (Fig 4-3, left) such as Nim (Azadirachta), Boabab (Adansonia)", "pockets of short trees and shrubs like Albizia, Baphia, Milettia, Clausena, Lonchocarpus, Carissa, Dicrostachys (Nyarko 2002, Oppong-Anane 2006, Coulter 2016) growing to an "average height of 5m"(Programme 1991). The Akuapem-Togo mountain range is covered by this type of vegetation which extends to land near the foothills (Glover 2013).

In a study Stow (2013) found high spatial differences in the distribution of the vegetation which is more dense along the far western portions of the study area and near the Akuapem hills, but decreasing southwards towards the coast where the tree cover is more sparse, particularly Silk cotton. This change is attributed to reduction in rainfall levels and humidity (Brammer 1967).

"The grass cover" contains several mixes with *Vetiveria fulvibarbis* dominating. *Vetiveria fulvibarbis* prefers heavy soils. Other commonly occuring grass species like Sporobolus, Imperata or Rhznchelytrum and *Ctenium newtonii* which does well on sandy soils, are symptomatic of overgrazing and over-cultivation, especially Sporobolus (Programme 1991, Oppong-Anane 2006). Where the grasses; "*Ctenium newtonii, Brachiaria falcifera, Schizachyrium schweinfurthii*, and *Andropogon canaliculatus*" dominat on a gravelly soil, it is indicative of a grazing area in good condition. Grasses such as "*Panicum maximum, Hyperthis dissolute"*, and the "occasional *Andropogon gaynanus* var bisquamulatus" dominate areas with higher rainfall levels (Oppong-Anane 2006) but may appear as indicator plants in response to land which has been scotched with fire (Programme 1991) or in response to abundant water such as along river courses.

Within the Coastal land are "two vegetation" zones; "wetlands and dunes". The wetlands are "highly productive" and have been important source of livelihood for the fishing communities along the coast. They are habitats for fish, birds, water fowls, reptiles and other forms of wild life and are dominated by mangroves; the red and white mangroves and forms an important link with the lagoons (Ibid. 12).

The current situation however shows a habitat which has been heavily polluted and completely destroyed (Plate 4-2).

(a) (b)

Plate 4. 2: Coastal Scrub and grassland with isolated short trees (a), Extensive flat area cleared of mangrove forest and exposed (b). Source: Author 2014, Field Survey

Within the wetland and dunes zone are “salt tolerant grass species”. Some of the salt tolerant grasses cover substantial potions of the wetland, occupying low lying areas surrounding the lagoons. They form part of the wetlands and provide an important habitat as well as food for fish and other forms of wildlife associated with the lagoon (Programme 1991). The dunes made of sea sand are naturally formed by the action of wind and sea waves but is stabilized by a collection of grass and shrubs. It stretches along the beach along which also grows coconut and palms, providing shade, protection for the beach, and a source of livelihood for natives who sell the fruits. However due to poor management practices, about 80% of the coconuts planted in the 1920s have been lost through felling, disease and coastal erosion (Programme 1991).

4.2 Social Attributes of Study Area

4.2.1 Population: The total population of the study area according to the 2010 Population and Housing Census is 2,561,213 (Table 4-1). Incidentally GAMA is also the most populous region in Ghana with a population density of 1,235.8

compared with the national average of 103.4 persons per sq km, a trend which has continued since the 1960s (GSS 2014, Services 2014).

The area serves as a major "driving" force for "development" attracting large numbers of people from various parts of the country and the sub-region, primarily because the capital city is located there. In addition the area hosts most of the critical medical, educational, economic and industrial facilities in the country (Programme 1991).

Table 4. 1: Population Distribution among administrative districts in research area

District	Population 2010	% of Region	Growth Rate	Literacy Rate	Mean Population Density
Accra Metropolitan Area (AMA)	1,665,086	41.5	2.2	89	35,684.8
Ga South	411,377	10.3	3.9	87.9	436.1
Ga Central	117,220	2.9	3.1	92.8	11,964.4
Ga West	219,788	5.5	2.9	92.3	3,085.8
Ga East	147,742	3.7	2.8	93.6	1,930.2

Source: Ghana Statistical Services 2014, 2010 Population and Housing Census

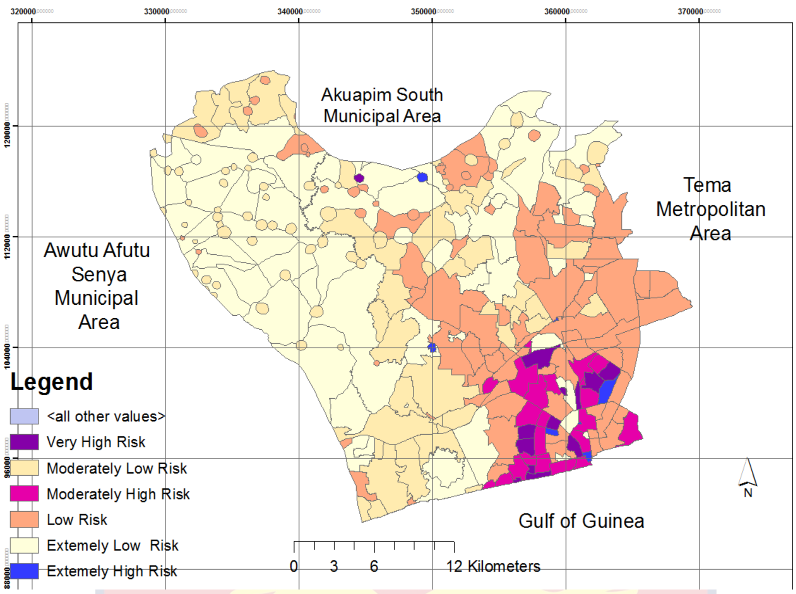


Fig. 4. 2: Population density distribution (2014) within the 5 Administrative Districts of the study area

The most densely populated areas of the study area lies to the South-Eastern and moves towards North-Eastern direction (Fig 4-2).

4.2.2 Land use/Land cover (LULC)– The Land use and Land cover of the study area include forestry, agriculture, fishing, lagoons, wet lands, surface water bodies, settlements, transportation, earth material extraction, tourism and recreation (Programme 1991). The area has seen considerable land cover change in the last 40 years as a result of migration from other parts of the country and the sub/region, natural population increase, expansion of agricultural activities especially in the area of horticulture, and the spread of urbanized surfaces (Stow 2013, Awotwi 2014).

Admittedly these “driving forces” resulting in change in land cover and land use have varied in scale in space and time (Pobi 2007) but there is a consensus on expansive land-based resource consumption and deterioration of the environment due to urbanization (Plate 4.3). This has resulted in extensive Land cover/land use change in the study area(Moller-Jensen 1994, Atuguba

2006, Cengiz 2013, Benza 2016, Coulter 2016). This is typified by a LULC which changes from a relatively wild natural vegetation cover to cultivated land for agricultural production followed by low density development, to high density urbanized areas (Benza 2016, Coulter 2016).

This is depriving farmers of good arable land as land becomes urbanized continually, especially along the periphery of urban areas (Bhatt, Gupta and Gogoi 2009) with "open spaces" within built up areas being converted into active sites for vegetables production and horticultural nurseries in lieu of the contractors' axe (Programme 1991). The combined effects of these LULC change is "habitat fragmentation", which is the uncontrolled growth of urban areas and the continued conversion of land resources (Antwi 2014, Benza 2016) and this has so impacted natural ecological areas that, they are unable to provide such critical services as stormwater management to control floods.

Plate 4. 3: Densely populated Accra city centre with very little vegetation
Source: Felix Krohn\Flickr

4.3 The Landscape Character of the Study Area

An attempt to describe the study area in terms of all the features of an urban landscape and how these features have changed over time and the extent

(Gökyer 2013) is a very daunting task, mainly because it is like setting a precedence.

4.3.1 Topography and the Urbanized Areas: The study area with its splash of isolated outcrops and rocky hills is a relatively flat terrain (Programme 1991, Darko 1995) with a complex mix of urbanized surfaces, isolated patches of vegetation and bare soil dominating the landscape (Gökyer 2013). The urban area can be likened to an exhibition with no clear character; an area that lacks "identity" with no defined tastes or tune to characterize growth (Programme 1991), which to some is what makes the place exciting. The area is home to a number of ethnic groups in Ghana the dominant one being the Akans, with their dominating designs which have come to represent the indigenous architecture (Merihellum 2012).

There are old Victorian, colonial style buildings, a few Forts and Castles (Ussher Fort, James Fort, Christiansborg Castle), a splash of the modernized traditional and modern international architecture all mixed up in a maze creating different flavours and tastes in different parts of the urban area in what is described as a "profusion of contemporary vernaculars"(Wiley 2013). Mostly along the coast between Jamestown and Osu are dotted such Victorian style architecture as the High Court and the Supreme Court buildings, the Central Post Office, and the old ministries buildings now housing various Regional and District Administrative Offices juxtaposed with traditional houses for the chiefs and indegenous buildings for the locals.

Within this neighbourhood which also contains the remnants of the old city, are historic buildings used as slave holdings during the "Transatlantic Slave trade" but which have been converted to residential use(Wiley 2013). This dark history had great influence on the architecture of the communities, leaving a foot print of "labyrinthine residential fabric", a convoluted form with narrow alleys which were developed to evade "slave" raiders (Plate 4.4), leaving little space to lavish on such public commodities as refreshing open spaces, parks for recreation, riparian areas along water courses, or even drainage ways.

(a) (b)

Plate 4. 4: Narrow convoluted alleys in old settlements in Accra, without paving (a), modernized with paving (b) Source: Author, 2015 Field Survey

This has continued to this day to define how communities are built. As a consequence residential areas often become flooded during intense rainfall events (Programme 1991, Mahama 2011, Wiley 2013). Coincidentally, these areas also have some of the most important monuments of post-independence era like the Kwame Nkrumah Mausoleum, Independence square, among others.

4.3.2 Gated Housing: A popular concept in residential development in the study area is gated housing. These are residential facilities and housing estates which are walled to provide security against intrusion (MacDougall 2011). This system of housing development is popular and does not only restrict public space but also access, free flow and connectivity in the urban environment, negatively impacting on communities (Obeng-Odoom 2014). This has produced a situation where during rainfall, stormwater run-off from the roofs of buildings and other impervious surfaces are released into public space at point sources. This is then funneled between enclosing walls. As the stormwater accumulates, the enclosing walls restrict flow, serving to funnel and speed up surface flow which picks up sediments and other solid material as it moves along, resulting in floods (Zahran, Brody et al. 2008).

The gated house concept has also restricted access to water features, especially with building facilities located along water courses, a situation which even affects rescue work during floods as first respondents cannot readily access trapped and distressed persons carried by quickly accumulating, fast moving stormwater runoff.

4.3.3 Patchy Vegetation Mosaic**:** There has been stories told by people who settled in the communities some twenty years ago about how the entire neighbourhood had only a handful of inhabitants with a lot of vegetation through which were flowing streams and rivers. A story is told about a Lake in part of the study area which was so extensive that first timers to the city mistook it for the sea. Today all those vegetation, streams, rivers and lakes have all but gone, leaving only small "patches" and "mosaics" and replaced by urbanized surfaces(Gökyer 2013, Antwi 2014).

The patchy vegetation may have established through secondary growth, or planted as landscape plants in private residence, or mass planted as part of urban afforestation and reforestation program or as a buffer to protect existing facilities, street planted, or remnants from farmed lands (Programme 1991, Stow 2013).

Thus most of the existing vegetation such as the mass planted trees used as buffer around the Weija Dam for instance, or the urban forest (like the Achimota forest) and similar such planted areas which were established as part of an "afforestation and reforestation" program (Bank 2000) does not depict the original vegetation of the study area.

Although vegetation, especially trees is so important to the hot and sunny climate of the study area, their extent and use in built up areas has been associated rather with socio-economic status (Stow 2013). Thus areas with more vegetation, usually landscape trees and shrubs, are associated with middle to upper income residential areas which have extensive parts of their plots landscaped as well as road side plantings. In contrast areas with little to no vegetation, are usually dominated by low income residential housing. The downtown areas of the study area and along the coast are areas with the least amount of vegetation(Stow 2013).

4.3.4 The Dying Lagoons, Waste Management and Drainage**:** There are a number of lagoons such as Korle, Chemu and others located along the coast in the study area, and although severely polluted and sedimented (Aglanu 2014) provide habitat for wild life and fish (Programme 1991) and a source of income for the locals from fishing activities. The rivers which have been heavily urbanized serve as channels to carry waste and stormwater from built-up areas (Plate 4.5).

Plate 4. 5: Illegal Settlement in Fadama within the flood plain of Odaw river filled with waste. Source: Author 2014, Field survey

4.3.5 Riparian areas: Uncontrolled development and urbanization has led to complete loss of riparian areas in the study area. Riparian areas are naturally occurring vegetated areas along water bodies that can protect the water courses and promote filtration and infiltration (Warren, Younos et al. 2009). It is therefore not uncommon to find water courses running close to, through developed properties or even against developed properties. In this way the least amount of rainfall results in flooding of entire neighbourhoods.

4.3.6 Open Spaces and Green Areas: As has already been explained based on the historical experience of the people, the concept of open spaces is alien in the study area, constituting only "about 5% of the urban" area ((NDPC) 2010). This is made up of recognized designated areas like the urban forest (Achimota forest), buffer zone around Weija Dam, and non-designated areas used for farming, green spaces within educational facilities, private yet to be developed lands, institutional lands like the Catholic Church lands and a few areas which serve to protect water ways. Within the city the very few open spaces may be decorated with monuments and prescribed to avoid vandalism or entirely paved over (Plate 4.6).

Plate 4. 6: A concrete paved public space in a suburb of Accra,
Source: Author, Field Survey

4.3.7 Eye Sores and Illegals: Extensive areas, which could be as much as 72% of the study area is made of illegal settlements(Cohen 2006, Okyere 2013). One such illegal settlement is the Old Fadama (aka Sodom and Gomorrah) which happens to be the most important squatter settlement (Farouk 2012) in the country with several others scattered throughout the metropolis. This is consistent with trends in other developing countries where urban areas have large illegal settlements (Annez 2010). The old Fadama informal settlement has been built on the flood plains of the Korle lagoon (Plate 4-5) with activities which have led to constriction of the river course creating floods any time it rains (Farouk 2012).

The study area has a number of rock and "lateritic gravel" extraction and "sand" "winning" sites for building and road construction (Programme 1991). Such areas have become 'sours' in the landscape which generate large volumes of sediments (Plate 4-1) when it rains resulting in blockage and floods on some main roads. Other eyesores punctuating the landscape is the open waste dump sites for the disposal of solid waste generated from both domestic and industrial sources some of which find their way into drainage canals creating blockages during rainfall, as well as the large number of telecommunication masts of varied sizes and designs towering over buildings in the landscape.

4.3.9 Transportation: The research area has one internal air transport terminus with both local and international services but no water transport system (Programme 1991), so transportation is by road with a limited rail service. The road network like in other African urban areas, makes up less than 7% of total land area, 50% of which is paved with bitumen (Habitat 2013). The road network doubles as drainage conduits for draining neighbourhoods. Within communities most streets are yet to be paved thus contributing to the yield of sediments from built up areas (Plate 4.7).

Plate 4. 7: An unpaved street in a residential area: Author 2015, Field Survey

4.4 The Threat of Urbanization

Currently rapid urbanization has “forced” “governments” in Africa and other developing poles to make “urbanization a development priority”(Zhang 2008, Hald 2009). Although there does not seem to exist “sufficient data to accurately” define the “magnitude” of Africa’s urbanization (Kulindwa 2006), Africa is considered the least urbanized continent in the world with over 70% of its population still rural, but currently the continent has the fastest rate of urbanization of over 3.5% per annum (Bjeren 1971, Kulindwa 2006).

Sadly Africa’s urbanization is not taking place in the context of “industrialization” and “economic development” (Locatelli 2009) but is driven by growth in spatial extent and population characterized by a net gain in rural-urban migration, natural population growth resulting from more births and less deaths, and administrative reclassification of communities which allows such communities to be considered as urban (Bjeren 1971, Cohen 2006). Thus based on administrative reclassification, a number of settlements previously considered rural are elevated to urban status but with little basic infrastructure in place.

Usually the basis for reclassification is numerical which unfortunately also varies from one African country to the other. For instance while in Ghana a settlement with a population of 5000 or more is considered to be urban (Acquaah-Harrison 2004), in other African countries the figure may vary from as low as 500 in Uganda to as high as 20,000 in Nigeria, with most others averaging around 2000 (Abebe 2013).

This basis for reclassification without any tangible base line in economic viability has encouraged little "investment in infrastructure" for most of the urbanized communities (Acquaah-Harrison 2004) painting a negative image for urbanization in Africa(Cohen 2006).

Urbanization in Africa and other developing continents thus follows a different pattern from what pertains in developed countries where there is a defined proportion of vegetation, impervious surfaces and soil surfaces with services like paved roads, water supply, sewerage collection, housing etc in an urban setting (Biggs 2010). Accordingly, urbanization in Africa has attracted various descriptions including "demographic urbanization" (Sangsore 2003), "parasitic spaces"(Locatelli 2009) which has resulted in "resource depletion" and "environmental degradation" (Kulindwa 2006) with continued incidence of flooding (Fig 4-7) showing the results of years of unplanned development of the urban space (Goodwin 2012).

"Rapid urban growth" is considered the most crucial issue confronting developing countries and this has led to what has been described as a "leap-frog kind of development"(Abebe 2013), a pervasive feature of urbanization in

Africa in which development is carried out on "unauthorized land" (Afeku 2005) with the hope that infrastructure provision will catch up over time. The situation has deteriorated to the extent that today about 72% of "development" in urban areas in Africa is on land not approved (Plate 4-8) for development and thus illegal (Afeku 2005, Karley 2009, Habitat 2013).

Plate 4. 8: A section of illegal settlement on a Ramsiar site, Accra. Source: Author, 2014

This has bred the "slum formation"(Report 2011), illegal settlements with hardly any form of infrastructure spread all over major developing urban centers (WCED 1987). "Urban sprawl" is also used to delineate such development in the peri-urban areas characterized by "low density" housing and commercial areas (Grizans 2009). In a city like Accra, the phenomenon is brought about by the rich building in the fringes of urban settlements (Afeku 2005) and the poor settling on public lands in the inner city, resulting in uncontrolled "conversion" of vegetated lands to urban use (Habitat 2013).

This has created low density sub-urban areas characterized by horizontal spread of impervious surfaces which can only be described as "wasteful" and "destructive" of land resources (McHarg 1992, Habitat 2013). The wasteful spread of impervious surfaces combined with the delayed introduction of services and infrastructure like stormwater drainage facilities, the removal of vegetative cover and natural flood dispersal systems, has so compromised the urban landscape that, floods results from the least amount of rainfall (Karley 2009, Biggs 2010).

Africa is considered to be the most vulnerable continent to the possible effects of climate change (Perret 2008) as seen in reduction in stream and river flow levels over recent times due to low rainfall (Perret 2008). To address this imminent challenge, Perret suggests "adaptation" (Perret 2008).

The situation is not all grey though; some countries in Africa like South Africa, Egypt, Mozambique, Botswana have already shown promise and have structured development in some urban areas to ensure adaptation which is also sustainable (Habitat 2013).

This presses home the fact that the urban environment which was "moulded" to meet the needs of various activities, including economic activities which it housed in the past, may no longer be suited for the present challenges associated with rapid urbanization and climate change, requiring adaptation to guarantee the continued strong role of urban areas in national economies in Africa (Grizans 2009). And unless adaptation is made a priority in development strategies, there is an imminent threat not only to such economies, but life and property from floods. A pattern depicting the links to the various factors relating urbanization and floods is summarized in Fig.4.3.

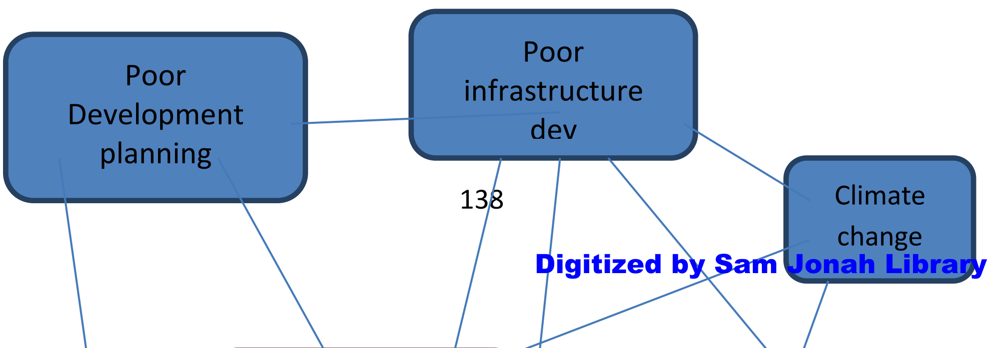


Fig. 4. 3: A partern to urbanization in Sub-Saharan Africa.

4.5 Approaches to flood management

4.4.1 Flood management**:** Stormwater management to control floods in the study area as in other countries in Africa is not based on a central drainage policy but on various general management guidelines developed by relevant departments (Personal communications. 2015 Registrar, Engineering Council Ghana, Accra-Ghana; Personal Communication. 2015. Drainage Engineer, Hydrological Services Institute, Headquarters. Accra-Ghana.). Stormwater management to control floods is rather based on adhoc measures designed to meet the challenge of the day (Tengan 2016) and not derived from long term solutions which is supported by science that will be beneficial to the population and the environment (Andoh 2016, Ouikotan, van der Kwast et al. 2017).

In the research area stormwater management to control floods rely on a conventional conveyance system which is combined with non-structural measures. Non-structural measures involve dredging and desilting, widening and removal of obstructions in stormwater drainage ways to improve flow (Plate 4-9) and to reduce blockage as well as education of the masses on proper waste management and to create awareness on how to protect lives during flood events.

Plate 4. 9: Dredged and widened Stormdrain in a suburb of Accra. Source: Author 2014, Field Survey

It also involve enforcement of standards for building construction enshrined in building codes and planning regulations (Planning 1958, Programme 1991, Andjelkovic 2001, Twumasi 2002, (NDPC) 2010, Frimpong 2014). The drainage system combines both sewerage water and stormwater run-off water through a system of conveyances which is concrete lined in some parts, terminating in an estuary or lagoon.

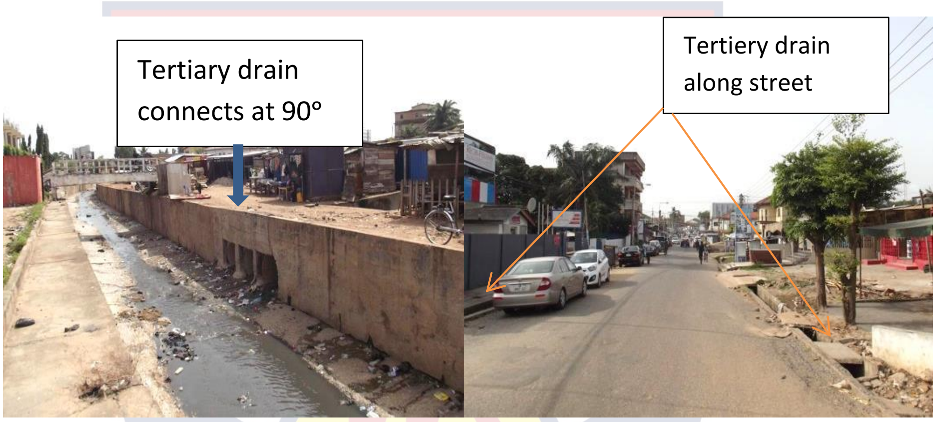
Design of drains is guided by the concept of return period(City-of-Lincoln 2000, PWUD 2000). The return period is the frequency a certain flood event of a given intensity will occur within a specific priod of time of 1,2,5,10,……..500 years (Scholz 2004, Xeflide 2007). It is used to measure the impact of a flood in terms of its mangnitude, which gives an indication of typical features of that frequency of occurance (Gyekye 2011).

ISWM (2010) expressed the return period in terms of duration and volume of rainfall generated from a given event. The return period can be expressed in percentage of "statistical probability", thus a flood event of 50% probability of occurance within a year has a 2-year return period but one with a 10% propability of occurnace in a given year is a flood event with a 10-year return period (EPA-USA 2002). Generally the lower the return period the less dangerous the effect of flooding(Dingman 2002).

In the study area three types of drains are identified, tertiary, secondary, and primary (Personal communications. 2015 Registrar, Engineering Council Ghana, Accra-Ghana). Tertiary drains are designed for a return period of 5years and collects stormwater runoff from the communities (Plate 4-10) into the secondary drains, which have a return period of 15years.

Plate 4. 10: A tertiary drain within a community. Source: Author 2014, Field Survey

Tertiery drains are usually designed “straight”, concrete lined with 90º inter-connections, and where constructed along paved roadways may run “parallel” to roadways (Plate 4-11) with no consideration for biodiversity (Corbett 1997). The secondary drains connect to primary drains through culverts and bridges and have a return period of 25years.



(a) (b)

Plate 4. 11: Tertiary drains connected to secondary drain at 90º (a), Tertiery drains running parallel to paved streets (b). Source: Author 2014, Field Survey

Most drains in the study area are directly linked to bare pervious areas (Plate 4.13a) and have to be desilted and dredged at least once a year to remove heavy sedimentation and or accumulated debris to facilitate flow (Personal Communication. 2015 Drainage Engineer, Hydrological Services Institute, Head Quarters. Accra Ghana). The system of drains allows impervious areas to be directly connected to drainage system through both point sources and non-point sources, creating a situation where urbanized surfaces serve as “stormwater superhighway” (Plate 4-12a) and quicky converys stormwater to overwhelm drainage systems, resulting in floods(Plate 4-12b) (Hunt 2006).

(a)

(b)

Plate 4. 12: A Section of a primary drain with adjacent pervious surfaces, Accra (a); A flood scene during the main rainy season in 2015 (b). Sources: Author 2015, Field Survey & Social media

The efforts made by individuals in the study area to protect themselves and their property from the effect of flooding cannot be down played. In some places residents had adopted novel measures to prevent flood waters from entering their property (Plate 4.13).

Plate 4. 13: A flight of stairs constructed to protect a house from floods, Accra. Source: Author 2014, Field Survey.

Others have concrete paved their immediate surroundings to protect the buildings and property from moisture intrusion and floods. Rain (2011) have noted that although this practice is common in the study area, it does not help address the flooding problem, but rather transfers the problem downstream.

4.4.2 Institutional Arrangement**:** Flood management in the research area has been described as "confusing", because no particular institution has the responsibility to manage stormwater to control floods (Programme 1991). The lead institution, though, is the Hydrological Services Institute, one of many government institutions under the Ministry of Water Resources Works and Housing. This institute has the mandate to propose a conveyance system for water courses, ensure periodic dredging, research into appropriate means for flood management to be able to appropriately advise government (Personal Communication. 2015 Drainage Engineer, Hydrological Services Institute, Headquarters. Accra Ghana.).

Another critical institution is the Water Resources Commision which is responsible for all water resources and has developed a management document, part of which is on flood management in relation to the possible effects of climate change (Water-Resources-Commission 2007). The document recognises "rainwater harvesting" but not as one of the strategies to address flooding, but rather to supplement water supply. The policy mentions dams and other forms of storage structures, use of "early warning systems" and reinforcement of buffer zones as the key strategies for flood control (Water-Resources-Commission 2007).

Other departments are the "Ghana Meteorological Agency" responsible for providing climate related data and forcasting rainfall events. The "District

Assembly", is another critical body mandated to implement and enforce laws and by-laws on stormwater management to control floods within communities (Water-Resources-Commission 2007). The National Disaster Management Organization (NADMO) monitors and manages disasters in the country but is not recognized as one of the key players in stormwater management to control floods by the Water Resources Commission.

4.4.3 Cumulative Effects of Floods on Physical Development - A lot of work has been done in an effort to evaluate the cost of floods on development in developing countries. What is generally accepted among researchers on the issue is that as urban areas expand, the frequency of flood events increases, with occurrence tending to extremes, putting life and property at risk(UNEP 2006, Jha 2012, Asumadu-Sarkodie 2015, Steiner 2016).

Ouikotan, van der Kwast et al. (2017) stated that between 1970 and 2015 there were a total of 227 major flood events within the West African sub region resulting in 3,162 fatalities, 73.5% of which occurred between 2000 and 2015. A comprehensive work done by Okyere, Yacouba and Gilgenbach (2013) showed that between 1960 and 2007, about 90 incidence of floods were recorded within GAMA, with recurrence interval of 0.52years/flood. They estimate that between 1980 and 2010 floods resulted in about 400 casualties and "economic" loss of US$ 33.5 million.

Indeed the problem of flooding has become so pervasive in recent times that it is considered the number two on the list of national disasters in Ghana (Asumadu-Sarkodie 2015), the severity of impact increasing with increasing frequency(Aboagye 2012). Below is a summary of some of the recorded major flood events between 1955-2016 (Table 4.2).

Table 4. 2: Incidence of flooding, casualties and damage in parts of Ghana

Flood Date	Casualties	Rainfall Level/No. People affected	Structures affected		Source
1955			Roads, bridges, railway trucks, residential areas, industrial estates		(Amoako and Boamah 2015)
June 1959		192mm (7.56" rainfall)		Heaviest ever in Accra	Graphic Online, June, 05 2015
1960			Infrastructure, residential areas, industrial estates		(Amoako and Boamah 2015)
1963			Infrastructure, residential areas, industrial estates		(Amoako and Boamah 2015)
June, 1968 In Accra		25,000 people	Properties		(Asumadu-Sarkodie 2015, Tengan 2016)
1968-2014	409	3,9mil			(Asumadu-Sarkodie 2015)
June 29, 1971 In Secondi-Takoradi			Several houses collapse,		(Tengan 2016)
1973			Infrastructure, residential areas, industrial estates		(Amoako and Boamah 2015)
1986			Infrastructure, residential areas, industrial estates		(Amoako and Boamah 2015)
1991	unknown	2000,000	Infrastructure, residential areas, industrial estates		(Okyere 2013, Amoako and Boamah 2015)
July 5, 1995 Accra		A return period of 50yrs. 700,000	Low laying areas, Achimota VRA		(p.499)(Okyere 2013)

			substation, transportation	
June, 13 1997 Accra			Transportation affected, Odaw and Onyasia full	(p.499)
1999 Three Northern Regions		300,000		(p.499)
1999, Accra	Many deaths	Much of Accra affected		(Karley 2009)
June, 2001 Accra	Up to 20	100,000/ 144,025	Houses submerged in affected areas	(p.499)(Karley 2009, Aboagye 2012, Okyere 2013)
2002	Unknown		Infrastructure, residential areas, industrial estates	(Amoako and Boamah 2015)
2005 Three Northern Regions	20	350,000		(Karley 2009)
2007 Three Northern Regions		307, 127		(p.499)
10/08/2007		333,600		(Okyere 2013)
August 2008, Accra		58,000	Mallam	(Karley 2009)
17/06/2009 09/2009		139,790 324,602		(Okyere 2013)
June 2010 Accra	36	33,602	Houses, bridges, washed away roads, effect on education, agriculture	(Asumadu-Sarkodie 2015, Tengan 2016)
June 2010 Swedru		3000		(Tengan 2016)
October 2010 Three Northern regions		161,000	55 communities submerged	(Tengan 2016)
Nov 2010 Afram plains		2,800	120 villages and Towns, 850 buildings, farms,	(p.500)

			markets, roads affected	
February, 2011 Accra			Extensive damage to property	(p.500)
July, 2011 Atiwa District	5	105	Farms affected	
Nov, 2011 Accra	14	81,473		(Okyere 2013)
26 Oct. 2011	14	43,000	17,000 people lost their homes	(UNEP/OCHA 2011)
May, 2013 Accra			Houses, roads, economic activity	
June, 2014 Accra			Houses, roads, economic activity	
June, 2015 Accra	150		House, property, roads, economic activity	

Source: PhD Research, Asiedu 2020

4.6 Summary of Chapter

The chapter covered the landscape character of the research area, Ga East, Ga West, Ga South, Ga Cetental and Accra Metropolitan Assembly within GAMA in Ghana which has a population density of 1,235.8 persons/sq km (national average, 103.4 persons/sq km) covering an area of 891 sq km. The area lies within coastal Savannah ecological zone, has bimodal rainfall and receives the lowest amout of rainfall per annum in the country. Rainfall average between 730 and 800 mm per annum.

The area has no perennial rivers or streams with most of them urbanized into a network of artificial drains lined with concrete to facilitate quick dispersal of stormwater from communities. Stormwater management is thus based on these system of conveyance classified as tertiary, secondary and primary. Berms have been constructed along the non-cannalized sections of the streams and rivers to protect surrounding communities from floods while community members have also developed innovative approaches to protect their properties from floods.

There are a number of lagons along the coast such as Korle, Chemu, Kpeshie which form natural depressions and receive to disperse stormwater but their ability to perform this function has been compromised by heavy siltation and infilling with solid waste. The vegetation is classified into shrubland, grassland and mangroves and has been adversely affected by bush fires, agricultural activity, firewood extraction and urbanization. Open spaces within settlements are almost non-existent with the few converted to agricultural use or paved over. This is creating a vast expanse of urbanized surfaces with no clear character or boundaries.

The architecture is dominated by modernized traditional and modern international designs with a splash of a few old Victorian and colonial style buildings. The area also has historical buildings used as slave holdings especially in places like Osu and Jamestown from the Trans-Atlantic Slave trade era. The expanding peripheral areas consisting of low density housing take up most of the urban space. Transportation is mainly by road with limited rail service. The road network which is 50% tarred with bitumen within communities is used as conduit for draining communities through surface drains. Sediment generation from communities is a major challenge which results in quick siltation of surface drains.

There is no central policy on stormwater management to control floods but there are about 15 government establishment all of which are collaborators in water resource management. The Hydrological Services Institute is the lead Government agency which serves as a consultant to the government on stormwater management. Data supports an increasing incidence of flooding in the study area in extent, frequency and intensity leading to loss of life, damage to property and disruption to socio-economic activities.

CHAPTER FIVE

RESULTS, DISCUSSIONS AND SUMMARIES ON CHAPTER FOUR

5.0 Challenges in Assessing Data and Design Methods implementation

Assessign Site Documentation - I had difficulty in obtaining introductory letters from respective Administrative Authorities to allow me to enter the communities to conduct interviews. The few materials I received on stormwater management to control floods in the research area could not be cited as it had no publication data on it. Earlier researchers have encountered similar challenges in data collection from developing countries(Cohen 2006, Frick-Trzebitzky 2018).

From the survey I had the impression that respondents were getting fartiqued by the many interviews from 'so called' researchers about situations which never seemed to change.

I encountered challenges in implementing the living Labs concept. The challenge is summed up by Jones (1992) when he states that "interpersonal difficulties" in "designing" occurs when the interventions required threaten to burry the interest of participating actors. For instance experts during field interviews were asked whether the existing system of stormwater management to control floods was performing well and whether given the present trends the system's performance would improve in the next 10 years.

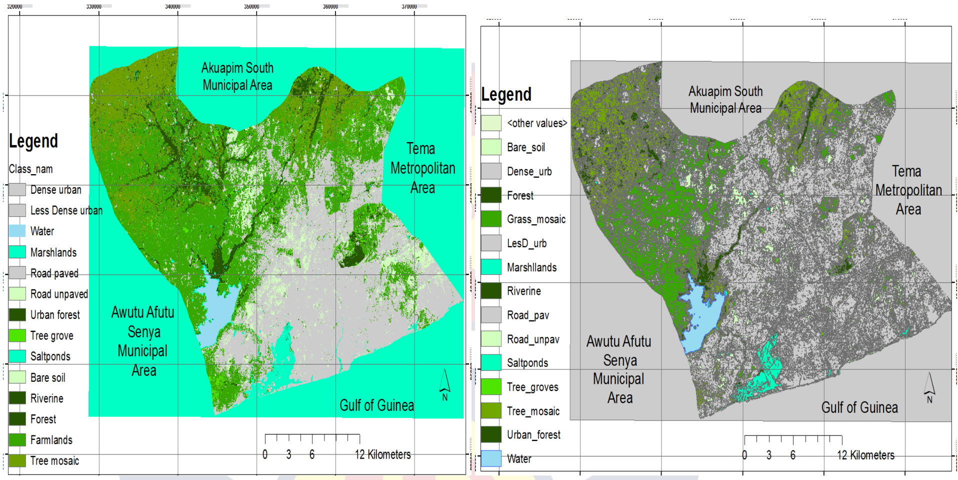
Although almost all admitted that it would not, they were adamant that the problem was not because the current system which relies on hydrologically efficient conveyance system to address stormwater management and flooding is defective. They attribute the challenges faced by the system to poor waste management, non-compliance of the citizenry to basic development standards, and poor engineering, among others. In fact, out of the number of experts interviewed (51 respondents) only 4% admitted that the system is not working and thus the need for a different approach.

Interestingly similar responses are reflected in the common knowledge. With the exception of a single individual, all others were of the view that the system will work if more concrete surface drains were installed. This individual with basic level education surmised that having carefully studied trends in his village and compared them to the urban setting; he believed that the problem of flooding was as a result of the poor management of the environment in terms of destruction of natural places of attenuation. This attitude may be explained by "cognitive dissonance" which is the difficulty of admitting erroneous behavior and in parallel the tendency of blaming someone else but never oneself for a lack of action taken (Lara 2010), conditions which might have hindered the process to generate innovative ideas.

5.1 Data Preparation

Data preparation was fundamental to incorporating spatial data into a GIS environment and involved using the correct coordinate system for the research area to ensure compactibility between the different data sources and layers, especially as the coordinate system for the research area has not been defined for use in the Arcmap software (Thomas, Sannier and Taylor 2000). The use of the rainfall erosivity values interpolated over the study area using kriging had a number of draw backs key of which was the limited raingauge stations (6 stations) spread over the 891 sq km with a distribution of 148.6 sqkm (57.4 sqmile) per raingauge location. This showed very sparse density compared with the suggested less than 4 miles apart (NRCS 1993). However in a data scarce developing country such as the research area there were few options than to adapt the available data for the research.

5.1.1 Image classification - The classification of Landsat images are shown (Fig 5.1) based on similar work by (USGS 2012, Mariwah 2015). The classification identified 14 Land cover classes, (ref Appendix 2 Table 2 for details).



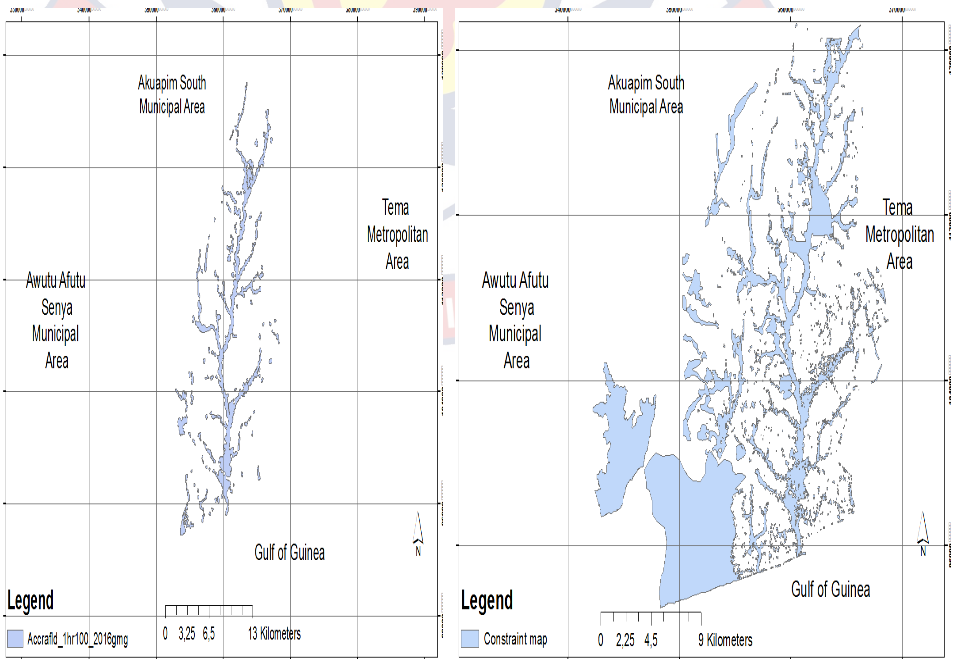
(a) (b)

Fig.5. 1: Classified 2002 Landsat image a) and Classified 2014 Landsat image b)

Accuracy Assessment - Classification of Landsat images into land cover types yielded accuracies of 75.4 and 73.6% for 2002 and 2014 images respectively (Details in Appendix 2 Table 2 & 3). Similar results had been obtained by (Johnson 2002) who reported overall accuracy of 73.4%, (Bogoliubova 2014) also produced an overall accuracy of 71.5% which was considered "not satisfactory", falling outside the range of minimum requirement of 85% and 90% by (Anderson, Hardy, Roach and Witmer 1976). I realized that accuracy could be greatly improved if similar land cover types like tree groves and rivering areas were combined.

5.1.2 Flood Map - The flood risk map classification produced three classes as low, moderate and high risk areas (Fig 5.2). Moderate and low risk locations were areas considerate to be of low risk for the location of detention/retention basins while high risk areas where those close to water bodies (Raghunath 2006). The flood maps were used to define flood plains and areas within the study area vulnerable to floods and were used as "visual tools" to communicate the hazard level in different parts of the study area (Jha 2012).

As noted by (Raghunath 2006) high risk areas should not be developed for housing but should be preserved to give more room to stormwater to avoid floods(CDOT 2004), however within the research area all such areas had been developed into residencial facilities. The flood risk map was part of the constraint map which was prepared by combining a flood risk map (from a 1hr in 100mm rain event) with reports from field survey showing flood prone areas, salt ponds, wetlands within the study area.



(a) (b)

Fig.5. 2: Flood map for 1hr in 100mm rain (a) and Constraint map (b)

5.2 Soil Infiltration Rate and Hydrological Soil Groups

This section is based on a paper I authored (Asiedu, J. B. (2020). Infiltrating to Control Floods - Suitability of Infiltration based Systems in Sub-Saharan Africa. *American Journal of Earth and Environmental Sciences, 3*(1), 1-12.)

Soil Hydrological grouping - Using the minimum near saturated hydraulic conductivity values, I derived a prelimary classification of the soils into hydrological soil groups (HGS) (Table 5.1).

TABLE 5. 1. HYDROLOGIC SOIL GROUPS FOR SOILS OF THE FOCUS AREAS

Focus Loctn	RainG Loctn	Major Soil	Soil Association	% Coverage	HSG[1]	HSG*
Area1	Accra Academy	Acrisols	Nyigbenya-Hatcho Complex	100	C	C
Area2	Pokuase	Acrisols	Oyarifa-Mamfe	63.4	B	C
		Leptosols	Fete-Bediesi	21.6	B	C
		Acrisols	Korle Consociation	15.0	A	-
Area3	Mempe huasem	Livisols	Damfa-Dome	62.5	A	D
		Acrisols	Oyarifa-Mamfe	4.3	B	C
		Acrisols	Nyigbenya-Hatcho	33.2	C	D

Note: HSG Hydrological Soil Group as obtained from literature sources and from the Harmonized World Soil Dababase (HWSD) HSG[1]- Hydrological Soil Groups based on field infiltration tests. Source:* Asiedu, J. B. (2020). Infiltrating to Control Floods - Suitability of Infiltration based Systems in Sub-Saharan Africa. *American Journal of Earth and Environmental Sciences, 3*(1), 1-12.

The classification of Nyagbenya-Haacho under HSG C is supported in the literature by (Adjei-Gyapong 2002, Ashiagbor, Forkuo, Laari and Aabeyir

2013). The same cannot be said for Oyarifa-Mamfe complex, an Acrisols which was classified as C based on work done by (Adjei-Gyapong 2002, Ashiagbor, Forkuo et al. 2013) and data from the Harmonized World Soil Database site(FAO/IIASA/ISSCAS/JRC 2012). Also using the Phillips approach (Phillips 2015) Damfa-Dome complex is classified as HSG D.

These differences in hydrological soil groupings between the field based classification and the literature based classification may be due to the method used. It could also be due to the extent of the research as a small scale field work covering a limited area will be more detailed than a small scale field method over an extensive area. Another fact which could explanin the difference is the constant change under different land cover experienced by soils in urbanized areas (Asiedu 2018), derived from physical processes like erosion(Jadczyszyn 2005) and variations within same soil type (Chow 1988, Stibinger 2014).

5.3 RUSLE Model and Soil Loss

This section is based on a paper I authored "Assessing the threat of Erosion to Nature-based interventions for stormwater Management and Flood control in the Greater Accra Metropolitan Area, Ghana" Journal of Ecological Engineering, 19 (1), 2018

5.3.1 Soil Loss - The maximum soil loss of 69.592 ton/ha/yr recorded by the model is considered high according to the FAO soil loss classification scheme (1967) cited by (Silva da 2010, Kusimi 2015) which provided four classes of soil loss as follows; Very low< 10, Moderate10-50, High 50-120 and Very High > 120. Lahlaoi (2015) working in Morocco (North Africa), classified soil loss of between 20-30 ton/ha/yr as high and although a range of 7-20 is moderate, such losses can still be considered as significant.

On a regional basis, the estimated soil loss is high compared with soil loss of about 50 tons/ha/yr quoted by (Obalum 2012). Kamaludin (2013) used a similar approach and reported soil loss values ranging between 0 and 95.5/ ton/ha. (Jadczyszyn 2005) researching on mainly sandy soils in Poland reported "annual average" "losses" of between 0.8 to 16.5 t/ha/yr. The observed result is not inconsistent with the low rainfall erodibility, low soil erodibility, low slope degree and the relative high "clay content" of "more than 30%"(Obeng 2000) of majority of soils of the study area. The reason is that most of the study area (> 70%) where the relief condition is low (Figure 4-6) soil loss which ranged 0 – 5.185 t/ha/y was also very low (Silva da 2010, Kusimi 2015, Lahlaoi 2015).

The Sediment Delivery Ratio (SDR) of 0.2415 is considered low according to (Kamaludin 2013) who, using the same approach but working under different conditions, had 99.4% classified as very low; 0.5% as low; 0.06 as moderate and 0.04 as high. The estimated Sediment yield of 16,8064 (T/ha/yr) is higher than the range of 0 and 13.79 t/ha/yr reported by (Kamaludin 2013) but lower and within range of 0 to 193 t/ha/yr reported by (Kusimi 2015) who worked on soil erosion in the middle belt region of Ghana.

5.3.2 Implication for a Nature-Based Stormwater Management System - The life of infiltration-based stormwater management facilities like bioretention, detention basin, or rain gardens, bioswales depends on the extent of clogging by sediments. Infiltration-based stormwater management facilities become gradually less efficient as they are clogged by "fine silt" and "sediments", making it important to contain sediment generation within the catchment of such facilities, especially in areas with high sediment yields (Industries 1993, Stephens, Graham and Reid 2002, Lucas 2010, Liu 2014, PWUD 2014, Shafique 2016).

Where potential erosion is high, there will be a high possibility of system failure or the need for frequent maintenance(PWUD 2000). Additional "problems" with "stagnant water" and "aesthetics" may increase the cost and reduce the attractiveness of the system (Le Coustumer 2008). What is clear from the soil loss model is that the naturally occurring soils, except in limited places do not generate enough sediment to pose a threat to an infiltration based intervention. The main threat though comes from human activity which pervades the urban landscape and accounts for between 70-90% of the cause of erosion(ACOPS 2003).

5.5.3.Erosion and Siltation Management Interventions - (Raghunath 2006) has stated that the best way to control siltation is to introduce interventions which will control it at the point of generation and this can be done using measures that protect the soil like establishment of vegetation in exposed land areas and introduction of interventions which reduce the volume and speed of flow of stormwater generated runoff to drainage channels, thus prevent erosion and siltation. One way to achieve this is to manage stormwater at the plot level to reduce the amount which will escape to cause erosion, and generate sediments to clog drainage systems.

5.4 Hydrogeology

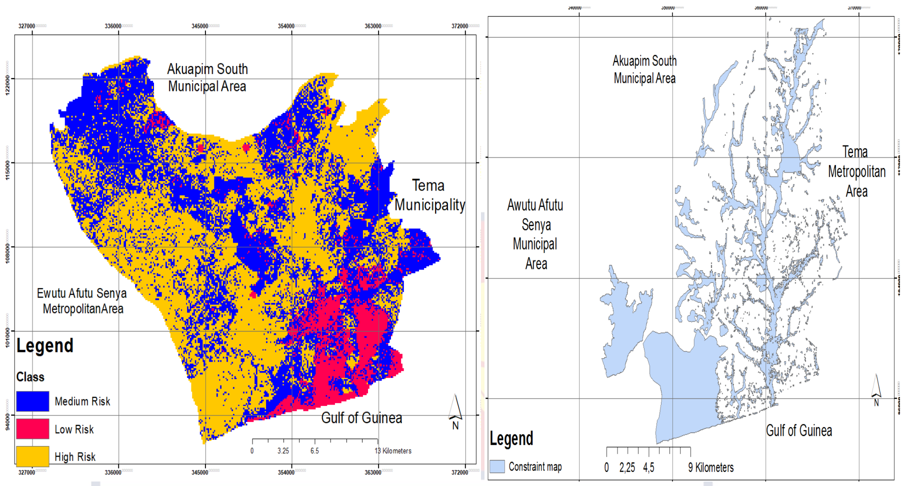
The hydrogeology data in the form of borehole depths in meters ranged between 6.7 m and 29.6m with an average of 8.9 for the 173 locations. This covered about 70% of the study area with the rest of the area having no borehole data, probably because these areas have relatively good source of municipal tap water. The results from the hydro-geological data analysis produced a ranking for the location of infiltration based systems like infiltration well, infiltration trench, detention and retention basin. The ranking was from < 7 m to very high of $\geq$ 17m below the surface of the soil (Table 5-4). Thus the greater the depth to ground water, the higher the ranking. Areas with ground water depths of less than 7 m were rejected as unsuitable but areas with ground water depth of 7m or more were given a high ranking and accepted. The data range of 6.7m - 29.6 m was lower but within the range of 4.8 m and 70 m provided by(Nyarko 2000).

The location of infiltration based systems for controlling stormwater in relation to ground water levels is very critical. Endreny (2009) has cautioned that where infiltration based interventions for stormwater management to control floods have been implemented *enmasse*, there could be welling up of ground water levels which could be as much as 1 - 2 m per rainy season and this has the potential to adversely affect foundations and structures.

A number of researchers have sought to project the acceptable depth to ground water for location of infiltration-based interventions such as (Environmental-Resources 2007) who suggested "no less than 2 feet", (PWUD 2006) a "3ft" "buffer" "between the bottom" of the infiltration based intervention and the "seasonal high groundwater table", while (PWUD 2000) suggests at least 60cm ("2 feet") above the ground water table.

5.5 Multicriteria Suitability Overlay Analysis

The results of the multi-criteria suitability overlay analysis produced a schema which is made of two maps; a Factor map and a constraint map (Fig 5-3). The Schema for detention/retention basin (Fig 5-4) gave three classes of suitability as high, moderate and low areas. Low risk areas were highly suitable areas outside the constraint area which were possible locations for the detention and retention structures. Some areas within the contraint map could also be used for locating retention basins (Palanisamy, 2015, p. 310). For the second model based on Rain gardens, Infiltration trenches and Infiltration wells (Fig 5.5), the model results also produced three suitability levels, with low risk areas outside the constraint map considered as possible locations.



(a) (b)

Fig.5. 3: Factor Map (a) and Constraint map (b)

MacDonald (2006) in explaining the significance of categories of suitable locations, states that "high land suitability" means areas where the land has more of the factors that makes it suitable for a particular function while areas with low suitability has far less of the factors that makes it suitable for the particular function.

Similar descriptions have been given by (Herrington 2010) who gave a range from the "darkest gradations" with the "highest value" to very poor locations with the "lightest tones" and "least significant values". From the results the Multicriteria Suitability Overlay Analysis model was able to "condense and organize" the seven spatial layers (Lee 1982) to reduce the complex properties of the layers to shades of tones or numbers which could be valued in relation to suitability for the location of a given intervention.

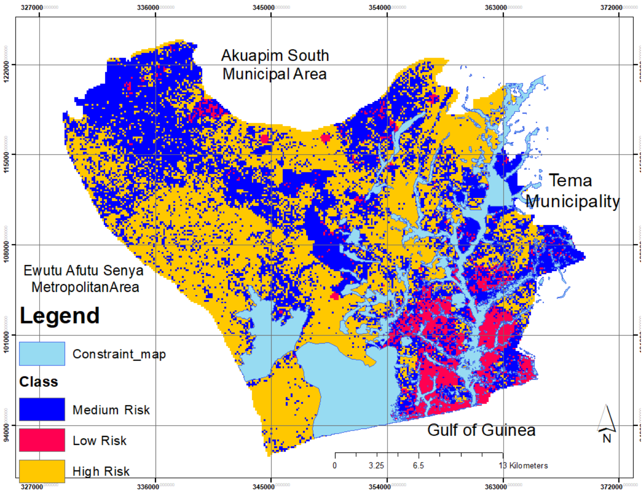


Fig.5. 4: Multicriteria Suitability Overlay Schema for Detention/Retention Basins

Steiner (1983)and (Rinner 2011) has stated that a "multi-criteria" "overlay" method is a process to determine the appropriateness of a particular piece of land for a given function where "inappropriately" locating an intervention in the context of a developing urban area, could make worse an already bad situation (Yang 2013). This makes "location" and "placement" of interventions for stormwater management to control floods key to “effectiveness” (Martin-Mikle 2015), a bridge which the schema is designed to close as a critical step in selecting suitable locations (Yang 2013).

The schema was used to determine the best place fit for that particular purpose (Steiner 1983) and this means selected locations may not have all the ideal characterisitics to fit them for identified use, thus the need for further reiterative analysis. The process is a nature-based approach because "nature" "serves as a guide" to the location and ultimately "design" (Herrington 2010, Yang 2016) of interventions to address storm-water management to control floods.

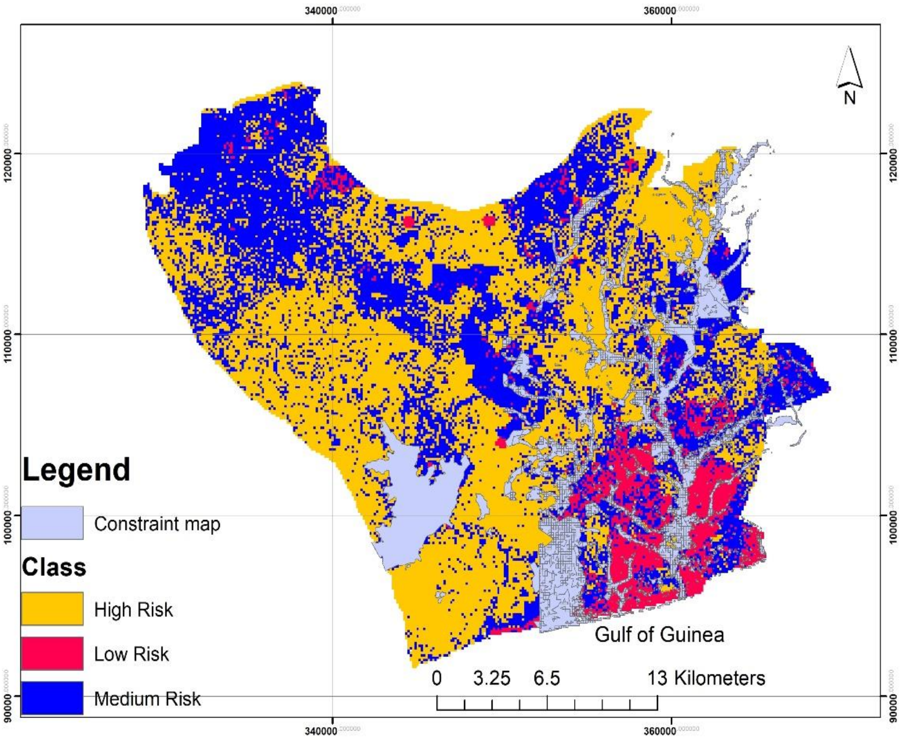


Fig.5. 5: Multicriteria Suitability Overlay Analysis Schema for Infiltration Wells, Trenches and Basins

The process is scientific as it "integrates an assortment of scientific data" such as "meteorology" in the form of rainfall data, "geology", hydro-geological data, "soils", erosion, population density, land cover which is modeled in a GIS environment using multi-criteria "map overlay method" as "a means to reveal" the best locations for an intervention(Herrington 2010). Although the process has been described as subjective, given the unique condition of the study site, the method presents the best option to a thorough analysis of the urban landscape for a comprehensive stormwater management and flood control schema.

The technique does not produce "plans" but is a tool which can be used by planners and various "stakeholders" as a "comprehensive" "guide" to "develop new land-use plans for their watersheds" for the location of various interventions for stormwater management and flood control (MacDonald 2006). Its role in the design process will thus be to help deal with the "complexity of large scale conditions" (Motloch 2001, von Seggern 2008) by aiding in site selection, as one of the tools which can be applied at the regional level by Landscape architects, urban designers and other environmental designers in the selection of suitable locations for nature based interventions to control floods.

Low Impact Development (LID) practices like detention/Retention basins and infiltration systems are designed to reduce stormwater runoff (Passeport 2013), thus the application of the schema should ensure that interventions are located in areas where they will be most “hydrologically effective” and efficient. It is also necessary that further "field investigation" is carried out to verify the selected best locations (Martin-Mikle 2015), with implications for the design of interventions (Passeport 2013).

5.6 Stormwater Runoff Estimation

Land cover analysis - There were no significant differences in imperviousness between the three focus areas at 5%, however, level of imperviousness decreased from Area1 (54.1%) to Area3 (22.0%) (Table 5-2).

Table 5. 2: Summary of Landcover types for the focus areas

	% Coverage		
Land cover	**Area1**	**Area2**	**Area3**
Rooftops (i)	35.0	22.6	14.8
Paved Streets(i)	6.4	1.2	0.7
Unpaved Streets (p)	5.6	9.3	5.9
Bare soil(p)	1.8	0.6	0.7
Pavement(i)	1.0	1.3	5.3
Uncomplete developt (i)	0.32	1.7	1.23
Play field (Bare)(p)	0.3	0.2	0.2
Backyard garden (p)	0.04	0.1	-
Trees(p)	4.2	4.8	5.25
Undeveloped vegetated(p)	0.04	6.9	0.62
Farmland(p)	0.0	0.9	20.1
Leftover space (paved)(i)	11.4	16.8	0
Lafeover space (bare)(p)	34.1	16.8	15.1
Leftover space (veg)(p)	0.0	16.8	30.2
Total Cover	100	100	100
% Imperviousness	**54.1**	**43.7**	**22.0**

Note: (i) impervious surfaces; (p) pervious surfaces. Source: PhD Research, Asiedu 2020

Percentage coverage of partially completed buildings (Table 5-2) varied from Area1 (0.32%), Area2 (1.82%) to Area3 (1.23%). The percentage of bare surfaces increased from Area1(41.8%) to Area3 (21.9%). Area1 and Area2 with imperviousness > 40% is classified as high density urban areas whilst Area3 with < 40% is low density urban area (Su 2014). There was a clear trend in the runoff coefficient and imperviousness, which decreased from South (Area1, 0.7437) to north (Area3, 0.4081) with signicant differences between the three focus areas ($p<0.001$).

Runoff coefficient values are indicative of how susceptible an area is to runoff generation with higher values showing higher potential. The results although close, is still lower than the range of 0.7 and 0.95 suggested by (Asumadu-Sarkodie 2015) for urban areas. This could be explained by the increasingly dispersed nature of settlements as built up space grow outwards into surrounding agricultural lands (Biggs 2010).

The observed trend in partially developed plots, decreasing open bare areas and imperviousness from southern older parts (Area1) towards northern newer periurban developments (Area3) partially conforms to the Wolman model (Biggs 2010). The trend also seem to be entrenching the slum condition in developing urban areas, producing uncontrolled lateral spread of impervious surfaces (Bank 2015).

Roof size analysis - There was a clear trend between imperviousness and roof area for both small roofs (< 81m^2) and large roofs (≥ 81m^2). While roof area (for large roofs) increased from Area1 (182.2 m^2), Area2 (195.6 m^2) to Area3 (248.5 m^2), imperviousness decreased in the same direction (Table 5-2 & 5-3). The percentage of imperviousness from roofs which ranged between 14.8 and 35% is close to the 25 – 35% reported by (Gogate 2012).

The roof size distribution between the three focal areas showed significant difference at 5% with Area1 producing far more small roofs, the number decreasing from Area1 to Area3 (Table 5.3).

TABLE 5. 3: ROOF SIZE DISTRIBUTION BETWEEN THE FOCAL AREAS

Parameter	Area1	Area2	Area3	P-Value
Mean Roof Area≥81m²	182.2	195.6	248.5	0.005
Mean Roof Area<81m²	27.6	27.2	28.5	
Number of	14,129	9,954	5,355	
Roofs≥81m²	27,727	13,176	5,994	
Number of				
Roofs<81m²				
%Roofs≥81m²	77.1	84.4	88.6	
%Roofs<81m²	22.9	15.6	11.4	
Combined Roof Area ≥81m²	2,574,823.8	1,946,618.3	1,330,914.4	
Combined Roof Area<81m²	764,125.5	358,596.9	170,839.10	

Source: PhD Research, Asiedu 2020

Hydrological Soil Groups (HSG) and Choice of CN value - The choice of CN factor values for the land cover types were based on HSG for the different soils of the three focus areas (Table 5-4) as described(Asiedu 2020). Area3 was assigned three different HSGs for the different soil groups with corresponding CN factor values for each land cover type. Area1 had only one soil group and thus had a single HSG with corresponding CN factor values for the land cover types. The composite approach yielded a CNw of 89 for Area1, and 83 for both Area2 and Area3 (Table 5.4).

Table 5. 4: Land cover types, HSG and CN factor values

Land Cover	Area1 HSG	Area2 HSG	Area3HSG	C N*	S*
Rooftop	C	B, A	A, B, C	98	1
Paved Strt	C	B, A	A, B, C	98	
Pavement	C	B, A	A, B, C	98	
PC Building	C	B, A	A, B, C	98	
Left Over Space (paved)	C	B, A	A, B, C	98	
Unpaved Str	C	B, A	A, B, C	Dirt Road	1
Baresoil	C	B, A	A, B, C	Fallow, Bare	2
Left Over Space (Bare)	C	B, A	A, B, C	Fallow, Bare	
Playfield (bare)	C	B, A	A, B, C	Fallow, Bare	
Backyard	C	B, A	A, B, C	Cultivated Land	1
Farmland	C	B, A	A, B, C	Cultivated land	
Trees	C	B, A	A, B, C	Wood/ Orchard	2
Undeveloped vegetated	C	B, A	A, B, C	Wood/ Orchard	
Left Over Space (vegetated)	C	B, A	A, B, C	Herb, Poor& culitvted	1,3
CNw	**88.9**	**83.4**	**83.2**		

S* - Source 1. ISWM, *Hydrology*, in *iSWM Technical Manual*, E.a.D. North Central Council of Governments, Editor. 2010, Integrated Storm Water Management (iSWM): Arlingron, Texas. 2. USDA-NRCS, *Hydrologic Soil-Cover Complexes*, in *National Engineering Handbook*. 2004a, United States Department of Agriculture, Natural Resource Conservation Service: United States. 3. USDA, *Urban Hydrology for Small Watersheds*, in *TR-55*. 1986: USA.

Rainfall and Runoff Analysis - I chose the rainfall evaluation months (Feburary to December) to include the most rainy periods of the year, when most floods also occur in the research area (Gyekye 2011, Gyekye 2013). The seven-year evaluation period (between 2006-2015) was chosen to ensure that there will be little or no land cover change to affect the validity of the results for the 2014 reference year (Lambin 2006) and also to meet the short term hydrologic criteria for the use of the CN model (Ponce 1996).

Differences in daily rainfall levels (>40mm) between the three focus areas (Table 5.5) from February to December for the data period were not significant at 5% (0.669). The same trend was also noted for direct run-off at 5% (p=0.196). Daily median direct runoff for Area1 was 35.8 mm, Area2, 21.1 mm and Area3, 22.1 mm. The highest daily rainfall for Area1 was 313.8 mm in June 2009; the highest for Area2 was 139.6 mm in May 2009, and for Area3, 148.3 mm in June, 2015. The results showed no significant changes in rainfall and direct runoff values for the period under consideration between months (Fig 5.6) and the years (Fig 5.7).

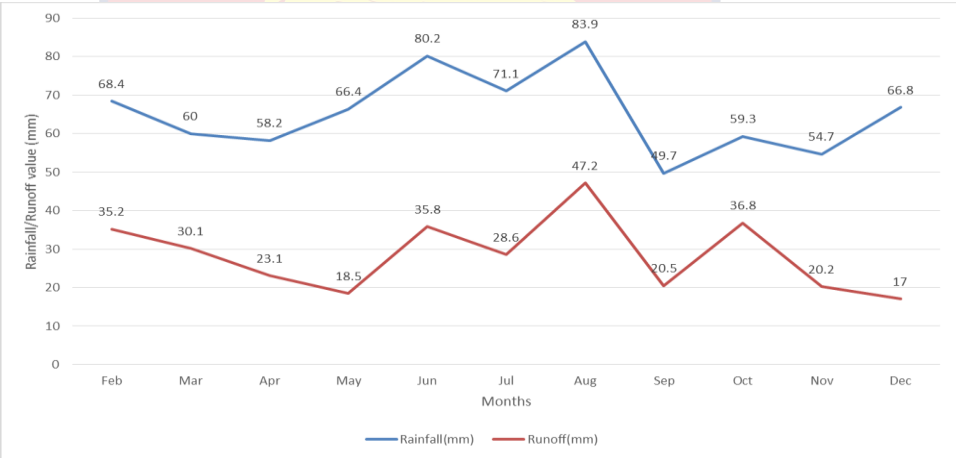


Fig.5. 6: Daily average rainnfall and runoff trend by month from 2006-2015

Effective runoff which is the difference between rainfall and infiltration capacity (Ponce 1996) ranged between 522,033 m^3 and 265,690 m^3. Gogate (2012) has observed that water from roofs and roads represents by far the major contribution to urban surface run-off and the results confirm this trend where roof runoff alone contributed between 14.7% and 32.6% to effective runoff (Table 5.5).

Table 5. 5: Runoff levels and Runoff volumes from the three focus areas.

	Area1	Area2	Area3	P – Values
MDRainfall (mm)	68.6	62.8	69.2	0.669
MDD Runoff (mm)	35.8	21.1	22.1	0.196
CDHRW(m^3)	170,279	60,802	42,420	<0.001
EMDRunoff (m^3)	522,033	265,690	287,992	<0.001
% DHRWater	32.6%	22.5%	14.7%	<0.001
Runoff Coefficient	0.7437	0.40803	0.4081	<0.001
Annual Rainfall (mm)	848.0	846.0	1057,5	

Notes: MDRainfall; Mean Daily rainfall >40mm, MDD Runoff – Median Daily Direct runoff (mm); CDHRWater – Combine Daily Harvestable roofwater per rain event, EMDRunoff – Effective Mean Daily Runoff (m^3) per rain event, % DHR water – % Daily Harvestable roofwater which is the ratio of total harvestable roof water and effective daily runoff per rain event between 2006-2015. Source: PhD Research, Asiedu 2020

Pickett, Cadenasso, Grove, Nilon, Pouyat, Zipperer and Costanza (2001) had earlier reported that 13% of rainfall in urban areas falls on buildings and the results produced a clear trend to support this.

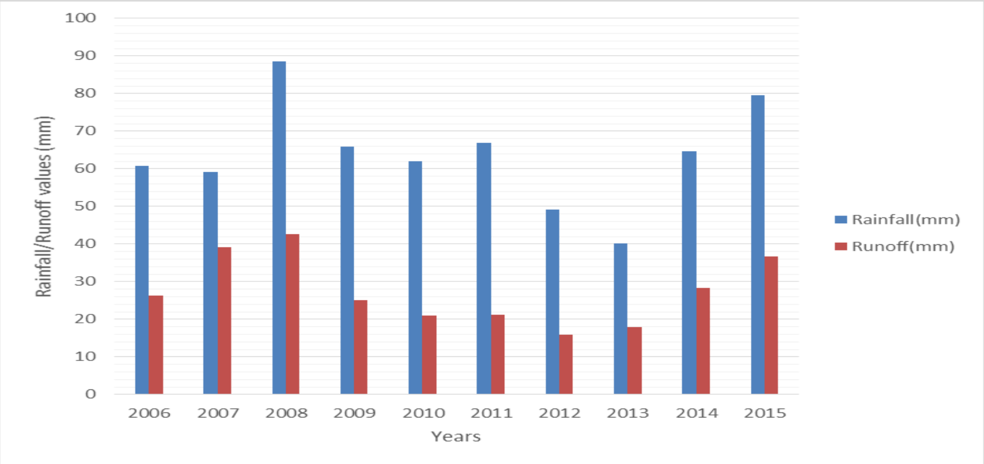


Fig.5. 7. Daily average rainfall and runoff trend by year from 2006 and 2015

The maximum roof size (≥81 m^2) and minimum roof size (<81 m^2) I used for the model is similar to roof sizes chosen by Lani et al (2018) who reported on work in Belgium where roof areas of 100m^2 minimum were used. Others have used 66.3 m^2(Takagi 2018) and 70 m^2 (Juliana 2017).

Harvestable roofwater per rain event for the three focus locations was significantly different, decreasing from South (Area1), 170,279 m^3 to North(Area3), 42,420 m^3 (Table 5-5). Effective runoff volume was significantly different at 5% decreasing from South (Area1) towards North (Table 5.5).

Roof size did not seem to influence the volume of harvestable roofwater but showed an inverse relationship between the two as harvestable roofwater decreased from Area1 to Area3 whilst roofsize increased in the same direction. The estimated direct runoff values from the focus areas which averaged between 46.2 mm and 21.0 mm was higher than the 20 mm stated by (Houdeshel 2012) and will require a number of interventions to considerably reduce runoff levels.

Although there was no clear trend in extent of bare surfaces, development was always at the expense of vegetation cover, creating a lot of cleared and bare spaces and this has adverse effect on infiltration. Wilcox, Breshears and Turin (2014) has noted that as the extent of bare ground area increases, the influence of plant cover decreases in its effect on infiltration. For communities in the study area, as is the case in other developing countries, building development proceeds social infrastructure and services(Biggs 2010), creating a situation where plots of land may be acquired and completely developed but it may take a long time before any services and infrastructure are introduced into the area. At this time the streets are unpaved, much of the existing vegetation has been cleared, with exposed soil compacted due to traffic from construction vehicles, equipment and other human activities. Thus stormwater runoff from the roofs of buildings falling with great kinetic energy flows over compacted pervious and impervious surfaces to be released into the community through point sources or as sheet flow, in rills developing gullies and picking sediments as it speeds along.

The sediment-laden stormwater run-off then flows through the community in concentrated bursts where there is no depressions and natural places of attenuation to store, or vegetation to intercept. This combined with a hydrologically efficient drainage system, results in fast accumulation with high flow rate of stormwater runoff per unit time and a shortened “runoff travel time” (Andjelkovic 2001). This creates the condition for fast accumulation of stormwater which is not dispersed quickly enough by the urban landscape, resulting in floods. This way, "even small rainfall events” generate large volumes of stormwater runoff (Lu 2011) and this is what may be fuelling the perception that the intensity and frequency of flooding is increasing.

In all the focal loctions, farmed or fallow plots and landscaped areas on developed plots provided the main green space in the communities. These "green space" comprising a "diversity of plantings including trees, shrubs, grasses” and herbaceous perennials, "provide a contrast with built environments" but had not been integratively designed to perform the "specialized functional role of stormwater management" to control floods in the communities(Kazemi 2011), thus although they might have some value in mitigating urban runoff, their value in flood control is very minimal.

The level of imperviousness in all three locations, although not statistically insignificant, has impact on stormwater generated runoff. Liu (2014) has observed that impervious surfaces "generate 16 times more runoff" than pervious vegetated surface of the same size. Under tropical conditions in a developing country, (ActionAid 2006, Bhattacharya-Mis 2011) observed that reduced infiltration due to imperviousness lead to increased "runoff" generation about “6 times” more than what was generated under pre-development conditions. Where the extent of impervious has increased by more than 10%-25%, the impact on stormwater generation leading to floods is “more prominent” (Yang 2013).

Zahran, Brody et al. (2008) considers "flood discharge" to be 250% higher in urbanized areas “compared with forested catchments" as a direct result of increased impervious surface cover. Shafique makes a similar comparism stating that while 10% of rainfall in pervious areas become runoff, it is 55% for urbanized impervious areas, thus as the extent of imperviousness increases, stormwater generated runoff will also increase (Shafique 2016).

The challenge then will be to introduce interventions which will reduce the volume of runoff generation in the communities to replace lost depression storage and other places of attenuation, cleared vegetation to intercept, and pervious areas to infiltrate stormwater sufficient to prevent fast accumulation leading to floods.

This research, based on the results, takes the position that a combined use of infiltration based interventions and rainwater harvesting could be used as critical interventions to address flooding problems in the study area. And this could easily be done by capturing and storing for domestic use or infiltrating at the plot level roofwater within plots. This will translate into between 14.7% – 32.6% reduction in total runoff generated within the communities, to "keep runoff volumes low" and reduce speed of flow, increase runoff travel time to make it easier for the rest of the stormwater runoff generated outside plots to "infiltrate and or evaporate" (Echols 2007) or be conveyed through the conveyance system without causing floods.

Fortunately the concept of rainwater harvesting is not new and has received a lot of attention in recent times as a means to ease pressure on existing public water supply systems, reduce soil erosion to control floods during rain events (Asare 2013, Shepherd 2016, Amisigo undated) and a means to adapt a fast urbanizing area to the possible impact of climate change (Boelee 2013).

The importance of stormwater generated runoff especially at the plot level cannot thus be overemphasized. This is because, of the two main types of flow, overland flow and channel flow, the strength of runoff is determined more by the extent of channel flow. Where channel flow is long and extensive the effect on flooding in low laying areas is also extensive. This situation is worsened by roof water whose impact "concentrate" as it flows over impervious and compacted pervious surfaces, excessively shortening overland flow to less than 30m before turning into confined paths(Chow 1988). This way the time of concentration is reduced leading to flooding. By retaining roof water on individual plots, overland flow will be shortened by infiltration or storage in storage tanks, flow rate and volume will reduce and time of concentration will increase, with subsequent reduction in incidence of floods downstream.

5.7 Return Period

The results of the frequency analysis for the 6 rain gage locations show no particular trend in return period for all stations. Two stations Accra Airport and Mempehuasem with the longest data period produced rainfall with 50yrs return period (Table 5.6). But the design of interventions was based on the 25 year return period because it is close to the maximum daily rainfall for the three focus areas and also given the limited 44 year rainfall data period used, a 25 year return period will give a more accurate prediction than a higher return period (Cudwoth 1989).

Table 5. 6: Depth Duration Frequency distribution of Return Periods by Weibull's method

RainGauge Location	Data Period	**2**	**5**	**10**	**20**	**25**	**50**
Accra Aca	16	45.3	100.1	172.6	219.8	234.9	284.2
Accra Airport	43	36.9	100.8	145.9	222.2	245.3	277.9
Pokuase	40	60.0	124.7	166.4	218.7	227.5	278.7
Mempeh-uasem	43	6.8	72.1	125.3	177.6	206.4	266.9
Weija	32	35	111.1	161.6	213.8	223.1	284.2
KorleBu	18	27.3	89.6	138.2	198.6	237.9	275.7

Source: PhD Research, Asiedu 2020

The return period also called flood frequency analysis is used to predict how often a rainfall event of a particular magnitude will occur within a year(Xeflide 2007).

5.8 Design Notes on Storage and Infiltration based structures

Two main categories of stormwater management and flood control systems are identified in the literature as minor and major drainage systems, and conventional and non-conventional systems of stormwater management. Conventional and non-conventional systems have structural and non-structural components. Non-conventional systems have been developed into state-of-the-art interventions for stormwater management to control floods and are grouped into source control and treatment based systems. And this state of the art system is the one the research recommends.

5.8.1 Non-structural control strategy - The Non-structural control strategy that I recommend is educational. The results suggests that roofwater at the plot level could contribute 14.7% - 32.6% to stormwater runoff in communities, thus any strategy that seeks to address stormwater management should target education of the public on plot level management.

For this reason I recommend that education on stormwater management at the plot level should focus on roofwater which could be infiltrated and or harvested for reuse. Roof water harvesting is a well known practice that is popular throughout the communities, but it needs to be promoted as a means not just to meet the household water needs and thus reduce the burden on municipal water supply systems, but as an integral and critical part of stormwater management to control floods(ActionAid 2006, Dehais 2011, Palanisamy 2015).

5.8.2 Structural Control Strategies - Based on the results of the research, I recommend four source control methods - infiltration wells, infiltration trench, rain-gardens and roofwater harvesting for plot level stormwater management to control floods. At least one infiltration based system could be installed per plot where space will allow to infiltrate 20-30% minimum of roof water in addition to a storage tank for roofwater harvesting.

5.8.2.1 Infiltration wells: These are also called dry wells and can be constructed on site by excavating up to depths of 1.5 m or more (between 5-50 m deep) to infiltrate roofwater in residential areas. Deeper wells will encourage drainage by gravitational force (Vertical Drainage) where the water table is deep but shallow wells will encourage lateral drainage especially where the ground water level is high.

The well should be filled with grade type gravel (≥ Ø 38mm and ≤ 75mm) and may be located underground or surface, covered with concrete, grassed over or left open and decorated with pea shingles or similar decorative material. Where installed surface, it should be raised above the finish grade to prevent runoff from spilling over into it with the surroundings grassed or paved.

It should be constructed to receive only roofwater through a downspout and can be circular (0.75m – 1.2m diameter), rectangular or square with sides stabilized using 125 mm sancrete blocks (or 100 mm blocks), precast concrete rings or similarly durable material. Where the sides of the infiltration well is sealed, infiltration will be limited to the bottom in which case the subsoil should have minimum infiltration rate of 5mm - 12.7mm/h (0.2-0.5 inc. per h).

It should be located at least 3 m downslope of any foundation. Where it has to be located closer or upslope, an impermeable liner should be installed at the side closest to the foundation and/or the separating distance should be longer to prevent any seepage which could affect foundations. It should be located not less than 7.6m upslope of a septic tank and 15.2 m from a borehole or handdug well. To enhance smooth transition between the infiltrating chamber and the underlying soil allowing drainage within 24-48 hrs, a 300 mm bed of rough sand should underlie the infiltrating chamber.

It can be installed in areas with good drainage as well as in areas with impermeable underground soil layers (such as lateritic hardpan or clayey layer). In such areas the depth should be greater than the impermeable layer. The bottom of the infiltration chamber should be at least 3m above the seasonally high ground water table. A litter trap should be installed with the downspout to prevent leaves and other debris from blocking the system.

5.9.2 Rain garden**:** Rain gardens works by infiltrating stormwater runoff through a filter bed. It should not be installed close to foundations, but must be set off at least 3 m downhill of foundations. It can be installed in higher elevation areas or within a plot as a retrofit by creating a shallow depression that allows 150-450mm of ponding. The depression is first created by excavating to a depth of 450 mm - 1200 mm before refilling with engineered soil mix made of sand (85-88%), silt + clay (8-12%) and 3-5% organic matter for soils with very poor infiltration rate. Excavation should be made to a flat bottom but a large surface area to prevent clogging.

The system should be designed to drain in 40-72hrs with a min infiltration rate of 1.3 cm/h (best range of 2.5mm – 15.2 cm/h) and side slope of 4:1 (vertical / horizontal). It shld be planted and not surfaced with rocks as that will increase the incidence of clogging. A pretreatment area made of 1.2 - 1.5 m wide strip of lawn laid to 5-10% slope from pervious areas and 2% for impervious areas should be established around the raingarden to filter off sediments to prevent clogging.

5.9.3 Infiltration Trench**:** Best installed in areas with infiltration rate of 12.7 mm/h – 305 mm/h, making it unsuitable for soils in hydrological soil group D. It can be installed as a stand alone or in series with retention basins or under a swale to improve storage capacity and infiltration efficiency.

Size. Depth range between 90 cm – 300 cm but width should be up to 240cm and can be trapezoid in cross section or rectangular. The infiltration trench may be constructed surfaced where it is covered with decorative stones or subsurface where it is covered with a semi permeable membrane and layers of topsoil and grassed. It can also be under ground and covered with concrete where it receives only roofwater.

To prevent the topsoil from migrating into the infiltrating chamber, a permeable geotextile is installed to cover the top of the gravel filled trench before 300 mm layer of topsoil is overlaid and planted. To ensure a smooth migration of stormwater into subsoil, especially where the sides of the trench is sealed, a 150-300 mm sand filter bed is prepared to interface the infiltrating chamber and the subsoil before overlaying with the gravel layer. The infiltrating chamber can be backfilled with grade course stones/ gravel of 38-75 mmØ.

Filter strip. Stormwater runoff flow from impervious or pervious surfaces may be directed to flow into the trench as sheet flow. To prevent siltation, a filter strip of 6 m width should be installed upslope along the trench, at < 12-15% slope with the trench laid at 3% forward slope or less. Installation will not be ideal for areas with greater slope. Runoff from heavy sediment generating areas should have a more extensive filter strip of up to 15m width.

Proximity to foundations. Infiltration trenches should be installed not closer than 6 m downslope of any foundation or 30 m up slope and 30 m from any water supply well. Where space will not allow, an impermeable membrane should be installed at the side adjacent to the foundation to prevent seepage to affect the foundation. Installation in light industrial areas, fuel dumps, mechanic shops, washing bays should be avoided completely to prevent contamination of underground water resources.

For the study area, to ensure long life for this intervention, it should be designed to receive only roof water from a downspout or point source. Where drainage is poor or the watyer table is seasonally high, an underdriain should be installed to drain away excess water.

5.9.4 Bioswale**:** Also called a vegetated or grassed swale. It is a shallow impoundment designed to carry stormwater and at the same time filtrate and infiltrate stormwater runoff to recharge ground water. Vegetated swales can be designed as part of the conveyance system along roads, streets and within residential areas. They can be constructed to infiltrate stormwater runoff through an *insitu soil* or an engineered soil media.

Construction. It is constructed as a channel with a forward slope of 1.0 - 6%. Forward slopes of less than 1% should be avoided as this may stagnate flow as well as slopes of more than 6% which could result in scouring. Check dams may rather be installed in steep sloping areas. It is constructed to a trapezoid shape with cross sectional area of bottom width 60 cm – 240 cm and side slopes of 1:4 – 1:10. The design should allow a ponding depth of about 45 cm (18 inches) for a 10year design storm flowing at the rate of 0.5 m/s – 2.0 m/s. It can be constructed over an infiltration trench but should be located at least 100 cm above the seasonally high water table (see section on infiltration trench fro details)

5.9.5 Retention Basin**:** This strategy is a treatment based system mainly for stormwater runoff volume control and ground water recharge through the capture of both small and large storms of 50.4mm and 254 mm daily rainfall through detention and retention basins. The strategy is to strategically locate retention facilities either online or off line in areas with high ground water levels but detention basins in areas with lower ground water. The retention basins may be constructed by excavating to depths of 1.5 - 3 m and designed with a ponding depth of not less than 90cm (average 120cm -240 cm deep).

Retention basins may be fitted with an under-drain connected to existing stormwater drains. The size will vary depending on site conditions but will generally be constructed with a side slope of 1:3 or 1:4, slopes stabilized using local materials such as boulders and a filter bed consisting of 30cm topsoil and planted over 45 cm - 60cm clean medium aggregate concrete sand laid to a forward slope of 2% minimum. The bed of topsoil and sand may contain clay to help remove heavy metals and other pollutants.

Average ponding time could be 14days or more. To reduce the effect of high levels of sediments in stormwater runoff, a forebay could be constructed for each of the basins. This will serve to dissipate the force of the inflow and to serve as a sedimentation area which can be periodically cleaned.

Pre-treatment - This is installed to receive stormwater runoff before it enters the storage structure. This can be in the form of a thin strip of lawn at the verge of the basin or a strip of gravel verge 200-900 mm wide, installed along the perimeter of the storage structure. Retention basins must be designed for a particular design storm which for this research is a 25years with a 24-72hr drain time

Vegetation – the importance of vegetation in a retention basin cannot be over-emphasized. It serves to encourage sedimentation, filtration and infiltration of stormwater runoff into the growing media through the roots of the plants. The choice of plants however must be based more on native plant species which are known to do better as they are adapted to the environment and soil. One such well adapted vegetation is the Vetiver grass (*Chrysopogon zizanoides*), a grasslike sage well adapted to grow in wet and dry lands.

The Case Study

Deductions from the Case study - the main take-away from the main case study was the bottom up approach used to get the population interested which convinced them to consider an alternative means to flood control. This indeed is a smart way to flood control. The second was how the water harvesting systems were monitored over time to determine their effectiveness. The other cases provided inspiration for the development of the multicriteria overlay suitability analysis.

5.9 Field Survey

A total of 116 people were interviewed made up of 50 experts and 69 members of the public. The following summarizes the responses as expert views and common views.

5.12.1 The Common Views from Community members – respondents identified flooding as a major challenge and went on to identify the causes, suggesting what could be done to ddress the problem (Table 5-7). Almost all responded identified

Table 5. 7: Summary of response - common views

Response	Score (%)
1. Flooding as a problem	96.8
Causes of Floods	
2. Improper waste disposal, blockage of drains	64.5
3. Poor governance	58.1
4.Poor planning	9.7
5.Loss of natural places of attenuation	41.9
6.Urbanization	22.6
7.Poor design - poor engineering, undersized drains	38.7
8.Heavy rains	3.2
Solution to the problem	
9.Desilting, Dredging, widening of drains	38.7
10. Construction of more concrete drains	77.4
11.Education of the masses	12.9
12. How sustainable Is the solution	71
Not Sustainable	

Source: PhD Research, Asiedu 2020

Floods as a problem (96.8%) with an equally large number suggesting that the only means to address the problem was through the introduction of conventional approach (77.4). Respondents (71%) observed that unless the conventional approach is fully applied together with non-structural approaches like waste management, desilting, the situation will worsen. Respondents where clear that the conventional approach in its present state is not sustainable with 70% agreeing that the flooding situation will worsen over time.

The common views showed that the public is aware of the flooding problem and that they believe the best way to address the perennial flooding problems was through the construction of more surface drains.

5.12.2 The Expert Views**:** The interviews were centred on how the stormwater management system was performing. This line of interview lead to the causes of the floods, how the situation can be addressed and an overall assessment of the conventional approach (Table 5.8).

Table 5. 8: Summary expert response

Response	**Score %**
1.Flooding as a problem	
Flooding as a problem	41.7
Flooding as a serious problem	54.2
Causes of Floods	
2. Improper waste disposal, blockage of drains	28.8
3.Poor governance – enforcement, building standards	75
4. Poor planning	37.5
5. Loss of natural places of attenuation	41.7
6. Urbanization	20.8
7. Poor design	25
8. Lack of policy on stormwater management	25
9. Lack of education	33.3
10. Loss of places of attenuation	41.7
Solution	
11. Engineering solution (conventional approach)	70.8
12.Desilting/dredging	70.8
13.Rainwater Harvesting	4.2
14.Use of Retention basins	12.5

Source: PhD Research, Asiedu 2020

Respondents where divided on the issue of sustainability of the conventional approach with 45.8% accepting that the system is sustainable while 33.3% said the opposite.

Insites from Experts responsible for Policy development and Design of interventions;

i. Ghana does not have any stormwater management policy but relies on various policy documents logged with collaborating institutions and departments

ii. Periodically government engages consultants to produce drainage master plans, this is sent to the Hydrological Services Institute for review and advice. The dates for the different reports and master plans were given as 1958 for the first master plan followed by 1963, 1985, 1995, 2000 and 2005. Other reports were also produced such as the 1960 NODECO report, the Water Tech report. Unfortunately the researcher could not see any of these documents. The explanation was that frequent relocation of the offices has led to the loss of the documents. Unfortuntely over the years budget constraints has not allowed the institute to conduct research to provide the kind of technical backstopping to advice government on stormwater management and floods.

iii. The design of public stormwater drains has been based on the concept of return period

iv. The drainage system is categorized into tertiary, secondary and primary drains

v. Some of the primary drains empty into the lagoons some of which are actually below sea level (Example the Odaw River empties into the Korle Lagoon which is below sea level). This causes the stormwaters to stagnate, resulting in floods

vi. Government favours the hydrologically efficient system because of the unstable nature of the tropical soils which could easily fail with the tropical wet climate

vii. The current position of the government is to introduce retention basins because drains will not be enough

5.12.3 The Researcher's Observations**:** In the course of the survey the researcher made the following observations:

- Berms had been constructed along the water courses in most communities to protect from floods (Plate 5-1a). However this has its own problems too as it results in stormwater runoff from the communities accumulating and stagnating behind the berms

(a) (b)

Plate 5. 1: Berms constructed along a water course to protect a community in the research area (a) Active vegetable farming with irrigation systems along a stream in Dzorwulu Community in the Research area (b). Source: Field Survey

Makeshift toilet facilities have been built along water courses, a situation which creates a health risk. Walled facilities along water courses block access to the water feature. Some house owners interviewed consider that as a means to protect their property and did not see anything wrong with that. In some communities there are vegetable farming activities along the water courses (Plate 5-1b). Irrigation systems had been developed by farmers to irrigate their plots of vegetables using the streams as source of water. This was observed in the Haacho and Dzorwulu communities and other places as well.

Vegetation along the water ways had mostly been removed either to widen the water way or to open up the water way. A number of auto mechanic shops were identified along the water courses and this is a major challenge as their activities directly pollutes the water courses. In the course of the survey the researcher was struck by the few opportunities in the study area for recreation.

The fear of ejection has made the public reluctant to respond to interviews on floods. There is also a form of interview fatigue on the part of the public as they have seen too many interviews to believe this will bring the much needed relieve, and this is affecting cooperation.

5.10 The Public Forum

The public forum was developed and patterned after Latz (2008) and Herbert Dreiseitl (Personal Communication 2017, Atelier Dreiseitl. Überlingen, Germany) both of which used public forum to generate support and interest for their design proposals. In fact Herbert Dreiseitl (Personal Communication 2017, Atelier Dreiseitl. Überlingen, Germany) even added an exhibition which included visits to various sites of interest relevant to various proposed interventions. In this research however, this opportunity could not be provided to the participants, except by way of pictures capturing various forms of interventions for stormwater maagement.

The aim of the public forum is captured by Chris Jones in his book Design Methods (Jones 1992) as follows: *to make more public the design process and its outcomes so that the public who is affected by the design decisions can foresee what can be done and be able to influence the choices that are made…………*

For this research, the forum was organized to - desserminate the major findings of the research which was that roofwater may contribute between 14.7% and 32.6% to stormwater runoff within communities. The forum was also used to publish the range of measures the research identified for stormwater management to flood control which included roofwater harvesting, infiltration of roofwater and the use of a schema to guide the location of interventions. The forum was used to discuss the implications of the findings and to invite comments and suggestions.

The forum was titled "Infiltrating through to control Floods: a Case for Sustainability" and was held on the 13th of February, 2018 at the Accra Metropolitan Assembly, Accra Ghana. The invitees included experts with government establishments from the fields of hydrology (Hydrological Services Institute, Institute of Water Resources of CSIR and Water Resources Commission), soil science (Soil Research Institute of CSIR), Civil Engineering and Architecture (Urban roads, Architectural and Engineering Services Limited, Engineering Council), planners (Planners Association of Ghana), Surveyors and Geologists (Survey Department, Department of Geological Survey), Meteorologist (Ghana Meteorological Association) and the five Municipal/Metropolitan Administrative areas within which the study was conducted. The regional coordinating council was also invited through the office of the Greater Accra regional minister.

The host of the forum was the Accra Metropolitan Assembly who graciously provided a venue and refreshment for the program. The Municipal and Metropolitan administrations were to invite community members within their jurisdiction to participate in the forum. To further ensure participation of the actors, several follow-ups were made through personal visits, Email messages and telephone calls to which assurances of participation were received.

During the discussion session among several questions and suggestions, a participant suggested that the best way to ensure recognition and adoption of the findings of the research as a basis to address the problem of perennial floods in the urban area was to consult with politicians and get them to adopt the research as part of their political manifesto. This way there will be a guaranteed implementation of the results of the research.

Post Forum Follow-up: The researcher decided on a follow-up to show appreciation to participants and to interact with those who could not attend to update them of the findings of the research and to seek their imput. In all nine of the invitees were contacted (Engineering Council, Architectural and Engineering Services Limited (AESL), Hydrological Services Institute, Water Resources Commission, Urban Roads, Survey Department, Water Research Institute, Ga South Municipal Assembly, Ga Central Municipal Assembly and the Greater Accra Regional Minister's office).

The Strategic Brief: Discussions from the public forum lead to the development of a strategic brief for the research. This states that - based on the findings of the research that 14.7% to 32.6% of stormwater runoff in communities may originate from the roofs of buildings, any strategy for stormwater management should target roofwater management at the plot level but implementation should be over an entire watershed, guided by a schema.

To further encourage the participation of actors the Living labs model was applied at the plot level to get actors to participate in the innovative solution to the problem of perennial floods.

The central motif of flood control in communities was very appealing to the actors, however most of the actors seem limited by their own scope of ideas to address the problem and were set on only prevailing ideas which was the use of hydrologically efficient drainage systems in stormwater management. And this is reflected in responses from interviews and discussions with enablers and the end-user who saw the only solution to the perennial floods to be essentially, the construction of more hydrologically efficient systems, improved waste management, better compliance with construction standards, and improved engineering design of drains.

A minority of enablers though were open to the idea of storage structures like retention basins which could be located upstream of settlements to prevent fast accumulation of stormwater runoff in the communities.

The absence of any form of incentives, (financial), to sustain active participation of actors also decimated interest as the project proceeded.

5.11 Summary of Chapter

Analysis of data generated from the three focal areas showed a trend where imperviousness decreased from Area1 to Area3 although the differences were not statistically significant. Rainfall levels and direct runoff for the data period 2006 – 2015 did not show any significant change between focal areas, the years and months. Small roofs (<81m^2) made significantly high contributions to runoff generation in Area1, with the magnitude decreasing to Area3. The percentage of runoff contributed from the roofs of buildings for all three focal areas ranged between 14.7% for Area3 and 32.6% for Area1. The field survey showed high support (>70%) for conventional approach to stormwater management from both experts and the general public (common views) but varied with the sustainability of the approach. The research identified infiltration wells, infiltration trench, rainwater harvesting and raingardens in addition to retention and detention basins as possible source control and treatment based interventions for stormwater management to control perennial floods in the study area. A public forum was organized to inform the public about the findings of the research and to get them involved in finding a solution to perennial floods in GAMA.

Area1 -

Unique landscape features - the area is a mix of residential, commercial and government institutions. The area extends from Abbosey Okai, Kaneshie, Bubuashie, Russia, Darkoman, Mataheko, West Abbosey Okai with residential and commercial centres. There are several educational institutions including Central University, Marshalls University, Accra Academy Senior High School and a number of basic schools. The area has flood hot-spots extending from South-eastern to the North-eastern part (Kaneshie First light to Obetsebi-Lamptey Circle area), coinsidentally these areas also have primary concrete stormdrains which are canalized and underground. Another hot spot extends from the South-western to the North-western part. There are no natural surface water bodies in the area as they have all been urbanized. The soil type, Nybgenya-Haacho complex is susceptible to formation of lateritic hard pan on exposure. Bare and exposed areas have developed the lateritic hard pan as determined by soil profile tests, affecting infiltration and leading to more sediment ladened runoff generation.

Area2 -

Some Unique Features of the area - The area extends from Chantan, Tabora, New Achimota, Sowutoum, Lamnava, Trantra Hill, Ablekuma and is mainly residential with commercial activities along a small section of the road. Part of a decommissioned open quarry lies within the area. There is a Catholic facility which covers extensive parts of the area with vegetation. The area has one University (Pentecost University) with Secondary and basic schools. The flooding hot-spots run along the south eastern to the north eastern side and in fact the entire university campus lies within the flood hot spot. There are three main soil types in the area - Oyarifa-Mamfe complex, Fete-Bediesi complex and Korle consociation. Fete-Bediesi is the most extensive (covers 63% the area), is well drained but susceptible to erosion, have low fertility and contains lateritic concretions. There are limited concrete lined stormwater drains in the area.

Area3 -

Soil type - the area has three main soil types, Damfa-Dome complex, Nyigbenya-Haacho and Oyarifa-Mamfe complex.

Unique features /General description: The area covers Hatcho, Agbogba, Atomic and the netire Ashongman community including the estates is mainly residential with one central commercial center along the main road. There is a private University and two public university campuses located close by. Part of a nuclear facility also falls within the area. There is an important flood hot spot which lies along the Onyasia River; a major river which drains the area and has its flood plains progressively urbanized. Extensive vegetable farms have been established along some partions of the river which is used to irrigate the farms. The topography is gentle sloping with underlying Quarzt Schist bedrock which has formed an impenetrable layer, affecting infiltration.

CHAPTER SIX

6.0 APPLICATION OF DESIGN METHODS

At this point in the research a lot of information has been gathered from the literature review, the case study analysis, and the field survey. These were integrated into the design process through the lenses of four design methods – optimizing essential functions, concept test, analysis and synthesis, using the vehicle of the living lab model. Pre-prepared tools like the schema were also applied in site selection.

Design Methods: Design methods were means used by the research to develop well defined steps for "understanding" and guiding the design process (Yüncü 2008). It involved both ideas generation and the generation of form. Ideas generation was modeled after the living labs concept where end-user, enablers, and a driver (the researcher) "collaborated" in the development of the initial "concept models" for a design to address stormwater management to control floods (Eriksson, Niitmano et al. 2006, Katzy, Pawar et al. 2012, Schuurman, Ballon et al. 2016).

The process was based on an "open innovation" which is a "nonlinear innovation process" developed within a "regular home" environment that ensured "cooperation" between users, enablers, the driver and other collaborators (Schuurman, Ballon et al. 2016). The driver (researcher) "functioned" as an "intermediary" whilst the user community was integral in arriving at an innovative solutions (Capdevila 2014, Schuurman, Ballon et al. 2016).

The second part was influenced by the works of Lynch, Jones, Alexander and Rowe where the "concept-test" and "analysis and synthesis" design methods were used to generate ideas for the concept drawing. Detailed designs were also prepared from "drawings" and various "graphic representations" used as research instruments (Deming 2011). This is against the background that there are not many scholarly works on design methods in landscape architecture, with only few authors like Lynch (Lynch 1971), Jones(Jones 1992), Alex (Alexander 1964), and Rowe (Rowe 1982) writting extensively about it.

Lynch in his book Site Planning identified several design methods which are used in the generation of form in the landscape. Among these, I adopted a mix of incremental improvement (or adoption), optimizing essential function and behaviour settings. I used “Incremental improvement" to make small but consistent adjustments in the design in order to arrive at a definitive form, by adapting principles from case studies as explained by Lynch (Lynch 1971), Rowe (Rowe 1982), (Lidy 2006) and Milburn and Brown (Milburn 2003). This was done by identifying a case, studying to understand the case before applying generalized principles from the case to the design.

Design by behaviour setting, required dividing the site into "relatively independent, stable patterns of customary behaviour" as defined by the activities or processes that governed the use of a place. Some of the activity patterns identified in this research included children at play in a school setting, stormwater runoff pattern in a compacted pervious area, circulation in a commercial area, how open spaces in an enclosed area are used during school hours and over the week-end. These were carefully studied and relevant interventions introduced to address the identified challenges.

The approach involving Optimizing essential functions required the identification of a central motif, the solution to which was pivotal and primary to all others, in the process of which other problems in the environment were also addressed. It involved identifying in general terms the critical elements which shape a place and influences performance by evolving a form to enhance performance. The form was then adapted to meet other challenges in the landscape (Lynch 1971). "Form" as used in this context relates to "Landscape form" which is the way in which the parts of a landscape are assembled into a composition(Nijhuis 2011). For this research, the dominant factor was the flooding motif for which various interventions were developed.

The mix of approaches chosen for the research was most appropriate because of the complex nature of the challenge of stormwater management to control floods and also because a mixture of approaches is better than a “single method” (Lynch 1971, Jones 1992). Arguably the whole research methodology looks a bit complex, mainly because of the large scale of the study area and the complex nature of the problem the research is addressing. Coincidentally, Steinitz identified a direct relationship between the scale of a project and the level of complexity of the analytical process to the effect that the larger the scale the more complex the method of analysis should be (Steinitz 2010).

Design Process and the Design**:** The Design process is a "sequence” of design “activities" (Anonymous 2016) or steps that the researcher undertook to address the problem of perennial floods in urban areas in developing countries, using the Greater Accra Metropolitan area as the focus of the research.

As defined by (Lidy 2006) it is the "generic thought process of a designer", in this case the researcher as "he designs" (Deming 2011) or the series of activities, called "operations" carried out in order to "find[ing] out" how to address the challenge of stormwater management to control floods. The process involved searching for ideas as well as being able to crystallize the ideas through the development of a design proposal (Krull 2008, von Seggern 2008).

Integration of Research: The design process was broken down into stages at which research information were integrated into the design. (Milburn 2003) summarized these stages as "before", "during" and "after design".

The "before design" stage allowed the researcher to build a repertoire of information to address the design problem through field studies, internet and library search, and the review of cases (detailed in chapters 2-6). At the design stage I used the repertoire of information to influence the development of the design concept as it relates to a site. The "after design" stage involved "evaluation" and "justification" of the "design", which was beyond the scope of the research due to time limitation.

During Design: Where design actually starts in a design process is debatable, but (Latz 2008) consider the start of the design to be when a design brief is prepared. Lynch has stated that design starts when budget is assigned to behaviour settings but intimates that design doesn't have any defined moment, especially as regards site selection which should be a reiterative process, subject to a lot of criticism and changes until a final pattern emerges. For this research the design process started when I applied the schema to the site to guide the selection of possible locations for the interventions.

Thus at the "during design" stage of the research, the Multicriteria Suitability Overlay Analysis (schema) was developed to guide the selection of possible locations for nature based interventions to address stormwater management to control floods (Details in Chapter 5).

A number of researches have adopted a variation of this approach and this research took particular inspiration from the works of (Nemcova 2012), (Terrasa-Soler 2012) and (Jauslin 2012). Nemcova et al developed a GIS based tool, the Lima Ecological Infrastructure tool (LEIS) and used it to capture, store, analyse and synthesize spatial data by delineating places with challenges, potentials and constraints(Nemcova 2012). Terrasa-Soler et al also (Terrasa-Soler 2012) researched to develop stormwater treatment strategies and adopted a methodology where field data obtained from extensive field surveys was developed into spatial layers and visually analysed.

This research adopted a varied approach where the spatial data was analysed in a GIS environment. The Multicriteria Suitability Overlay Analysis (schema) was thus used as the first step in the site selection process.

6.1 Summary of Findings - Literature Review, Field and Site survey and Case study review

The entire research was divided into two main phases. The first phase led to the organization of a public forum and the development of a brief for stormwater management. This was to control floods at the watershed level in the research area based on results of field survey, interviews, documentation, literature research and case studies. The following were the main findings at this stage;

a. Urbanization and its impact of increased imperviousness, eratic rainfall and inadequate drainage are the key drivers causing floods in urban areas

b. Effective stormwater management must begin at the plot level, where the roofs of buildings may contribute between 14.7% and 32.6% to stormwater runoff

c. Interventions to address stormwater management should be watershed-wide with different locales within the watershed receiving different treatment(s)

d. For effective performance of stormwater interventions to manage runoff a schema was developed and used to guide the location of proposed interventions.

6.2 Developing Strategies

The following action strategies were developed to implement the strategy developed from the public forum

Action strategy1 – to design interventions to retain stormwater runoff at the plot level to provide multiple uses through infiltration to recharge ground water and roofwater harvesting for reuse

Action strategy2 – to develop and apply a schema to guide the location of interventions in the focus locations

Application of the Strategies: The next step involved the application of the action strategies at the three focal areas, Area1, Area2 and Area3

Area1

Proposed interventions - Roofwater harvesting for non-portable use at the plot level should be adopted for both small (<81m^2) and large roof buildings (≥81m^2) and this can be combined with infiltration wells or trenches to manage up to 95% of roof water at the plot level. Where space is limited, at least one of these interventions should be adopted. Harvested water could be used for irrigation of gardens, lawns and other planted areas, flashing of toilets and washing. Within the flooding hot spots, interventions should be limited to roofwater harvesting.

Communal underground storage systems for rainwater harvesting to accommodate extreme rain events is recommended for highly dense areas.

Area2

Proposed Interventions - At the plot level rain water harvesting should be combined with infiltration wells or trenches to retain 95% of roof water on site. In addition infiltration trenches could be integrated into the street system in areas where the streets are yet to be paved. The infiltration trenches should be installed to receive stormwater runoff from the roofs of nearby houses. Online stormwater retention/detention basins could also be installed along existing natural non-cannalized drainage lines within the communities.

Area3

Proposed Interventions - roofwater harvesting in surface storage tanks should be encouraged within plots. Retention basins could be constructed along the Onyasia River to store water for all-year vegetable and nursery production. This intervention could be located close to the active centers for vegetable and nursery production and will be important in reducing the volume of water which descends from the Akuapim mountains during heavy downpour. Communal infiltration tanks could be installed in strategic locations to infiltrate roofwater to recharge ground water resources. This will help avoid plot level infiltration problems due to the underlying geologic feature of Quartz Schist which has formed an impermeable layer which limits infiltration.

6.3 The Design Process and Design

During Design

Site selection: Site selection is an integral part of the design process(Latz 2008) and is used to find alternative locations and to determine which alternative best serves a particular purpose. It begun with a general search over the research area guided by a schema before narrowing down to a few alternative locations. The exercise is based on some established guidelines by which one location may be considered better than the other for a particular use (Lynch 1971). The schema was used to block off areas (Ibid. 22) which does not meet conditions for the location of a particular intervention. To block off unsuitable parts of the site, suitable locations in the schema were made transparent and overlaid on the site (Plate 6.1).

Different schemas were prepared for various types of stormwater management systems to control floods. For this research I prepared one for infiltration trench, infiltration well and infiltration basin, at the plot level, and the other for retention and detention basins at the community or watershed level.

All areas which fell within highly suitable areas but outside the constraint map were selected as possible locations for infiltration based interventions. Similarly all areas which fell outside the constraint map and within good location areas of the factor map were considered as possible locations for the detention and retention basins. This was followed with several iterative activities to further refine the locations on site to determine the best location. It must be added that space was a limitation in most cases and there were locations within the constrain map of the detention and retention basins which could be considered as good locations. This is based on (Palanisamy, 2015, p. 310) who suggested that interventions such as storage based interventions could be located close to water ways and "storm drains to replace lost riparian environments"

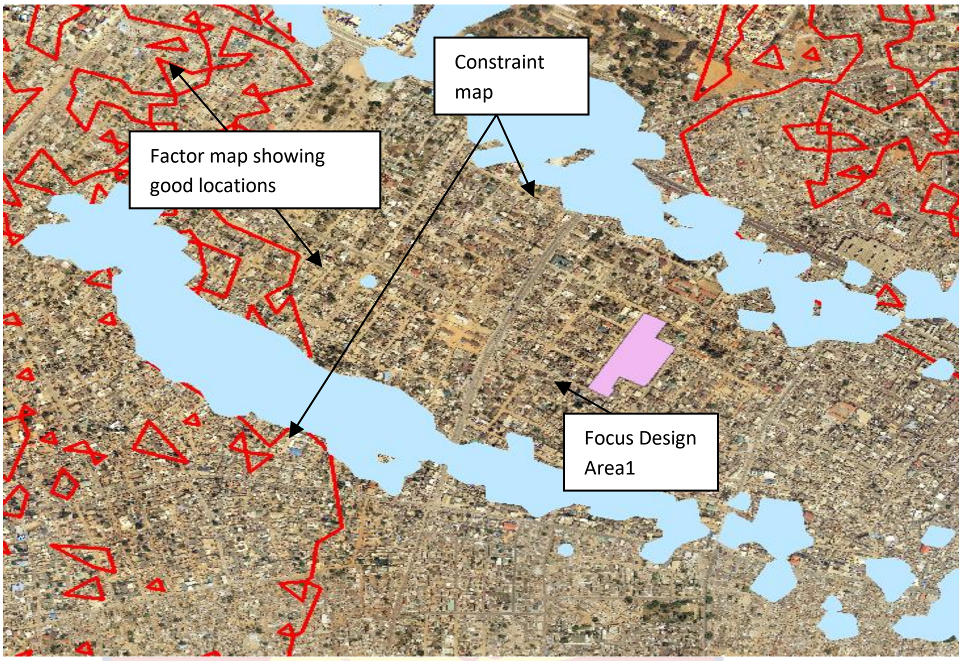


Plate 6. 1: A Schema for infiltration system Site selection

The second step in the screening process involved reconnoitering to "eliminate any obvious unacceptable localities". At this stage the selected sites were treated as alternative sites (Plate 6-2), each of which was analyzed in some depth for the most critical factors to produce a "preliminary lay out"(Ibid. 22).

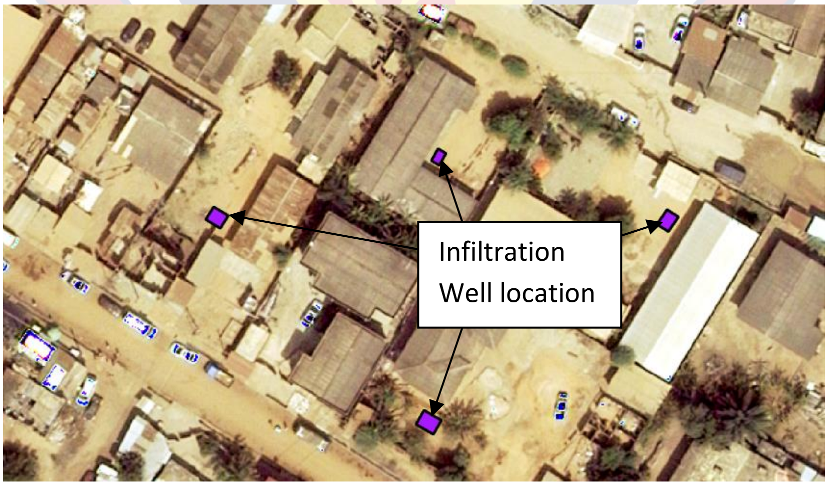


Plate 6. 2: Site selection - A preliminary location for Infiltration wells/Infiltration Trenches

This way site selection was made a multi-step activity which was continually modified through out the design process, buttressed by "days" of quiet meditation on the "character" of the site and its possibilities (Lynch 1971).

The following describe the next stages of the design process which was applicable to the entire study area. The same process was adopted for the detailed design at the plot level.

Development of Activity Diagram: This phase of the design process following site selection was used to identify and study patterns of activity within the focus areas and its immediate surroundings. The pattern of activity is composed of "activity clusters" which includes both "existing" and projected "behaviour" "patterns" and is used to show the activities or uses developed in the landscape over time (Ibid. 25, 28) within, around and between particular locations. Several activity diagrams can be combined to form a behaviour setting which is explained as "small localities bounded in time and space within which there is some stable pattern of purposeful human behaviour".

For the three focus areas, how these behaviour settings were combined with "ecological systems" to work together was the key to a successful intervention and integration (Ibid. 13). The patterns of activity identified at the focus areas included activity clusters such as children at play in a school setting, stormwater runoff pattern in a compacted pervious area, the pattern of pedestrian and vehicular circulation, wind action and the changing direction of the sun and its effect on activities during the day, etc.

In developing the design based on the brief, the research adopted "placement of activity according to accidents of site" and "pattern developed as a logical total organization of activities and their linkages .... with some general visual form in mind". The former considers the most appropriate location for a particular intervention based on a set of standards while the later is about locating interventions based on how they associate with each other and other features in the landscape.

Although these approaches may look orderly and “efficient”, Lynch cautions that it could result in small and sensitive values in the landscape being overlooked (Lynch 1971). To avoid this both approaches were “developed” through a “long process of trial” and reshaping with hours of careful observation of the site aided by photography, “until a new” form imerged that incoperated all the values of the site(Lynch 1971).

Behavior Support: This was the development of a plan to support various activities in the landscape. In this research the following basic tests were applied: "is there space and time” to do what is is intended in the design? (Ibid. 37)- for instance space for a fooball park, space for a sand pit for pupils, or engage in similar child oriented activities, space for a retention basin or water storage tanks and a seating area, and whether activity areas are sufficiently protected from the scotching sun.

Lynch explains that in these terms the researcher/desiger must be familiar with the intended users of the facility, their desires, wants and lifestyle which can be by putting onceself in the shoes of the users and trying to imgine the types of activities which will engage them most. And this was partly achieved during long hours of careful observation and study of the respective focus areas.

Program: A program is a "statement of detailed criteria". The development of a "program" was "the first step” in the design process (Ibid, 28). The program for the sites was "generated" by "intuitively" summarizing the main points of what the design was about. According to Lynch, "program requirements" must indicate the intended users and whether the objectives are properly associated with the specifications (Lynch, 1971, p. 29). It should describe the final designed product based on the linkges established between potentials and constraints, challenges, the site and user aspirations.

"The designer", or the enabler, who is the researcher, the "client and users should all be parties to preparing the program"(Ibid. 28) a condition which was met where actors participated under a living lab model. Aided by the actors the program for this phase of the research was divided into separate sections, each section being independent but linked to the preceding or proceeding one (Ibid. 28). The "program elements" were built around the units of behaviour which provided the details of the program. The details included settings defined by thresholds (eg expected rate of usage) or "qualities" (eg. For recreation or relaxation), indicating the targeted users of the design (Ibid. 29).

Program - Outline

i. Summarizing the main points of what the project is about:

ii. Specify who the design is intended for – pupils, teachers, parishners

iii. State the necessary thresholds for use and intended qualities

iv. Restrictions of the proposed design (adequate size, access, slope suitability, use etc)

v. Potentialities

vi. Identify strategic cluster of activities (classification)

vii. Establish linkages between classified activities

6.4 Design Interventions at Plot Level – Living Lab model

6.4.1. Identification, selection of facilities and Application of Living Lab model- the approach was to use the living labs model to generate innovative ideas to retain roofwater at the plot level based on the findings that 14.7%-32.6% of stormwater runoff generated in the communities originate from the roofs of buildings.

The Living Labs model was used to implement this action strategy to retain at least 90% of roofwater at the plot level, patterned after the case study (Yamashita 2015).

To test how this could be implemented in the study area, I identified facilities like church buildings, school buildings, residential facilities, and commercial facilities within the three focal areas (Area1, Area2, and Area3), located them on the ground aided by 20cm pixel size orthophotos and visited them. After a short introduction of the subject of the research, I interviewed the owners, users, managers of the facilities (called the actors) on how stormwater was being managed on their facilities and what can be done to improve it.

Out of the number of facilities visited, two were selected, one each from Area1 and Area2 to take part in a living labs model to address the problem of stormwater management on site. The selection was based on level of cooperation with the actors during the interview, extent and complexity of the site. For each of the selected sites a design brief was prepared out of which the design proposals were developed. No site was selected for Area3 because of an underlying impervious Quartz Schist layer as explained in Chapter 5.

The interviews brought up some interesting facts. All the facilities visited relied on public drains to manage stormwater. Roofwater harvesting was not a priority even in areas without municipal water supply. Participants expressed surprise at the link between roofwater and floods and were actually excited about the possibilities. In fact one participant requested for an estimate if an intervention could be designed and implemented within his plot.

6.4.2 Site Analysis: For the two selected sites there were 5 separate discussions with the actors using the living labs model during which the actors willingly participated and cooperated. I also had more than 5 site visits in addition to the regular discussions. I spent between 30min to 10 hours per visit and used the visits to gather data on circulation, activity patterns, and conducted field tests (infiltration tests and soil profile tests). The two selected sites were for Area1, Living Labs Site1 (LLSite1) and for Area2 Living Labs Site2 (LLSite2).

Living Labs Site1 (LLSite1): The site belongs to a religious organization and sits on a crest (34m elevation) and has a church building, housing facilities, a cluster of basic schools - and a French School for both basic and senior high school levels. The parish has about 2600 parishioners including a Resident Priest, an Assistant Priest, and 10 supporting staff. The schools have 1923 pupils and 82 teachers.

Site History: I got some historical information on the site from a 70 year old Parishner (Personal Communication, 2018. Parishner. Living Labs Site1, Accra-Ghana). He explained that the site in the 1940s was an undeveloped wilderness overgrown with mango trees (*Mangifera indica* L), Nim trees (*Azadirachta indica*) among others. By 1948 buildings started springing up. The first buildings were wooden structures and were for a school. This was later followed by a more permanent structure for a church building and the place has continued to grow until today.

The site has a special place of significance to the parishioners and the community especially with the establishment of a football park, which was initially called the YOC Park (Youth Opportunity Center Park). This became a focal area around which buildings developed in the community. In the 1960's the church made the first effort to grass the open space which formed the core of the park, but this failed as rains washed away the topsoil with the planted grass. Similar efforts were made later, involving the use of bulldozers to plough the place and later top soiled after which the place was grassed. Unfortunately, these also met the same fate. All the current trees on the site, are foreign to the site and the park area has never been put to any other use, he concluded.

Site Description: The site is walled-off with sandcrete blocks within a residential area in a suburb of Accra. The cluster of schools consists of kindergarten, primary, and Junior high schools and a Senior high school with four head teachers responsible for the day to day running of the schools. There are a number of petty traders who sell to the pupils in addition to a canteen which provides food for the pupils during school days. Although the schools are Local Government schools and are controlled by the Ghana government, there is a quasi management arrangement with a religious organization, the Parish Priest serving as the manager.

The facility has a Church building and several other buildings housing the resident priest and his assistants with offices in addition to class room blocks and lavatory facilities. There are flexible paved areas for parking, pedestrian walk ways which are also used for hosting social events. There are extensive bare areas part of which serve as a football park and doubles as a car park during Sunday church services (Plate 6-3).

The estimated total land area is 27,809.9m^2 (6.742acres) with 14 completed buildings and one un-complete, a wooden structure for a canteen, small kiosks and stalls with a total roof area of 6889.6m^2 (1.7 acres). The church building has the largest roof area of 1,220.1m^2 (Table 6.1).

Stormwater Management - The site does not have its own organized system for Stormwater management but relies on a public drain and extensive.

Table 6. 1: Landcover types and Composite CN for FDDS1

Land Cover	Area (m^2)	Area (A) (acres)	% Coverage	%CN values	Composite CN (CN_1)
Vegetation	2,697.7	0.6666	9.7	86	0.083422002
Paved Surface	5,946.1	1.4693	24.8	98	0.242789581
Roof Area	6,889.6	1.7025	21.4	98	0.209533469
Bare Surfaces	12,340.6	3.116	45.3	91	0.412625146
Total Area	27,809.9	6.872		CN_1	0.948370198

Source: PhD PhD Research, Asiedu 2020

Plate 6. 3: A Section of extensive bare football park at LLSite1

pervious areas to drain the facility. A single concrete surface drain drains the site into a public drain to the north (Plate 6.4a). A second surface drain drains a Junior High School classroom block area into an open unpaved street (Plate 6.4b).

(a) (b)

Plate 6. 4: A Section of LLSite1showing surface drain in paved area (a) A section of site showing surface drain which drains a school building (b)

In a discussion with the headmistress of the school, she explained that the surface drain around the school building was provided to avert continuous flooding of the classrooms during rainfall. She explained that the area receives large volumes of runoff from higher elevation areas and although the soils are free draining, the large influx is not drained quickly enough, thus the need for the surface drains.

Although the Parish initially planned to harvest rainwater this was abandoned in favour of a borehole due to the high cost of installing rain gutters and storage structures. They were also not sure whether they will be able to harvest and store enough water for dry season use. The proposed rainwater harvesting was intended to meet water needs but not to address stormwater management on site (Personal Communication, 2018. Parish Priest. Living Labs Site1, Accra-Ghana).

The borehole which the parish currently relies on seemed a more attractive alternative to provide water for flashing toilets, washing and cleaning parts of the facility (Personal Communication, 2018. Parish Priest. Living Labs Site1, Accra-Ghana). The water is first pumped into large surface poly tanks (two large 21m^3 capacity) from where it is distributed to the buildings.

Field Tests – I run Infiltration and soil profile tests (Plate 6.5) across the site to determine the infiltrating characterisitics of the soils of the site. The tests gave a range of 14 mm/h to 190 mm/h for areas with lateritic hard pan 1.2m below ground but 300 mm/h for areas with hard pan more than 1.2m below ground level. However, low elevation areas which had accumulated a lot of sediments due to erosion from higher elevation areas had the highest infiltration rate of between 600 and 850mm/h.

Plate 6. 5: Soil profile tests pits at LLSite1

Vegetation: The site has a few trees to provide shade, such as *Millettia thornningii* (Miletia), *Swietenia macrophylla* (Mahogany), *Albizia lebbeck*, and *Blahia sapida* (Ackee Apple), Eucalyptus sp. All the trees are not native to the site. A few specimen trees like the Araucaria sp and 'weeping willow' - used for wind break and shrubs (Acalypha, Crotons) can also be found. A lawn grass has established over a very small area to the north eastern part of the site.

Soils: The soils of the site belong to the Nyigbenya-Haacho complex and is part of a group of soils described as well drained except in places where iron pan concretions occur. The soils are very shallow, with poor organic matter content and develop iron pan on exposure (Brammer 1967, Obeng 2000). The presence of lateritic iron pan layer was confirmed in soil pit excavations across the site (Plate 6-3).

In addition the extensive area of bare soil in the site have also become compacted due to heavy pedestrian and vehicular traffic, creating a “nearly impermeable surface crust” which results in less infiltration and high surface runoff generation during rainevents (Pachpute 2009). The result is heavy deposition of sediment in lower elevation areas where infiltration was also better.

Access and Circulation: The site is accessed through two main points, the southern and north eastern gates. A third access, the north western gate, is provided for emergencies. Vehicular access to the site is restricted to only the southern gate during week days but, both gates during week-ends. Within the site both vehicular and pedestrian circulation is undefined, vehicles criss-crossing the site with pedestrians. A centrally located football park is not restricted to traffic by pedestrians man or vehicles and actually provides parking space on Sundays during church services (Plate 6-1). The site is bound by streets to the north (unpaved), south (paved), west (unpaved) and east (paved).

Recreational facilities: There is a grass-free football park and a small play area for kindergarten pupils. The football park is utilized by mainly male pupils who play in groups during school hours and by the public in off school hours. Other areas, usually with bare soil surfaces are also adopted for play. The bare and sunny nature of play areas forces pupils to seek shelter in shaded areas around buildings and under the few shade trees (Plate.6-6). A play area for kindergartens is not yet ready for use and is hardly adequate for the over 200 KG pupils.

Plate 6. 6: Pupils hurdle in shaded areas for play space, to avoid the intense heat from the sun and bare surfaces.

Challenges of LLSite1: The extensive bare surfaces generate a lot of sediment laden runoff which ends up in nearby communities. The extensive bare surfaces absorb heat from the sun and this combined with the buildings radiate heat, creating a heat island effect for the area. The heat island effect results in pupils huddling in scarce shaded areas to avoid the heat and for play space during play time (Plate 6-6). Continued exposure of the pervious areas has resulted in lateritic iron-pan formation which affects infiltration leading to more runoff generation.

The extensive bare surface generate a lot of dust during dry periods, which is blown into offices, classrooms and nearby residences. This affects class room activities and poses a health risk to pupils, residents, teachers, and the near-by community. Some teachers interviewed explained the seriousness of the situation when during the dry seasons of the year, whirlwind-laddened with dust particles picked from the extensive bare surfaces and litter, is thrown into classrooms and offices.

Potential of site: The collection of buildings on site provide a good potential for rainwater harvesting which could be infiltrated or stored for irrigation, flushing of toilets and other uses. Currently, although the site has borehole facilities to provide water, the service is not extended to all parts of the site, thus the site has to rely on the municipal water supply system to make up for the shortfall. I estimate that about 700m^3 of roof water could be harvested from a single rain event of 101.6 mm (4″) from the site.

The extensive bare areas including the football park could be conditioned and irrigated to provide a soft play area for pupils. Leaf litter combined with food leftovers from canteen and food venders could be composted to improve soil fertility for planted areas which will also greatly reduce the burden of waste management on site. Part of the extensive bare area could be developed as extra play space for the kindergartens.

These interventions will not only address the problem of erosion, stormwater generated runoff but also stop the dust generation from bare areas and prevent runoff from escaping to nearby communities to cause floods. It will also reduce the heat island effect created by the bare soil surfaces, enhance the landscape experience of the area provide a hands on approach to waste management for pupils, teachers and parishioners. The high elevation of the area (Between 28 m - 34 m above sea level) relative to the rest of the community will ensure good drainage.

The extensive bare surface area when vegetated will have immediate impact on pupils, and will provide educational value to pupils, teachers, the parishioners and the surrounding communities. The area could become a show case and an example to other communities on what could be achieved with on-site stormwater management.

Constraints: The grass free football park serves for parking on Sundays during church services while in the afternoons and on week-days it is used for sporting activities. The development of the football park may have to absorb this dual function or an alternative parking space may have to be created. The parish Priest explained that any intervention should be designed and executed over a short period to avoid disruption to school activities and this is a constraint given the volume of work required. Another constraint will be the cost implication of the project which will involve installation of roof gutters, down spouts, connecting pipes and storage structures.

Design brief: A design brief was agreed on by the actors which states that roofwater from the buildings of the site will be managed on site to ensure at least 90% retention to provide multi-functional values.

Living Labs Site2: This was a private property with a commercial extension. The site has a two-storey building housing a family of twelve, an uncompleted 20 capacity hostel facility for students under construction and a commercial ground water extraction activity (Plate 6-7). During discussions I was informed of plans for further development on other parts of the site.

The site is at a high elevation area (77 m) with total land area of 3181.6516m^2 (0.7862 acres). The two structures on the site have a combined roof area of 996.6 m^2 (0.25 acres) which can generate harvestable

Plate 6. 7: A Section of LLSite2 showing existing structures on site

roofwater of 115.4m^3 from a single 142.5mm rain event. A third proposed structure will increase the roof area to 1,068.8m^2, generating 123.8 m^3 harvestable roofwater from the same rain event. The total runoff volume generated from the site from an annual rainfall of 846 mm (33.3") was estimated at 1,749.6 m^3. Sizing of rainwater infiltrating wells was based on 25 year return period of 227.5mm.

Site Description LLSite2: The site lies in a residential area with undulating terrain. The site is naturally drained by infiltration, and has no surface drains, excess runoff channeled to a nearby public drain. In addition to the built structures, the site has a few fruit trees such as *Persea americana* (Avocado), *Mangifera indica* (mango), *Citrus jambhiri* Lush (Rough lemon), and *Cocos nucifera* (Coconut). Both the mango and the Avocado are of a local variety and can grow to attain large size. The soils of the site belong to the Korle consociations, are very shallow and susceptible to erosion(Brammer 1967, Obeng 2000).

The soils of the site are well drained although they contain a lot of lateritic concretions. Infiltration tests run across the site gave a range of 120 mm/h to 920 mm/h. The lowest infiltration rate was recorded at the lowest elevation of the site where a borehole is located. Average infiltration rate is about 474.7 mm/h, ignoring outliers.

The site has no paved surfaces except the roofs of buildings and a short ramp to the garage, with an imperviousness ratio of 33.3%. The place is airy with the ground covered by a mixture of grass and herbs which are cleared occasionally with a weedicide. The site is almost adjacent to a facility by the Catholic church and close to a private university, the Pentecost University. The area does not have a reliable supply of municipal water and thus rely on private vendors to provide portable water to residents.

A commercial activity of borehole water harvesting is carried out on-site. Borehole water is pumped into subsurface concrete tanks and into surface poly tanks from where it is sold commercially to the public (Plate 6-8).

(a) **(b)**

Plate 6. 8: A section of LLSite2 showing subsurface concrete water tank for storing borehole water (a); A 3,333gal capacity polytank for storing Borehole water (b)

The site can generate harvestable roofwater of 115.4m^3 from a single 142.5mm rain event. A third proposed structure will increase the roof area to 1,068.8m^2, generating 123.8 m^3 harvestable roofwater from the same rain event. The total runoff volume generated from the site from an annual rainfall of 846 mm (33.3") was estimated at 1,749.6 m^3. Sizing of rainwater infiltrating wells was based on 25 year return period of 227.5mm.

6.4.3 Challenges and development of Outline Proposals

Challenges with the Living Labs model: Bayazit (2004) has observed problems with the participatory system of design methods. The whole idea of the Living Labs model was to capture and include tangible innovative ideas from the actors for whom a design solution is intended at the early stages of the design process. The surprising element I observed was the resignation of the actors to accept any proposals I forwarded without much interrogation or discussion. Although earlier one-on-one discussions had been used to solicit interest and ideas, this was not matched by an enthusiasm to review the 'tit bits' I had put together and presented.

When I raised this concern during one opf our sessions the response was that they were fatigued by the process, especially as they did not see the possibility of immediate implementation of the proposed interventions. Another reason for the lack of extensive discussion could be because participants saw the whole exercise as a means to help the researcher (as mediator or enabler) to "earn his marks", as put forth by one participant, but not as a critical path to finding real solutions to the problem of stormwater management to control floods.

In fact although all the actors admitted and identified with the problem of stormwater management, it was felt that in order of priority, this was not a top priority for them because there were other more pressing needs like on-site waste management, or construction of a Common room for teachers, which to them required immediate intervention. The lack of a more intense discussions may also have been due to their inability of the actors to directly link loss of life and property to stormwater generated from the site. In fact, earlier an actor had noted that despite the good intentions of the project, the actors do not feel morally obliged to address the problem.

Site analysis and Design Proposal LLSite1: The site was divided into four intervention zones: Zone A, B, C and D based on the peculiar situation in each area (Fig 6.1).

This was developed after careful study of the pattern of activity on site, and the use to which parts of the site was put as described by Lynch (Lynch 1971). Lynch explained that in developing an activity diagram for a site program, it is important to classify the activities by putting together groups of related activites.

The zones were divided as finely as possible and this required thinking-out "strategic clusters of activities" consistent with the programme (Lynch 1971). The following briefly explains the activities in each zone.

Zone A - Football Park: i) establish roof water storage system and develop an irrigation system for an intensively used football park, ii) provide extra parking space away from football park iii) install infiltration wells and infiltration trenches to infiltrate roof water.

Roofwater storage system to irrigate football park – The key factor considered for zone A was how to retain moisture on the football field to ensure continual growth of the grass. Four options were provided and discussed out of which one was chosen for detailing.

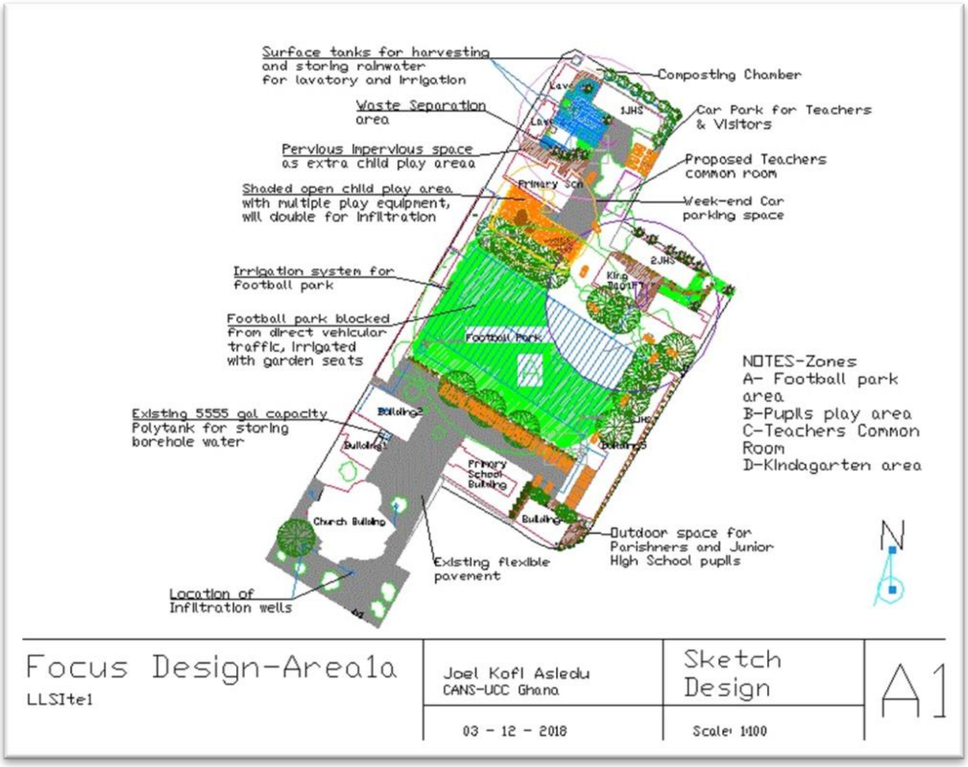


Fig.6. 1: Concept drawing (Sketch design) for LLSite1

a. Roofwater will be harvested and stored directly on the field in trenches filled with rocks. This option will take advantage of the underlying hardpan on the field to ensure that harvested roofwater is stored long enough on the field for continual growth of the grass. This will be a variant of the case study and will be the least expensive of the options but will not guarantee all- year moisture supply.

b. The football park will directly receive roofwater which will be stored on the field by escavating the entire field and filling with rocks before overlaying with topsoil and grassed. This was a direct inspiration from the case study but the excavation of the entire field and filling with the rocks makes it very expensive. Moisture supply will however be guaranteed.

c. Roofwater will be harvested and stored in underground tanks (precast concrete rings) and pumped into trenches on the field. This is similar to options a) and b) all of which allow the field to be moistened by subirrigation. These options will ensure continuity between introduced topsoil and the *insitu* soil to prevent the topsoil from being washed away. Option (c) will be the most expensive of the options but will guarantee year round moisture supply to the field.

d. The last option involve harvesting roofwater into storage tanks and using pumps to overhead irrigate the field. This however will not ensure continuity between imported topsoil and underlying soil which may cause the topsoil to be washed away.

I decided to adopt option (a) as a rough estimate estimate showed that to be the least cost intensive.

Zone B - Children Play Area: Provide protected extra play area for pupils. Screen-off class room block from view to football park.

Zone C - Teachers Common room area: i) define space for teacher's common room building, ii) develop an irrigation system to vegetate the area using harvested roofwater iii) provide space for composting chamber iv) install infiltration trenches for lower elevation school building

Zone D - i) partly pave area to control erosion ii) develop an irrigation system for lawn and planted areas, iii) install an infiltrate well.

Sizing of Infiltration systems and water storage structures - Runoff for the site was quantified as described under chapter 3 and was used to estimate runoff coefficient. Harvestable roof water was calculated and was used to size infiltration systems and water storage tanks (Ref chapter 3).

Rainfall data for the month of June, 2014 was used to estimate effective runoff for the entire site (2,567.97m^3). Estimated harvestable roof water was 706.9m^3 (186,743.2 gallons). Runoff volume calculated as a percentage of total runoff was 27.5%. Sizing of infiltration systems and water harvesting structures was based on a 25year return period of 234.9mm.

Development of Design Proposal for LLSite2: A design proposal was developed after several meetings with the actor (Fig.6.2). The design proposal was based on a brief developed with the actor which states that roofwater will be harvested and infiltrated on site to recharge ground water to allow ground water harvesting for both commercial and non-commercial use.

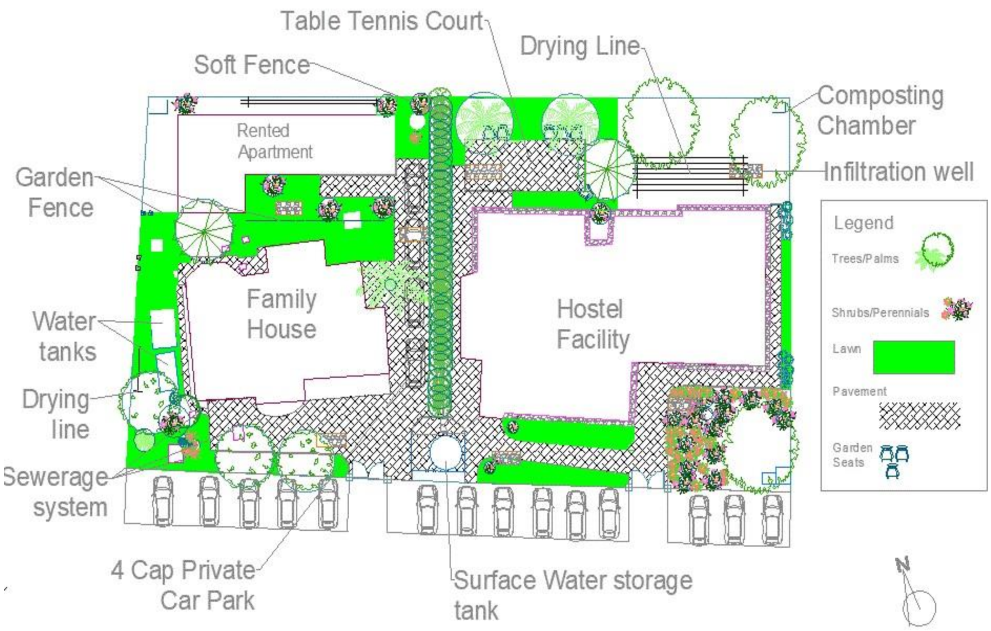


Fig.6. 2: Outline design proposal for stormwater management for LLSite2

The following outlines the components of the design proposal.

i. Introduction of garden fence, and a 'reinforced' soft fence to separate activities between the private residence and the hostel facility under construction. The fence should not affect the commercial borehole water activities. A garden fence is also introduced to separate various acitivities between the housing facilities.

ii. Installation of paved surfaces for pedestrian access, family social activities and car parking

iii. Space for a third structure, a semi-detached apartment to rent out to the public

iv. an outdoor play area and service area for hostel facility

v. Infiltration wells to manage roof water

vi. planted areas and lawns to provide soft surfaces

Detailed Design –

LLSite1: A detailed design was used to give dimension to the various surfaces and structures (Fig.6.3) proposed in the Outline design proposal. The following explains how roofwater harvesting, infiltration well, infiltration trench, and irrigation systems were developed in the detailed design based on design concepts adapted from the Case study.

The detailed design was developed based on option (a) where roofwater is harvested and stored in trenches on the football park to irrigate the park by sub-irrigation as previously explained (Fig 6.3). Detailing for the various components is referenced from A1…………An.

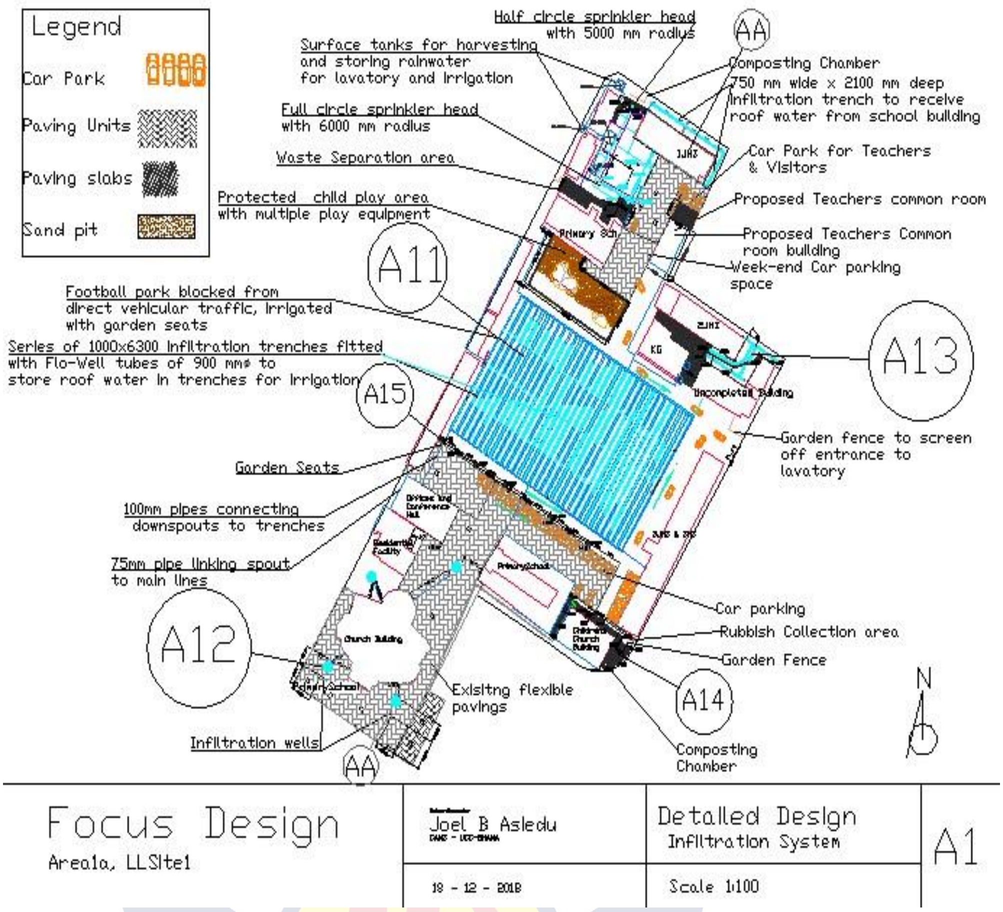


Fig.6. 3: Detailed design showing location of infiltration wells and trenches

Detailed Design – Planting Plan: The standards for the establishment of the lawn including irrigation were based on (Smith 1997, Beard 2001, FDU 2008, Huang 2008, England 2011). The field is prepared by excavating to cross falls 1:50 - 1:60 and longitudinal fall 1:80 - 1:100. Topsoil of sandy loam texture is laid to 300 mm depth and top-dressed with 80% sand. Overhead irrigation system was designed according to (Smith 1997, FDU 2008, England 2011).

The introduction of trenches, overlaid with successive layers of grade gravel, a sand bed interface and topdressing the topsoil with 80% sand will increase infiltration to prevent the topsoil from washing away. It will also create the neccassary buffer to prevent compaction from intensive use of the football park. Garden seats were provided, the existing tree canopy around the field was also reinforced and flower beds established to provide shade, ground cover and color (Fig 6-4 & Table 6.2).

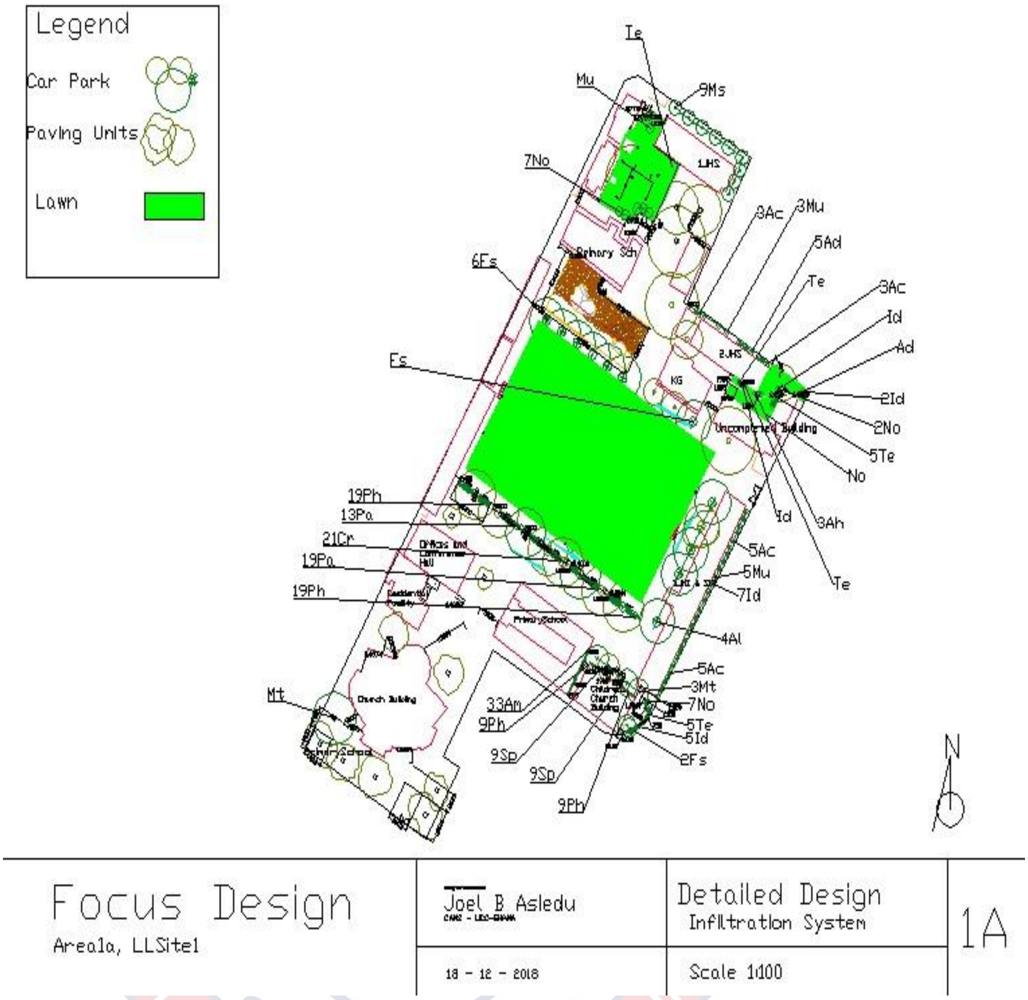


Fig.6. 4: Detailed Design LLSite1 – Planting Plan

Table 6. 2: LLSite1 Planting Plan – Schedule of Plants

Planting Schedule			
Bot Name	Common Name	Symbol	Quantity
Trees			
Albizia lebeck	Womans tongue tree	Al	4
Ficus benjamina	Weeping Ficus	Fs	9
Millettia thonningii	Millettia	Mt	4
Schrubs			
Acalypha wilkensiana macrophylla	Copperleaf	Ac	16
Acalypha hispida	Cats Tail Acalypha	Ah	3
Allamanda cathartica	Allamanda	Ad	6
Ixora duffi	Double Red Ixora	Id	16
Murraya exotica	Orange Jasmine	Mu	9
Nerium oleander	Oleander	No	17
Thunbergia erecta	Bushclock vine	Te	13
Herbaceous Perennials			
Amaranthus tricolor	Josephs' Coat	Am	33
Crossandra infundibuliformis	Firecracker flower	Cr	21
Pachystachys lutea	Lollypop Plant	Pa	32
Phormium tenax variegatum	New Zealand flax	Ph	47
Setcreasea purpurea	Purple Heart	Sp	18

Source: PhD Research, Asiedu 2020

Infiltration Wells: Infiltration wells and infiltration trenches were used to infiltrate roof water into the ground as laid out in the detailed design (Fig.6.3). Detailing for infiltration wells and infiltration trenches are provided in (Fig.6.5 & Fig. 6.6). Consideration was given to proximity to foundations, drain time (NJSBMPM 2004, Government 2015), size and depth of infiltration chambers, distance to water table, soil type and infiltration rate as detailed in Chapters 2 and 5. Where space will not allow the minimum distance to foundations, an impermeable liner of black polyethylene with 0.1524mm minimum thicknes was installed on the building side of the infiltration well (Frasier 1983).

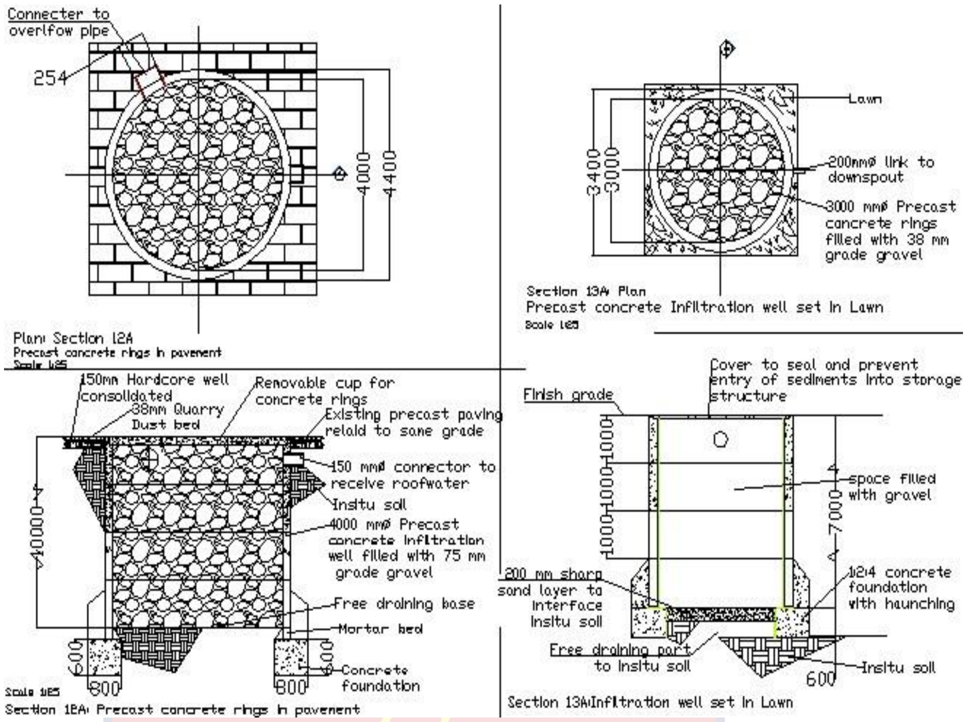


Fig.6. 5: Detailing LLSite1 12A & 13A- Infiltration well

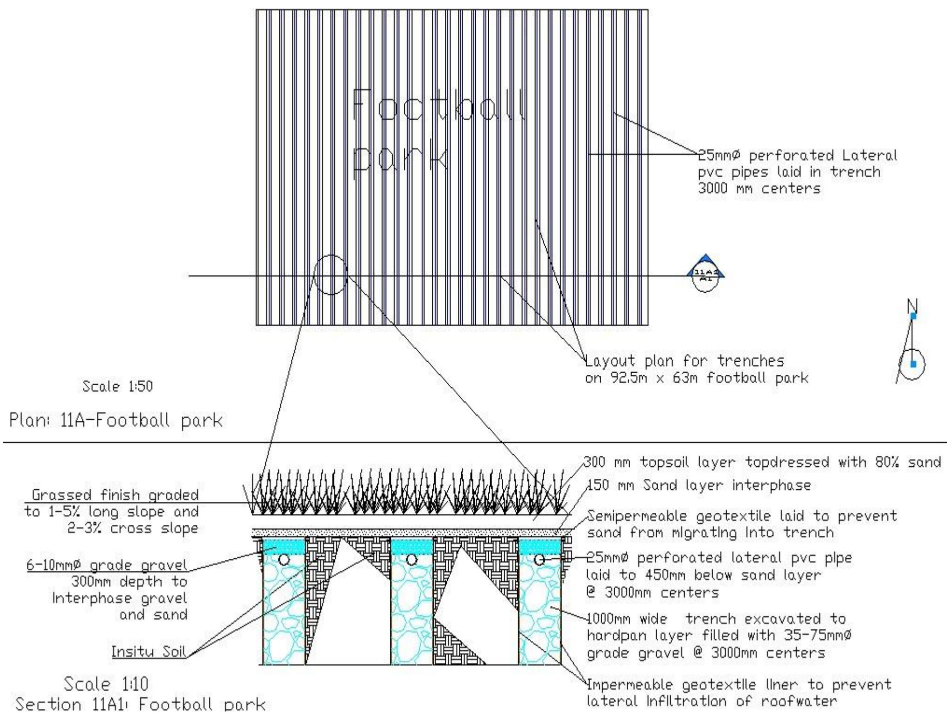


Fig.6. 6: Detailing LLSite1 11A - Infiltration trench on Football park

Detailing for Pavements - Detailing for pavings is referenced to Fig 6-3 and provided in Fig6-7 and Fig 6-8. All pavements were laid to minimum slope of 1:50. Detailing standards were according to (Holden 2004).

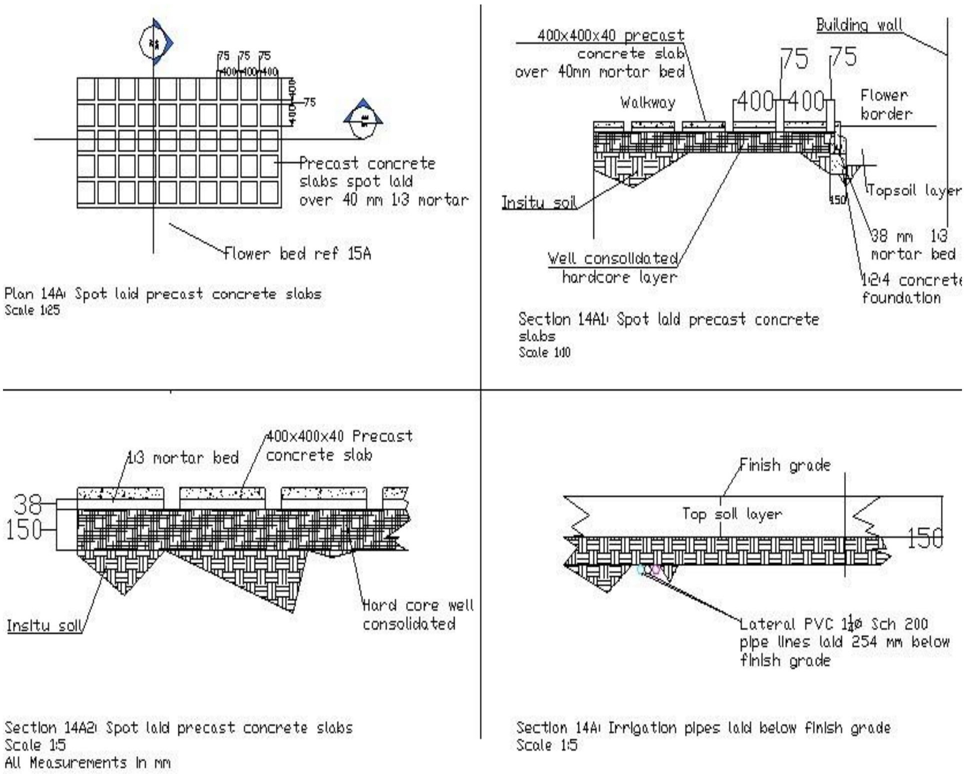


Fig.6. 7: Detailing LLSite1 14A - Spot paving

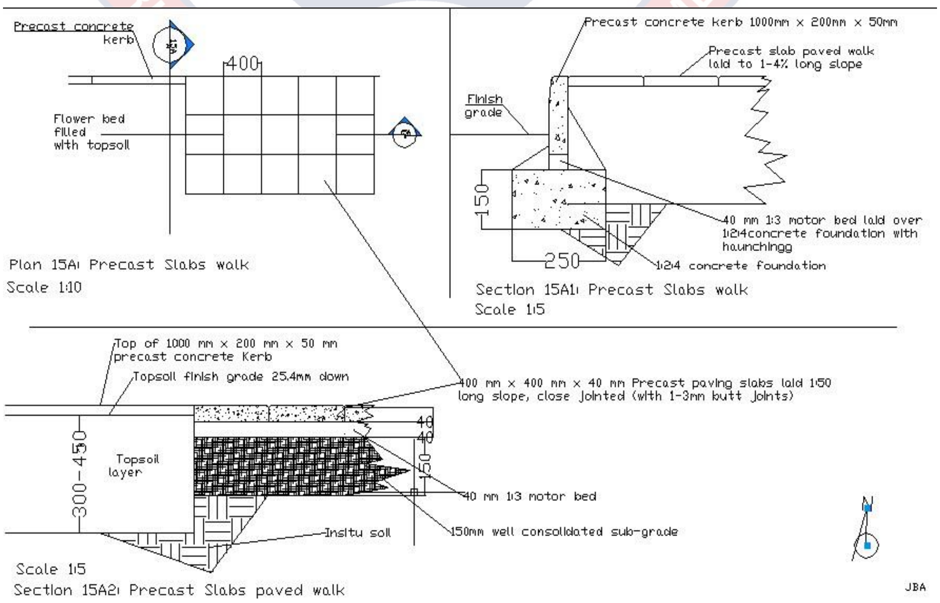


Fig.6. 8: Detailing LLSite1 15A -Jointed Slabs walk, Edging and Flower bed

Irrigation system: Three types of irrigation systems were used in the design. Subirrigation, drip and overhead sprinkler irrigation systems. Crop water requirement for the football park was estimated at 1.61m^3 per day based on (CSFWD 2010). Standards for lay-out and distribution, pipe sizing and pressure in pipes and sprinkler heads are as described by
(Israelsen 1950, USDA-SCS 1991, Smith 1997, Burt, Clemmense, Bliesner, Merriam and Hardy 2000, NJSBMPM 2004, NRCS-USA 2005, CSFWD 2010). Pump size for the irrigation system was estimated at between 1.5 - 2 horse power.

The selection of the systems of irrigation was influenced more by "environmental and social" considerations than just "economic efficiency" (Burt, Clemmense et al. 2000). This is because the irrigation system was developed for the beneficial use of rain water on the site. This was to be achieved through storing and re-using roof-water for irrigation or infiltration purposes instead of releasing it into the public drain which could accumulate to course floods in low lying communities.

The choice of the sub-irrigation system enabled the otherwise impermeable soil of LLSite1 to be used to store rainwater which will provide moisture to grassed areas by capillary action, maintained from moisture deficit as the grass cover looses moisture(USDA-SCS 1991). Subirrigation will help provide offseason irrigation to ensure continuous growth of the grass(Varshney 1995). A successful implementation of the design will provide an example to the pupils on the useful role rainwater can play with the possibility of the site becoming a facility from which the rest of the community can learn about the beneficial effect of rainwater harvesting.

Sectional views – a sectional view was used to depict a pictorial view of how the various components in the design relate to each other. A single view which span the full length of the site was used (Fig 6-9).

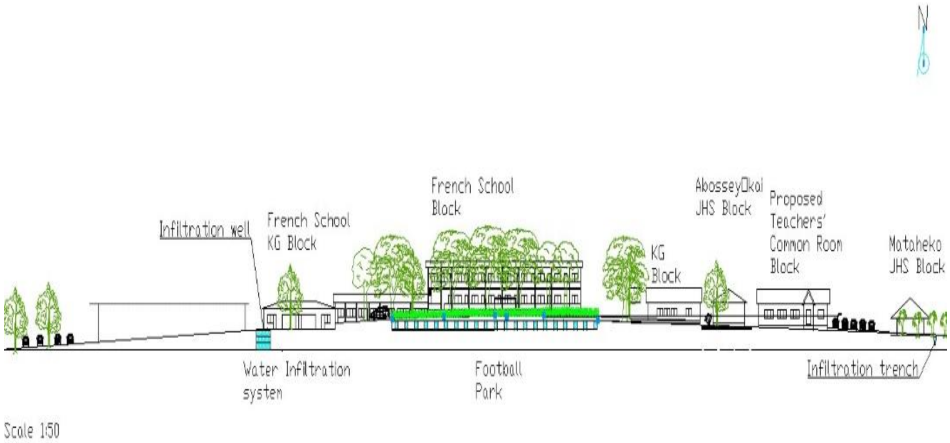


Fig.6. 9: Detailed Drawing LLSite1 - Section AA

Detailed Design – LLSite2: Detailed Design for LLSite2 followed a similar pattern as described above for the LLSite1 and has a hard landscape, planting plan and irrigation plan.

Hard Landscape – The detailed design for the hard landscape show location and types of flexible paved areas for both paving blocks and paving slabs, public and private car parking, garden fences, service areas, play space and planted areas. It also show location of buildings, infiltration wells relative to buildings and service structures (Fig 6-11). Detailing for the components is provided using the references B1…………Bn.

Infiltration well: The infiltration wells were designed with a 25year return period rainfall of 234.94 mm. Each of the 6 infiltration wells have the same size (3000 mm Ø) and were designed to 2.4 m maximum depth to infiltrate 75-95%

of roof water (Fig 6-10). The construction details (Fig 6-11) is same as was provided under LLSite1.

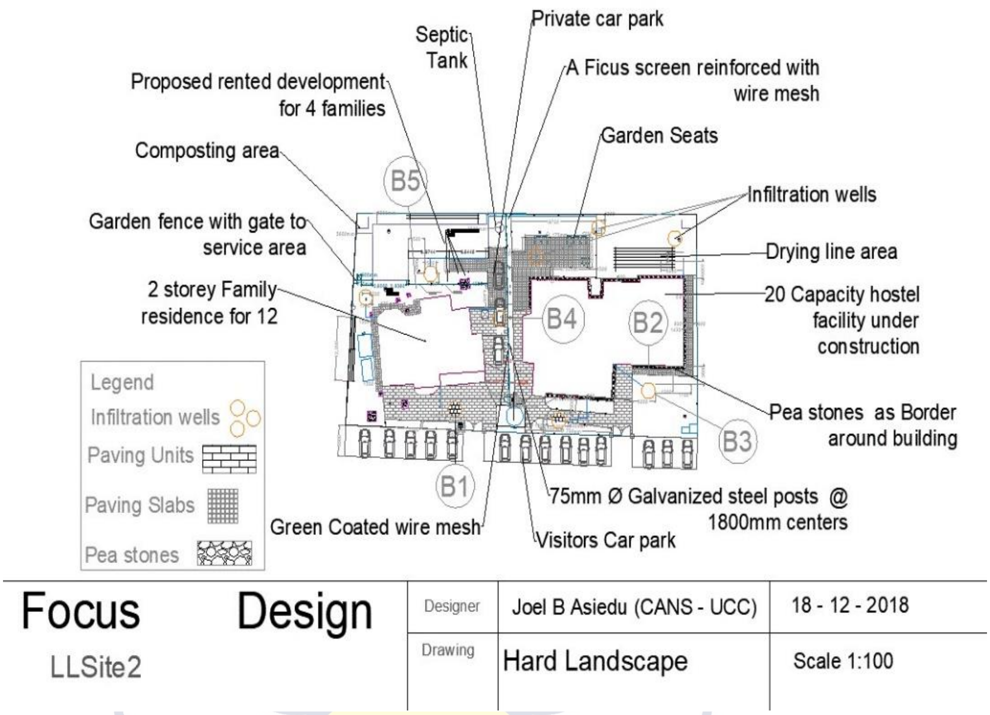


Fig.6. 10: LLSite2 Hard Landscape drawing

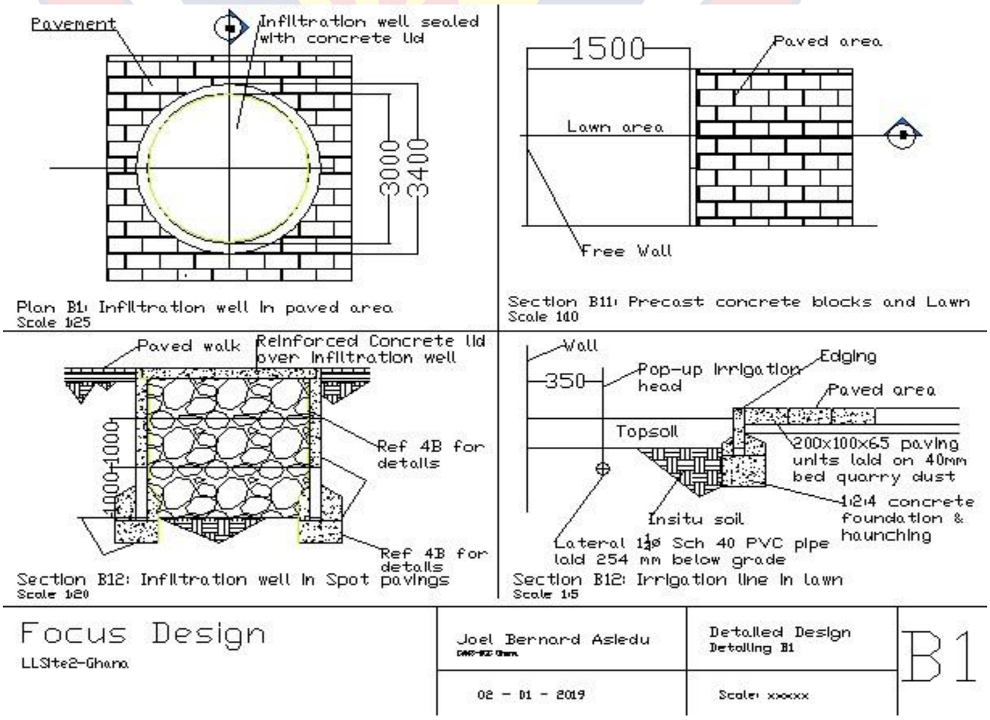


Fig.6. 11: Detailing LLSite2 B1– Infiltration well in paved area

Paving blocks and Paving slabs – detailing for laying of paving blocks and slabs are as provided in the detailing (Fig 6-12 & 6-13).

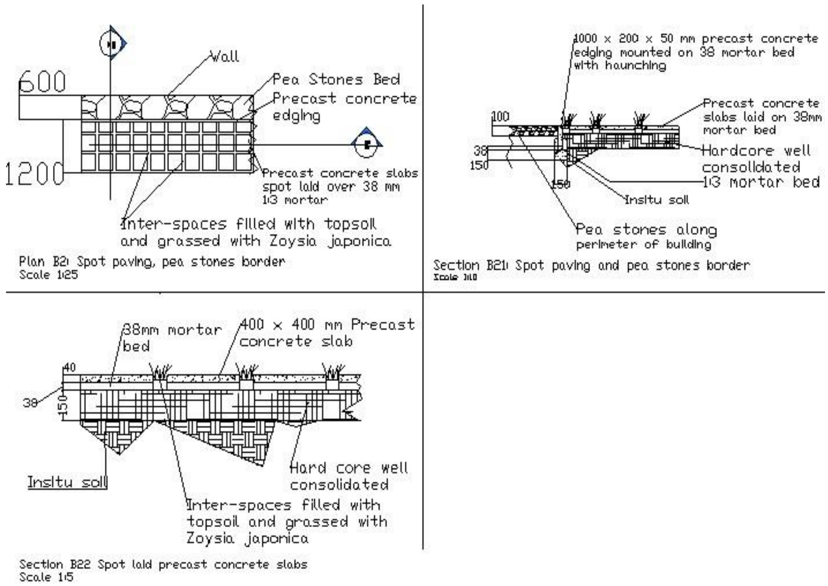


Fig.6. 12: Detailing LLSite2 B2 - Paving Slabs and border

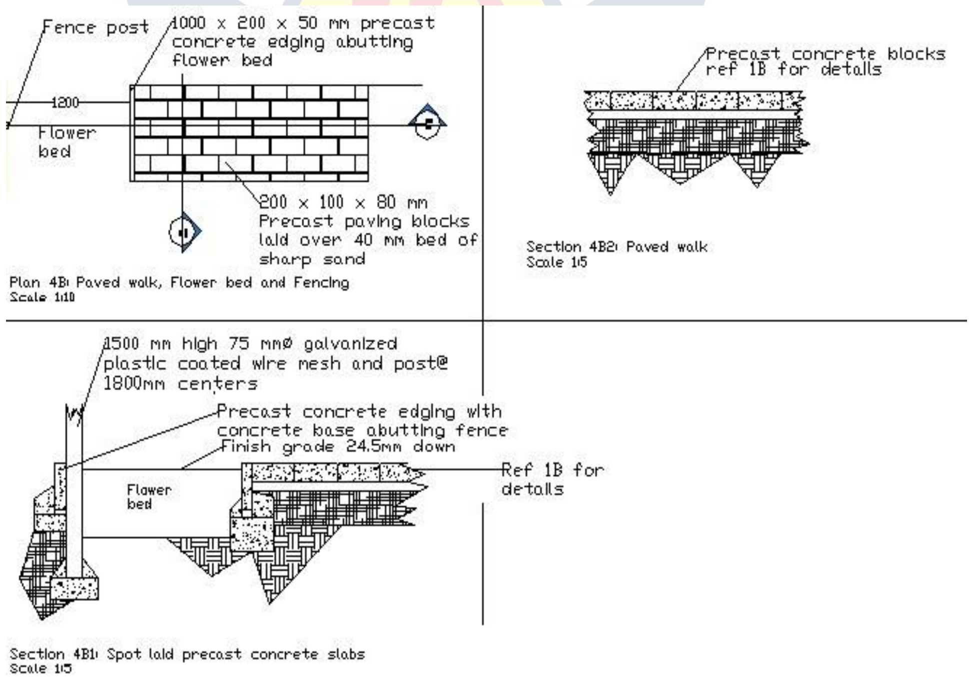
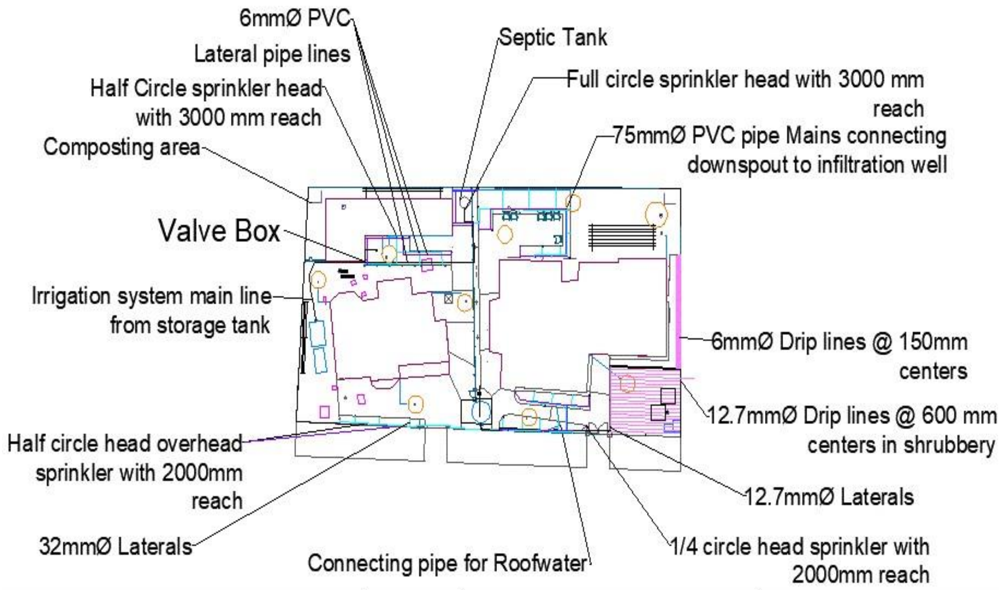


Fig.6. 13: Detailing LLSite2 B4– Galvanized wire fence, border and pavement

Irrigation System: Water for irrigation is provided by existing storage structures on site. A pump system extracts ground water into existing surface and sub-surface water storage tanks. Water is pumped from the storage tanks to irrigate lawns using a combination of overhead Sprinkler irrigation system and a drip irrigation system.

The detailed design for irrigation system showed location and dimensions for irrigation system installed for planted areas (Fig 6.14, 6.15 &6.16).



Focus Design LLSite2	Designer	Joel B Asiedu (CANS - UCC)	18 - 12 - 2018
	Drawing	Irrigation System1b	Scale 1:100

Fig.6. 14: LLSite2 Detailed design for Irrigation system

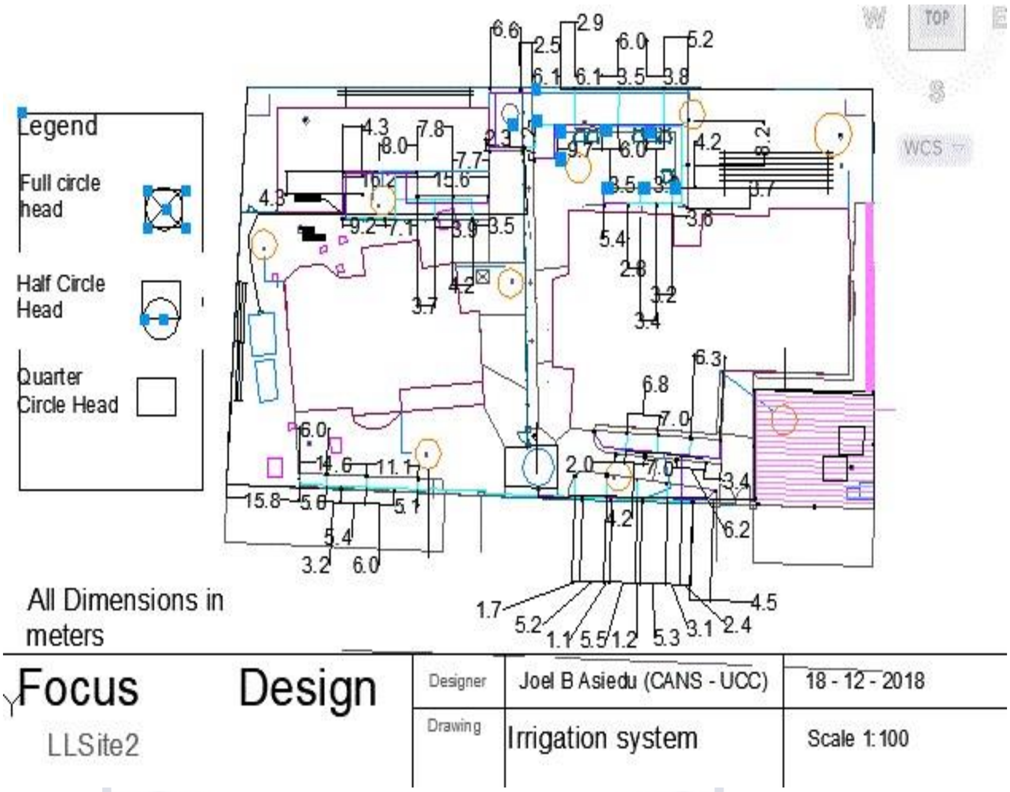


Fig.6. 15: LLSite2 Plan - Detailing for Irrigation System

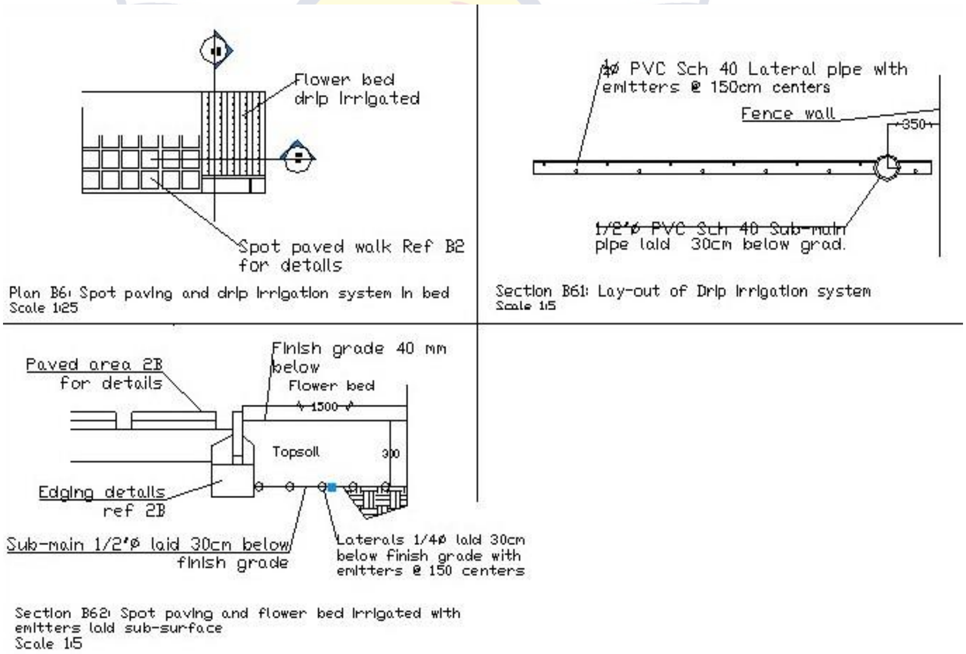


Fig.6. 16: Drip irrigation system detailing in a flower bed

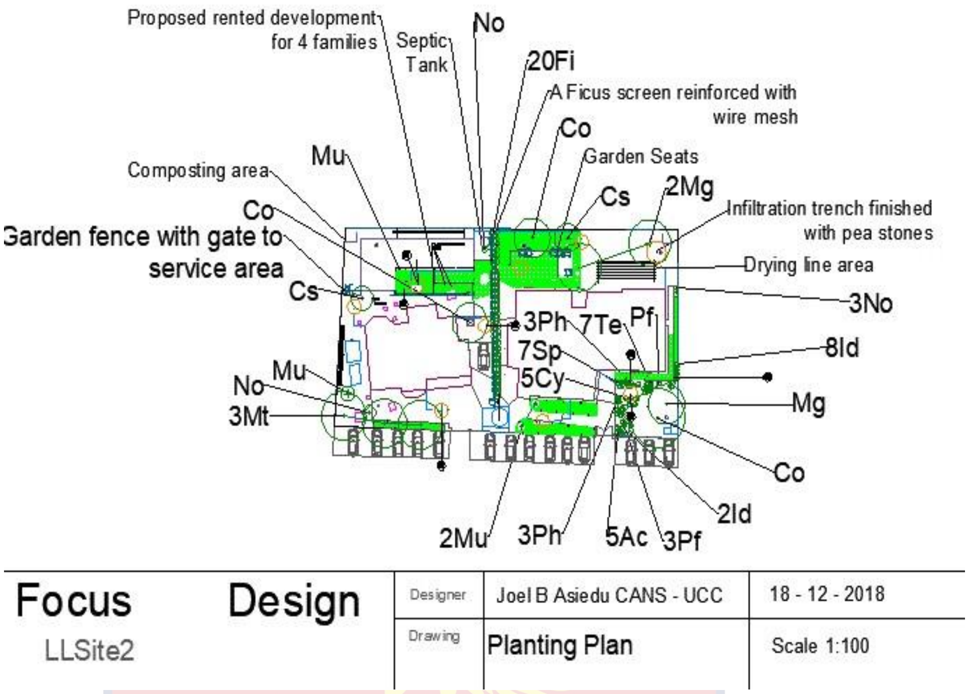


Fig.6. 17: LLSite2 Planting Plan

Table 6. 3: LLSite2 Planting Plan - Schedule of Plants

	Plant Schedule		
Trees	**Common Name**	**Symbol**	**Quantity**
Cocos nucifera	Coconut	Co	1
Citrus sinensis	Sweet Orange	Cs	2
Ficus benjamina	Weepinf Ficus	Fi	20
Mangifera indica	Kent Mango	Mg	1
Milletia thonningii	Milletia	Mt	2
Shrubs			
Acalypha wilkesiana Macrophylla	Copperleaf	Ac	5
Ixora duffi	Double Red Ixora	Id	10
Murraya exotica	Orange Jasmine	Mu	4
Nerium oleander	Oleander	No	5
Pseudomussaenda flava	Dwarf Mussaenda	Pf	4
Thunbergia erecta nana	Bushclock vine	Te	14
Ground covers/Herbs			
Cyperus alternifolius	Umbrella plant	Cy	5
Phormium tenax variegatum	New Zealand Flax	Ph	6
Setcreasea purpurea	Purple Heart	Sp	7
Lawn			
Paspalum notatum	Paspalum		

Source: PhD Research, Asiedu 2020

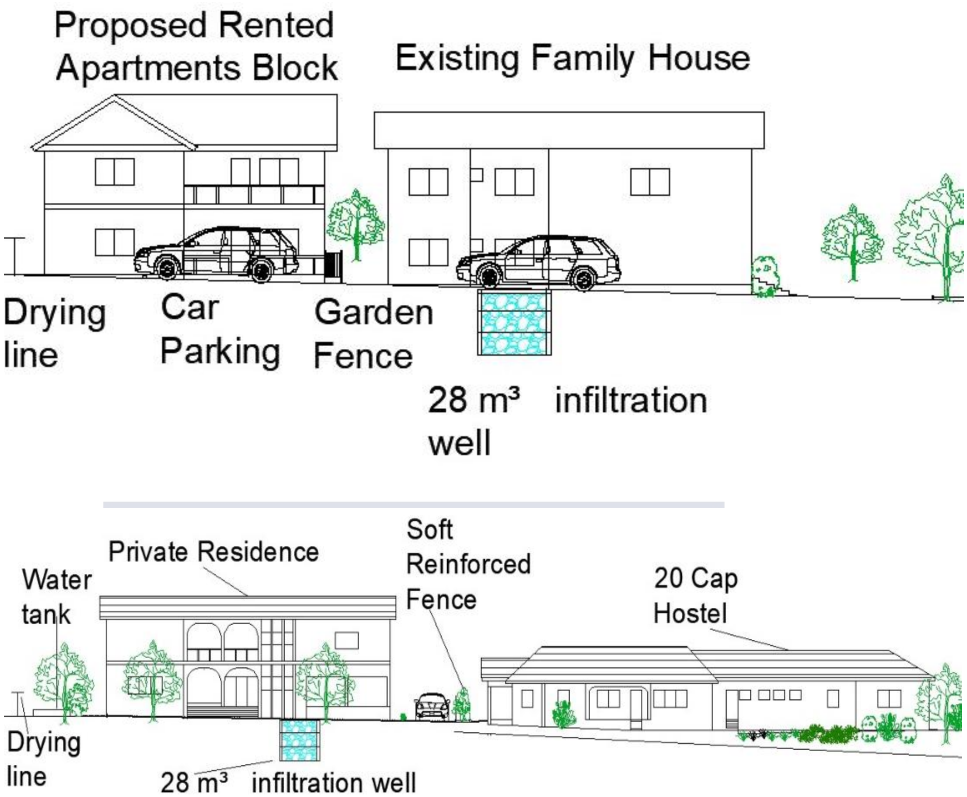


Fig.6. 18: Sections showing relative locations of structures for Focus Design Discussion Site (Area2)

6.5 Summary of Chapter

Landscape architecture Design methods were adopted and applied to the design of stormwater interventions at the regional and plot levels. The design of the interventions was based on findings from literature review, site documentations, field survey, and case study research.

To meet the trendy requirement to explain every step of the design process a public forum was organized to disseminate the findings of the research and to invite the public and experts to participate in evolving interventions to address the problem of stormwater management to control floods in GAMA. Herbert Dreiseitl and Peter Latz had used a similar approach to engage the public to ensure support for their projects and in the evolution of a design.

The research found that up to 32.6% of stormwater generated runoff that ends up causing floods in built up areas originate from the roofs of buildings. To address this challenge strategies were developed to target stormwater managment at the plot level.

The research agrees with earlier findings that intervention which aim at controlling stormwater at source must be implemented catchment- wide to be effective. A catchment-wide approach will require interventions to be located at specific places to be most effect. To address this, the research developed a schema which can be applied to an entire area to guide the location of interventions for best result. The stages in the process is summarized in Fig 6-19.

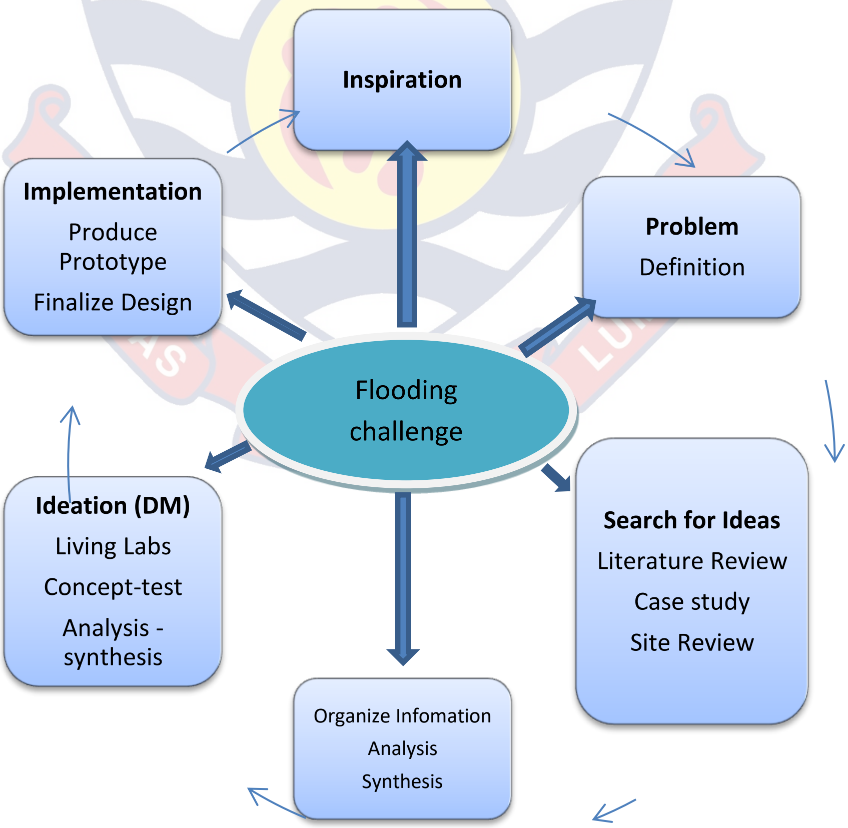


Fig.6. 19: The Design Cycle Adapted from Linden, 2001

The key findings of the research were reduced to two main strategies and three action strategies. These were then applied to each of the three focus research areas, Area1, Area2 and Area3.

Design at the plot level was used to integrate stormwater management to control floods with various activities within the plot. The process began with the formation of Living Lab model sites; one each from Area1 and Area2 and the development of outline design proposals for on-site stormwater management. Each outline desing proposal was developed into a detailed design. The research used stormwater management to control floods at the plot level to achieve both utility and amenity values.

The research demonstrated how critical data from research and the case studies were used to shape the pre-design and during design stages. Design methods were used to systematically improve the design by adopting design ideas from the case study to improve the research, thus showing how incremental adoption can be used to improve a design. Behaviour settings were used to guide the development of form in dividing each design discussion site into discrete units while working to meet the central motif of flood control through stormwater management.

The design shows how the central motif of flood control was used to also address other critical problems in the environment such as erosion, dust generation and intense heat from bare surfaces.

CHAPTER SEVEN

SUMMARY OF FINDINGS, CONCLUSIONS AND FURTHER RESEARCH

7.0 Introduction

The research was focused on a fast growing metropolis within the Greater Accra Metropolitan Area (GAMA) in Ghana and was built on the central motif of flood control in an urban area. The research was set up to address two main questions:

a. Why has the current approach to stormwater management to control floods failed in the study area? And

b. How can stormwater be managed to control floods?

Three objectives were set to address these two central questions with three focal areas Area1, Area2 and Area3 selected within the research area to focus the attention of the research. The areas were randomly selected to represent levels of imperviousness in different parts of the urban area and to reveal any trend in imperviousness from south to north, ranging from Area1 which had the highest population density and was the most impervious with 54% imperviousness, Area2 with 43.7% and Area3 with 22%.

7.1 Summary of Findings

7.1.1 Objective I: to assess the existing stormwater management system to determine the cause of its failure.

This objective was met through an exhaustive literature review, site document review, field survey of experts and common knowledge. The following were the main highlights.

Literature Review - To be able to determine why the current approach to flooding has failed, I begun to look at how the problem of floods in urban areas has been defined in the literature, in terms of the causes of floods. This was followed with other literature on the types of floods, and interventions which have been developed to address floods. The outcome of the review has been detailed under chapter 2. The following are the major conclussions.

The systematic reviewed process was used to review 45 literature sources, and was combined with site documentation, interview of experts and common knowledge on the causes of floods in urban areas and why the interventions to control floods have failed.

The results of the literature review identified and grouped the causes of floods into direct and indirect causes. Direct causes of floods include intense rainfall, increased imperviousness and poor or inadequate drainage systems. Indirect causes include siltation, blockage by waste, poorly constructed drains, and construction in low laying areas among others. These do not directly cause floods but add to the flooding problem.

I am of the view that interventions which target the direct cause of floods could be the first step in addressing the problem of perennial floods. Through the literature review I have tried to explain the relationship between flooding and the various factors in the urban environment which have worked to worsen the problem of floods. To further deepen understanding in flood issues, and shift it from the current impact-based-knowledge, it was necessary to quantify the contribution to floods by impervious surfaces which I sought to achieve in the research.

The literature identified several types of floods; fluvial, pluvial, urban, river, storm surges, ground water flooding, estuarial flooding, flash floods, all of which can be classified as either inland or coastal floods, deep or shallow floods. Of all the types the most common and destructive is flash floods (Zahran 2008, Kazmierczak 2011, Watson and Adams 2011, Ortega 2014).

There are two main systems of stormwater management to control floods. One is based on a conveyance system which can be either conventional or non-conventional while the other is the minor and major drainage systems developed using carrying capacity.

The conventional system is the most popular in developing countries which includes the research area and involves the traditional hydrologically efficient conveyance system in which the drainage system, both surface and sub-surface is encased in concrete with the aim of removing stormwater as quickly as possible from developed areas (Warren, Younos et al. 2009, Burns 2012).

This conventional system over time has led to orphaning of surface and underground water bodies, relocating the flooding problem and negatively impacting on hydrology of an area due to its negative impact on infiltration (Echols 2007, Warren, Younos et al. 2009, Garrison 2011, Barbosa 2012, Burns 2012, Vietz 2016). It is also criticized because it provides no room for biodiversity, destroying the "ecological functions" of natural drainage systems (Greco 2014).

The second group of stormwater management system, which is a combination of interventions is called green infrastructure or Low impact development (LID). In the review, green infrastructure was defined as a natural, semi natural or artificial system designed to mimic and restore hydrological processes for the conservation of natural resources, ecosystem functions and to provide associated benefits to man. It is a system which includes the use of infiltration systems (bioinfiltration, infiltration well, infiltration trench), storage systems (retention and detention systems) and rainwater harvesting and has been developed as state of the art system for stormwater management to control floods.

Site Documentation and Field Survey*:* I relied on interviews to make simple deductions from experts and common knoweldge to inform on how and why the stormwater management system has failed (Ref. Chapter 4). Most of the data obtained from the research area were spatial. No particular document on stormwater management was obtained from government or nongovernment sources in the research area. There were however, several discussions and interviews with experts and government officials related to stormwater management.

These discussions and interviews revealed that there is no government policy guiding stormwater management. The expert interviews revealed that the Hydrological Services Institute serves as a consultant to the government of Ghana on stormwater management. However, because the institute has not been well resourced over the years, they are unable to carry out the necessary research based upon which to provide technical advice on stormwater management to the government.

This situation confirms assertion in the literature that stormwater management issues to control floods in developing countries are treated on adhoc basis (Tengan 2016) and that in most cases, the drainage systems are established "without any scientific basis"(Ouikotan, van der Kwast et al. 2017).

The expert interviews also confirmed that government favours the conventional system of stormwater management which is made up of only a conveyance system; a tertiary, secondary and primary drains. These have been built respectively using 5 years, 15years and 25 years return periods.

A majority of the experts (95.9%) considered perennial floods in urban areas to be a major threat which affects socio-economic activities during the rainy period of the year. About 71% of the experts were of the view that the conventional approach to stormwater management to control floods was the way to go. They agreed that although the system may have its challenges it will be able to meet the needs of the developing urban area provided those challenges are addressed. The challenges they referred to included using non-structural methods such as dredging, desilting, educating the public to avoid dumping refuse into the public drains and to avoid building in drainage ways, enforcement of building regulations to improve the drainage system. This they explained will ensure the smooth flow of stormwater and thus prevent the perennial floods.

The public showed an equally strong support (97%) for the conventional system of stormwater management with 71% agreeing that the system is the way to address the flooding problem.

Researcher's Observations: I observed during the field survey that indeed, a number of the secondary and primary drainage ways had been dredged, widened, straightened and have vegetation along their banks cleared. Berms have been constructed along sections of water courses which run through communities. But the construction of berms was preventing stormwater runoff generated from adjacent communities to be drained away, creating stagnation in the communities.

There were water marks on building in communities along the water courses showing the effect of flooding and increasing impact of stormwater generated runoff in the communities. Interestingly some of these locations had been developed by the governement to house government workers. Interviews from members of the community showed that the buildings in the area had been deteriorating, with increasing incidence of ground water intrusion.

Although flooding and its causes are considered to be multi-dimensional (Okyere 2013) peeling away the layers of urbanization and increased imperviousness, a drainage efficient system together with the loss of natural places of attenuation, one is able to draw a clean line on how stormwater management to control floods has failed.

I am of the view that the combined effect of these factors have created an urban landscape where stormwater runoff which could have infiltrated, intercepted by vegetation, or stored in depressions rather runs off compacted surfaces or impervious surfaces as stormwater runoff. The stormwater runoff energized as they fall from the roofs of buildings moves swiftly over impervious and compacted pervious surfaces and without any form of attenuation quickly accumulates in hydrologically efficient drains.

The hydrologically efficient drains swiftly carry runoff from communities into secondary drains which continues into the primary drains. By the time the stormwater reaches the primary drain the speed and the volumes are so large that the receiving lagoons which have also been partly urbanized are unable to disperse them fast enough, resulting in floods. The situation though is worsened by poor engineering, silted-up drains, blocked gutters, urbanized natural places of attenuation and poorly sited structures in natural drainage ways, creating flooding situations in diverse places up stream and downstream.

Despite the confidence shown by the experts and the public in the present system of stormwater management, I cannot but disagree. Based on the findings of this research, it is my position that the current system of stormwater management which relies on only drainage efficient conveyance system to quickly disperse stormwater from settlements will not be enough to meet the ever increasing demand for more impervious surfaces from shelter, transportation and other utilities to meet the needs of the growing urban population.

It is safe to predict that the quantity of stormwater generated runoff will continue to increase with any rain event, with or without the added threats from climate change.

7.1.2. Objective II: to develop interventions that target the management of stormwater runoff.

To address this objective, I reviewed case studies to adapt principles to help solve the perennial problem of stormwater management to control floods in the research area. I also isolated the role of impervious surfaces in stormwater generation to establish the basis for a stormwater management.

The Case Studies followed the criteria set by (Francis 1999a, Johansson 2003, von Seggern 2008, Levy 2009). Several cases were reviewed but later discarded after further review and site visits.

No direct precedents were found so I adopted a case which was central to the research and an amalgamation of approaches and methods from other cases. These cases included the Green infrastructure plan for La Parguera Puerto Rico (Terrasa-Soler 2012), the water sensitive design project in metropolitan Lima, Peru(Nemcova 2012) and principles abstracted from (Steinitz 2010) and (Frick-Trzebitzky 2018). The single case adopted which was central to the research was the Smart interventions to adapt urban areas against floods in some cities in Japan (Yamashita 2015).

Although the case is sited in Japan, it fitted well with the theme and the challenges of the research. The case was based on "Smart adaptation of urban areas to flooding" by (Yamashita 2015) and derives from citizens of an urban area and their quest to find a solution to flooding. What is interesting about the case is that just like in the research area, the citizens were fixated on the use of conventional structural measures to address flooding. But the state authorities together with some citizens who were equally fixated on finding an alternative solution to flood control agreed to adopt the smart adaptation approach, the success of which served as an example to other communities.

There were challenges though. Unlike the case study, where there was a standing citizen organization working to find a solution to the problem of flooding, there was no such thing for the research area. A number of papers have been produced from the case such as(Yamashita 2015) and (Yamashita 2016) but no awards so far. The key findings from the case study were the combined use of infiltration, rainwater harvesting and reuse of rainwater to address flooding problems in urban areas.

Based on the outcome of the case study review and the literature review I decided to determine the contribution of imperviousness to stormwater runoff generation in the urban area. This was done using the Curve Number approach where direct runoff was modeled from 7years rainfall data for the three focus areas within the research area. The results showed that the roofs of buildings contribute between 14.7% to 32.6% to stormwater runoff, which accumulate to cause floods in communities.

Outline of findings for Objective 1 and Objective II – The following outlines and main findings;

a. Urbanization and its impact of increased imperviousness, inadeguate drainage and intense eratic rainfall are the key drivers causing floods in urban areas.

b. Effective stormwater management must begin at the plot level, where the roofs of buildings contribute between 14.7% - 32.6% to stormwater runoff which accumulate and cause floods in communities.

c. Interventions to address stormwater management should be located watershed-wide with different locations within the watershed receiving treatment(s) unique to their situation.

d. For effective performance of stormwater interventions to control floods, a schema must be developed to guide the location of proposed interventions.

These four findings were coalesced into two strategies and applied to the three selected focal areas.

Development and Application of Strategies:

Strategy 1. Develop a schema to guide the location of interventions.

The development of the schema to be applied at the regional level/watershed and at the plot levels was inspired by the 'Water Sensitive design of open space systems' research (Nemcova 2012), and works by Terrasa-Soler (2012), Jauslin (2012) and the "Application of Scale in Design Decisions" (Steinitz 2010).

Its development was patterned after Ian McHarg's overlay analysis and was used to fit the huge volume of data obtained from the study area, literature search, internet search, case study and field survey into a kind of pattern on which to base the design (Lynch 1971). These were used to prepare a series of spatial layers as similarly done by (Lopez-Marrero 2011).

These sets of data were used to run a multicriteria suitability overlay analysis model in an Arcmap environment. The result was a schema. The schema was composed of two maps, a constraint map and a factor map (Lopez-Marrero 2011). The elements used to form the factor map were a set of criteria that influence, enhance or detract from finding suitable location for a particular stormwater management intervention. The factor map was modelled on land cover, soil series, geology, hydrogeology, population density, infiltration rate, slope and soil loss maps. The maps were ranked and weighted as described by (Steiner 1983, Triantaphyllou 1995, Uy 2008, Panhalkar 2011, Rinner 2011) before they were used in the model.

A different set of variables were used to build the constraint map. These were a set of criteria that exclude an area from the analysis based on the set objectives (Lopez-Marrero 2011). The constraint map was formed from combining a 1hr in 100 mm flood map and surface water bodies and areas with special soil water conditions identified during the site survey. The elements selected to run the model and the ranking and weighting were applied depended on the type of intervention to be used. For instance, in locating infiltration based interventions, factors like population density used as a proxy for imperviousness, hydrogeology, soil type, geology, and infiltration rate were given high priority. For this research, infiltration based interventions were determined to be best suited to high population density areas which usually are highly impervious. Thus in weighting and ranking, areas with higher population density were ranked high.

The weight awarded to population density was also made high in relation to the other elements. Another element which was critical is hydrogeology. Hydrogeology map ranking was based on depth to ground water. Thus areas with higher ground water were ranked lower compared with areas with deep ground water or with no ground water. In the same way the hydrogeology map was given a high weight relative to the other elements because of its critical effect on infrastructure.

The Schema produced three location suitability categories as low suitability, moderate suitability and high suitability.

Action Strategy – In applying the schema to guide the location of interventions, two sets of schema were produced. One schema was produced for guiding the location of retention and detention basins while the other was for infiltration based interventions. For each of the schema, the moderate and high suitability locations were made transparent. This was then overlaid on high resolution Orthophoto of the research area to guide the selection of possible areas for the interventions.

Strategy 2: Introduce interventions to manage stormwater runoff at the plot and catchment levels to provide functional and amenity values.

Action strategy i – Use retention and detention basins to capture stormwater runoff from pervious surfaces at the catchment level to provide functional and amenity values.

Action strategy ii – harvest, store and infiltrate 65-95% of roofwater at the plot level to provide functional and amenity values

7.2.3 Objective III: To determine how the strategies can be integrated into a developing urban area

Application of Strategies – This involved taking the strategies and applying them to the three focal areas; Area1, Area2 and Area3.

Area1

Proposed interventions - Due to the high density of development within this focal area, communal underground storage systems for rainwater harvesting are recommended to accommodate extreme rain events in place of retention and detention basins. Roofwater harvesting for non-portable use at the plot level should be adopted for all buildings combined with infiltration wells or trenches to manage up to 95% of roof water. Where space is a limitation, at least one of these interventions should be adopted at the plot level. Harvested roofwater could be used for irrigation of gardens, lawns and other planted areas, flashing of toilets and washing. However, within flooding hot spots, interventions should be limited to only roofwater harvesting.

Area2

Proposed Interventions - Online stormwater retention/detention basins could be installed along existing natural unpaved drainage lines within the communities. At the plot level rain water harvesting could be combined with infiltration wells or trenches to retain up to 95% of roof water on site. Where space will be a limitation at least one of the interventions should be adopted at the plot level. In addition, infiltration trenches could be integrated into the street system. The infiltration trenches could be installed on unpaved streets to receive stormwater runoff from impervious surfaces in nearby houses and alleys.

Area3

Proposed Interventions - Retention basins should be constructed along the Onyasia River to store water for all-year vegetable and nursery production. These interventions could be located close to communities and will be important in reducing the volume of water which descends from the Akuapim mountains during heavy downpour as well as provide irrigation water for vegetable farming and nursery production centers.

Communal infiltration tanks could be installed in strategic locations to infiltrate stormwater to recharge under-ground water resources in place of infiltration wells at the plot level. This is due to the impermeable quarzt schist layer which underlies the area, making individual infiltration wells too expensive. Rainwater harvesting and reuse in surface storage tanks could also be encouraged within plots.

Application at the Plot level

Application of the action strategies at the plot level was built on the living labs model which was used to involve community members to generate innovative ideas to address the problem of stormwater management at the plot level.

Site Analysis: Site analysis begun the process to find suitable locations for stormwater interventions at the watershed level.

Site Selection: Site Selection was the next phase and combined specific aspects of the proposed interventions to determine which part or parts of the site will best meet these conditions. This is actually a screening process to eliminate bad locations. It required working to select one of several options for the location of a particular intervention. For this research at the watershed level, I applied the schema to help identifiy possible places to site various interventions.

The interventions were retention and detention basins, infiltration wells, infiltration trenches and a water tank. In this research, I prepared two schema; one for locating infiltration based interventions and the other for locating retention and detention basins. Each schema was overlaid on a high resolution orthophoto of the research area and used to guide the selection of the sites.

Application of Design Methods: Following a successful site selection, design methods such as incremental adaptation, optimizing essential functions, synthesis and analysis and bahaviour patterns were applied to define form (details in Chapter 6).

Optimizing of essential functions was used to shape the design by adopting stormwater management to control floods as a central motif thoughout the design process. Thus by addressing this central motif, the design also addressed other challenges in the urban landscape.

A similar principle is seen in the case study(Yamashita 2015), where a central motif of stormwater management to control flooding is used to address other problems as well in the landscape. This was achieved by a combined use of roofwater harvesting and infiltrating stormwater at the plot level and using retention and detention basins and large storage tanks at the watershed level.

Incremental improvement is the second design method adopted and involved the use of information from the case study to systematically improve a design. Again, this approach was used to inspire the research in terms of what was possible. In the case study, rainwater was harvested and stored in cisterns for reuse in irrigation, flashing of toilet and washing. In the research, roofwater was harvested, stored for reuse to flash toilets, irrigate to create soft play spaces or infiltration into the ground to recharge ground water reserves.

The final design brief was developed for each focus area during the focus design phase using the Living Lab model.

Design Brief: The outcome of the forum was used to finalize a design brief for the study area.

Action Strategy II: Action Strategy II followed a typical process of design applied at the watershed level and at the plot level. Application at these levels was used to show how the schema proposed in Strategy 2 could be integrated into the design process at the plot level. The process is summarized, adopting the Design Cycle from Linden (2001).

Living Labs model: The researcher adopted a grass root system which involved approaching various facilities identified within the research area and engaging them to address the problem of perennial floods at the plot level. Facilities like church buildings, School buildings, Private residence, Commercial buildings were identified within the three focus areas in the research area. Their location was aided by high resolution orthophotos combined with Google Earth images.

Owners of the identified facilities were contacted and the discussions began. After the initial discussions, two facilities were selected for a more detailed discussion, using the living labs model. The users of the facilities (called actors) together with the researcher (as the mediator) worked to develop innovative ideas to manage roofwater on site.

The discussions using the living labs model led to the development of a final design brief from which design proposals were developed and used for the final design drawings and detailing.

For the two selected sites, Living Labs Site1(LLSite1) and Living Labs Site2 (LLSite2) harvested roofwater was used to irrigate a football park. The irrigation enabled establishment of other planted areas and to increase the density of plantings on the facilities. This was used to address the problem of erosion, prevent creation of dust bowl from bare areas and reduce stormwater generated runoff on the site.

The design was used to manage roofwater by designing infiltration wells and trenches to infiltrate stormwater to recharge ground water. The effectiveness of the design will be based on the design storm of 25years return period used to design the interventions.

7.2 Conclusions

The research has been used to chart a path to determine how stormwater management to control floods in an urban area can be achieved. This has been as a result of years of painstaking effort at arriving at a solution which will be based on current literature research, a detailed survey of the study area and a case study showing what has been achieved elsewhere.

The research found that perennial floods in urban areas are as a direct result of increased imperviousness occasioned by rapid urbanization in an urban era. This has compromised the ability of the natural landscape to impede, detain and store, infiltrate and evapotranspirate stormwater.

The extensive imperviousness created by urbanization creates a situation where stormwater falling from the roofs of building is further energized by impervious surfaces and compacted pervious areas in the urban area. This results in fast movement of runoff which quickly accumulates. The fast accumulating stormwater is quickly conveyed from hydrologically efficient drainage systems to be dispersed into lagoons and finally the sea. The large volumes of stormwater are not dispersed quickly enough by the dispersal agents and this results in floods. Meanwhile, the natural dispersal agents have been so compromised by urbanization that they have been rendered almost ineffective. The role of elements like poor garbage collection resulting in blockage of drains, silted up of the drainage system, development that does not conform to development control, and highly variable rainfall may all play a role in worsening an already bad situation.

The continued urbanization of the land will require that steps such as the development of a schema, integration of rainfall harvesting and use of infiltration wells, infiltration trenches, rain gardens and retention basins, as has been elaborated in this research are taken to douse the impact of urbanization both for the benefit of the population and the environment. It will be appropriate at this point to quote late King of Sri Lanka, Parakramabahu, that "No drop of water that falls to Earth should flow back into the Sea without first serving mankind"(Turner 2014). The continued use of the hydrologically efficient system in stormwater management, to the researcher’s mind, is like carrying barrels of water and throwing them into the sea. The situation is not only creating the floods which urban dwellers in developing countries have become familiar with, but is also orphaning underground and surface water resources. A better way is to introduce a system as has been shown in this research which seeks to reduce the volume of stormwater entering the drainage system by encouraging at source control through storage for reuse, evapotranspirate and infiltration. This will not only help improve the environment as the harvested water is used to irrigate the immediate environment to increase biodiversity, but also the stored water can be used to meet the non-portable water needs at home.

A successful implementation of the findings of this research both at the watershed and plot levels will become an educational resource for the pupils, teachers and the surrounding communities on what is possible with rainwater harvesting. This can then be replicated elsewhere as has been shown in the case study. A watershed-wide implementation of the results of this research will have implications for job creation as well. The research community will have to develop local-based techniques on infiltration which must be reviewed through continuous research to protect life and property and to deepen understanding on how the natural elements of the urban landscape can be harnessed to control floods. The reuse of rainwater for irrigation will require irrigation designers and give a further boost to the landscape industry in urban areas in developing countries. The implication for further training and research cannot be overemphasiszed for the succcess of any long term interventions. The example of Singerpore will be a useful reference here where the authorities developed research themes, established institutions and developed tailor made training programmes to train citizens in the management of the ABC policy(Irvine 2014). The ABC policy was developed in part to manage stormwater to prevent floods.

The research emphasized the use of nature based interventions to reduce stormwater volumes by using at source control methods where stormwater is managed as close to the point of generation as possible. Although this was the priority, the intervention introduced has the ability to improve stormwater quality. Managing roof water before it gets in contact with surface pollutants preclude any further contamination and thus ensure that stormwater is used in as good a form as possible. In addition, the researcher considered the direct effect of flooding which is evident for all to see and which needed immediate attention as the basis to generate interest in stormwater management to control floods. The research believe this will generate the needed interest which can be expanded to include quality issues.

Finally, this will help address the perennial flooding problem which stormwater from the roofs of buildings and other impervious surfaces contribute to worsen.

7.3 Recommendations

A drawback of the schema was the quality of the data. For instance, the hydrogeology map and infiltration rate maps were produced using interpolation due to insufficient data. The rainfall erosivity map used as an input for the soil loss map was also interpolated over the research area because the raingauge locations in the research area were very few and far apart.

A raingauge location density of 0.75sq miles (NRCS 1993) is the standard and this is far less than the 57.4 sq miles per rain gauge loction used in the research. However, I had to work with this limitation given that at the regional level it was just not “practical” to do a more extensive work given the limitation of time (Ponce 1996). I recommend further work to improve the output of the schema. The rational is that the number of raingauge locations for instance in the research area may be higher than it has been provided officially. There may be private and ancillary government agencies who may be operating raingauges which might not have been captured. These could be identified and their data used to improve the model. The constraint map was based on 2014 data, but could be updated with time and the same is with some of the other elements. In addition, the processes applied in developing the model have been made transparent enough for expansion and improvement as more information becomes available.

7.4 Further Research

The following research areas will be important. A soil map that relates the infiltration characteristics of the soils of the urbanized areas should be prepared. This will make it easy for researchers to determine the preliminary suitability of soils for various interventions and also determine the effect of interventions on near by structures. Research on cheaper and safer ways of storing harvested water at the plot level will be another research priority. The research was focused on reducing stormwater quantity and thus did not consider quality. However it is necessary to do further work in this area especially in terms of the effect of the type of roof material on the quality of harvested roofwater. Earlier works have shown that not all roofs should be used to harvest rainwater(Lawson, LaBranche-Tucker et al. 2009). It will be important to map out the roof types in the study area and determine the material. This way, target interventions can be introduced to avoid any problems which may arise with mass rainwater harvesting and reuse.

Opportunities also exist to research into ground water conditions throughout the study area. This should be used to provide a comprehensive update on ground water conditions in every part of the study area. This way it will not be too difficult to know which interventions will be suitable to which localities. Through the research I identified several watersheds within the study area which could be adopted as design units(Su 2014). These design units have unique characteristics in terms of imperviousness, soil type, geology, land cover types, surface form, even rainfall level, hydrogeology, (slope) etc. The opportunity then exists to extract these information and apply them in determining the best interventions for stormwater management to control floods within these units.

Standards must be developed on how much roofwater can be infiltrated on a plot relative to roof area and plot size. This will help prevent the situation envisage by(Coombes 2000) on the possible effect of mass adoption of infiltration at the plot level on foundations. It will be critical to perform an audit of the system using existing Environmental assessment tools to determine the effect of mass implementation at watershed-wide scale on urban hydrology and structures based on the various soil types in the research area. There is the need to provide cost benefit analysis on the entire system to serve as a guide to developers based on the work of Aerts (2018).

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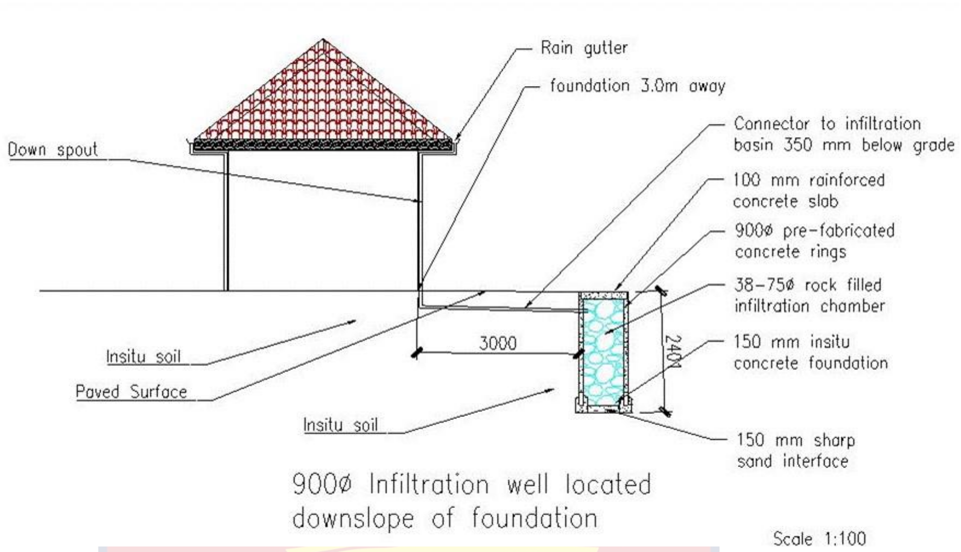
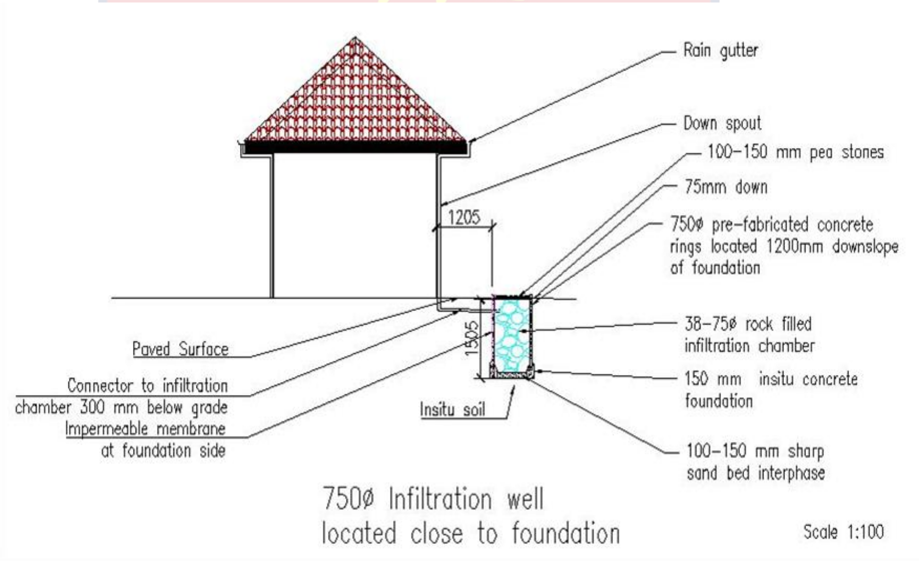
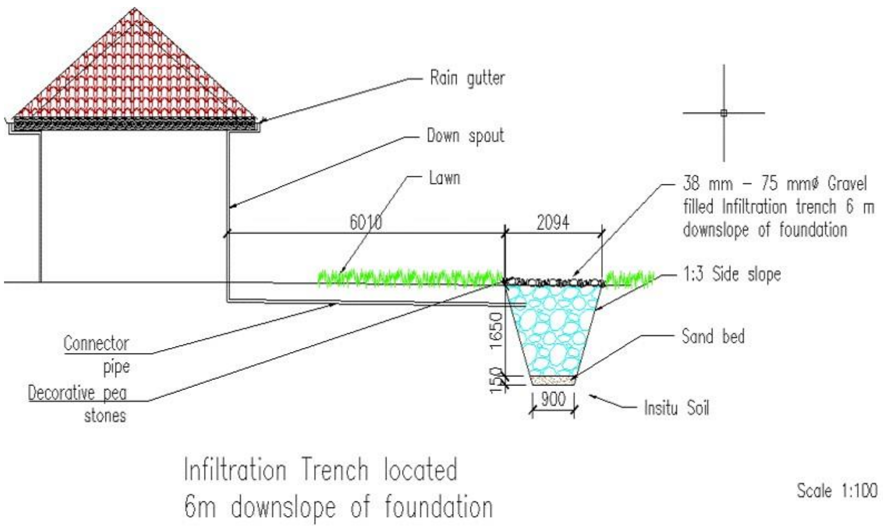
AppendixFigure, Tables and Maps



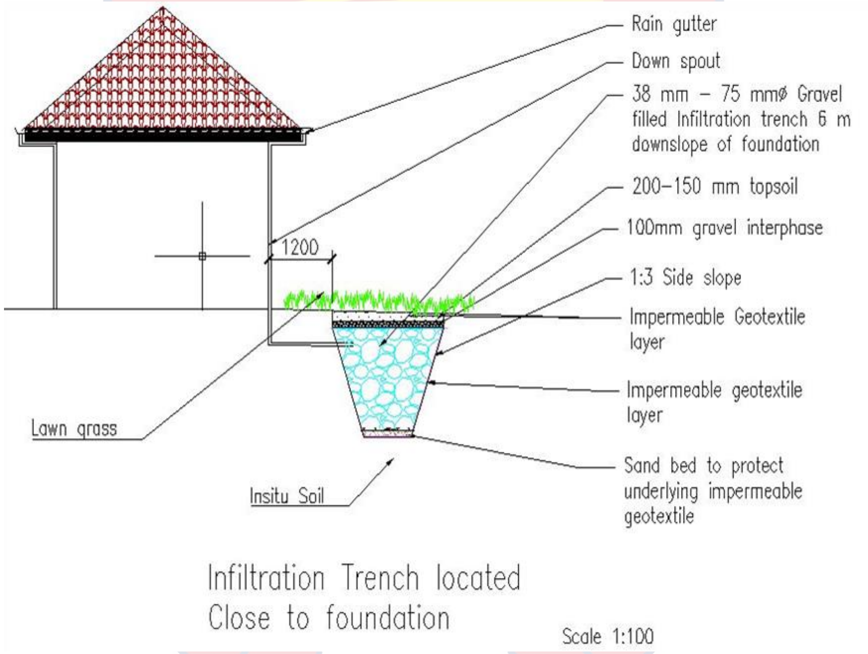
ApFig.1 1: Standard relationship between infiltration well and foundation



ApFig.2 1: Infiltration well located close to building foundation



ApFig.3 1: Infiltration trench in standard relation to foundation



ApFig.4 1: Infiltration trench located close to boundation

ApTable1 1: C factor and P factor values from literature and the internet sources

Source/Site	Factor	Comment
(Levermann 2013)	K value factor	Plinthosols soil type (sandy loam texture) which belongs to Ferrasols soil class
(Erencin 2000, B.A.S.M.A.A. 2003, Kamaludin 2013, Kusimi 2015, Panagos, Borrelli, Meusburger, Alewell, Lugato and Montanarella 2015, Panagos 2015)	C factor Fallow land - 0,5 Forest (mix) – 0.0001-0.003 woodland scrub – 0.003-0.05 Complex cultivation patterns 0.07-0.2 Bare soil – 1 Asphalt – 0,7 Riverine (low cover)- 0.2 Marshlands same as forest 0.001 Urban and Recreation area 0,8-0,9	Solonetz, with different K values for wet and dry conditions; Wet 0.12 - 0.19 t yr^{-1} MJ^{-1} and dry areas 0.27 - 0.34 t yr^{-1} MJ^{-1}
(Prasannakumar, Vijith, Abinod and Geetha 2012, Kusimi 2015)	P_factor Fallow land/riverine – 0.5 Forest – 0.01 Urban forest – 0,7 Built-up and barelands - 1 Water - 0	
(Kamaludin 2013)	P factor Forest - 0.1 Agric areas; Mixed hort & orchard - 0.4 Newly cleared land - 0,7 Urban and bare land - 1.0	

ApTable2 1: Land cover types and their descriptions, C factor and P factor values

Landcover Classes	Description	C_Factor	P_Factor
1.Dense Urban	Highly developed areas with 80-100 coverage and < 20% vegetation	0,8	0,01
2.Less Dense Urban	Mix developed and vegetated areas with 30-80% un-vegetated cover and 20-70% vegetation	0,9	1
3.Urban Forest	Designated forest areas made of 25-100 non-natural woody vegetation	0,05	0,7
4.Tree Groves	Cemeteries, Government facilities, Universities campus, Undeveloped private land with extensive tree coverage	0,05	0,1
5.Marshlands	Periodically saturated, salty and waterlogged areas including Ramseur site	0,001	0,01
6.Salt-pond	Salt mining area	0	0,01
7.Water	Still and moving water like Lake, River, Ponds	0	0
8.Bare soil	Exposed soils free of any form of cover, bare areas within developments, sand winning and gravel pits	1	1
9.Road paved	Bituminize, concrete, Asphalt roads	0,7	0,01
10.Road unpaved	Unpaved roads	1	1
11.Riverine	Vegetation along rivers	0,21	0,5
12.Forest	25-100% Tree dominated disturbed secondary forest areas located in difficult and inaccessible areas	0,003	0,1
13.Farmlands	Mixed Farms, fallow areas, grass with sparse trees, cultivated land with 75-100% herbaceous cover	0,5	0,4
14.Tree Mosaic	Tree dominated mixed shrubs	0,003	0,1

Preparing C factor map: C factor values corresponding to the various classes were identified from literature and internet sources and used to prepare a raster map.

Slope

DTM raster file was used to generate a slope map in % in ArcMap. The resulting raster map was Re-classified using the Reclassify tool as follows.

ApTable3 1: Slope Classification

Value	Slope%	Class
1	0-2	Poor
2	2-7	Good
3	7-15	Poor
4	15 - 111.6	Poor
5	111.6 - 351.4	Poor

Derivation of individual parameters for Slope Map;

FA – derived from a DEM for the site using the Flow accumulation tool as follows; ArcToolbox > Spatial Analyst Tools > Hydrology > Fill > input Raster (DEM) > Output raster (FloDir_Fill) > Flow Accumulation > Input Raster (FloDir_fill) > Output Raster > FlowAcc_Flow.

CS – cell size (30m), same as the DEM

S – slope angle was determined using the Slope tool in percentage derived from the DEM; ArcToolBox > Spatial Analyst Tools > Surface > Slope > input Raster DEM > output Raster (Dem _slope).

m – was given as 0.5 because the slope angle was greater than 5%.

Accuracy Assessment

ApTable4 1: Land-cover (2014) classes, description and Accuracy level

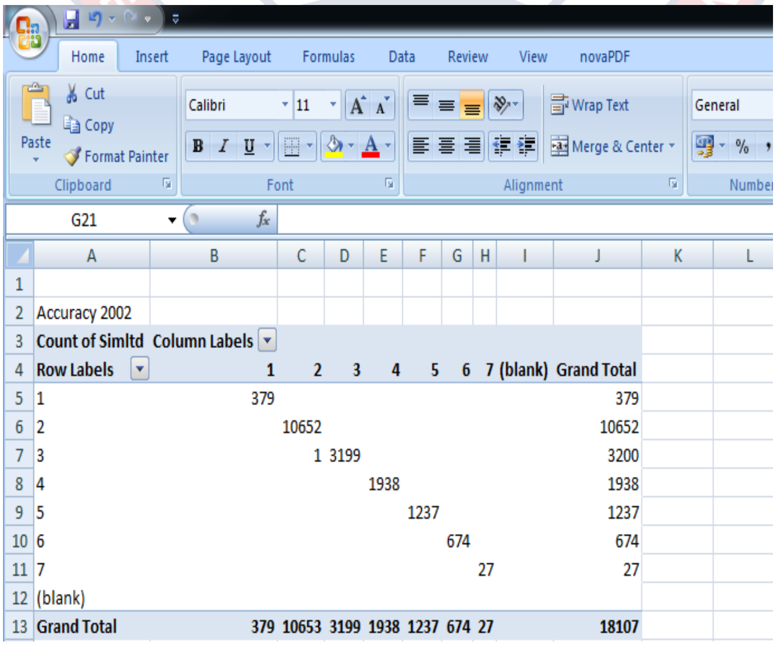
Class	Description*	Class _ID	No of Features	Correctly Class Pixels	Producer Accur ('02)	Producer Accur ('14)
1. Bare Soil	Areas with bare soil, stone/rock quarries, sand pits, gravel pits	66	82	74	0,8415	0,9487
2.Dense Urban	High developed areas with 80-100% surface cover & < 20% vegetation	1	140	111	0,85	0,8162
3. Forest (Mix)	Areas covered by trees of > 6m high, neither deciduous or evergreen	139	40	39	0,65	0,8864
4. Farmlands	(Planted and cultivated farmlands)	141	190	138	0,7071	0,6935
5. Less Dense urban	Mixed developed areas (30-80%) & vegetation (20-70%)	10	220	152	0,7741	0,6230
6 Marshlands	Emergent herbaceous wetlands	51	80	66	0,9114	0,9296
7. Riverine		110	140	79	0,4188	0,5374

8. Road paved	Bituminized, concrete, ashphalt	67	142	86	0,7394	0,8600
9. Road Unpaved	Gravel roads	82	180	112		0,5926
10. Salt-ponds	Salt winning areas	57	123	121	0,8067	0,9643
11. Tree Mosaic		165	141	93	0,6596	0,7381
12. Tree groves	Cemeteries, Atomic Energy, Univ Campuses, Hospitals/Korlebu, Private space (Catholic facilities), etc	32	80	72	0,90	
13. Urban forest	Officially designated forest in urban area	26	101	72	0,84	0,9863
14.Water features	Lakes, river, ponds	165	141	93	0,8357	1,0000

Notes: Description based on (USGS 2012). Overall Accuracy for 2002 (75,4%) and for 2014 (73,6%), with Kappa 0,7247 and 0,7122 respectively.

ApTable5 1: Accuracy Assessment summary for 2014 Classified Landsat 8 image

Class name	Row No of Pixels	Column No of Pixels	Correctly Classified Pixels	Producers Accuracy	Users Accuracy	Overall Accuracy
Dense Urb	140	136	111	0,79	0,82	
LesD Urb	220	244	152	0,69	0,62	
Urb Forest	101	73	72	0,71	0,99	
Tree grove	80	129	72	0,9	0,56	
Marsh land	80	71	66	0,83	0,93	
Salt-pond	123	150	121	0,98	0,81	
Water	130	101	101	0,78	1	
Water	130	101	101	0,78	1	
Bare soil	81	78	74	0,91	0,95	
Road paved	142	100	86	0,61	0,86	
Road unpav	180	189	112	0,62	0,59	
Riverine	140	147	79	0,56	0,54	
Forest	40	44	39	0,98	0,89	
Farm lands	190	199	138	0,73	0,69	
Tree mosaic	140	126	93	0,66	0,74	


Accuracy 2002

Count of Simltd / Row Labels	1	2	3	4	5	6	7	(blank)	Grand Total
1	379								379
2		10652							10652
3		1	3199						3200
4				1938					1938
5					1237				1237
6						674			674
7							27		27
(blank)									
Grand Total	379	10653	3199	1938	1237	674	27		18107

ApFig5 1: Accuracy Assessment of 2002 Imperviousness model using the Pivot table

ApTable6 1: Physico-chemical properties of some soils of the Accra plains at the series level

Soil Type	Silt (%)	Fine Sand (%)	Clay (%)	M_value	OM % (a)	Struct-ure (b)	Permb (c)	K-Factor
Oyarifa Mamfe	13.3	34.9	8.5	4,410.3	2.13	2	3	0.038982
Korle - Adentan	3.4	66.2	30.4	4,844.16	7.74	2	4	0.018739
Nyigbenya	17.7	98	0	115.7	1.14	2	2	0.000676
Alajo	8.4	79.1	12.5	7,656.25	4.99	2	5	0.05197
Sakumo	54	35	11	7,921	2.064	2	5	0.07655
Danfa-Dome	42	35	24	5852	2.167	2	5	0.053648
Fete	42	35	23	5,929	2,167	2	1	0.05438
Bediesi	25	32	12	5.0164	0.91		3.5	0.0507
Adawso-Bawjiase	14	1	30	1050	2.31	2	3.5	0.007454
Ayensu-Chichiwere	16	74	10	8100	1.204	2	1	0.085216
Nyanao-Opimo	16	74	10	8100	1.204	2	3	0.085268
Keta	54	35	11	7921	2.064	2	3	0.0765
Simpa-Agawtaw	13.5	27.3	7	3794.4	0.58	2	2.5	0.03799
Oyibi-Muni	46.4	3.2	50.4	2460.16	5.1	2	5	0.01402
Songaw	54	35	11	7921	2.064	2	5	0.000029
Chuim-Gbegbe	54	35	11	7921	2.064	2	3.5	0.000029
Sango	54	35	11	7921	2.064	2	5	0.000029
Chemu	54	35	11	7921	2.064	2	5	0.000029

Calculation of K_factor: Soil Erodibility factor (K Factor) was calculated for each soil series using the formula adopted from (Tallis, Ricketts, Guerry, Nelson, Ennaanay, Wolny, Olwero, Vigerstol, Pennington, Mendoza, Aukema, Foster, Cameron, Lonsdorf, Kennedy, Verutes, Kim, Guannel, Papenfus, Toft, Marsik and Bernhardt 2011).

$$K = 27.66 \, x \, m^{1.14} x \, 10^{-8} x((12 - a) + (0.0043 \, x \, (b - 2)) +$$

$$((0.0033 \, x \, (c - 3))$$

where K is the Soil Erodibility factor (t ha/MJ mm); m is - (%silt + % very fine sand)(100-%clay);

'a' is organic matter (%); b is a structured code where (1) represent very structured or particulate, (2) fairly structured, (3) slightly structured and (4) is solid 'c' is profile permeability code: represented as (i) rapid, (ii) moderate to rapid, (iii) moderate, (iv) moderate to slow, (v) slow and (vi) very slow. Table 4 shows the calculated K factor values which were used to prepare the K factor map, at 30m resolution.

Weighting and Ranking

The following table (ApTable 7) with explanatory notes summarizes the ranking for the various soil characteristics based on capability for a Detention/Retention basin.

Aptable7 1: Summary of detailed ranking process for soils for a Detention/Retention Basin

Soil Characteristics	**Excessive Rapid (1)**	**Very Good (2)**	**Good (3)**	**Moderate (4)**	**Poor (5)**
Drainage; excessive (1**), Very Well (2), Well drained(3), moderate(4), Poorly drained(5)	1.0	0.8	0.6	0.4	0.2
Soil Depth; extensive(≥200), Very deep(150-200), Deep(90-150), Moderately deep(30-90), Shallow(<30)	1.0	0.8	0.6	0.4	0.2
Depth to water table; no water, very deep, moderate, close to surface, surface water	1.0	0.8	0.6	0.4	0.2

Agric Value; Quarry rocks*, poor, moderate, good, very good	1.0	0.8	0.6	0.4	0.2
Iron Pan; not present, few, moderately, present, very present,	1.0	0.8	0.6	0.4	0.2
Reactn to exposure; hardpan on exposure, erosion & hardpan on exposure, only hard pan, only erosion, none	1.0	0.8	0.6	0.4	0.2
Slope: 1-7%,8-18%, 19-25, >25%, 0-1/ flat	1.0	0.8	0.6	0.4	0.2

Notes: Quarry rocks* - areas rich in quarry rocks could be rehabilitated when the quarry is decommissioned, becoming an asset. Drainage** this was equalled with profile permeability in (Tallis, Ricketts, Guerry, Nelson, Wolny, Olwero, Vigerstol, Pennington, Mendoza, Aukema, Foster, Forrest, Cameron, Lonsdorf, Kennedy, Verutes, Kim, Guannel, Papenfus, Toft, Marsik and Bernhardt 2011)
Notes on table: Rocky areas** - areas which are currently rocky with little agricultural potential, but may have a bedrock with high quarrying potential may be developed into a retention basin after decommissioning. Drainage*- Drainage classification was based on profile permeability according to (Tallis, Ricketts et al. 2011). Soil depth* - soil depth categorization based on (Senayah 2013a, Senayah 2013b); Water table depth* - based on (Martin-Mikle 2015, Lim 2016); Slope* based o(Environmental-Resources 2007, Brooks 2011a).

Based on the above criteria the soils were rated. ApTables 8 & 9 below show the results.

ApTable8 1: Ranked soil types of the study area (Part1).

Soil	Drainage	Soil depth	Water table depth	Iron pan	Slope	Total	Rank
Adaiso	10	6	10	10	10	46	0.6
Akroso	6	10	10	10	10	46	0.6
Adawso	6	10	10	10	10	46	0.6
Agawtaw	2	10	10	10	10	42	0.6
Awaham	2	2	10	10	10?	34?	0.2
Ayensu							
Alajo	2	10	10	10	10	42	0.6
Bediesi	6	10	10	10	6	42	0.6
Beraku	2	10	10	6	10	38	0.6
Bejua	2	10	10	10	10	42	0.6
Bawjiase	10	10	10	10	10	50	1.0
Chuim[1]	10	6	10	10	6	42	0.6
Chichiwere[2,1]	10	10	10	10	2	42	0.6
Danfa[1]	10	6	10	10	6	42	0.6
Dome[1]	2	10	10	10	6	38	0.6
Densu	2	10	10	10	10	42	0.6
Fete	10	2	10	10	6	38	0.6
Gbegbe[1]	6	6	10	10	6	38	0.6

Haatso[1]	10	10	6	10	2	38	0.6
Kakum[1]	2	10	10	2	2	26	0.2
Keta[1]	10	10	10	10	2	42	0.6
Korle[1,2]	10	2	10	10	6	38	0.6
Krobo	6	2	10	10	6	34	0.2
Muni[8]***	2	10	6	10	2	30	0.2
Mamfe[1]	10	6	10	6	6	38	0.6
Nyigbenya	10	10	10	6	10	46	0.6
Nyanao	10	2	10	10	6	38	0.6
Nta[2,1]	10	6	10	6	10	42	0.6
Oyarifa	10	10	10	6	6	42	0.6
Opimo	10	10	10	10	6	46	0.6
Oyibi[8,1]	2	10	6	10	2	30	0.2
Simpa	10	6	10	10	10	46	0.6
Songaw[1]	2	10	10	10	10	42	0.6
Sutawa	10	10	10	10	10	50	1.0
Truku[1]***	2	10	2	10	10	34	0.2
Toje	10	10	10	10	10	50	1.0

Note: X*** soils known for their very poor qualities Notes: Classification for Soil quality parameters for Infiltration well and Trench
Drainage - 6-10 were classed as good; 4 as moderate and 2 as Poor

Soil Depth - 6-10 as good; 4 as moderate and 2 as poor
Depth to Water Table - 6-10 as good; 4 as moderate and 2 as Poor
Iron Pan Presence - 8 - 10 as good; 4-6 as moderate and 2 as Poor
Slope - 10 as good; 8 as moderate and 2-4 as Poor

ApTable9 1: Soil ranking system (part 2)

Soil Characteristics	**Good (1.0)**	**Moderate (0.6)**	**Poor (0.2)**
Drainage; excessive (1**), Very Well (2), Well drained(3), moderate(4), Poorly drained(5)	1.0	0.6	0.2
Soil Depth; Deep extensive(≥150), Moderate(30-150), Shallow (<30)	1.0	0.6	0.2

Depth to water table; no-very deep (10), moderate (6), close to surface - surface (2)	1.0	0.6	0.2
Agric Value; Quarry rocks*, poor-moderate (10), good (6), very good (2)	1.0	0.6	0.2
Iron Pan; not present-few, moderately, present-very present,	1.0	0.6	0.2
Reactn to exposure; hardpan on exposure - erosion & hardpan on exposure(10) only erosion- none (6),only hard pan (2)	1.0	0.6	0.2
Slope: 1-7% (10); 8-18% (6); 0-1/flat, 18-25%, >25% (2)	1.0	0.6	0.2

ApTable10 1: Reclassification of Soils

Reclass range	Rank
> 51	1.0
49-50	0.8
47-48	0.6
37-46	0.4
< 37	0.2

4.8.3 Soil Map Ranked and Weighted: Soils were ranked based on their physico-chemical characteristics and suitability for particular infiltration-based/nature-based intervention. In this research the importance of soil types was in their effect on run-off estimation. (USDA 1986) suggested that soils in urban areas as well as impervious surfaces are very critical to stormwater management to control floods because not all parts of the urban area is covered with impervious surfaces, a fact previously stated in relation to developing countries. The ranking system for the soil types is summarized in a table in the Appendix.

The attributes of each of the soils were ranked based on their relative importance to a particular stormwater intervention. The soil map was also weighted relative to the other layers in the model. In ranking the attributes of the various soils, the total values given to each soil type was ranked, weighted and used to populate the attribute table of the soil map. The map was then converted from Polygon to a raster at 30m cell size and stored in a geodatabase.

ApTable11 1: Ranked and Weighted Soil types from most suitable (1.0) to least suitable (0.2) for a Retention/Detention Basin

Reclassed Range	Rank	Weight
> 51	1.0	0.3
49-50	0.8	0.3
47-48	0.6	0.3
37-46	0.4	0.3
<37	0.2	0.3

ApTable12 1: Weighted Land Cover Classes for 2014

Classes	**Ranking**				
	0.2	**0.4**	**0.6**	**0.8**	**1**
Bare Soil			0.6		
Dense Urban		0.2			
Forest (Mix)			0.6		

Farmlands				0.8	
Grass Mosaic				0.8	
Less Dense Urban					1
Marshlands	0.2				
Riverine				0.8	
Road unpaved			0.6		
Road Paved			0.6		
Saltpond	0.2				
Tree Mosaic		0.4			
Tree grove		0.4			
Urban Forest		0.4			

Ranking and Weighting Multicriteria II

Geology

ApTable13 1: Geology graded for Infiltration well and Infiltration trench

Geology Type	**Main features**	**Wght**	Ranking		
			1.0	**0.6**	**0.2**
Granitoid pegmatite	Shallow ground water	0.5			0.2
Impure Sandstone	V hard, resistant to weathering, good bearing cap	0.5			0.2
Lower Sandstone formation	Good bearing cap	0.5			0.2
Middle Shale formation	Low bearing strength, foundatn failure	0.5	1.0		
Marine, fluvial sedimentary	Low laying, poor bearing, high ground water	0.5			0.2
Phyllite unit	Deeply weathered, boreholes present, carries rivers	0.5		0.6	
Quarzt Schist Unit	Good ground storage capacity	0.5		0.6	

Quartz Schist	Flat areas, clayey soil	0.5			0.2
Quartzite unit	V hard, good bearing cap, quarried	0.5			0.2
Red Continental	Low laying, lagoon area	0.5			0.2
Slightly Consolidated Coble colluvium	Extracted for construction	0.5			0.2
Unknown					
Weather Resistant Magnetic biotite	Very hard rock, quarried	0.5			0.2

Hydrogeology

Conversion to Raster: The Borehole point feature was converted to a raster using the Spatial Analyst Kriging tool. This allowed spatial display of the classes of depth.

ApTable14 1: Hydrogeology classified, Ranked and Weighted for a Detention/ Detention basin

BH Depth Category	Depth Range (m)	Depth Class	Ranking (R)					Wght (W)
			0.2	0.4	0.6	0.8	1.0	
1	0 - 3	Very low	0.2					0.6
2	3- 7	Low			0.6			0.6
3	7- 15	Medium					1.0	0.6
4	15 - 17	High				0.8		0.6
5	>17	Very High		0.4				0.6

ApTable15 1: Reclassification of Soils; Rank1 - ranking for infiltration well and trench

Reclass Range	Rank	Reclass	Rank[1]
> 51	10	50	1.0
49-50	8	38-46	0.6
47-48	6	< 38	0.2
37-46	4		
< 37	2		

Land cover*

ApTable16 1: Weighted Land cover classes for 2014 (for Infiltration Trench and Well)

Classes	**Ranking**				
	0.2	**0.4**	**0.6**	**0.8**	**1.0**
1. Bare Soil			0.6		
2. Dense Urban				0.8	
3. Forest (Mix)	0.2				
4. Farmlands	0.2				
5. Grass Mosaic	0.2				
6. Less Dense Urban					1.0
7. Marshlands	0.2				
8. Riverine	0.2				
9. Road unpaved			0.6		
10. Road Paved	0.2				
11. Saltpond	0.2				
12. Tree Mosaic	0.2				
13. Tree grove	0.2				
14. Urban Forest	0.2				

Flood Map

ApTable17 1: Flood map reclassification for Detention/Retention Basin

Class	Ranking		
	2	**6**	**10**
Very High risk area	2		
High Risk	2		
Medium risk		6	
Low Risk			
Very Low risk			10

Soils

ApTable18 1: Relationship between World Soil Group Classification and Ghana Soil Series Classification

General	Series	Description	Drainage	Usage cultivatn
Acrisols	i. Nyigbenya-Haacho complex	Thin OM, very Shallow to very deep, susceptible to erosion, highly erodible Not suited for arable crop production	Well drained	Not suitable, residential areas developed over soil. Some types like Tefle black clay have deep and wide cracks when dry
	ii.Oyarifa-Mamfe complex Oyarifa, Toje[5,1]	Contain ironstone concretions & gravel, low fertility, liable to erosion, no concretn and gravel. Toje occur patchily	Excessively Well drained	Suitable for cereals, pineapple, tree crops

		among Nyigbenya series		
	iii.Fete consociation[5] Kitasi series iv.Korle consociations	V shallow, on steep slopes, susceptible to erosion, Too limited in extent		Suitable for long term afforestation, tree cultivation
Fluvisols	Ayensu-Chichiwere compl Chichiwere[1]	Extremely sandy, subject to flooding	Well drained	Not good for intensive agric, good for nursery and vegetable cultivation
Lixisols	Adawso-Bawjiase/Nta-Ofinso compd Assoc[3,1]	Gentle undulating includes Adaiso series which is very gravelly and stony. Mined for construction, susceptible erosion	Moderate well drained	Soils too shallow but used for annual and semi-perennial food crops
Lithic Leptosol/Haplic Lixisol (Chromic)	Nyanao-Opimo Compd Associations[6]	Steep hilly and rocky terrain. For quarry in rock chippings and quarry dust	Well drained	Not suitabl for agric production but for forestry
Leptosols	Fete-Bediesi complex	Hghly erodible Deep - v deep	Well – moderate well	Suitable for agricultural production

Luvisols	i.Simpa-Agawtaw complex	Gentle topo Hard pans in profile Easily flooded erodible	Poorly drained	Unsuited for deep rooted crops
	ii.Danfa-Dome[1] complex	concretionary clay loam	Well drained, deep, cancerous cracking clay	Suited for irrigatd rice, sugarcane, vegetables and cotton
Plinthisols	i.Chuim-Gbegbe Association[1]	Clayey which tends to harden on exposure	waterlogged	
Thionic Fluvisols	ii.Songaw consociation	Constitutes worst type of soil in Ghana, salt intrusion, Supports marsh grasses and sedges, low laying around areas lagoons	waterlogged	
Rhizophora - Fluvisols	iii.Oyibi-Muni *Associations Truku series	Very soft and smooth, waterlogged throughout the yr	waterlogged	
Solonetz	i.Oyrifa-Mamfe complex ii. Korle consociation	Rocky but good for subsistence farming. Hand cultivatn	Well drained???	Middle to upper slopes

	Alajo Consociation [1]	Hard when dry and plastic when wet. Excavations retain water very well		

ApTable19 1: Detailed Physico-chemical properties of soils in the Soil series map

Soil type	Class Gh (Series)	Clay	Silt	Sand	OM	Texture class	Soil depth (cm)	Slope (%)	Hydrogp/drainage
Adawso Bawjiasi /Nta-Ofinso[3] Compd Associatn[1,3]	Adawso -	66	1	33	3.7	SC	183	2-3%	Well/mod
	Bawjiase -	ND	ND	ND	5.37	SCL	193	3-5	
	Adaiso -	4	10	86			94		
	Akroso	27.4	8.6	64	3.9	SCL	229	3	poor
	Nta	7	23	70		FS	127	1-3	excessive
	Densu[2] - Ofin	34.4	28.9	36.7		CL LS S	179 >120	0-3 1-3	Imperfect Poor
	Kakum –	44	15.7	40.3	2.50	CL	155		Poor
	Chichiwere					SL SCL S	>120	1-3	POOR
Alajo consociation	Alajo series[1]	35.3	5.5	59.0	4,99	SL	200	0-2%	
Akuse Consociations	Akuse Ashaiman Nungua	13	10	82	3.0				
Fete-Bediesi complex	Korle series Fete series					SL	>30	8-16	Excessive

	Bediesi[3]/	43	17	40			>150	3-8	moderate
	Oyarifa	63	9	28	0.9				
	Sutawo/	45.3	23.1	31.6	2.1	SC	>130		moderate impermeable
	Beraku	19	18	63			87		
	Krobo/	19	18	63					
	Bejua				2.2				
Fete Consociation	Fete Seseme Kitasi Salom					SL			Excessive Well drain Do Do
Korle Consociation	Korle Nyibgenya Adentan Manfe				7.74 7.77		shalw	mod	Well drain
Nyanao/ Opimo	Nyanao[3]					Rocky	< 20	8-16	
Compound Asoc.	Opimo[3]	ND	ND	ND		SC	269	3-8	Well drn
Nyigbenya-Haatso complex	Nyigbenya[1] Korle, Fete, Papao, Alajo	42.5	5.1	52.4	1.1	GrSCL	150	2-6	Well drn
	Haatso series[1]	72.1	3.1	24.8	16.3	SCL	200	0-2	Very well drained
	Toje[1]	62.1	3.3	34.6	0.5	C	150	2-6	
	Adentan[1]	35	8	56.5	7.74	SC	>150		

	Chichiwere[2]					S/LS	>120	0-3	Excessive
	Tefle Series[4]	43.4	32.8	23.7	3.47	SC			Poorly drn
Oyarifa/ Mamfe compl	Oyarifa	63	9	28	2.1	SC	229		
	Mamfe	59	2	39	7.77				
	Beraku	48	17	35	2.9	SC	>180		Poor drn
	Krabo series					LS,S	>120	2-3	Imperfect drained
Oyibi-Muni Assoc.	Oyibi[8]	45	44	10		SL	>120		Poor
	Muni[8] Truku, Keta	50.3	48.5	1.3		C	145		Poor
Simpa-Agawtaw complex	Agawtaw	39	10.5	50.5	0.58	SC	107	1	Poor
	Simpa Nyibgenya	28	2.8	81.7			246		

Notes on Table: Soil Research Institute (1964) Accra Plains Soils map 2. Survey Division, (Brammer 1958, Brammer 1967, Adu 1992, Asiamah 1999, Adjei-Gyapong 2002, Boateng, Yangyuoru, Breuning-Madsen and MacCarthy 2013, Eze 2015)[1,4], (Corporation 1968, FAO 1981, Asiamah 1999, Senayah 2013a, Senayah 2013b)[2,3,6], (Brammer 1967, Obeng 2000)[5], (Adu 1992)[7], (Allotey, Asiamah, Dedzoe and Nyamekye 2007)[8]. There were insufficient data on the following soils in the literature; Agawtaw consociations, Chuim-Gbegbe Association, Danfa-Dome complex, Ayensu-Chichiwere complex.

ApTable20 1: Physico-chemical Properties of some Hydrologic Soil Groups (HSG) in Ghana under Classified World soil groups

Soil Group Classificatn Ghana	Soil Group Classificatn World	Clay (%)	Silt (%)	Sand (%)	Texture Class	Soil depth (cm)	Slope	HSG	Drainage
Forest Ochrosols	Acrisols HWSD 1046	36	24	40	CL	20 > 200		C	moderate
Savanna Ochrosols	Plinthosols	22	29	49	L	20> 156	Upper slope	C	Well drained
Lithosols	*Leptosols (associated inclusions) HWSD60	23	34	43	L	0-30		C	Imperfectly
Rubrisols HWSD 1530	Luvisols *	40	21	30	SCL				
Rubrisols HWSD 1453	Lixisols (subsoil)	37	19	44	C L				moderate
Tropical Grey Earth	Solonetz	39	10.5	50.5	SC	30≥ 167	1 % flat		poor
Alluviosols HWSD1327	Fluvisols	20	39	41	L	20≥ 80			poor

Sources: (Kauffman 1998, Adjei-Gyapong 2002, United States Department of Agriculture 2009, FAO/IIASA/ISSCAS/JRC 2012, Ashiagbor, Forkuo et al. 2013)

Multicriteria Suitability Overlay Analysis (MOSA) - Infiltration Well/Trench

Variables: These were the layers identified by literature as critical to the installation of Infiltration Trenches and also Infiltration wells.

1.Hydrogeology (Depth to water table; 0-3; 3-12; >12 after reclassify)

2. Infiltration rate (a min of 12.7mm/h for)**** ignore as distribution makes it irrelevant

3. Slope

4. Soil type

5. Geology

6. Land cover

7. Population density

8. Soil erosion

ApTable21 1: Factor maps graded for an Infiltration well and Trench

Element/Factor	Good (1.0)	Moderate (0.6)	Poor (0.2)
Hydrogeology	>17m	3-17m	0-3m
Infiltration Rate	> 120mm/h	15-120mm/h	< 15mm/hr
Slope	2 -7%	7-15%	2% > slope > 15%
Soil type	0.50	0.38-0.46	< 0.38
Geology*			
Land cover*	>0.80	0.60-0.80	1-60
Population Density (Value) Persons/km^2	10-1600	1600 < 35000	> 35000
Erosion (T/Ha/y)	0 -7	7 -20	> 20

Polygonization of Multicriteria Suitability Overlay Analysis (MOSA) map and Flood map: The MOSA map and a reclassified 100mm in 1hr flood map were converted from raster to polygon. The MOSA map was first reclassed as indicated in ApTable 22 1 below before being polygonized.

ApTable22 1: Class range for Reclassed MOSA map

Value Range	Grade
112-184	1
184-232	2
232-254	3
254-298	4
>298	5

The factor map and variable maps which formed the MOSA maps were polygonized. The two polygonized maps were then overlaid. For location of detention/retention basin, grades 3, 4 and 5 were considered the best. Grade 5 was for high elevation areas which will require some amount of ground modification to fit the intervention.

Population Density

Population density map was rasterized and reclassified. This was difficult as there was no correlation between the density values and the values derived in the raster map. So i opened the attribute tables of both the polygon and the raster map and selected from the polygon based on defined population density ranges. This was used to march and define the rank in the raster map.

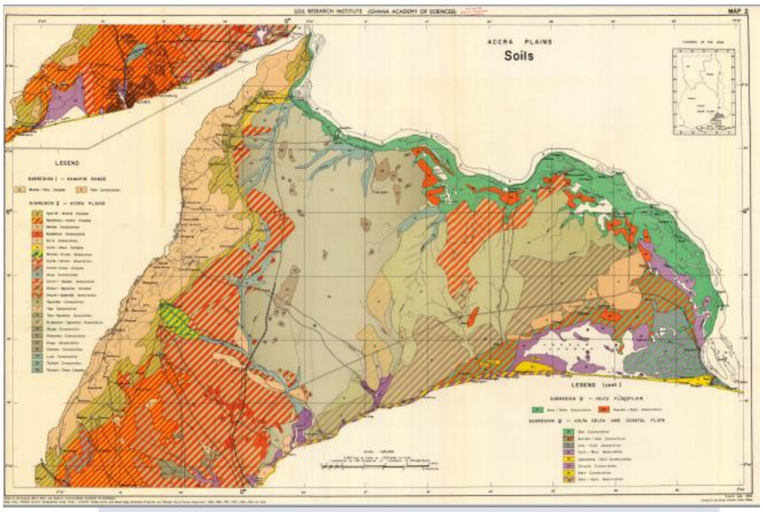
The table below (ApTable 23 1) summarizes the average growth rate for the various administrative districts.

ApTable23 1: Estimated population used to derive average population growth rate

District	Population Years					Ave Growth Rate
	2010	**2011**	**2012**	**2013**	**2014**	
Ga South	411,377	425,664	437,812	451,180	464,537	3.1
Ga West	219,788	224,212	229,452	234,584	239,851	2.2
Ga East	147,742	150,575	153,932	157,227	160,596	2.1
AMA	1,665,086	1,704,349	1,750,144	1,795,115	1,841,091	2.5
Ga Central	117,220	119,341	121,891	124,398	126,960	2.0

MOSA-II - Reclassified

The Layers were used to run the model as previously described in MOSA-I (Retention Basin and Detention Basin) resulting in a raster map which was polygonized and re-classed to define three classes as poor (0.2), Moderate (0.6) and Good(1.0). The Objective ID ranges used in the reclassification were; 1-60 (Poor), 60-80 (Moderate) and > 80 Good. Areas within the study area classified as Good and even moderate were considered as suitable for location of an infiltration well or Infiltration trench.



ApMap1 1: Accra plains soil map

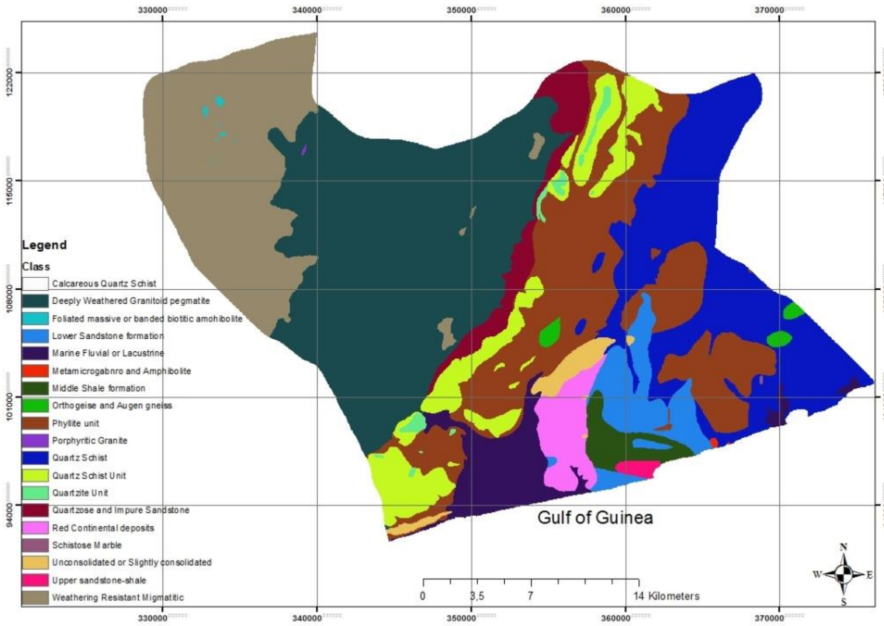
4.8.5 Geology Map Preparation, Ranked and Weighted - Data on geology is one of the important "subsurface conditions" as it relates to "foundation conditions" and the "water table" on the site(Lynch 1971). The geological materials of the study area and their description provided the basis for further analysis. Although in many places the soil material consisting of eroded depositions were sufficiently deep to render the condition of the bedrock “irrelevant” (Bell 1999), there were situations where the condition of the bedrock was very relevant as it defined the type of stormwater management intervention to introduce. For instance there are parts of the study area where the underlying bedrock is Quartz Schist. These are bands of predominantly Quartz rock with occasional bands of Schist which are highly impervious and have created what the locals call a "high water table" situation. Areas with such unique geological influence were identified and screened out for a communal-type infiltration based intervention.

A detailed geological map (ApFig 6) based on the works of (Okla, Abel and Muff 2006) was obtained from the Geological Survey Dept of Ghana, from which the study area was clipped out. The table below (ApTab. 24) summarizes the geological types, their basic characteristics and ranks assigned to them as relates to site selection for a retention/detention basin.

ApTable24 1: Ranked and Weighted Geological features of study site for Detention/Retention Basin

Geology Type	**Main features**	Wght	**Ranking**					
			1.0	**0.8**	**0.6**	**0.4**	**0.2**	**Rank**
Granitoid pegmatite	Shallow ground water	0.6					0.2	0.2
Impure Sandstone	V hard, resistant to weathering, good bearing cap	0.6					0.2	0.2
Lower Sandstone formation	Good bearing cap	0.6				0.4		0.4
Middle Shale formation	Low bearing strength, foundatn failure	0.6		0.8				0.8
Marine, fluvial sedimentary	Low laying, poor bearing, high ground water	0.6					0.2	0.2
Phyllite unit	Deeply weathered, boreholes present, carries rivers	0.6		0.8				0.8
Quarzt Schist Unit	Good ground storage capacity	0.6	1.0					1.0
Quartz Schist	Flat areas, clayey soil	0.6				0.4		0.4
Quartzite unit	V hard, good bearing cap, quarried	0.6			0.6			0.6
Red Continental	Low laying, lagoon area	0.6					0.2	0.2
Slightly Consolidated Coble colluvium	Extracted for construction	0.6		0.8				0.8
Weather Resistant Magnetic biotite	Very hard rock, quarried	0.6			0.6			0.6

The ranks and weights were used to populate the attribute table (Geo_R and Geo_W)) and the resulting map used to generate a raster map at 30m resolution.



ApFig.6 1: Geological map of study area

Slope Map Ranked and Weighted: A slope map was prepared from a DEM at 30m resolution using the Slope tool in ArcMap 10.1. The resulting slope map was reclassified, ranked and weighted as summarized in (ApTable 25) and used to populate the attribute table of the slope map.

ApTable25 1: Slope map Classed, Ranked, and Weighted for Detention Retention Basin

Slope Class (%)	Rank	Weight
< 1%	0.2	0.5
1-7	1.0	0.5
8-18	0.8	0.5
19-25	0.6	0.5
> 25	0.4	0.5

Soil Erosion Map, Ranked and Weighted: A soil erosion map (soil loss map) produced from the RUSLE model as explained above was reclassified - using the Reclassify tool in ArcMap and the various class categories ranked. Areas with high erosion were ranked low while those with low erosion potential were ranked high. The rationale is the possible effect of sediment generation as a result of erosion on the life of an infiltration based system. Literature indicates facilities located in high sediment yielding soils clog quickly, negatively impacting performance. The ranking was based on (Silva da 2010, Kusimi 2015) and gave five soil loss classes as summarized in ApTable 26.

ApTable26 1: Ranked and Weighted Layers for Infiltration well and infiltration Trench

Element/Factor	Ranking Low risk (1.0)	Moderate (0.5)	High Risk (0.1)	Weight
Hydrogeology (m)	>17	3-17	0-3	1
Infiltration Rate (mm/h)	> 120	15-120	< 15	0.9
Slope (%)	2 -7	7-15	2 > slope > 15	0.3
Soil type	50	38-46	< 38	0.8
Geology*				0.5
Land cover*				0.8
Population Density (Persons/km^2)	10-1600	1600-35000	10 > PopD. > 35000	0.7
Soil Loss (T/ha/y)	0 -7	7 -20	>20	0.3

*Details for Geology and Land cover maps ranking and grading provided in appendix

ApTable27 1: Soil loss rate generated from RUSLE, Ranked and Weighted for Detention Retention Basin

Class Range	Range	Class	Rank (R)	Weight (W)

< =7	0	Very Low	1.0	0.5
7-20	7	Moderate	0.8	0.5
20-50	20	Moderately High	0.6	0.5
50-120	50	High	0.4	0.5
>120	>50	Very High	0.2	0.5

Land Cover Map, Ranked and Weighted: Fourteen Land cover types were identified in the Landsat (2002 and 2014) images used for the classification. These were weighted based on their contribution towards successful introduction of a Retention/detention pond. The ranking and weighting applied to the various Land cover types is summarized in the table below (ApTable 28 1).

ApTable28 1: Ranked and Weighted Land cover classes for 2014 for Detention Retention Basin

Classes	**Weight (W)**	**Ranking (R)**				
		0.2	**0.4**	**0.6**	**0.8**	**1.0**
1.Bare Soil	0.6			0.6		
2.Dense Urban	0.6	0.2				
Forest	0.6			0.6		
Farmlands	0.6				0.8	
Grass Mosaic	0.6				0.8	
Less Dense Urban	0.6					1.0
Marshlands	0.6	0.2				
Riverine	0.6				0.8	
Road unpaved	0.6			0.6		
Road Paved	0.6			0.6		
Salt-pond	0.6	0.2				
Tree Mosaic	0.6		0.4			
Tree grove	0.6		0.4			
Urban Forest	0.6		0.4			
Water bodies	0.6				0.8	

Hydrogeology, Reclassify, Ranked and Weighted: Hydrogeological data in the form of Borehole depths at different locations in the study area were obtained from the Water Resources Research Institute of CSIR, in Accra-Ghana and used as a direct measure of level of water table (Lynch 1971). The bore-hole data which was in excel format with coordinates for borehole location was edited to remove extraneous materials and imported into ArcMap as a .csv file. The locations were verified using the Display XY Data tool in ArcMap. This allowed the geographical locations to be displayed in a map (Fig 4-13).

Transcript of Interviews

Foundation for Interviews

A very important observation was the ease with which people welcomed me when I approached them for an impromptu interview on their views relating to flooding. In most cases I am forced to adapt to the persons situation to either walk along when he is on the way to work and be fielding questions as we walk or sit with him in the work place and hold the interview. This seems to be most convenient for most people rather than arranging for convenient time when the interviewee may even be agitating about how to perform before a stranger who is coming to ask questions, or the consequences of 'talking too much'. Also the interviewee may not have built up defences and may more likely flow freely with his response.

The researcher also observed 'interview fatigue' on the part of community members who complaint that they often had people come around asking all sorts of questions about the flooding situation but nothing came out of it.

Pre-arrange interviews also did not always go well as the interviewee who promised to provide certain documents suddenly realize he has forgotten them. Interestingly postponing the interview due to the absence of such support documents always yielded the same result; 'sorry i forgot the documents again'. This was my experience with a number of experts with whom I arranged an interview. To date most of the documents promised have not been received, but

I just went ahead and had the interview without those supporting documents. The challenge however is how much value to give their response as experts in their field with technical support from existing reports and other forms of documentation to support their responses missing.

Interview Questions

The interview questions were centred around the central question of how and why the system has failed. The same questions was asked in adifferent ways to ensure consistency in response.

Do you consider flooding a challenge in the metropolis? Respondents were asked to rank the impact of the flooding problem from 1-5, 5 being the most serious.

Do you think the question of flood management has been properly identified?

What should be done to address the problem

Is the present system of flood management working?

How do you see the situation in the next 10 years?

Transcript of Expert Discussions

1. Personal Communications. 2015. Drainage Consultant, Registrar, Engineering Council Ghana (MPhL Water Resources Engineering), Accra-Ghana. The discussion lasted about 45min and cantered on the drainage system in the country and flood management policy in Ghana. The following facts were established;

Ghana essentially has no flood management policy but various general guidelines have been developed by relevant agencies and departments to prevent flooding centered on the construction of drains and the necessary standards for construction, post flood management and early warning systems.

Currently the use of retention basins is being courage as a means to manage floods in the country

Classification of Drains in Ghana;

Drains are put into three classes; Tertiary, secondary and primary drains

Tertiary drains- road side drains, usually small drains servicing communities, also along roads to protect road pavements and used as conduits to disperse water from communities to larger drains

Secondary drains – takes water from tertiary drains and are larger than tertiary drains

Primary drains – forms the major water courses, major drains like the Odaw, Lafa drain, Kpeshie drain, etc. Maybe concrete lined entire length, partly or not at all (a big swale??)

Standards for construction;

Drains in Ghana designed according to capacity and return period of flooding

Tertiary drains – return period of 1 in 5 years; assumes that there could be peak flooding once in every two years; once every 3yrs; once every 4yrs or at most once every 5 yrs in the life of the drain

Secondary drain – constructed with the assumption that there could be peak flooding once every 5-15years

Primary Drains; designed and constructed with a return period of 15-25 years

Bridges and Culverts – designed and constructed with a return period of 50years

Very large/ Major Bridges – constructed with a 1 in 100yrs return period

Water retention basins – 1 in 100yrs

Follow up

Qu: Do you consider flooding and its management a challenge?

Ans: Yes; a challenge because of structural issues, ie structures that are made to convey flood waters have problems, some adequate, others not. There also serious management issues, enforcement of laws, etc

Qu: Why is the flooding challenge still persisting?

Ans: No country in the world can stop flooding completely. Structures are built for a given return period- in Ghana most structures are built to 1-50yrs return period, What we are therefore doing is to mitigate the effects of floods, control the effects to prevent undue damage

Qu: what has been the approach to flood management?

Ans:

Qu: How successful has been the approach? Has it been successful at all?

Ans:

Qu: Has the problem been properly addressed?

Ans: flood problems have been identified, solutions has also been identified, but the implementation is the problem. We have had drainage master plans since 1963, 2000, 1995, 2005.

Qu: How do you see the future of flood management 10yrs from now at the rate we are going?

Ans: Not answered, due to interruption.

07/05/15

2. Personal Communication. 2015. Drainage Engineer, Hydrological Services Institute, Head quarters Accra-Ghana. Discussion lasted about 30-45min. Centered on drainage and flood management in Ghana.

Flood Management Policy; that Ghana does not have any policy on flood management but generally the Hydrological Services Institute which is responsible for flood management in the country uses the following approach;

Determines or proposes a conveyance system for water courses for possible implementation/construction

Preferred option over the years has been use of concrete lined drains. Explains that this is best for the country as open drains with steep banks will easily fail under peculiar soil type and tropical wet climate conditions, thus a concrete drain serves for stabilization, facilitating smooth discharge of water as well

Periodic dredging of drains to remove sediments

Current position is the introduction of retention basins as means to address the challenge of flooding because drains alone will not be enough

How Government arrives at a decision to adopt a particular approach to flood management;

The government may contract a consultant to develop a drainage master plan for country, but this has to be review and rectified by the in statute for possible adoption. He confessed that the institute should rather be instituting its own research to be used as a guide in flood management, unfortunately she is not been doing that but rather relying on the initiative of politicians who after attracting a loan or grant may propose to carry out flood management interventions.

The above creates the impression that the various stakeholders (????) with interest in flood management have very little to no input in what strategies to adopt in flood management

Historical Data: although the researcher was informed that there were historical data on drainage in the form of a drainage master plan for 1958, 63, 85, 95, 2005, persistent requests yielded no results

and various reports submitted by consultants on drainage in the Greater Accra area, none of these documents I was told was available. This was because due to numerous relocation of the offices of the Hydrological Services, the documents were lost in transit

3. Personal Communications. 2015. Geodetic Reference Network Section, Survey Dept Accra-Ghana.

Qu: How do you see the problem of flooding?

Ans: Floods have become recurrent because 'there are no compelling policies and laws which ensure that development is referenced to established reference marks/ bench marks for land development'. Construction is thus based on information provided by the civil engineer or planner with little reference to geometric (information about the site) engineering. And this could be one major reason floods are so rampant in the study area. The presence of such standards will force contractors to conform to a general baseline; a reference baseline for building construction which will prevent the situation where whole communities are established below sea level and will thus, always be prone to flooding.

Personal Communications. 2015. AMA Drainage Engineer (Head of Unit, Works Dept. AMA), Accra-Ghana

Mr Sarbah sees the flooding problem more as a technical challenge due directly to engineering challenges in the drainage system in the metropolis. Sites the Bubuashie – kaneshie channel as an example where floods occur because of the limited size of inlet culverts that connects the drainage system from Bubuashie to the underground system at Odorkor – Obeystebi Lamptey drain.

Talks about how desilting and dredging of drains is carried out periodically (twice a year in April/May and July/August) as a means of managing the flooding problem in the metropolis

Laments about the huge bill resulting from these yearly exercises, about $5.2mil for the period 2009-2010

Talks about the dangerous open drain at Accra Academy and also how the Lafah water channel is to be reconstructed over the entire course of 7.8km

5. Respondent: Afful, De-Graft (MSc. Civil Engineering) Deputy Director Maintenance and Operations. Urban Roads Headquarters. Accra

Qu: do see flooding as a challenge in the Greater Accra area

Ans: Yes, it's a problem; ranked 5

Qu: what approach have you been using to address this challenge?

Ans: construction of primary drains (road side drains); this actually is not our responsibility, but we have gone out of our way to construct these to protect the roads from floods

Desilting of primary and secondary drains; this responsibility falls with hydrological services but we have taken it up

Qu: what guided the choice of this approach? On what basis did you decide on this approach?

Ans: because they are causing harm to our roads, and someone is suppose to do that but if it's not being done you do it to protect the road

Qu: are there no other options?

Ans: for floods the only option the drains to carry flood waters from the roads

Qu: do you have any stakeholders?

Ans: Hydrological Services, Ministry of Local Government

Qu: do you consider road construction and surfacing as part of the approach to flood control?

Ans: no, paving roads is to provide cover for the pavement not for flood management

Qu: how will you rank your approach in terms of its effectiveness?

Ans: the question will not be right if I answer it; because a lot of factors come into play when dealing with flooding but if they do everything right our approach will be the best to address the problem. And that is why we have collaboration with the Local authority that have to make sure the drains are clean all the time to allow free flow of water

Ranked 5

Qu: How do you see the challenge of flood management 10yrs from now, given the limitations and the approach you are using

Ans: I think you are looking at things from the wrong direction and you will never be able to solve the problem. The problem about flooding is not because we do not have adequate drains but because people are misusing the drains. If we continue to do the things we are doing we will never solve the problem. The reason is that other departments and government agencies whose work should have complemented ours to achieve flood control are not doing their part. There are different agencies involved in this flood management and so you have a limitation; you stop somewhere hoping everyone will do his part.

As much as possible we have eliminated most of the flooding that will occur on our roads

Follow-up

Qu: Do you think the challenge of flood management has been properly identified?

Ans: The problem has been properly identified and the solution found but a lot of the time it is who should carry it out. Maybe you don't understand the whole system very well; the city authorities run the city and have been vested with the power to ensure development control, but what happens if they are not enforcing it. Urban roads does not have the power to enforce; its only the city authorities who does. So the solution is known, but those who should provide the guidelines are not doing their work

6. Respondent: J. K. Ahlija, Geomatic Engineer BSc. Head of Section, Survey and Mapping Unit, Survey Dept. Accra.

Qu1: Do you consider flooding a challenge

Ans: No, I do not consider flooding as a challenge because it is self inflicted, flooding is occurring because we have blocked drains which would have carried flood waters away with garbage, buffers created have been encroached upon by squatters.

Qu2: what should have been done?

Ans: We should apply the necessary punitive measures; punishment of offenders

Encroachers on buffers should be punished as well; most of those drains are natural drains

Dredging of drains, after which sanctions should be applied to offenders

The dept has the personnel to model the entire country in a 2D or 3D using the digital terrain model to address the problem, and that approach will solve the problem because then we can better appreciate the earth formation in 3D, so we can see the elevations, the highs and the lows of the elevation

This will be followed by the use of engineering methods to finalize the solution

Qu3: but there are laws already in existence?

Ans: well, we have not been mandated to enforce these laws, it is the assembly

Qu4: so far its been this same engineering methods we have been using over the years but to the same effect

Ans: yes, it has not worked because it's been adhoc; the proper base line in terms of levels was not taken and so the drains have been built but cannot drain the intended flood waters away. Now if the entire area is modeled in 3D, then you will be able to identify problem areas and introduce the necessary interventions.

Qu: what about the problem of land acquisition to implement the necessary interventions? How do you factor in land?

Ans: these drains are natural earth drains like wet lands, rivers, waterlogged areas etc, and buffers have been created for these features say 50 or 100 ft both sides and people should not be allowed to develop there. Most of our drains follow a certain course, running through liable to flooding areas, wet lands, waterlogged areas etc but were there is a need to acquire land; the executive instrument can be used for public use. Either use an executive instrument or legislative instrument.

Qu: how do you see the situation in 10yrs from now, giving the present situation?

Ans: situation will be worse, because of continued siltation blockage by garbage, reducing the volume of water. Most of the water we receive in Accra comes from the surrounding Accra, and this is in large volumes.

I am yet to see a policy on Land in this country

7. Respondent: P Gyau-Boakye, PhD Engineering. Former Chief Executive, Community Water and Sanitation Agency, Former Director, Center for Scientific and Industrial Research (CSIR) - **Water Research Institute**, Accra-Ghana. Member, Committee on Hydro-Meteorological Disasters, National Disaster Management Organization (NADMO). Accra Ghana (26/10/2015)

The respondent said he has been a member of the Committee on Hydrological Disasters in the country since 1998, of which flooding is the most important. The committee was tasked to find ways of meliorating the impact of floods throughout the country to help save lives and property.

Accra was identified as a major flood prone area with a number of hot spots. Anytime it rains preparations are made to receive calls from these hot spots for the necessary interventions to be introduced by a search and rescue team.

During my time on the committee, we experienced several flood disasters; in 1995 we recorded a major flood event in June 3-4th, were we recorded about 259mm of rainfall within 7hrs causing a lot of devastation. We then sent people around to find out why the rain had such a devastating effect. We realized that there were not adequate drains in the system, which subsequently led to the construction of the Odaw drains. The following were recommended;

The drains which were already in existence were chocked and not lined, and so to enhance water flow the drains should be desilted and concrete lined.

Secondly, the Korley lagoon should be prepared to receive the large volume of runoff received by the Odaw drain. An so simultaneously, the Odaw drains were constructed while the Korley lagoon was being dredged to facilitate drainage into the sea

Thirdly, urbanization had greatly disturbed the natural drainage system, thus the wetlands which served to hold up surface water for some time before releasing it into the system had been reclaimed and built over, more paved surfaces were being generated leading to the creation of huge volumes of runoff, which must find a way to be disposed off. The only way this runoff could be removed from the communities is through construction of surface drains, and these must be free to allow the free flow of surface water. Unfortunately, the drains have been turned into dumping sites for household refuse, which blocks the drains and prevent free flow of runoff resulting in floods.

Qu1: So far has the approaches been effective in addressing the challenge?

Ans: No, they have not been effect; and this is looking at things from a purely engineering approach where runoff must be quickly removed from the communities using concrete lined surface drains to avoid floods.

However long ago, the idea was developed that since the flood waters did not all originate in Accra but a great percentage of it is first generated from the upper elevation areas in the Akuapim mountains, which then migrate to add to the one generated in the urbanized Accra area, it may be necessary to build a retention dam upstream near Dome - Kwabenya along a major drainage way. The dam will then hold the runoff water generated upstream for a period before it is gradually released into the system. And so to this effect, the Hydrological Services department initiated the process to acquire a tract of land at Kwabenya, one of the suburbs of Accra. Unfortunately since this was not followed through, the land has been lost to developers. And this was proposed by the engineers.

Qu2: what policy was guiding you through this period to manage floods?

Ans: there was no clear policy, specifically on flood management, although there are bits and pieces on flood management in various documents hosted by various departments. For instance, Water Resources Management has a policy. Also the National Water policy (NWP) document talks about flood management using the rain harvesting approach and is hosted by the Water Resources Commission-Ghana. There are other policies which also contain various aspects on flood management which if we are to put together and implement may lessen the problem of flooding. So far NADMO has been trying to put all these policies together, serving as a coordinator.

Fourth, most of the culverts and bridges built to control floods have become under-sized.

These were built based on the data available but over time as the communities become more urbanized, they could not accommodate the volumes of runoff that was being generated, resulting in floods. So for the current situation; the sizes and heights of the bridges and culverts will have to change. And this is in line with engineering where one has to work with the data available

Another challenge identified has to do with engineering defects in the design of the drains. There have been situations were secondary drains have been designed to join primary drains at 90˚, a clear engineering defect and we don't know how it came to that. And so for communities in which such defects exists, the minor drain (secondary drain) will have to hold its waters until all the water in the primary drain has receded before they can also discharge, creating a build up and eventually flooding in such communities. This situation can be found in communities like Christian Methodist School area in Circle, Awoshie Mangoase, Krokroko communities.

Loss of water exchange areas such as wetlands, vegetated areas, swamps, diversion of water ways – all replaced with concrete or pavements combined with haphazard development were construction is done directly against the direction of drainage ways has also contributed to the flood situation in the metropolis. People carry out construction assuming that they can force water to flow according to the path they determine, but that is against nature; water will have its own way. An example is the diversion of the Lafah river to accommodate the construction of a filling station at Malam Junction, and this is the cause serious floods any time it rains. In addition the construction of the M1 highway where inadequate provision was made for discharge of the Lafah drain across the road has also worsened the situation. For this specific situation, although the contractor's attention was drawn to the possibility of the situation worsening it was ignored.

Qu3: Who supervises the construction of drains in Ghana?

Ans: Hydrological services; but there is not much interaction and coordination between them, Urban roads and High ways. Because Ghana Highways Authority, during the design of the drains should have consulted with Hydrological Services Institute to know whether the drains were adequate and also to be sure if it fitted into the drainage master plan for the area. He further added 'we all do our own thing' and that it was a complex type of thing.

Qu4: can you explain your statement 'we all do our own thing'.

Ans: this is based on the lack of coordination between various partners as exhibited in the construction of the Odaw drains and the dredging of the Korle lagoon. The drains were done by the Ministry of Local Government and the dredging by Ministry of Water Resources, Works and Housing and because of lack of coordination between the two consultants and the contractors, the dredging was done beyond the interphase where the Odaw river joined the Korle Lagoon. So at the end there was a situation where the dredged area was at an elevation 1.7m below the Odaw drain at the interphase, resulting in runoff carried by the drains being trapped at the interphase and thus not being able to flow smoothly through the lagoon

Qu5: From the approaches adopted so far, will you say we have been successful.

Ans: No, we haven't been successful; no single approach can be used successfully to reduce flooding. It will have to be a multiple approach. Building drains alone will not address the problem. In Europe they build the drains but there are floods and we cannot build to accommodate a million yrs return period. Part of the solution should be to create buffers, maintain wetlands.