PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

[Water Engineering]

Presented by

Timoth MKILIMA

MODELING OF STORM WATER RUNOFF FOR IMPROVING FLOODS RESILIENCE, WATER SUPPLY, SOIL AND ECOLOGICAL CONSERVATION.

THE CASE OF MSIMBAZI CATCHMENT IN DAR ES SALAAM, TANZANIA.

Defended on 02/09/2018 Before the Following Committee:

Chair	Prof. Rouissat Bouchrit	Affiliation (Tlemcen University)
Supervisor	Dr. Stephen Mbuligwe	Affiliation (Ardhi University)
External Examiner	Prof. Lotfi Mouni	Affiliation (Bouira University)
Internal Examiner	Dr. Houcine Ziani-Cherif	Affiliation (Tlemcen Univesity)

DECLARATION

I, Timoth Mkilima, the undersigned, declare that the thesis entitled *"Modeling of storm water runoff for improving floods resilience, water supply and soil and ecological conservation: The case of Msimbazi catchment in Dar es salaam, Tanzania",* is a result of my own work and that it has not been presented to any other learning institution for a similar award of degree, diploma or other professional. Where other sources of information have been used, they have been acknowledged. I understand that non-adherence to the principle of academic honesty and integrity, misrepresentation/fabrication of any idea/data/fact/source/ will constitute sufficient ground for disciplinary action by the university.

Student:

09/15/2018

Timoth Mkilima — Date

Supervisor:

08/10/2018

Dr. Stephen E. Mbuligwe — Date
Ph.D. (Louisiana, USA)
M.Sc. Engineering (Dar-Tanzania)
B.Sc. Engineering (Dar-Tanzania)

DEDICATION

I dedicate this work to Almighty God, my family and all who have helped me all the way to this achievement.

ABSTRACT

In rapidly urbanizing catchments, increase in stormwater runoff quantity may lead to numerous of serious problems such as flash floods, soil erosion and alteration of an ecosystem. Changes in land use usually affect stormwater runoff flow characteristics as much water has to flow on the surfaces rather than infiltrating to the ground due to increase in impervious surfaces.

The gap between the hydrologic responses to urbanization and the engineering solutions is wide. Most of the studies related to stormwater management have been more focusing on treating the issues separately leading to insufficient stormwater management systems. In order to have proper and sufficient stormwater management systems, more information is needed to link the above-mentioned cases together.

In this study, the HEC HMS model was used for rainfall-runoff simulation to quantify the amount of runoff generated with respect to the land use and precipitation data for runoff dentation facilities design. Satellite images for 1998, 2009 and 2018 of the catchment area were selected based on the quality of data and the available resolution. ArcGIS and GIS extension tools were used to extract hydrological characteristics of the catchment; HEC –HEC-HMS was used to simulate the rainfall-runoff process on Msimbazi river watershed which is the major watershed located in Dar es Salaam. The hydrological modeling was accomplished by dividing the watershed into different sub-catchments. To compute infiltration loss SCS CN method; converting excess rainfall to runoff model SCS unit hydrograph, and channel flow routing accomplished by using simple Lag routing method of the HEC-HMS model.

The land use processing identified five major land use classes namely; water bodies, forests, developed low intensity which its coverage changed from 61.67% in 1998 to 21.13%, developed medium intensity changed from 25.97% in 1998 to 61.12% in 2018 and developed high intensity changed from 3.82% in 1998 to 19.77% in 2018.

The computed peak discharge for the 1998 study year was 355.7m3/s, 402.7m3/s in 2009 and 437.8m3/s in 2018 which is an increase of about 23.08% from 1998 to 2018.

Some small sub-basins were merged to form five bigger sub-basins linked with a designed reservoir at each outlet of the five sub-basins. Which means reservoir 1 receives water form sub-basin 1, reservoir 2 from sub-basin 2, reservoir 3 from sub-basin 3, reservoir 4 from sub-basin 4 and reservoir 5 from sub-basin 5.

The peak inflows for all detention basins were observed in the extreme event of 20 December 2011, where reservoir 1 had peak inflow of 123.6 m3/s, reservoir 2 had 43.5m3/s, reservoir 3 had 37.5 m3/s, reservoir 4 had 60.5 m3/s and reservoir 5 had 19.2 m3/s. A total of 284.5 m3/s which is about 65% of the peak runoff discharge generated in the catchment.

The findings of this study will redound to the benefit of the society in Dar es Salaam and other places with similar characteristics since stormwater management has been a growing issue of concern in highly urbanized cities. The detention basins designed in this study will play a great role towards capturing and slowing runoff and extend flow period of the Msimbazi river.

RÉSUMÉ

Dans les bassins qui s'urbanisent rapidement, l'augmentation de la quantité d'écoulement des eaux pluviales peut entraîner de nombreux problèmes graves tels que les crues éclair, l'érosion des sols et l'altération d'un écosystème. Les changements dans l'utilisation des sols affectent généralement les caractéristiques de l'écoulement des eaux pluviales, car beaucoup d'eau doit s'écouler sur les surfaces plutôt que de s'infiltrer dans le sol en raison de l'augmentation des surfaces imperméables.

L'écart entre les réponses hydrologiques à l'urbanisation et les solutions d'ingénierie est large. La plupart des études liées à la gestion des eaux pluviales se sont davantage concentrées sur le traitement séparé des problèmes, ce qui a conduit à des systèmes de gestion des eaux pluviales insuffisants. Afin de disposer de systèmes de gestion des eaux pluviales appropriés et suffisants, davantage d'informations sont nécessaires pour relier les cas susmentionnés.

Dans cette étude, le modèle HEC HMS a été utilisé pour la simulation pluie-débit afin de quantifier la quantité de ruissellement générée par rapport aux données d'utilisation des sols et de précipitations pour la conception des installations de denture de ruissellement. Les images satellites pour 1998, 2009 et 2018 de la zone d'attraction ont été sélectionnées en fonction de la qualité des données et de la résolution disponible. Les outils d'extension ArcGIS et SIG ont été utilisés pour extraire les caractéristiques hydrologiques du bassin versant. HEC -HEC-HMS a été utilisé pour simuler le processus pluviométrique sur le bassin versant de la rivière Msimbazi, le principal bassin versant situé à Dar es Salaam. La modélisation hydrologique a été réalisée en divisant le bassin versant en différents sous-bassins. Pour calculer la perte d'infiltration SCS CN method; convertir les précipitations excessives en hydrogramme unitaire SCS du modèle de ruissellement, et acheminer les écoulements de canaux en utilisant la méthode simple de routage par lag du modèle HEC-HMS.

Le traitement de l'utilisation des terres a identifié cinq grandes catégories d'utilisation des sols, à savoir: les plans d'eau, les forêts, de faible intensité dont la couverture est passée de 61,67% en 1998 à 21,13%, l'intensité moyenne développée de 25,97% en 1998 à 61,12% en 2018 et la forte intensité développée de 3,82% en 1998 à 19,77% en 2018.

Le débit de pointe calculé pour l'année 1998 a été de 355,7 m^3 / s, 402,7 m^3 / s en 2009 et 437,8 m^3 / s en 2018, soit une augmentation d'environ 23,08% entre 1998 et 2018. Certains petits sous-bassins ont été fusionnés pour former cinq plus grands sous-bassins reliés à un réservoir conçu à chaque sortie des cinq sous-bassins. Ce qui signifie que le réservoir 1 reçoit de l'eau sous le sous-bassin 1, le réservoir 2 du sous-bassin 2, le réservoir 3 du sous-bassin 3, le réservoir 4 du sous-bassin 4 et le réservoir 5 du sous-bassin 5. Les apports maximaux pour tous les bassins de rétention ont été observés lors du phénomène extrême du 20 décembre 2011, où le débit 1 du réservoir 1 était de 123,6 m^3 / s, le réservoir 2 de 43,5 m^3 / s, le réservoir 3 de 37,5 m^3 / s et le réservoir de 60,5 m^3 / s et le réservoir 5 avaient 19,2 m^3 / s. Un total de 284,5 m^3 / s, soit environ 65% du débit de pointe produit dans le bassin versant. Les résultats de cette étude profiteront à la société de Dar es-Salaam et à d'autres endroits présentant des caractéristiques similaires, la gestion des eaux pluviales constituant un problème croissant dans les villes fortement urbanisées. Les bassins de rétention conçus dans cette étude joueront un rôle important dans la capture et le ralentissement du ruissellement et prolongeront la période d'écoulement de la rivière Msimbazi.

ACKNOWLEDGEMENT

Firstly, I would like to thank almighty GOD for good health, livelihood and helping me to a successful completion of this study with great achievements.

I gratefully acknowledge the funding received from the AUC for the scholarships and research grants towards the successful completion of my studies.

However, I give my special thanks to Dr. Stephen Mbuligwe who was my supervisor for the time to time assistance, guidance, advice and constructive criticism which enabled all stages of this research to be successful during the whole period of performing this research to its successful completion.

I am also grateful to staff members of the Pan African University Institute of Water and Energy Sciences (including climate change) for their assistance.

Table of contents

List of Figures

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

List of Tables

CHAPTER TWO

CHAPTER FIVE

List abbreviations

A:	Cross Sectional Area
ASTER:	Advanced Space borne Thermal Emission and Reflection Radiometer
CEP:	Cumulative Excess Precipitation
CN:	Curve Number
CP:	Cumulative Precipitation
CPL:	Cumulative Precipitation Loss
CSA:	Central Statistics Agency
DEM:	Digital Elevation Model
DFID:	Department for International Development
DR:	Direct Runoff
ECA:	Economic Commission for Africa
EP:	Excess Precipitation
ERA:	Ethiopian Road Authority
FAO:	Food and Agricultural Organization
GDEM:	Global Digital Elevation Model
GIS:	Geographical Information System
IDF:	Intensity-Duration-Frequency
HEC-HMS:	Hydrologic Engineering Center Hydrologic Modeling System
HEC-GeoHMS:	Hydrologic Engineering Center Geospatial Hydrologic Modeling System

HEC-RAS:	Hydrologic Engineering Center River Analysis System
HEC-GeoRAS:	Hydrologic Engineering Center Geospatial River Analysis System
HSG:	Hydrological Soil Groups
Ia:	Initial Abstraction
KML:	Keyhole Markhole Language
L:	Length
LULC:	Land Use/Land Cover
NEH:	National Engineering Handbook
NRC:	Natural Resources Conservation Service
NSE:	Nash-Sutcliffe Efficiency
P:	Rainfall
PL:	Precipitation Loss
Q:	Discharge
RGB:	Red, Green, Blue
SCS:	Soil Conservation system
Sin:	Soil Infiltration
STRM:	Shuttle Radar Topography Mission
TR55:	Technical Release 55
UH:	Unit Hydrograph
UNEP:	United Nations Environment Programme

USDA:	United States Department of Agriculture
USGS:	United States Geological Survey
USACE:	United States Army's of corps of Engineers
UTM:	Universal Transverse Mercator
V:	Velocity
WGS:	World Geodetic System

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

In this modernized World, there is a significant need to understand spatial patterns of land use/land cover change at local, regional and global scales. Understanding the way LULC change has been behaving is of fundamental importance for environmental monitoring, help in the processes of urban planning, and governmental decision making around the world.

One of the effects of land use change is its considerable impacts on hydrological processes by affecting the nature of surface runoff and water quality, hence further impact on ecosystems, biotic systems, and even on human health (Chunhao, 2011).

When the land-use and land-cover changes, it may have four major direct impacts on the hydrological cycle and water quality which includes; they can cause floods, droughts, changes in river and groundwater regimes, and they can affect water quality (Qihao, 2001). All over the World, floods are the most devastating natural disasters affecting human life than any other natural disasters (Okirya et al, 2012).

It was estimated, in 2010 alone 178 million people globally were affected by floods and the total financial losses caused by the floods in the exceptional years such as 1998 and 2010 exceeded $40 billion (Okirya et al, 2012).

Tanzania as many other developing countries are presently experiencing rapid population and economic growth especially in the urban centers. The provision of services, including storm water management, wastewater collection, treatment and disposal has however not kept pace with these developments.

Dar es Salaam with a population of 4,4 million in 2012 (NBS, 2013) has become the third fastest growing city in Africa and among the tenth fastest growing cities in the world (DIDP, 2010). With the high population-growth rate, concerns over food security and ways to find an income are high and widespread.

The accelerating population growth poses multiple challenges but which also offer opportunities for the city to improve and ensure the best possible service delivery to its current and future residents and at the same time to contribute effectively to the country's economy as a whole.

The risk of flooding in urban areas could be better approached by complementing adequate conventional sewer systems with sustainable urban drainage systems (SUDS) to properly accommodate stormwater generated. This may be the case of developing world cities like Dar es Salaam with incomplete sewer services.

Stormwater runoff problems and their associated impacts are most evident in areas where urbanization has occurred where the increase of impervious surfaces hinders proper infiltration of stormwater to the ground.

Land use changes affects both the quantity and quality of stormwater runoff generated. If urbanization is not properly coupled with proper planning and management, can dramatically alter the natural hydrological condition of an area due to increase in impervious cover.

Impervious cover or surface tends to decrease the amount of rainwater that can naturally infiltrate into the soil which in turn increases the volume and rate of stormwater runoff. As a result of these changes, more frequent and severe flooding are witnessed, and therefore potential damage to public and private property.

In this study, Geographical Information System (GIS) software packages are used for catchment characteristics processing along with hydrologic modeling software packages for runoff quantification and detention basins design.

1.2 Statement of the Problem

Dar es Salaam is experiencing significant growth and development (AfDB, 2014), with a corresponding increase in the amount of impervious surface covering the landscape. Rapid land use change in Dar es Salaam extracts a particularly heavy toll on stormwater runoff generation. Urbanization in the city has paved over or replaced previously open land with roads, driveways and parking lots, leading to an increasing amount of stormwater runoff. Land development has the potential for adversely affecting the quality of stormwater by increasing the amounts of stormwater runoff, which in turn increases flooding and soil erosion.

Inadequate and poorly maintained stormwater drainage and equally poor solid waste management systems significantly contribute to major flooding that frequently occurs in the City which marks to poor stormwater management systems.

The city is also under poor planning systems with an estimated 70-80% of residents in Dar es Salaam living in unplanned, largely informal settlements (World Bank, 2014).

Dar es Salaam is subjected to serious flooding incidents every rainy season and the magnitude of the problem seems to be increasing. In 2011, Dar es Salaam was hit by floods where around 50,000 people were affected with 23 people losing their lives and over 6,000 people were temporarily sheltered in schools around Dar Es Salaam (UNICEF, 2012). Many of them lost their homes and belongings (UNICEF, 2012).

The problem is exacerbated by the fact that, the gap between the hydrologic responses to urbanization and the engineering solutions is wide. Most of the studies related to stormwater management have been focusing on treating the issues separately leading to insufficient stormwater management systems. In order to have proper and sufficient stormwater management systems, more information is needed to link the above-mentioned cases together.

1.3 Significance of the Study

Understanding the hydrologic responses to urbanization while integrating the scenarios with engineering solutions will help in better stormwater management planning systems.

This study tries to link the effects of urbanization in a highly developing catchment on a stormwater generation and an engineering solution towards combating floods, highlighting the potential lying behind the stormwater towards cutting water supply demand as well as soil and ecological conservation.

Also, this study tries to explore the opportunities of turning stormwater runoff from being a waste and a disaster into being a useful resource to a human being and other water-dependent living organisms with the case of Msimbazi catchment.

The findings of this study will redound to the benefit of the society in Dar es Salaam since stormwater runoff induced problems such as floods and soil erosion have been growing issues of concern in the study catchment and other many places in the city. Also, the findings will help in filling the information gaps in the ongoing efforts towards fighting the above-mentioned runoff induced problems and make Dar es Salaam a better place to live.

Additionally, the application of the recommended approaches derived from the results of this study will help in proper stormwater runoff management by providing information for better planning systems and ensure attainability of sustainable developments through sustainable cities in Tanzania and elsewhere with similar conditions.

The increasing flooding incidents, soil erosion, and the rapidly growing water demand justify the need for more effective approaches for stormwater management in Dar es Salaam.

1.4 Study objectives

1.4.1 The main objective

- To assess storm water runoff scenarios and quantify the amount of storm runoff generated with respect to the selected rainfall event and land use characteristics of the Msimbazi catchment for engineering design towards improving floods resilience, water supply and quality protection as well as soil conservation and ecological conservation in Dar es salaam

1.4.2 Specific objectives

- To assess and characterize the watershed
- To determine the quantity of storm water runoff generated in the watershed with respect to land uses.
- To propose an integrated engineering solution for storm water management towards improving floods resilience, water supply, soil and ecological conservation.

1.5. Report outline

This study report is arranged in 8 chapters. Chapter 2 tries to include the views of different literatures on key point of the study especially the theories behind the software's and models applied in this research and major factors considered on hydrological and hydraulic modeling are presented. In Chapter 3, the existing situation of the study area is described briefly. In Chapter 4 the materials and methods used for the development of hydrologic modeling and detention basins design are presented in detail. In Chapter 5 both the hydrological modeling as well as detention basins results are presented and discussed. Chapter 6, practical interpretation and application of the study results are described. In Chapter 7, the study results summarized and implications associated with results as well as recommendations and limitations of the study are described in detail. On the final chapter, which is chapter 8 references used for this study are mentioned orderly.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition of terms

2.1.1 Hydrological cycle

The water, or hydrologic, cycle describes the pilgrimage of water as water molecules make their way from the Earth's surface to the atmosphere and back again, in some cases to below the surface. This gigantic system, powered by energy from the Sun, is a continuous exchange of moisture between the oceans, the atmosphere, and the land.

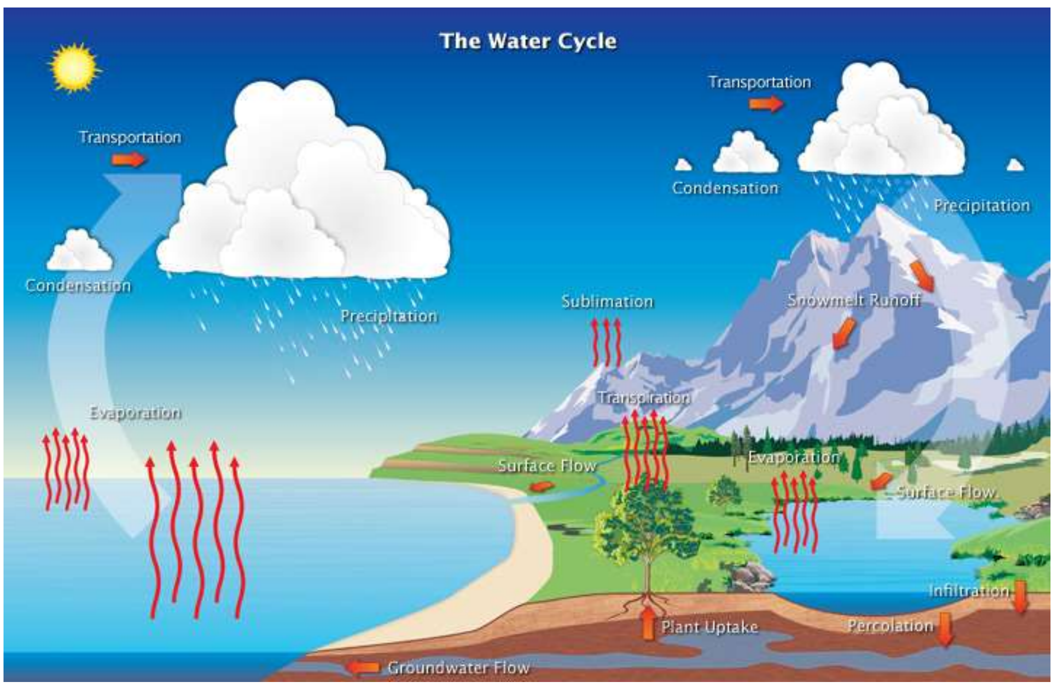


Figure 2. 1: Hydrologic cycle (NOAA, 2018).

Studies have revealed that evaporation process by which water changes from a liquid to a gas—from oceans, seas, and other bodies of water (lakes, rivers, streams) provides nearly 90% of the moisture in our atmosphere. Most of the remaining 10% found in the atmosphere is released by plants through transpiration. Plants take in water through their roots, then release it through small pores on the underside of their leaves. In addition, a very small portion of water vapor enters the atmosphere through sublimation, the process by which water changes directly from a solid (ice or snow) to a gas. The gradual shrinking of snow banks in cases when the temperature remains below freezing results from sublimation (NASA Earth Observatory, 2009).

2.1.2 Watershed

A watershed is an area or part of land that contributes runoff water to a common point. It is a natural physiographic of numerous interrelated parts and functions. It is the area of land where all of the water that falls in the particular area and drains off of it goes to a common outlet. Watersheds varies in sizes, where they can be as small as a footprint or large enough to encompass all the land that drains water into rivers that drain into a common point (EPA, 2012).

2.1.3 Storm water runoff

Storm water runoff is an amount rainfall or snowmelt that runs off the ground surfaces or impervious surfaces such as buildings, roads, and parking lots, and drains into natural or manmade drainage ways or any other places where it finds space (SFS, 2018). In most cases the storm water runoff, it drains directly into streams, river, lakes, sounds or the ocean (SFS, 2018).

In undeveloped areas, precipitation typically soaks into the ground due to less impervious surfaces. When buildings, parking lots, roads, paved surfaces and other hard surfaces are added to the landscape, it becomes difficult for the ground to absorb the water. Water from rain or snow storms, known as storm water, instead flows over the ground to streets, parking lots and roofs and into a water body or storm drain (SFS, 2018).

Stormwater runoff is often worsened by human activities (anthropogenic), and can contain nitrogen and phosphorus pollutants from fertilizers, pet and yard waste from different production sites. Because stormwater flows over hard surfaces directly into a water body or storm drain, leads to no opportunity for soil and plants or a water treatment facility to filter out pollutants. Urban and suburban areas produce much more stormwater runoff due to the high amount of paved and hard surfaces (impervious surfaces).

2.1.4 Flooding

Flooding is an overflowing of water onto land that is normally dry. Floods can happen during heavy rains, when ocean waves come on shore, when snow melts too fast, or when dams or levees break. Flooding may happen with only a few inches of water, or it may cover a house to the rooftop. They can occur quickly or over a long period and may last days, weeks, or longer. Floods are the most common and widespread of all weather-related natural disasters (NSSL, 2018).

Flash floods are the most dangerous kind of floods, because they combine the destructive power of a flood with incredible speed and unpredictability. Flash floods occur when excessive water fills normally dry creeks or river beds along with currently flowing creeks and rivers, causing rapid rises of water in a short amount of time. They can happen with little or no warning (NSSL, 2018).

2.1.5 Soil erosion

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage (OMAFRA, 2016). Erosion, whether it is by water, wind or tillage, involves three distinct actions – soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes (OMAFRA, 2016).

Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinisation and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process.

2.1.6 Ecology

Ecology is the scientific study of the distributions, abundance and relations of organisms and their interactions with the environment. Ecology includes the study of plant and animal populations, plant and animal communities and ecosystems. Ecosystems describe the web or network of relations among organisms at different scales of organization (EV, 2018).

Since ecology refers to any form of biodiversity, ecologists research everything from tiny bacteria's role in nutrient recycling to the effects of tropical rain forest on the Earth's atmosphere. The discipline of ecology emerged from the natural sciences in the late 19th century. Ecology is not synonymous with environment, environmentalism, or environmental science. Ecology is closely related to the disciplines of physiology, evolution, genetics and behavior (EV, 2018)

2.2 Stormwater related scenarios in Dar es salaam

2.2.1 Floods in Dar es salaam

Dar es Salaam region is located in shanties low-lying areas, which are often highly prone to flooding from a variety of mechanisms especially intense precipitation and poor stormwater management systems. The coastal erosion problems have also been reported along virtually the whole stretch of the mainland coast of the country and around the islands (Nyandwi, 2001), (Makotaet al., 2004).

Areas that are known to be severely affected include the Kunduchi (north of Dar es Salaam) and Bahari beaches (Griffiths, et al). At the Kunduchi beach area, the coastline has retreated for about 200m over the last 50 Years, destroying residential houses, public services (e.g., a mosque) and other tourism facilities (e.g., hotels), as well as the historic fish market (constructed in 1970s) and a seawall constructed to protect the Ocean road (Casmir, 2008). The average rate of erosion for the city area has been estimated at about 3 – 5 m/year (Fay, 1992). A number of earlier studies have been carried out on various aspects of coastal erosion, and different causes have been suggested such as coastal uplift (Alexander, 1966; 1969), sea-level rise (Fay, 1992), changes in hydrodynamic conditions such as longshore drift (Arthur, 1992), and other human activities such as extraction of sand from rivers for construction purposes, destruction of the fringing and barrier coral reefs by dynamite fishing, and removal of vegetation from mangrove swamps (Fay et al., 1988).

2.2.2 Storm water drainage status in Dar es salaam

The intensive urban development (in terms of housing, roads and other, developments) in Dar es Salaam have greatly increased the amount of runoff water and at the same time reduced the surface area which can absorb the runoff through ground seepage. This situation is compounded by the fact that all three municipalities lack adequate drainage network, particularly in suburban areas. Since the existing drainage systems are over 20 years old, most drains no longer serve their purpose due to misuse such as garbage dumps and lack of maintenance (Mwalyosi, 2014).

2.2.3 Urbanization in Tanzania

Since 1967, Tanzania's cities have become home to more than 30 million new residents (Smith, 2014). Dar es Salaam — Tanzania's primate city — has experienced the largest increase in population. Between 2002 and 2012, its population grew by more than 6% per annum, with over 70% of this increase being accounted for by inmigration from other regions (Smith, 2014).

Although Dar es Salaam is no longer Tanzania's political capital (Dodoma became the national capital in 1973), it remains the country's largest city, both in terms of population and business activity. Tanzania is 30% percent urban today and will be 50% urban by the year 2030. Since the national population will also increase substantially, Tanzania's urban population is expected to triple in size over the next 34 years.

This means that only one third of the urbanization infrastructure that Tanzania will need by 2050 has already been built. Yet it has taken around a century to build that existing third. The challenge facing the society between now and 2050 is thus to build twice as much as has yet been built but in just one third of the time.

According to (Wenban-Smith, 2014), a world Bank report on 'The Urban Transition in Tanzania' (World Bank (2009a)) notes that there are three perspectives on the term urban in Tanzania. The politico-administrative used by the Prime Minister's Office, Regional Administration and Local Government (PMO-RALG), The human settlements perspective used by the Ministry of Lands and Human Settlements Development (MoLHSD and the statistical perspective adopted by the National Bureau of Statistics (NBS).

From the 2014 African Development Bank (AfDB) report, it shows Dar es salaam is one of the highly growing cities in Africa as shown in table 2.1 below.

Table 2. 1: Growth of African cities from 2010 to 2015 (AfDB, 2014).

City	Country	Population % change(2010-2015)
Dar es salaam	Tanzania	85.2
Nairobi	Kenya	77.3
Kinshasa	DRC	71.8
Luanda	Angola	69.3
Adis Ababa	Ethiopia	62.4
Abijan	Ivory Coast	53.2
Dakar	Senegal	51.5
Lagos	Nigeria	49.5
Ibadan	Nigeria	49.3
Accra	Ghana	49.3

2.3 Hydrological modeling

According to (Sorooshian et al. 2008), a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behaviour and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

2.3.1 Types of models

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on the other criteria.

Deterministic model will give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs. In lumped models, the entire river basin is taken as a single unit where spatial variability is disregarded and hence the outputs are generated without considering the spatial processes where as a distributed model can make predictions that are distributed in space by dividing the entire catchment in to small units, usually square cells or triangulated irregular network, so that the parameters, inputs and outputs can vary spatially (Moradkhani et al, 2008).

Another classification is static and dynamic models based on time factor. Static model exclude time while dynamic model include time (Sorooshian et al 2008) had classified the models as event based and continuous models. The former one produce output only for specific time periods while the latter produces a continuous output. One of the most important classifications is empirical model, conceptual models and physically based models.

2.3.1.1 Empirical models (Metric model)

These are observation oriented models which take only the information from the existing data without considering the features and processes of hydrological system and hence these models are also called data driven models.

It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment. These models are valid only within the boundaries. Unit hydrograph is an example of this method.

Statistically based methods use regression and correlation models and are used to find the functional relationship between inputs and outputs. Artificial neural network and fuzzy regression are some of the machine learning techniques used in hydro informatics methods (Devia, et al,2015).

2.3.1.2 Conceptual methods (Parametric models)

This model describes all of the component hydrological processes. It consists of a number of interconnected reservoirs which represents the physical elements in a catchment in which they are recharged by rainfall, infiltration and percolation and are emptied by evaporation, runoff, drainage etc.

Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. Large number of meteorological and hydrological records is required for calibration.

The calibration involves curve fitting which makes the interpretation difficult and hence the effect of land use change cannot be predicted with much confidence.

Many conceptual models have been developed with varying degree of complexity. Stanford Watershed Model IV (SWM) is the first major conceptual model developed by Crawford and Linsley in 1966 with 16 to 20 parameters.

2.3.1.3 Physically based model

This is a mathematically idealized representation of the real phenomenon. These are also called mechanistic models that include the principles of physical processes. It uses state variables which are measurable and are functions of both time and space.

The hydrological processes of water movement are represented by finite difference equations. It does not require extensive hydrological and meteorological data for their calibration but the evaluation of large number of parameters describing the physical characteristics of the catchment are required (Abbott et al. 1986 a).

In this method huge amount of data such as soil moisture content, initial water depth, topography, topology, dimensions of river network etc. are required. Physical model can overcome many defects of the other two models because of the use of parameters having physical interpretation.

It can provide large amount of information even outside the boundary and can applied for a wide range of situations. SHE/ MIKE SHE model is an example (Abbott et al. 1986).

2.4 Introduction to HEC-HMS model

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic drainage basins. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems.

This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (USACE-HEC, 2010).

The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the water cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model.

In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgement (USACE-HEC, 2010).

HEC-HMS is a product of the Hydrologic Engineering Center within the U.S. Army Corps of Engineers. The program was developed beginning in 1992 as a replacement for HEC-1 which has long been considered a standard for hydrologic simulation.

The new HEC-HMS provides almost all of the same simulation capabilities, but has modernized them with advances in numerical analysis that take advantage of the significantly faster desktop computers available today.

It also includes a number of features that were not included in HEC-1, such as continuous simulation and grid cell surface hydrology (USACE-HEC, 2010).
The figure 2.2 below shows the HEC HMS working window with a graphical result from a processed catchment.

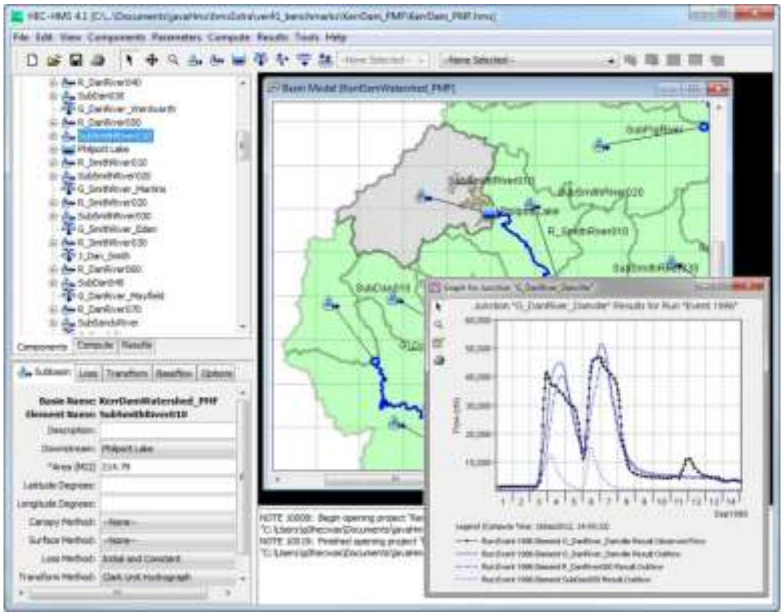


Figure 2. 2: HEC-HMS

2.4.1 HEC HMS basic tools

HEC-HMS model components are used to simulate the hydrologic response in a watershed. It includes basin models, meteorological models, control specifications, and input data. A simulation calculates the precipitation-runoff response in the basin model which is given input from the meteorological model. The control specifications define the time period and time step of the simulation run. Input data components, such as time-series data, paired data, and gridded data are often required as parameter or boundary conditions in basin and meteorological models (USACE-HEC, 2010a).

2.4.1.1 Watershed Explorer

The Watershed Explorer as in HEC HMS was developed to provide quick access to all components and simulations in a project. For example, the user can easily navigate from a basin model to a precipitation gage and then to a meteorologic model without using menu commands or opening additional windows.

The Watershed Explorer is divided into three parts: Which are; Components, Compute, and Results (USACE-HEC, 2010a).

2.4.1.2 **Desktop**

The Desktop holds a variety of windows including global parameter editors, and most importantly the basin map. Result windows including graphs, summary tables, and time-series tables can be shown in the Desktop, or optionally, outside the Desktop. All other windows cannot be moved outside of the Desktop area. The basin map is used to develop a basin model. Hydrologic elements (subbasin, reach, reservoir, etc.) are added from the toolbar and connected to represent the physical drainage network of the study area. Background maps can be imported to help visualize the watershed.

2.4.1.3 Component Editor

When a component or sub-component in the Watershed Explorer or hydrologic element in the basin map is active (use the mouse and click on the component name in the Watershed Explorer or select the hydrologic element in the basin map), a specific component editor will open. Data for model components is entered in the Component Editor. Required data is indicated with a red asterisk. For example, loss parameter data for a subbasin element is entered in the Component Editor for the subbasin (HEC, 2010a).

2.4.1.4 Message Log

Note, warming, and errors are shown in the Message Log. These messages are useful for identifying why a simulation run failed or why a requested action like opening a project was not completed (HEC, 2010a). By using the message log user can be able to identify errors and make a follow-up for corrections and proper simulations. Sometimes message log can use complex language that might somehow be difficult to understand easily. Generally, message log is good friend towards handling errors.

2.4.1.5 Basin Model Component

Basin model represents the physical watershed. The user develops a basin model by adding and connecting hydrologic elements. Hydrologic elements use mathematical models to describe physical processes in the watershed. It is based on Graphical user interface (GUI) and can import map files from GIS program to use as background (HEC, 2010a).

- **Hydrologic Elements**

The hydrologic elements are those which are used during the calibration and validation process of HEC-HMS model for selected basin. The following description gives brief information on each symbol that is used to represent individual hydrologic element.

- **Sub-basin**

Sub basin represents the physical watershed. It calculates precipitation losses, transforming excess precipitation to stream flow at the sub basin outlet, and base flow.

- **Reach**

Reach connects other elements together and convey stream flow from upstream to downstream in the basin model. Inflow into the reach element can come from one or many upstream hydrologic elements. Outflow from the reach is calculated by accounting for translation and attenuation of the inflow hydrograph.

- **Junction**

The junction element is used to combine stream flow from hydrologic elements located upstream of the junction element. Inflow into the junction element can come from one or many upstream elements.

Outflow is simply calculated by summing all inflows and assuming no storage at the junction.

- **Reservoir**

It stores runoff and releases runoff at a specific rate. Inflow into the reservoir element can come from one or many upstream hydrologic elements.

- **Source**

The source element is used to introduce flow into the basin model. It has no inflow. Outflow from this element is defined by the user.

- **Sink**

The sink element represents the outlet of the physical watershed. It has an inflow but no outflow. Inflow into the sink element can come from one or many upstream hydrologic elements (HEC, 2010a).

- **Diversion**

This element is used to represent diversion of specified amount of runoff to an outlet. It is based on a rating curve-used detention storage element or outflows. Outflow from the diversion element consists of diverted flow and non-diverted flow (HEC, 2010a).

2.4.1.6 Meteorologic Model Component

The precipitation and evapotranspiration data necessary to simulate watershed processes are stored in the meteorological model. The meteorologic model calculates the precipitation input required by a sub-basin element.

This model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapotranspiration for each sub-basin assigned to the model.

The newly added snowmelt method uses a temperature index algorithm to calculate the accumulation and melt of the snow pack. The evapotranspiration methods include the monthly average method and the new Priestly Taylor and gridded Priestly Taylor methods.

An evapotranspiration method is only required when simulating the continuous or long term hydrologic response in a watershed (HEC, 2010a).

2.4.1.7Control Specifications Component

The control specifications set the time span of a simulation run. Information in the control specifications includes a starting date and time, ending date and time, and computation time interval.

2.4.2 Hydrologic Simulation

The time span of a simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and a time interval.

A simulation run is created by combining a basin model, meteorologic model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin state information at a point in time, and ability to begin a simulation run from previously saved state information.

Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow, total volume, and other variables.

A time-series table and graph are available for elements. Results from multiple elements and multiple simulation runs can also be viewed. All graphs and tables can be printed (http://www.hec.usace.army.mil/software/hec-hms/features.aspx).

2.4.3 Model Optimization

Most parameters for methods included in subbasin and reach elements can be estimated automatically using optimization trials. Observed discharge must be available for at least one element before optimization can begin.

Parameters at any element upstream of the observed flow location can be estimated. Seven different objective functions are available to estimate the goodness-of-fit between the computed results and observed discharge.

2.4.4 Model Calibration procedures

Followings are the HEC-HMS calibration procedure to obtain the best (optimal) parameter values:

i. The first procedure begins with data collection in which for rainfall-runoff models, the required data are rainfall and flow time series and for routing models, observations of both inflows to outflow from the routing reach are collected.
ii. The next step is to select initial estimates of the parameters.
iii. Given these initial estimates of the parameters, simulate the HEC-HMS models for observed boundary conditions to compute the output, either the watershed runoff hydrograph or a channel outflow hydrograph.
iv. Then compare the computed hydrograph to the observed hydrograph to judge how well the model "fits" the real hydrologic system.
v. If the fit is not satisfactory, then do parameter optimization trails to adjust the parameters systematically.
vi. When the fit is satisfactory, HEC-HMS will report the optimal parameter values. The presumption is that these parameter values then can be used for runoff or routing computations that are the goal of the flood runoff analyses.

2.4.5 Limitations of HEC-HMS Model

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation and simplified flow representation.

Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results.

Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite.

2.5 Introduction to HEC-GeoHMS

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) has been developed as a geospatial hydrology toolkit for engineers and hydrologists with limited GIS experience (HEC-Geo HMS, 2013). HEC-GeoHMS uses ArcGIS and the Spatial Analyst extension to develop a number of hydrologic modeling inputs for the Hydrologic Engineering Center's Hydrologic Modeling System, HEC-HMS.

ArcGIS and its Spatial Analyst extension are available from the Environmental Systems Research Institute, Inc (HEC-Geo HMS, 2013). (ESRI). Analyzing digital terrain data, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the drainage network (HEC-Geo HMS, 2013).

The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate subbasins and streams (HEC-Geo HMS, 2013). Working with HEC-GeoHMS through its interfaces, menus, tools, buttons, and context-sensitive online help allows the user to expediently create hydrologic inputs for HEC-HMS (HEC-Geo HMS, 2013.)

HEC-GeoHMS is intended to process watershed data after the initial compilation and preparation of terrain data is completed (HEC-Geo HMS, 2013). The assembly of GIS data can be performed using standard GIS software packages that support ARC Grid format (HEC-Geo HMS, 2013).

Even though this user's manual provides some guidance and discussions on the proper approach for assembling data, HEC-GeoHMS is not intended as a tool for data assembly (HEC-Geo HMS, 2013).

When assembling data, it is important to understand how to use GIS software to put data of different types and formats into a common coordinate system (HEC-Geo HMS, 2013).

A few examples of required data include digital elevation models (DEM), digital stream alignments, and stream gage locations (HEC-Geo HMS, 2013).

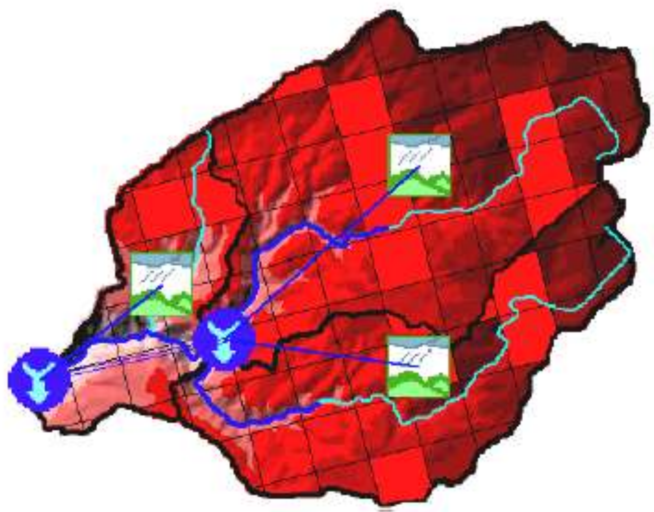


Figure 2. 3:HEC HMS model(HEC, 2010)

2.6 Watershed Delineation and Hydrological Structure

Following step-by-step procedure is adapted for the watershed delineation and identification of hydrological structure they are:

- Delineation of watershed area from available top sheet
- Identification of drainage network in the watershed
- Determination of all geometric parameters such as sub basin area, overland flow length, basin slope, and stream channel length and slope etc.
- Determination of composite curve number based on hydrologic soil group, land use/land cover and hydrologic condition etc. of watershed area and
- Formulation of hydrological setup with sub-basin, reach, junction sink and reservoir etc.

2.7 SCS Curve Number (CN) Method

Soil Conservation Services and Curve Number (SCS–CN) technique is one of the primogenital and simplest method for rainfall runoff modelling. One of empirical methods that is widely and global used by hydrologists, water project planners and water engineering, is the curve numbers method that has been suggested and supported by the department of agriculture natural resources conservation service of USA. Some applications of GIS are mapping curve number (CN) of catchment by using the digital data analysis, vegetation cover, land using and hydrologic soil groups (Abouzar Nasiri and Hamid Alipur, 2014).

Soil Conservation Services and Curve Number (SCS–CN) technique is one of the primogenital and simplest method for rainfall runoff modelling. Several models based on SCS–CN are being referred by different researchers worldwide used such as original SCS–CN, Mishra-Singh (MS) model (2002), Michel model (2005), and Sahu model (2007), commonly on the basis of the SCS–CN concepts, with some modifications are used. The curve number method (SCS–CN, 1972) is an adaptable and widely used for runoff estimation.

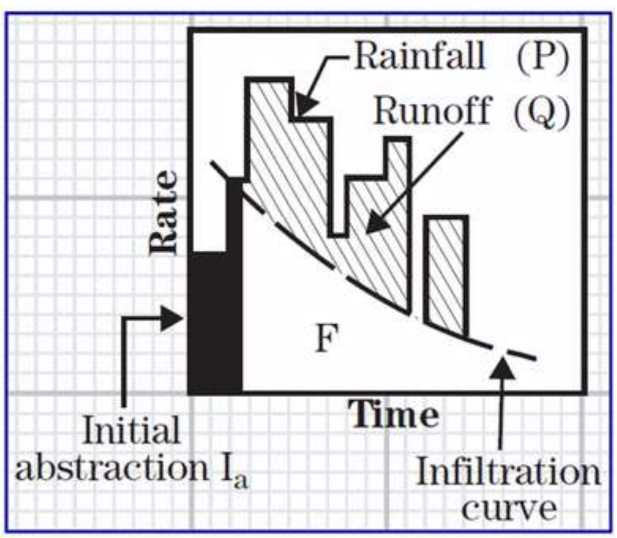


Figure 2. 4: Processes happening in a catchment (TR-55, 1986)

The SCS Runoff Curve Number (CN) method developed by Natural Resources Conservation Service (NRCS) used for estimating direct runoff from storm rain fall described on the following equation;

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad \text{2.1}$$

Where;

$Q = runoff(in)$

$P = rainfall(in)$

$S = potential\ maximum\ retention\ after\ runoff\ begins(in)$

$I_a = initial\ abstraction\ (in)$

2.7.1 Initial abstraction (I_a)

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Initial abstraction I_a is estimated from CN.

Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S \qquad \text{2.2}$$

Although the above relationship has been used but more recent research has found that I_a can be expressed as equals to 0.05S. I_a=0.05S may be a more appropriate relationship in urbanized watersheds where the CN is updated to reflect developed conditions.

By removing I_a as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 2.2 into equation 2.1 gives:

$$Q = \frac{(P-0.2S)^2}{(P-0.8S)} \qquad 2.3$$

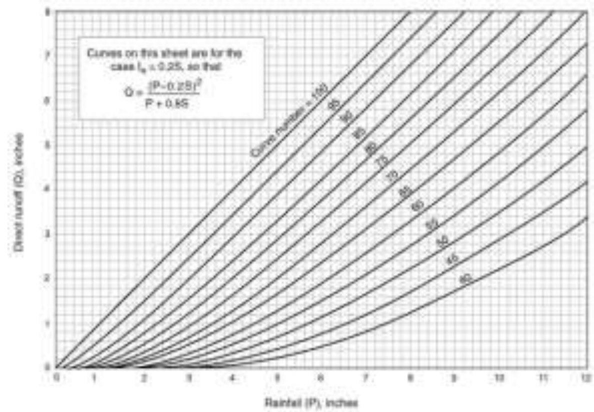


Figure 2. 5: Curve number s(TR-55, 1986)

When the drainage area consists of landuse with impervious cover (Directly Connected or Unconnected), TR 55 provides separate graphs for computing the composite curve number values depending on the percent of the impervious cover. However, it is a good practice to calculate the runoff from impervious area and pervious area separately and then add the volume (TR-55, 1986)

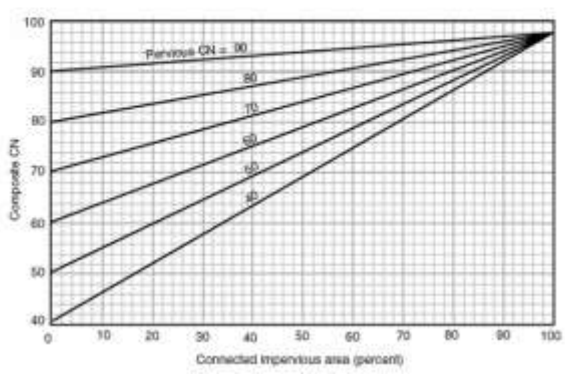


Figure 2. 6: Composite curve numbers(TR-55, 1986)

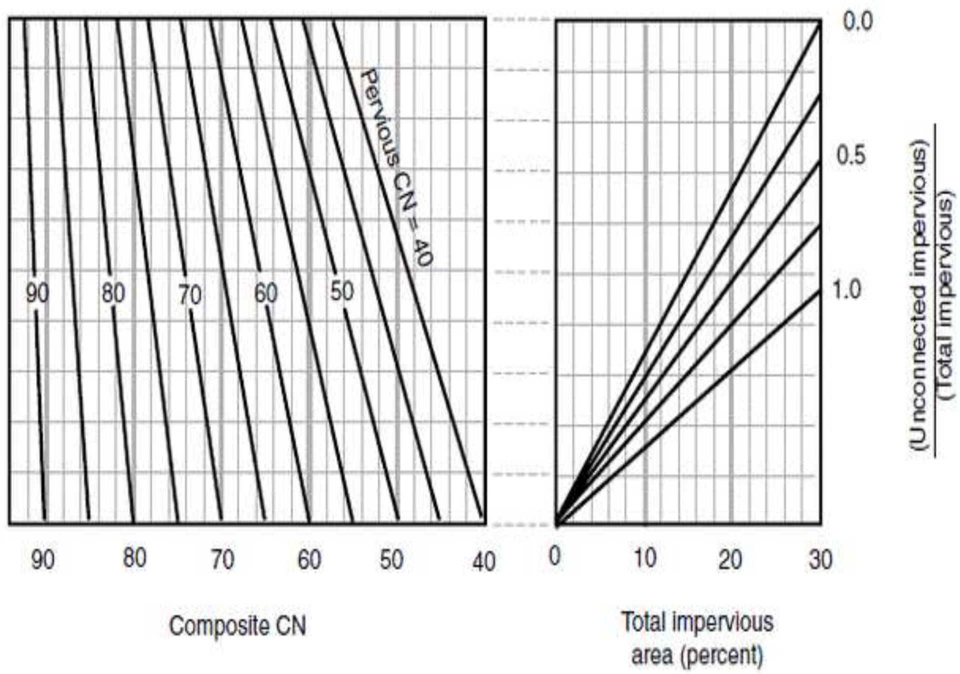


Figure 2. 7:Composite CN and total impervious s(TR-55,1986)

2.7.2 Potential maximum retention after runoff begins (S)

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, antecedent runoff condition, and impervious areas.

On the other hand, infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four HSG's (A, B, C, and according to their minimum infiltration rate (TR55, 1986).

The selection process of a hydrologic soil group should be done by considering measured infiltration rates, soil survey (such as the NRCS Web Soil Survey), or judgement from a qualified personnel in soil science or geotechnical professional.

2.8 Hydrologic soil groups (HSGs)

According to the USDA Natural Resources Conservation Service of National Engineering Handbook the four hydrologic soil groups (HSGs) are described as:

Group A

Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group B

Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group C

Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group D

Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimeters and all soils with a water table within 60 centimeters of the surface are in this group (NEH, 2009).

2.9 Landsat data

The Landsat program is the longest-running enterprise for acquisition of satellite imagery of Earth. On July 23, 1972 the Earth Resources Technology Satellite was launched. This was eventually renamed to Landsat. The most recent, Landsat 8, was launched on February 11, 2013. The images, archived in the United States and at Landsat receiving stations around the world, are a unique resource for global change research and applications in agriculture, cartography, geology, forestry, regional planning, surveillance and education

Landsat sensors record reflected and emitted energy from Earth in various wavelengths of the electromagnetic spectrum. The electromagnetic spectrum includes all forms of radiated energy from tiny gamma rays and x-rays all the way to huge radio waves.

The human eye is sensitive to the visible wavelengths of this spectrum; we can see color, or reflected light, ranging from violet to red. Today, Landsats 7 and 8 record blue, green, and red light in the visible spectrum as well as near-infrared, mid-infrared, and thermal-infrared light that human eyes cannot perceive (although we can feel the thermal-infrared as heat).

Landsat records this information digitally and it is downlinked to ground stations, processed, and stored in a data archive.

It is this digital information that makes remotely sensed data invaluable. “Observations from Landsat are now used in almost every environmental discipline,” explains John Barker, a Landsat 7 Associate Project Scientist and award-wining calibration expert.

Landsat data have been used to monitor water quality, glacier recession, sea ice movement, invasive species encroachment, coral reef health, land use change, deforestation rates and population growth. Landsat has also helped to assess damage from natural disasters such as fires, floods, and tsunamis, and subsequently, plan disaster relief and flood control programs (https://landsat.gsfc.nasa.gov/data/)

2.10 Detention ponds

Detention ponds temporarily store stormwater runoff, thereby reducing the peak rate of runoff to a stream or storm sewer. They help to prevent localized flooding and, if designed to do so, provide some water quality benefits and reduce streambank erosion downstream.

During a storm, runoff drains from impervious surfaces directly to storm sewers or waterways. Large storm events contribute a significant volume of runoff moving at an increased rate, which raises the potential for erosion and flooding downstream (DCCD, 2013).

Detention ponds are basins that receive and hold runoff for release at a predetermined rate, thereby reducing the peak runoff delivered to storm sewers and streams. The ponds generally are earthen structures constructed either by impoundment of a natural depression or excavation of existing soil.

Detention ponds are designed to release all captured runoff over time, and do not allow for permanent pooling of water (DCCD, 2013). Captured runoff is released through multi-level outlet structures consisting of weirs, risers, orifices or pipes, which provide for increased discharge as water levels in the basin increase

Detention ponds are generally ineffective at removing pollutants in runoff because they do not provide adequate holding time for solids to settle before water is released into a stream or storm sewer system.

However, extending the detention time of the basin and/or including a forebay to the basin in the design when space allows will enhance water quality and quantity benefits. Extended detention will require a larger basin. Forebays trap sediment to pretreat runoff prior to release to the main pond, and also provide additional temporary storage of runoff (DCCD, 2013).

In a case where thermal impacts to receiving waters, such as trout streams, are a high consideration, time for extended detention should be shortened, to avoid thermal effects in a detention pond (DCCD, 2013). Due to the ability of the detention ponds to contain a substantial volume of runoff, they are suited for placement at all sites with different conditions, including large sites.

2.10.1 Working mechanism

The runoff is collected and accumulates in a detention basin, the water that accumulates between the fore-bay and the embankment of the basin is released at a slow, controlled rate through the stone riprap to a bigger destination water body such as rivers, oceans, lakes etc. During this process, heavy pollutants settle at the bottom of the sediment forebay especially if the basin provides enough time for pollutants to settle. However, there are some extremely rare cases where the water level gets to the top of the concrete riser of a basin, the excess runoff in a basin flows directly through the barrel increasing its outflow. The grass on the forebay helps prevent erosion from constant inflows of water in a basin (DCCD, 2013).

Detention basins have the potential to provide ancillary amenity benefits as shown in table 2.2 below. They are ideal for use as playing fields, recreational areas or public open space.

Table 2. 2 Applicability of detention basins (NWRM,2013)

Biophysical impact		Rating	Evidence
Runoff	Store ruoff	High	Detention basins temporarily store runoff, then releasing it at a slower rate downstream, e.g. in to a receiving watercourse. The capacity to store runoff is dependent on the design of the basin, which can be sized to accommodate any size of rainfall event (CIRIA, 2007 identify up to a 1 in 100 year event as being not uncommon).
	Slow runoff	High	
Flood risk reduction	Flood control	High	Detention basins contribute to reducing the volume and rate of surface runoff, particularly from artificial surfaces (urban areas). Used in conjunction with other SuDS features, they can reduce the risk of surface runoff flooding and contribute to the reduction in peak river flows in small catchments.
Soil erosion control	Soil erosion control	Medium	Detention basins (sometimes with pre-treatment) can be effective in allowing the settlement of sediment entrained in runoff, preventing it from entering downstream watercourses. COWI (2014) note that sediment in urban runoff has relatively little influence on the catchment scale, but nevertheless there will be some local benefit, and when applied in rural (agricultural) areas the benefit may be more significant.

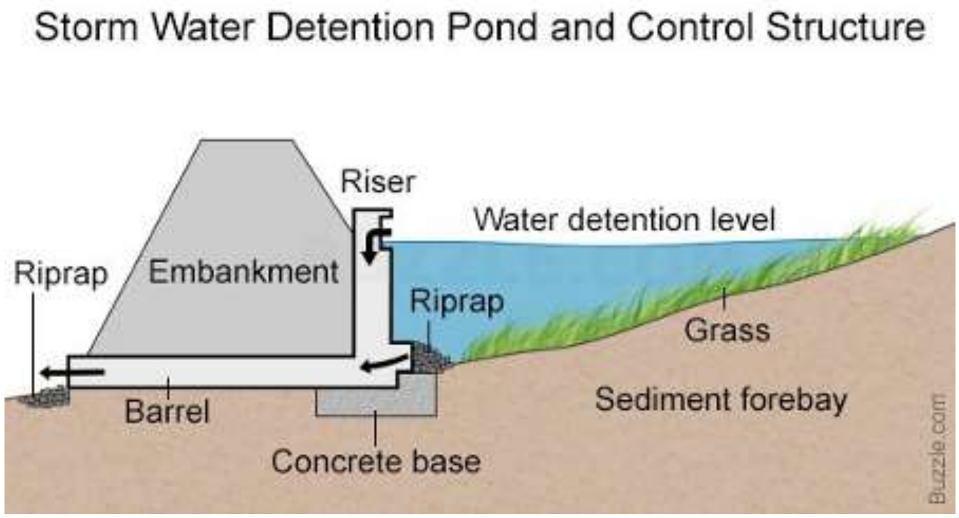


Figure 2. 8: Detention pond structure (HSN,2018)

2.10.2 General detention pond design considerations

- Suitable for capturing runoff from a drainage area of at least five acres
- Inflow and discharge hydrographs should be calculated for each selected design storm
- Location of basin should be down gradient of disturbed/developed areas on site
- Construction on or near steep slopes or modifying existing slope is not recommended
- Planting of native vegetation on floor of basin and embankments is recommended
- Floor of basin should be at least two feet above high water table
- Design for maximum water depth of 10 feet
- Design for length to width ratio of 2:1, minimum width of 10 feet; side slope ratio no greater than 3:1, maximum height of side embankments less than 15 feet
- Site placement should be at least 10 feet from property line and 50 feet from private well or septic system to address water quality concerns
- Forebay for should contain 10% to 15% of total pool volume
- Compaction of basin bottom should be avoided

- Outlet structures must be resistant to corrosion and clogging by debris, sediment and plant material (DCCD, 2013).

2.10.3 Maintenance Considerations

One of the most important maintenance needed for either of these basins is to ensure that the orifice does not become blocked or clogged (DCCD, 2013).

Keeping the pipes clear of debris will ensure the ponds and basins are functioning properly. Keeping up with maintenance can reduce costly repairs in the future. Other maintenance includes:

Identifying and repairing areas of erosion - A few times a year and after major storms, check for gullies and other disturbances on the bank (DCCD, 2013).

Removing sediment and debris - Keeping pipes clear of debris and removing sediment ensures proper function. Remove debris around and in ponds before it reaches the outlets to prevent problems (DCCD, 2013).

Maintaining vegetation - The amount of maintenance depends on the type of vegetation surrounding the basin. Some grasses need weekly mowing, and others can be maintained a couple of times a year (DCCD, 2013).

2.10.4 Selecting a reservoir routing method in HEC HMS

While a reservoir element conceptually represents a natural lake or a lake behind a dam, the actual storage simulation calculations are performed by a routing method contained within the reservoir. Three different routing methods are available. One is designed to simply represent the reservoir with a known storage-outflow relationship (HEC, 2010).

The second method uses a specified release and computes the storage that would result. The final method is designed to represent individual components of the outlet works (HEC, 2010).

There is also a choice for the None routing method. This option assumes no storage in the reservoir and all inflow is passed as outflow for each time interval of the simulation (HEC, 2010).

2.10.5 Storage methods in HEC HMS

There are three different options for specifying the storage relationship. The first option is the Storage-Discharge choice. The user must select a storage- discharge curve from the available curves in the Paired Data Manager (HEC, 2010).

The second option is the Elevation-Storage-Discharge choice. The user must select both a storage-discharge curve and elevation-storage curve from the Paired Data Manager. The final option is the Elevation-Area-Discharge choice (HEC, 2010).

In this case the user must select both an elevation-area curve and an elevation-discharge curve from the Paired Data Manager. With this choice, the program automatically transforms the elevation-area curve into an elevation-storage curve using the conic formula. Regardless of which option is selected, the routing is always performed using only the storage-discharge curve (HEC, 2010). After the routing is complete using the storage-discharge curve, the program will compute the elevation and surface area for each time step, depending on the selected storage method.

Interpolation is used when the Elevation-Storage-Discharge or Elevation- Area-Discharge storage methods are used. This means that it is not necessary for the storage-discharge and elevation storage curves used in the Elevation- Storage-Discharge method to contain matching independent variables. The two curves do not need to have the same storage values in each curve, or even have the same number of rows (HEC, 2010).

CHAPTER THREE

3.0 STUDY AREA EXISTING SITUATION ANALYSIS

In this chapter, the existing situation of the study area with respect to stormwater runoff is described. This chapter gives an overview of the existing situation of the study area to give a better understanding of what is really happening to the ground.

3.1 Urbanization

The catchment has been experiencing high urbanization rate and the impact of the urbanization on the catchment is being increasingly felt as a result of an increasing impervious surface which does not give sufficient space for water to infiltrate to the ground. These surfaces are one of the primary stressors impacting the whole hydrologic systems of the catchment. Land-use changes have been affecting the runoff quality and flow characteristics of the catchment, which in turn has been leading to increased runoff volumes and peak flows. The flash floods, soil erosion and environmental degradation, in general, are evident in the catchment as possible impacts of high urbanization rate along the catchment.

Figure 3. 1: Intensively urbanized Msimbazi catchment

3.1.1 Kisarawe sub-catchment

Msimbazi catchment originates from the higher areas of Kisarawe in Pwani region. The area has also been subjected to high urbanization rate as shown in the figure 3.2, figure 3.3 and figure 3.4 below.

Figure 3. 2: Kisarawe

The figure 3.3 from the Google Earth shows how the area was in 2005 and figure 3.4 shows how the area changed in 2015

Figure 3. 4: Kisarawe sub-catchment 2005

Figure 3. 3: Kisarawe sub-catchment 2015

3.1.2 Pugu sub-case area.

Pugu sub-catchment is located at the far end upstream of the catchment**,** Pugu is one of the highly urbanized areas along the catchment. The images 3.5 and 3.6 below show the difference in the catchment from 2005 and 2015 in terms of urbanization.

Figure 3. 5: Pugu sub-catchment 2004

Figure 3. 6: Pugu sub-catchment 2016

3.1.3 Jangwani sub-case area.

The figure 3.7 and 3.8 below show the trend of urbanization from 2005 to 2015 at Jangwani sub-catchment as it can also be seen that there are some development projects going on within the Jangwani floodplain. The Dar es salaam urban rapid transport services(Udart) headquarters are within the Jangwani valley. The 2018 rainy season flooded the area and damaged about 29 buses of the project.

Figure 3. 7:Jangwani 2005

Figure 3. 8: Jangwani 2015

3.1.4 Kinyerezi sub-catchment

Kinyerezi sub-catchment was being considered as an outskirt area of the Dar es Salaam City due to its location but currently is among of the highly urbanized areas in the catchment.

As the population keeps increasing in Dar es Salaam, also land demand for settlements has been rapidly increasing. Kinyerezi is one of the areas in Dar es Salaam with the high rate of new settlements establishment.

The sub-catchment is currently under high development pressure experiencing large-scale real estates developments such as the construction of villas, apartment complexes, office buildings, hotels and shopping malls, driven by enormous demand for residential housing, industrial as well as commercial premises.

The Kinyerezi sub-catchment rapid development in the pace of urbanization has put pressure on the river. The figures 3.9 and 3.10 below gives an overview of the situation in the sub-catchment.

Figure 3. 9: Kinyerezi 2004

Figure 3. 10: Kinyerezi 2017

3.2 Floods

Rapid urbanization in the study catchment has been changing the hydrological behavior of the catchment. Increased impervious surfaces lead to large, rapid increases in surface runoff in the catchments during the rainy seasons as less water percolates to the ground and much of it finds its way to the streams in the catchment.

Reduction in vegetation cover is also more evident in the catchment, allowing water to move much faster shortening the time which water used to spend moving from upstream to the downstream. This also contributes to the current flashy flooding scenario in the catchment.

The risk posed by floods in the catchment is exacerbated by the presence of unplanned settlements especially downstream of the catchment along the Msimbazi valley which makes even harder to plan for stormwater management facilities. The informality of settlements in the study catchment essentially comes from the processes through which such settlements evolve, develop and consolidate.

The catchment also contains squatter settlements, which connote illegality in land-holding systems. However, informal or unplanned settlements in Tanzania are recognized by the authorities. Their informality of the settlements in the study catchment emanates from the development of houses which does not follow the laid-down official procedures or planning procedures.

Flooding in the Msimbazi catchment has now become a chronic problem as it keeps on recurring each and every rainy season. When it floods some major roads in Dar es Salaam become inaccessible affecting activities in the city.

In December 2011, the catchment was hit by extreme rainfall event, which killed at least 23 people and left more than 4,500 displaced (Citizens, 2011).

The catchment has been receiving extreme flooding almost every year. The severe flooding in the Msimbazi catchment has been leading to damage of transport routes, collapsing of infrastructures (including bridges, walls, water supply and wastewater systems and buildings), accelerated soil erosion and loss of such as vehicles, livestock as well as killing people every year. The figure 3.11 and 3.12 below, show parts of the river during the 2018 rain season.

Figure 3. 11: Collapsed house along the river

Figure 3. 12: Flooding Msimbazi river

3.2.1 Flash floods

The hydrological system of the catchment is rapidly changing into flashy floods catchment due to the fact that the catchment remains almost dry for the longer period of a year than before while shorter time rainfall causing serious floods, the extreme and very destructive floods come in huge amount in a very short period and leaves the river almost dry for the rest of the year. The impacts are more evident downstream of the catchment along the Msimbazi wetland where the area is a geomorphic low-lying area

Figures 3.13 and 3.14 show the flashy nature of the Msimbazi river

Figure 3. 13: Msimbazi valley in May 2018

Figure 3. 14: Msimbazi river in June 2018

3.2.2 Ecological system destruction

Rapid development in the Msimbazi catchment has been modifying the hydrological system of the catchment in terms of the production and delivery of runoff to streams and the resulting rate, volume, and timing of the streams flow. This is mostly due to an increase in impervious surfaces as a result of development activities.

Among of the evident effects facilitated by the rapid urbanization rate in the catchment on hydrological condition of the catchment area is that streamflow rises more rapidly during storms and recedes more rapidly after storms, which is typically described as “flashy” streamflow.

The whole process has been leading to shorter wet periods in the catchment with longer dry periods as water travels faster towards the outlet downstream. The change is likely to alter optimum living conditions for some species in the catchment leading to their extinction.

3.3 Soil erosion in the study catchment

Soil erosion stands to be among of the serious effects of floods along the Msimbazi river. Due to the change in land use, change in the hydrological pattern of the catchment is now evident where more and faster-moving water is available to carry a larger sediment load.

In the processes, it is not only the very aggressive flooding water alone that has been eroding but also suspended abrasive particles, pebbles and boulders have been acting erosively as they traverse the surfaces of the streams, which is also a process known as traction. The catchment carries large floods causing erosion to happen very quickly in the catchment. The figures (3.15 and 3.16) below show part of the eroded banks of the Msimbazi river.

Figure 3. 15: Soil erosion on the river banks

Figure 3. 16: Soil erosion on the river banks

3.3.1 Soil erosin control methods

Soil erosion being threatening the residents in the catchment and as a way of trying to control, some residents along the Msimbazi river have been taking some measures to fight the problem, although in most cases the measures seem to be not sufficient enough to work against the highly aggressive flooding river during the rainy seasons carrying suspended abrasive particles, pebbles, and boulders.

Among the erosion control measures used in the study catchment, is the use of sandbags as shown in the figure 3.17 and figure 3.18 below. The soil erosion has also been threatening infrastructures (such as buildings, roads, bridges e.t.c) in the catchment.

Figure 3. 17: Soil erosion control sand bags

Figure 3. 18: Soil erosion control sand bags

CHAPTER FOUR

4.0 METHODOLOGY

In this chapter the materials and methods used in the whole process of generating storm water runoff for the Msimbazi river catchment are presented. The major activities conducted in this study includes the Digital Elevation Model processing, and preparing datasets for the Curve Number (CN) grid which includes land use classification, hydrological soil group preparation, merging of soil and land use shape files and creating CN Lookup table by the use of GIS and GIS extension tools; hydrological modeling using HEC-HMS.

4.1 Materials

In this part, all the materials used in the whole process of generating storm wate runoff for the Msimbazi river catchment to the accomplishment of the study are described.

4.1.1 Description of the study area.

The Msimbazi catchment is one of the Catchments in Dar es salaam located between latitudes 6°27’ and 7°15 south of the Equator and between longitudes 39° and 39°33’ East of Greenwich. The Msimbazi river flows across Dar es Salaam City all the way from the higher areas of Kisarawe district (Kisarawe hills) in the Coastal region and discharges into the Indian Ocean. Some of the streams forming the Msimbazi catchment are highly subjected into industrial and other anthropogenic pollution loading. Because of its location, as the river passes through the center of the city on its way to the Indian ocean, has been causing numerous of floods related disasters especially to the residents settled along the river banks.

The Msimbazi river is one of the longest rivers in Dar es Salaam, and flows roughly 36 kilometres from the Kisarawe Hills to the shores of the Indian Ocean. The rate of people establishing their settlements along the river has been highly increasing especially downstream of the river where also more disastrous events are witnessed every year. More than 65,000 people live downstream of its most polluted areas within 200 metres of the river bank. Based on census data, this means up to 232,000 living in adjacent wards also face serious flooding risks, as during the rainy seasons most of the houses along the catchment find themselves completely swallowed by the flooding water. The figure 4.1 below shows the delineated Msimbazi catchment.

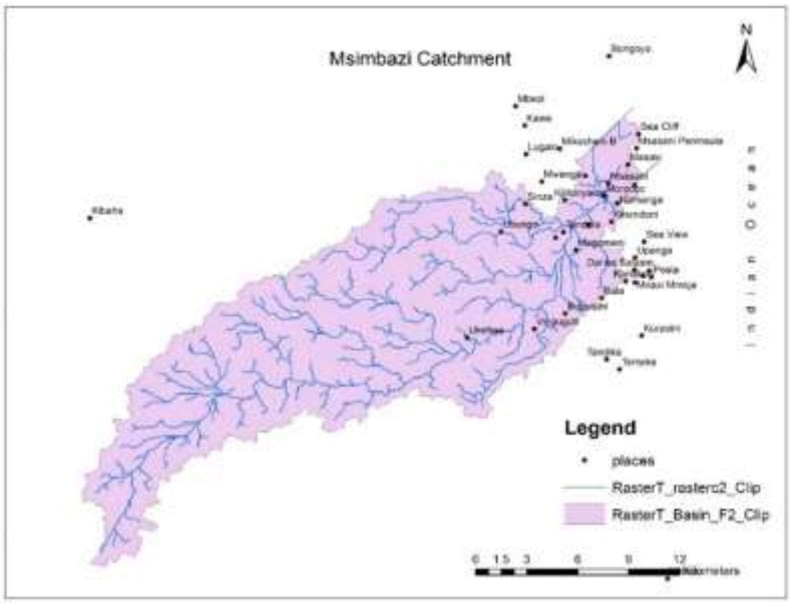


Figure 4. 1 Msimbazi river Catchment, Dar es Salaam.

Figure 4. 2: Msimbazi catchment on Google Earth

4.1.2 Description of the Datasets

4.1.2.1 ArcGIS, HEC-GeoHMS extension tool and HEC-HMS

Some of the software packages used in this study includes the ESRI's ArcGIS software for maps processing, Hydrologic Engineering Centers Geospatial Hydrologic Modeling Extension (HECGeoHMS) which is a public domain extension to ESRI's ArcGIS software and the spatial analyst extension. These are hydrology toolkits for engineers and hydrologists in executing different related tasks including storm water modeling. The activities ranges from the ability of the user to visualize information, document watershed/catchment characteristics.

Also the tools help in performing different spatial analyses, delineating basins and stream networks, constructing inputs for hydrologic models as well as assisting in preparation of well-organized reports. Therefore, use of HEC-GeoHMS can easily and efficiently create hydrologic inputs that can be used directly for the hydrologic modeling in HEC-HMS.

Figures 4.3 and 4.4 below show ArcGIS and HEC HMS main working windows respectively

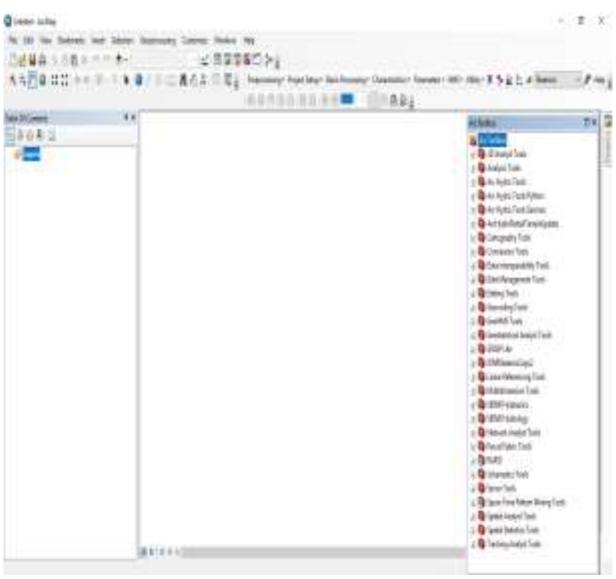


Figure 4. 3: ArcGIS window

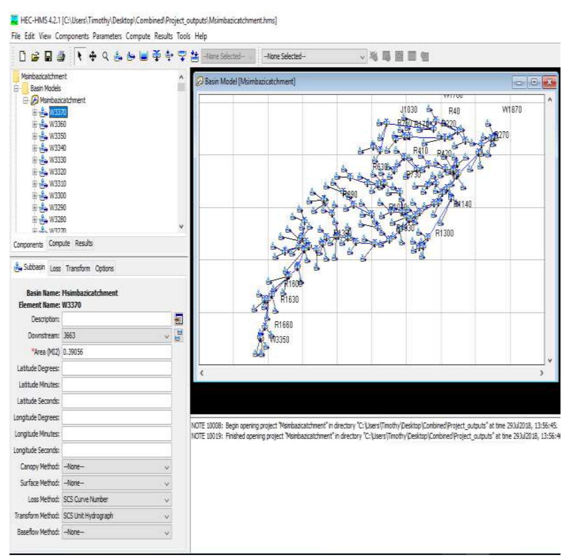


Figure 4. 4: HEC-HMS window

4.1.2.2 Digital Elevation Model (DEM) of the study area

A Digital Elevation Model (DEM) can be defined as a specialized database representing the relief of a surface between points which have known elevation. A rectangular digital elevation model can also be created by interpolating known elevation data on the ground acquired from sources such as ground surveys and photogrammetric data capture.

Digital Elevation Model is one of the key dataset used in this study, it was used to delineate the study catchment and provide inputs to the HE HMS model for storm water runoff modeling. The Digital Elevation Model which was used in this study was of 30m by 30m resolution which had to be reconditioned in order to account for the flat areas and was downloaded from the official website of United States Geological Survey (USGS) and can be freely accessed through the following link; http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3accg. Figure 4.5 below shows the clipped raw DEM of the study area.

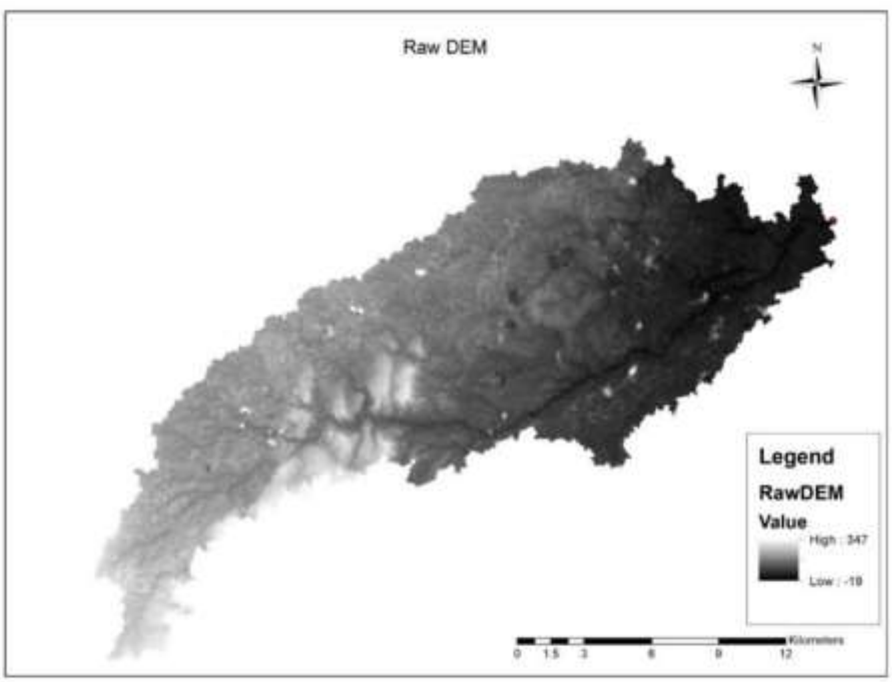


Figure 4. 5: Raw DEM

4.1.2.3 Precipitation data

In the basin model, the 30-days daily rainfall datasets were used as inputs. The basin model consists of four sub models, rainfall loss model, direct runoff model, base flow model and routing model. In the precipitation model, Theissen weights method was used. Theissen weights was determined and given values for each sub basin. Then the simulation time interval was determined with start and end dates of simulation.

4.1.2.4 Land cover/land use data

Watershed land cover has a great importance in estimating the basin’s curve number with the identification of soil textures and its permeability. This method has been widely applied to estimate storm runoff depth for every patch within a watershed based on runoff curve numbers (CN) (Qihao Weng, 2001). The first step for curve number generation is landsat data processing and analysis by using Arc GIS software package.

The landsat image used was downloaded from the official website of United States Geological Survey (USGS) and it is freely accessible by using the following link: http://earthexplorer.usgs.gov/. For this study the landsat data of the catchment for 2016 with a resolution of 30mX30m was selected and used. The process of selecting the satellite image based on the availability of hourly rainfall, quality of image and resolution available.

4.1.2.5 Soil data

Soil data is one of the required inputs in the process of creating Curve Number (CN) Grid of the catchment. There are four groups of soil hydrologic groups according to the classification of (USDA, 1986), namely A, B, C and D. Group A soil types is known for high infiltration rate; group B soils types is known for moderate infiltration rates; group C soil types is known for slow infiltration rate and group D soil types is known for very slow infiltration rate. In the soil map used in this study, three categories of the hydrological groups were identified which are group B, group C and Group D. Accordingly, the soil map of the study area found from Ministry of agriculture as shape file and all of these soil types found in the area categorized on three Hydrological Soil Groups (HSG), namely B, C and D.

4.1.2.6 Curve Number (CN) Grid

The Curve Number(CN) Grid is an empirical parameter which plays an important role in hydrology in determining direct runoff when the amount of rainfall is in excess. The method was developed by U.S. Natural Resource Conservation Service (NRCS) also known as the Soil Conservation Service (SCS)). In this study the Curve Number was developed from the merged land use and soil data in ArcGIS software packages and was used to estimates the effective rainfall with respect to cumulative rainfall, the land use, the soil type and the antecedent soil moisture condition.

4.2 Methods

In this part, the methods and procedures followed in the whole course of the study to its accomplishment are described.

4.2.1 Digital Elevation Model Data Processing

Overview

There are different ways of catchment delineation including traditional approach of processing topographical maps but this watershed delineation approach lacks behind in terms of accuracy and is time consuming approach. An automatic approach of watershed delineation from Digital Elevation Model replaces the traditional approach by the use of GIS software packages. High resolution Digital Elevation Model which can also be freely accessed from data sources produces high quality delineated maps. In this study, Digital Elevation Model was used to delineate the Msimbazi catchment using the ArcGIS software packages through number of procedures described below to develop basin model components in conjunction with HEC Geo HMS extension tool to prepare data for the HEC HMS model.

The United States Geological Survey (USGS) website provides 30x30m Digital Elevation Model data which can be freely accessed. In this study, 30x30m Digital Elevation Model was used downloaded from the official website of the United States Geological Survey (USGS) through the following link; http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3accg.

The combination of ArcGIS 10.3 and ArcGIS 10.5 to process the Digital Elevation Model during the delineation process as one of the require procedures towards the storm water modeling. The Digital Elevation Model had to be hydrologically reconditioned to ensure that the streams of interest are captured.

In summary, all the procedures of watershed delineation described below are grouped into two main forms which are those in raster format and those in vector format as listed below.

Raster based

- Projected DEM (considered as raw DEM)
- Fil (sink filled DEM)
- Fdr (flow direction grid)
- Fac (flow accumulation grid)
- Str (stream network grid)
- StrLnk (stream link grid)
- Cat (catchment grid)
- WshSlopePct (slope grid in %)

Vector based

- Catchment
- DrainageLine
- AdjointCatchment

4.2.1.1 Digital Elevation Model projection and clipping

The Digital Elevation Model acquired was in the form of GCS_WGS_1984 raster format, therefore in order to ensure that the Digital Elevation Model projection resembles the projection of the study area had to be changed to the Universal Transverse Mercator (UTM) with WGS-1984, UTM Zone 37S which is the zone of the case study by using the project raster tool of the Data Management tools in ArcGIS software. Then the projected Digital Elevation Model was clipped to the size of the catchment.

4.2.1.1.1 DEM projection

Digital Elevation Model clipping was done by using the ArcToolbox Project Raster Tool in the Data Management toolbox then Projections and Transformations toolbox where the Digital Elevation Model was required as input. The procedures followed were as follows; In ArcToolbox (Data Management > Projections and Transformations > Raster> Project Raster), then the project raster tool was double clicked to access the raster projection window.

The Digital Elevation Model projection process was necessary in order to match the projection of the Digital Elevation Model with the projection of the study Catchmen.t

4.2.1.1.2 DEM clipping

Digital Elevation Model clipping was done by using the ArcToolbox Clip Raster Tool in the Data Management toolbox where the Digital Elevation Model and catchment polygon boundary were required as inputs. The procedures followed were as follows; In ArcToolbox (Data Management > Raster > Raster Processing > Clip), then the clip tool was double clicked to access the clip window.

The DEM clipping process can only be done if the polygon boundary of a catchment is already available, otherwise the delineation process can proceed without this step.

4.2.1.2 DEM Reconditioning

Downstream of the Msimbazi catchment is almost flat, therefore when the flow of water reaches to the flat area it gets confused of the exact path to follow, therefore to eliminate this problem the Digital Elevation Model had to be reconditioned using the available streams shape-file of the catchment.

Digital Elevation Model reconditioning is a process of adjusting the DEM so that the DEM elevations direct drainage towards the vector information on stream position to ensure that the DEM output represents the actual situation on the ground.

DEM reconditioning is useful in the case where the vector stream information is more reliable than the raster DEM information due to accuracy issues.

Raw Digital Elevation Model was used an input to the function and the study catchment streams (linear feature class) were also used as a burning feature. Both had to be present in the map document successful reconditioning process. To accomplish the task, Terrain Preprocessing was selected followed by DEM Manipulation then DEM Reconditioning as shown in figure 4.6 below.

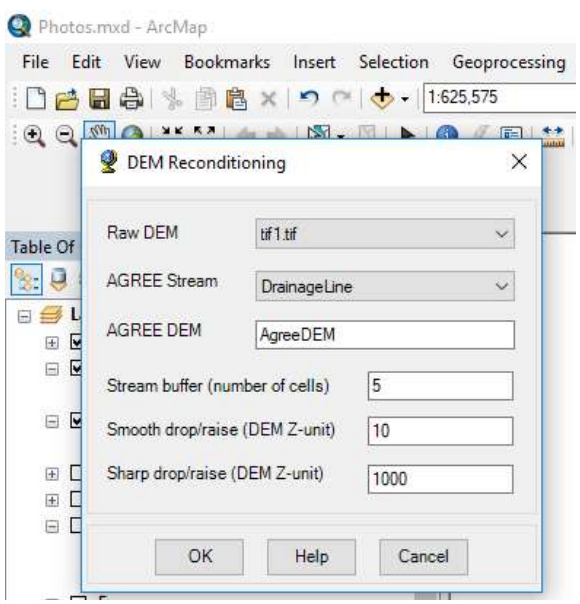


Figure 4. 6: DEM reconditioning

4.2.1.3 Filling sinks

The fill sinks tool in ArcHydro tools was used to fill sinks in the Digital Elevation Model. This was done to ensure that, if there are cells with higher elevation surrounding a cell with a lower elevation, hinders the water to flow and makes it trapped in the lower elevation cell, hence the water cannot flow out of the cell. Therefore, the fill sinks operation tends to modify the Digital Elevation Model and was used to eliminate the elevation problems to make the Digital Elevation Model hydrologically corrected and ready for the next step. The figure 4.8 below shows the hydro filled DEM.

Figure 4. 7: Fill sinks ArcMap window

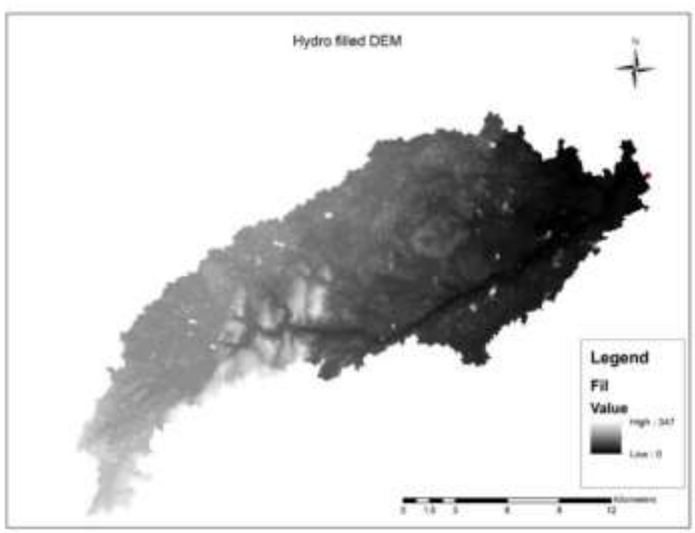


Figure 4. 8: Hydro filled DEM

4.2.1.4 Flow direction

Flow direction tool was used to indicate the direction of the steepest descent to a neighbor cell and defined for each grid cell. Generally, this function computes the flow direction for a given grid in which the values computed in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. This followed after filling the sinks as shown in the figures 4.9 and 4.10 below.

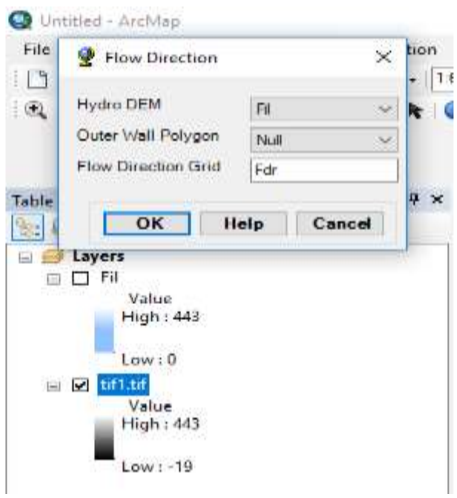


Figure 4. 9: Flow direction ArcMap window

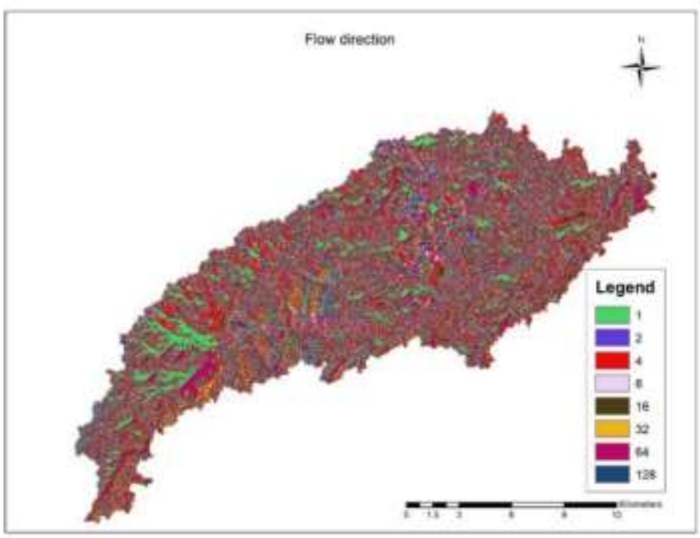


Figure 4. 10: Flow direction

4.2.1.5 Flow accumulation

This process involves defining the number upstream cells draining into any given downstream cell in the grid. Computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid of the particular watershed. This process depends on the flow direction to define the cells as shown in the figures 4.11 and 4.12 below.

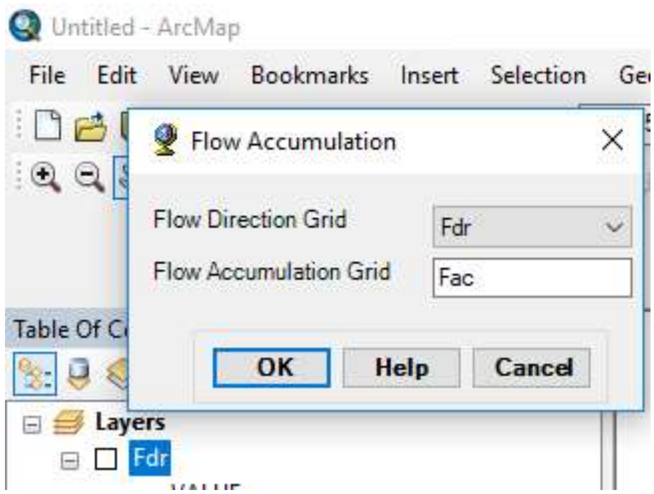


Figure 4. 11: Flow accumulation ArcMap window

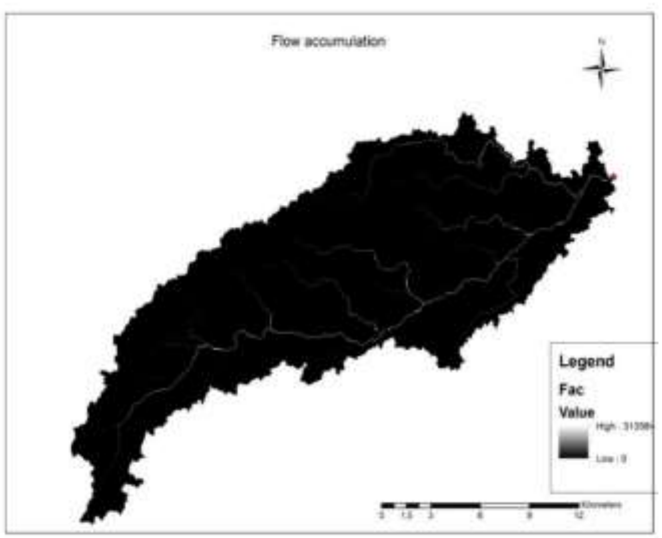


Figure 4. 12: Flow accumulation

4.2.1.6 Stream definition

In this process, the grid cells forming the stream network were defined based on a threshold number of grid cells that drain into a given downstream grid cell as shown in the figures 4.13 and 4.14 below.

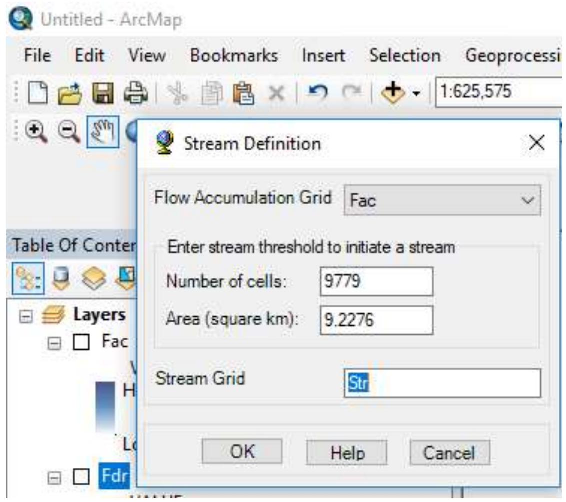


Figure 4. 13:Stream definition ArcMap window

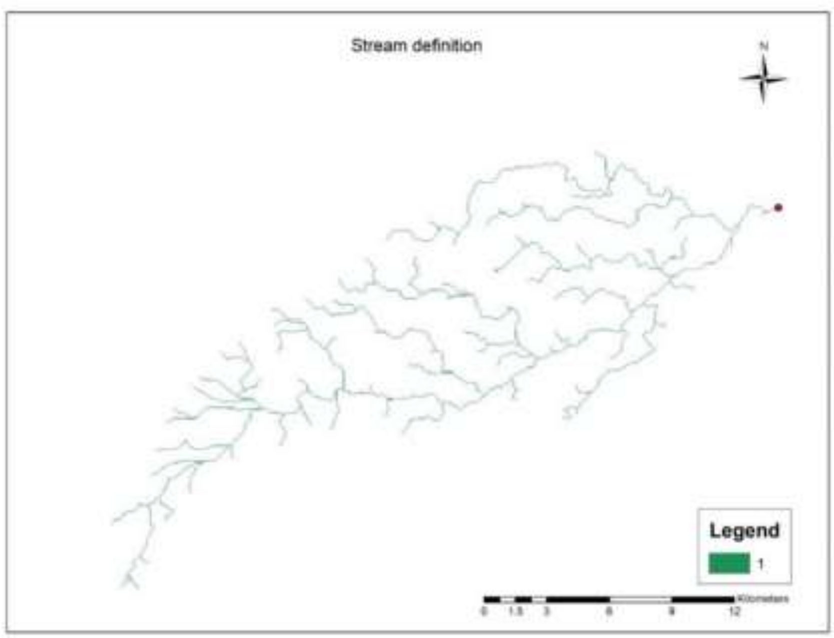


Figure 4. 14: Stream definition

4.2.1.7 Stream segmentation

Stream segmentation tool tends to create streams by splitting the stream as defined in the stream definition process at any junction. The figures 4.15 and 4.16 Below show the images from the stream definition tool.

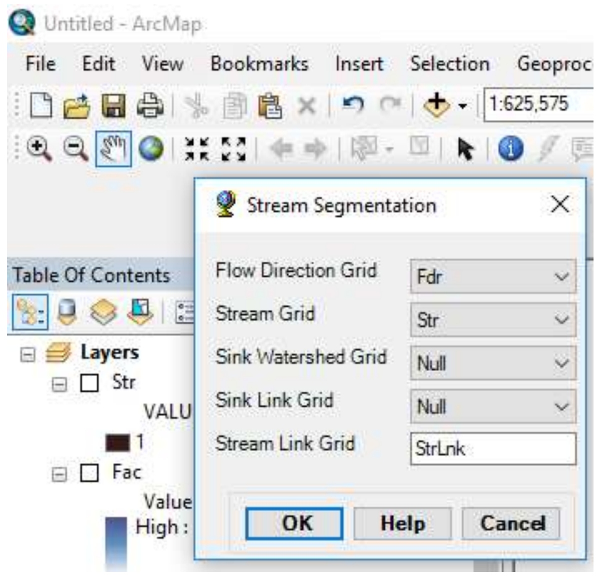


Figure 4. 15: Stream definition ArcMap window

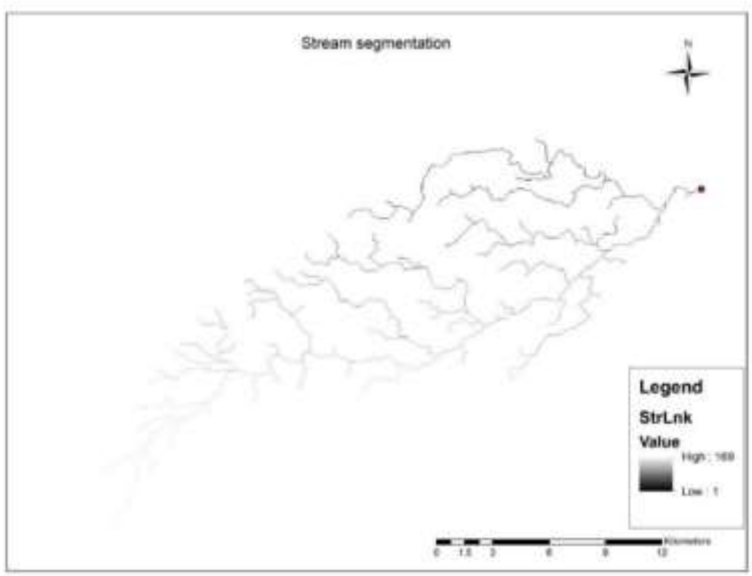


Figure 4. 16: Stream segmentation

4.2.1.8 Catchment grid delineation

The catchment delineation process followed by catchment grid delineation in the Terrain Processing tool of the Arc Hydro Tools. In this process, for every stream segment part defined by the stream segmentation process, the corresponding watershed is delineated and stored in a grid file as shown in the figures 4.17 and 4.18 below.

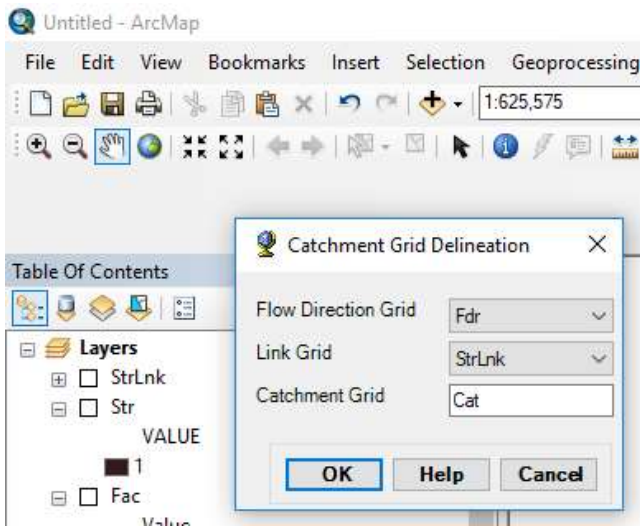


Figure 4. 17: Catchment grid ArcMap window

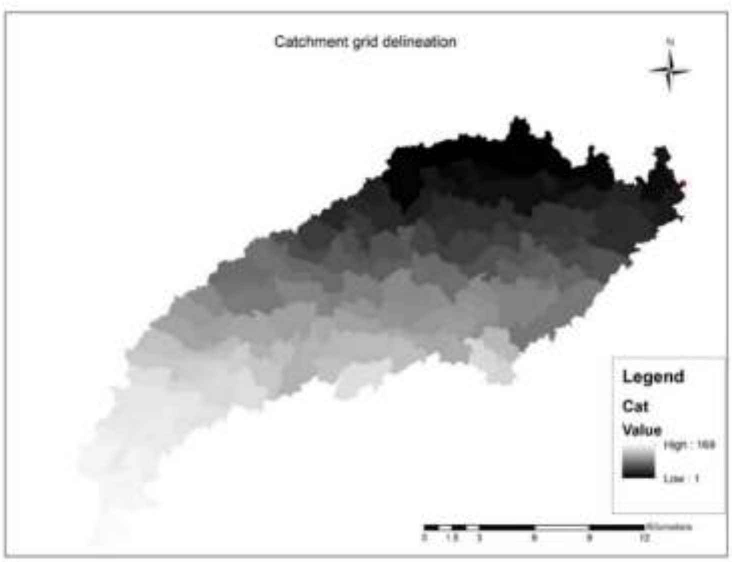


Figure 4. 18: Catchment grid delineation

4.2.1.9 Watershed slope

Watershed slope tool in Arc Hydro tools takes raw DEM as an input to compute slope of a watershed. The figures 4.19 and 4.20 show the image of the watershed slope computed from the slope tool in ArcGIS.

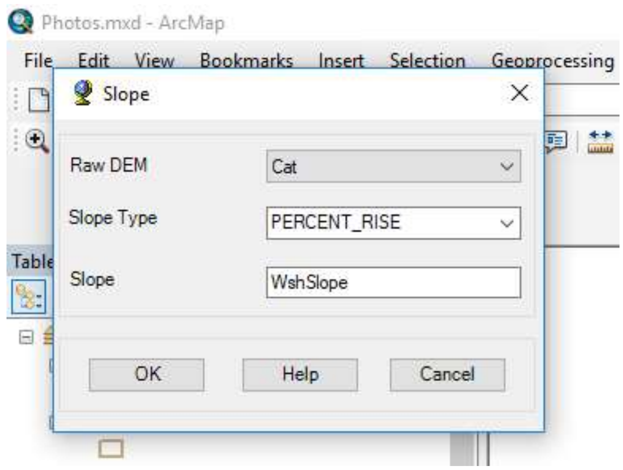


Figure 4. 19 Slope ArcMap window

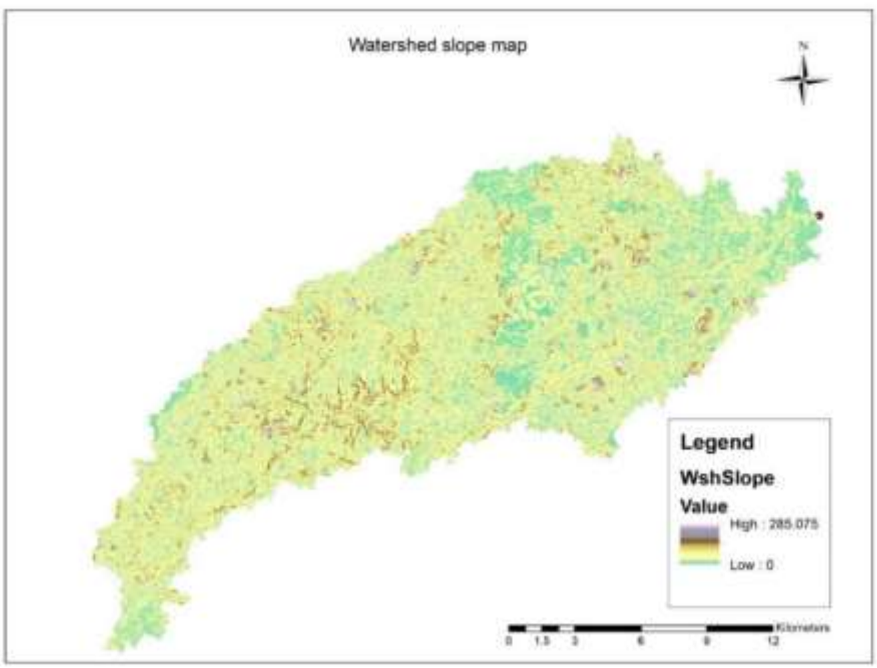


Figure 4. 20: Watershed slope

4.2.1.10 Catchment polygon processing

This process uses the polygon generated from the catchment grid to delineate the boundaries of each sub basin as shown in figures 4.21 and 4.22 below.

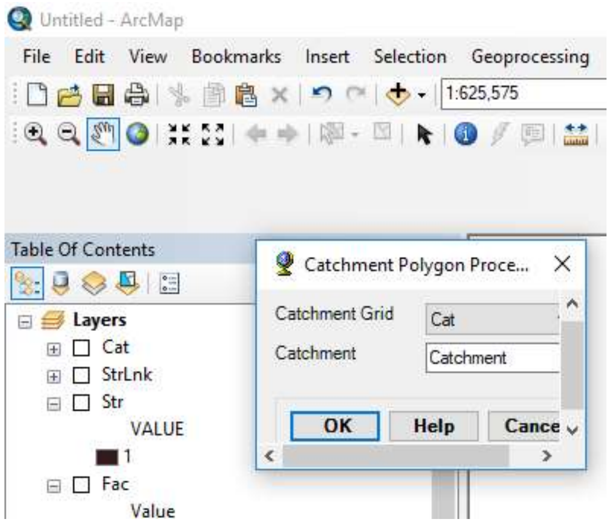


Figure 4. 21 Catchment polygon ArcMap window

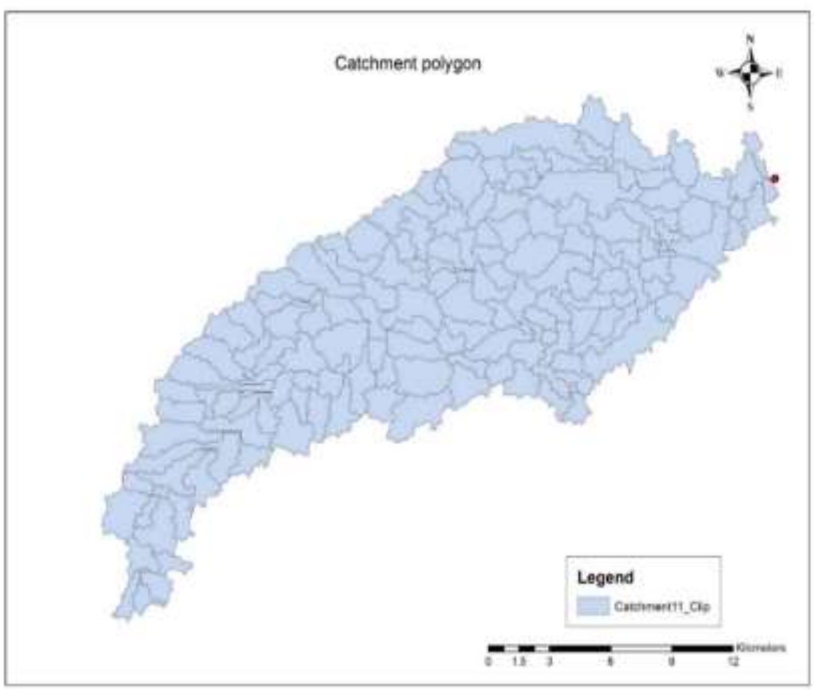


Figure 4. 22: Catchment polygon

4.2.1.11 Drainage line processing

This function uses the output generated from the stream segmentation grid and transforms it into a vector stream layer as shown in the figures 4.23 and 4.24 below.

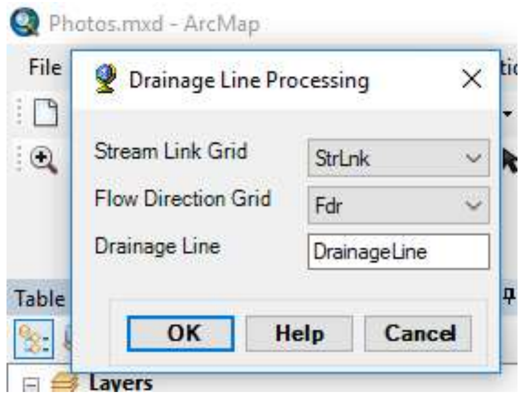


Figure 4. 23 Drainage Line ArcMap window

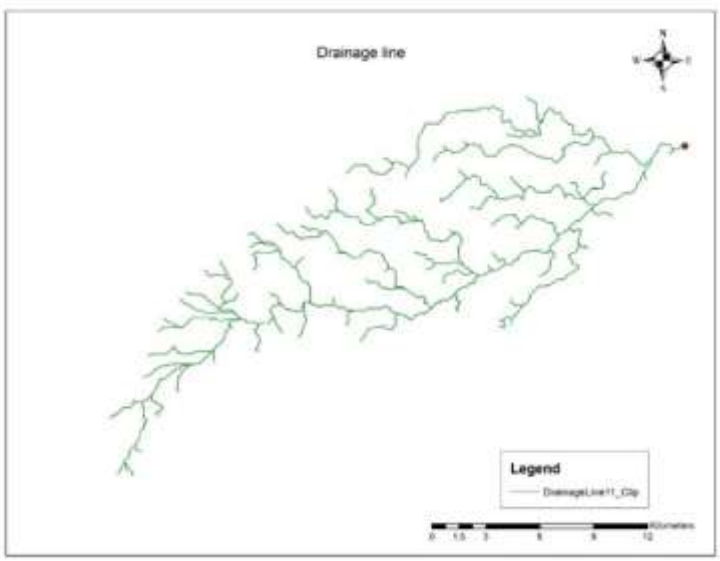


Figure 4. 24: Drainage line

4.2.1.12 Adjoint catchment processing

In this process, the upstream sub basins were aggregated at any stream confluence, if an error happens in the adjoint catchment processing might also lead to problems in auto-extraction of a catchment of interest especially when the DEM was not clipped to the size of the catchment from the beginning.

4.2.2 Curve Number (CN) Grid Inputs Preparation

General overview

Before generating the Curve Number(CN) Grid, several procedures have to be followed in order to prepare inputs for the Curve Number(CN) generation. Some of the procedures includes Landsat images processing, preparing soil data, merging land use/land cover data with soil data and creating CN Lookup table as described below.

4.2.2.1 Landsat data processing

4.2.2.1.1 Combining bands

After all the available bands of satellite image were loaded in the ArcMap 10.5, the Image Analysis tool was activated and the bands were combined by using composite bands function. The figure 4.25 shows the image of combined bands.

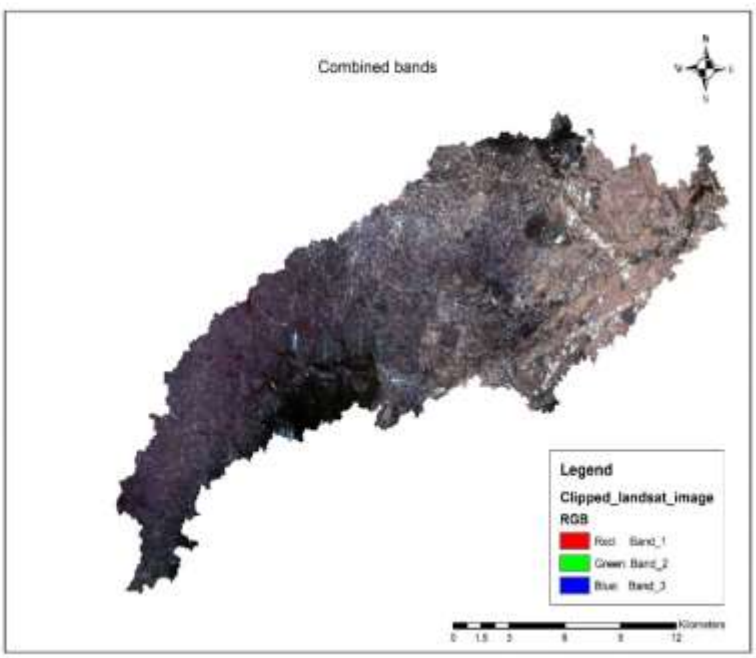


Figure 4. 25: Combined bands

4.2.2.1.2 Projection of the combined bands

After combining the landsat images previously in GCS_WGS_1984 raster format, the combined landsat image was changed to the Universal Transverse Mercator (UTM) projection raster form by considering zone of the study area which WGS-1984, UTM Zone 37S by using Project Raster tool in the Data Management tools.

4.2.2.1.3 Clipping landsat image

The projected landsat image was clipped to the size of the catchment using the shapefile of the case study.

4.2.2.1.4 Band color arrangement

For proper visualization of the landsat image, the individual bands composited in a 1,2,3(Red, Green and Blue (RGB)) was changed to 5,4,2 RGB combination in order to visualize the data in color. The colors can be arranged in many other ways but in this study, the 5,4,2 RGB combination was selected as it gives better visualization of the image for classification.

4.2.2.1.5 Land use classification

The Interactive Supervised Classification and the Maximum Likelihood Classification methods were used to perform the land use/land cover image classification using the Image Classification tool. Six categories of the land use in the catchment were identified, namely develop low intensity, developed medium intensity, developed high intensity, water bodies, wetland and forest.

4.2.2.2 Preparing Soil Data for CN Grid

There are four groups of soil hydrologic groups according to the classification of (USDA, 1986), namely A, B, C and D. Group A soil types is known for high infiltration rate; group B soils types is known for moderate infiltration rates; group C soil types is known for slow infiltration rate and group D soil types is known for very slow infiltration rate. In the soil map used in this study, three categories of the hydrological groups were identified which are group B, group C and Group D. Accordingly, the soil map of the study area found from Ministry of agriculture as shape file and all of these soil types found in the area categorized on three Hydrological Soil Groups (HSG), namely B, C and D. The soil map was clipped into the catchment size and then merged with the land use/land cover map.

4.2.2.3 Merging of Soil and Land Use Data

The CN grid generation requires both of the soil and land use data, therefore as discussed before both the land use class and soil class of the study area were prepared in shape file format. The two datasets are very important data for curve number (CN) generation. In order to be able to utilize the data for Curve Number generation the two shape files had to be merged by using the union function in the Analysis Tools of the Arc GIS 10.5 software package. The union function uses the both land use and soil feature classes as inputs. The output of the merged features contained attributes values from both the land use and soil data.

4.2.2.4 Creating CN Look-up Table

Curve number look up table plays an important role as an input table for CN grid generation. In this study, the CN Look-up Table was created by using create table function of Arc GIS 10.5.

In the table, columns for assigning Curve Numbers for Hydrologic Soils Group(HSF) were created. The columns represented by A, B, C and D in the table store Curve Numbers for each of corresponding soil groups for each land use category.

The Curve Number values are determined by using SCS TR55 (1986). According to the SCS TR55 (1986), the CN values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates.

4.2.3 Hydrologic Model Development and Run off Generation

General

This is the section where the methods, models and procedures that were used to generate the runoff for the Msimbazi catchment are described in detail. The rainfall-runoff modeling/simulation was performed by using the following HEC-HMS methods:

(i) Infiltration loss simulation; SCS CN method was used;

(ii) Converting excess rainfall to runoff model; SCS unit hydrograph (UH) was used

(iii) Channel flow routing was accomplished by the use of Lag routing method.

The main input data for the rainfall-runoff modeling is a topographic data's extracted from digital elevation model of 30m resolution

4.2.3.1 Datasets summary

For the rainfall-runoff simulation, the following datasets were prepared; hourly rainfall, CN lookup table, impervious percentage area and land use/soil union shape file of the Msimbazi River watershed. The process of preparation mainly involved the use of ArcGIS 10 software packages.

4.2.3.2 Creating Impervious Grid of the Project Area

Impervious grid was also an important parameter for the rainfall-runoff simulation. The impervious grid dataset was calculated with respect to the land use data. The TR-55 provides some information on impervious percentages with respect to a certain type of land use.

Impervious cover plays an important role on hydrological modeling especially in urban watersheds with high contribution in determining the amount of runoff generated in a catchment. The more impervious a land cover is, the more the storm water runoff will be generated as the surface does not provide space for water to infiltrate to the ground.

Therefore, impervious grid dataset was required in order to run the model in HEC HMS. Generating impervious grid in ArcGIS, automatically populates the data in HEC HMS rather typing the data manually.

Typing impervious grid manually in HEC HMS might be a tedious and time consuming work for a big catchment with many sub-basins.

Percentage of impervious grid of the land use was needed to map as a continuous variable and its value ranges from 0 to 100 percent.

Generally, 0 indicates the entire area is pervious almost all of the rain falling into the particular area infiltrates into subsurface of the area and 100 means all the available rainfall gives runoff and infiltration is almost 0.

The process of creating Impervious Grid of the Project Area involved main two steps as described below;

4.2.3.2.1 Converting classified land use map (raster) into polygon

The first step in the process of creating impervious grid using was to convert the classified raster land use map into a polygon feature class and add percentage of impervious column in the attribute table of land use polygon feature class.

The land use map had to be converted into polygon feature class in order to access the features of the classified land use map in attribute and export the table into excel for further processing.

The percentages of land use impervious were prepared in excel and opened in Arc GIS. The two tables (land use impervious from excel and land use polygon attribute table) were joined by using join function of Arc GIS.

The impervious percentages created in excel were populated in the impervious field added in the land use attribute table by the use of field calculator function.

4.2.3.2.2 Generating impervious grid

The second step is generating impervious grid using feature to raster function of the ArcToolbox. In the window, land use polygon was used as input feature while impervious percent column of the land use polygon attribute table was used as field to be mapped. This generated percentage of impervious grid as is a basic input for HEC-HMS project generation. Figures 4.26, 4.27 and 4.28 below show the impervious grid of the catchment for the years 1998,2009 and 2018 respectively

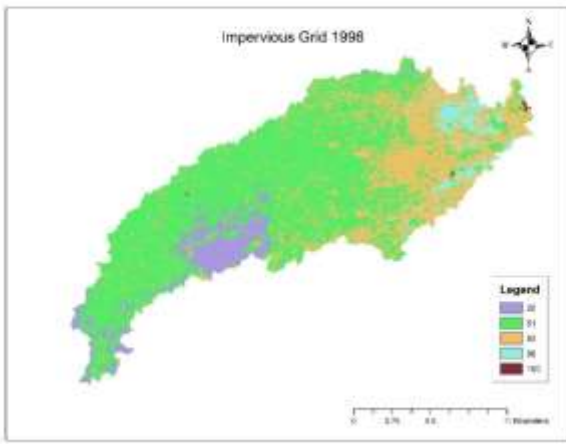
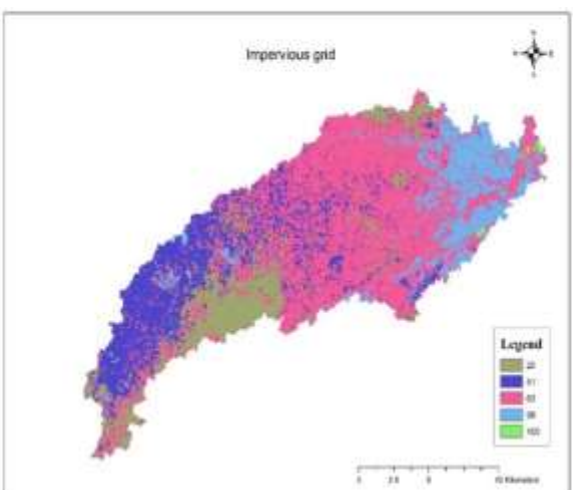


Figure 4. 26: Impervious grid 1998



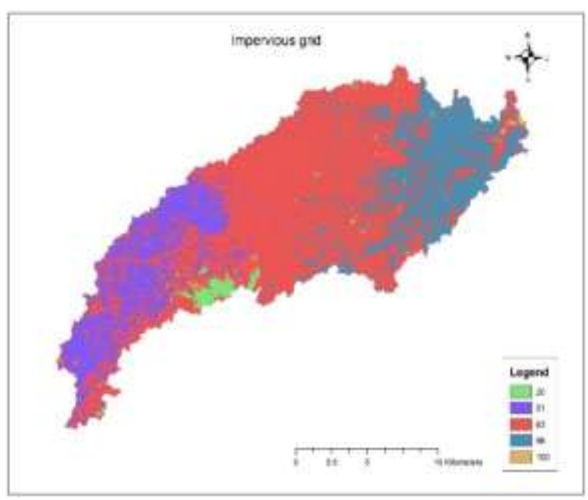


Figure 4. 27: Impervious grid 2009

Figure 4. 28: Impervious grid 2018

4.2.3.3 Curve Number Grid Generation

The following are the inputs required by the HEC-Geo HMS to generate the Curve Number Grid

- ❖ Merged land use and soil data
- ❖ Sink filled DEM
- ❖ CN lookup table

All the above listed datasets were created on the previous steps with their required formats, the files were used as inputs to generate the CN grid by the use Create CN Grid tool in the utility function of the HEC- Geo HMS extension. The Curve Number Grid is one of the required inputs to the HEC HMS modeling using SCS Curve Number method. Figure 4.29 below shows the Curve Number grid for the year 1998.

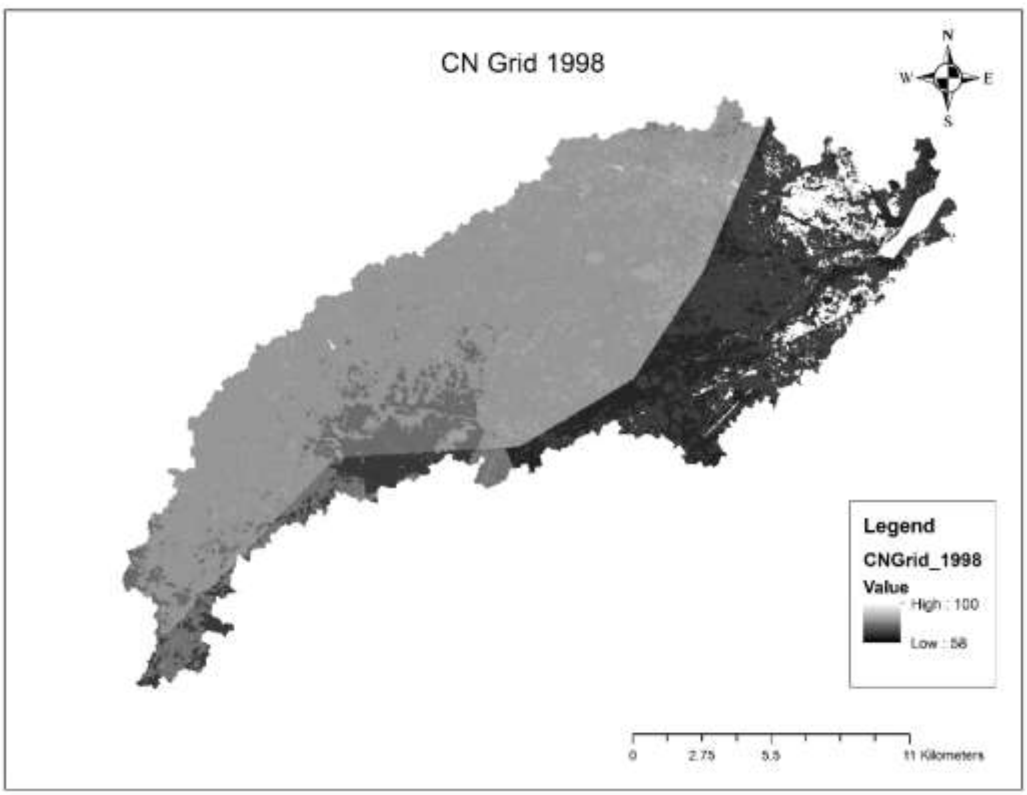


Figure 4. 29: Curve Number grid 1998

4.2.4 HEC-HMS Project Generation

To create an HMS project different tools of HEC- GeoHMS were used which are found in four main views namely;

- ❖ HMS project set up
- ❖ Basin characteristics,
- ❖ HMS input parameters
- ❖ HMS menus.

4.2.4.1 HMS project setup

The Project setup tool of HEC-Geo HMS was used to create HMS project which has the following four parts;

- ❖ Data management,
- ❖ Start new project,
- ❖ Generate project
- ❖ Remove project

4.2.4.1.1 Data management

The data management window takes raw DEM, Sink filled DEM, flow direction grid, flow accumulation grid, stream network grid, stream link grid, catchment, adjoint catchment and drainage line as inputs. These datasets were checked on the data management window of HEC- GeoHMS to ensure that each field has been assigned with the required map layer for project generation

4.2.4.1.2 Creating new HMS project

In the start new project window, the default parameters were used on the project area and project point. The process created the project point and project area feature classes. Also, on the project outlet window, the default parameters were used.

4.2.4.1.3 Generating the HMS project

The generate project tool was used to generate the HMS project. The data management window was checked again to ensure that each field is assign with appropriate map layer and HMS project is generated by creating a mesh (by delineating watershed for previously created main outlet of the Msimbazi watershed). In this process, a total of 151 sub basins and 83 junctions were generated, the figures 4.30 and 4.31 show the streams generated.

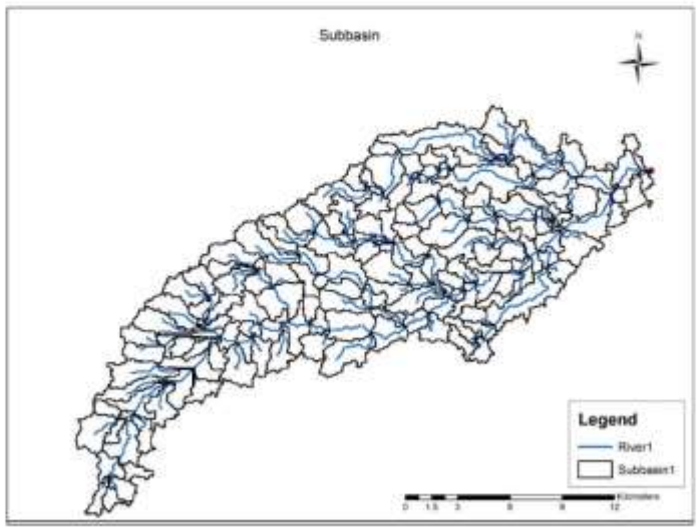


Figure 4. 30: Generated basins

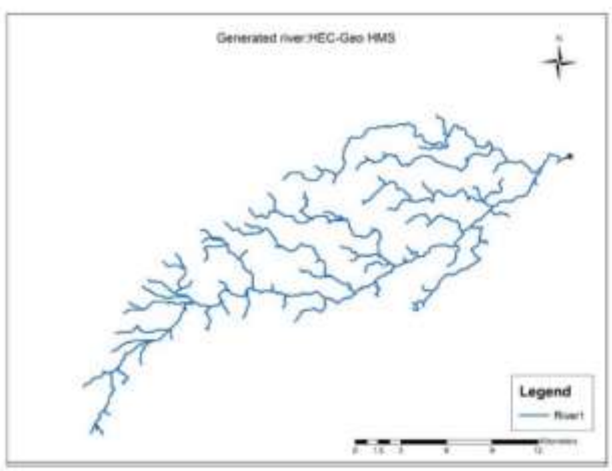


Figure 4. 31: Generated river

4.2.4.2 Extracting watershed characteristics

The process of extracting physical characteristics of sub-basins and streams into attribute tables is accomplished by using the basin characteristics tool of HEC- GeoHMS. The following are the physical characteristics extracted;

- River length

  In this process the length of each river segments is computed and stored by using the river name selected before as an input.
- River slope

  In this process, the river slope tool was used to compute the slope of the river segments and stores by using raw DEM and created river.
- Basin slope

  In this process, an average slope of each sub-basin was computed using the slope grid and sub-basin polygons.
- Longest flow path

  In this process, the longest flow path for each sub-basin of the Msimbazi catchment was computed by the use of raw DEM, flow direction grid and sub basins as inputs.
- Basin centroid

  In this process, a point feature class was created based on the size of each sub-basin and stored.
- Basin centroid elevation

  In this process, the elevation for each created centroid point was also created by using raw DEM and basin centroid as inputs.
- Centroidal longest flow path

  In this process, a polyline feature class was created by using this tool. The creation of this polyline showed the flow path for each centroid point previously created along the longest flow path of each sub basin of the Msimbazi catchment.

Figures 4.32 and 4.33 below shows the centroidal longest flow paths for the study catchment.

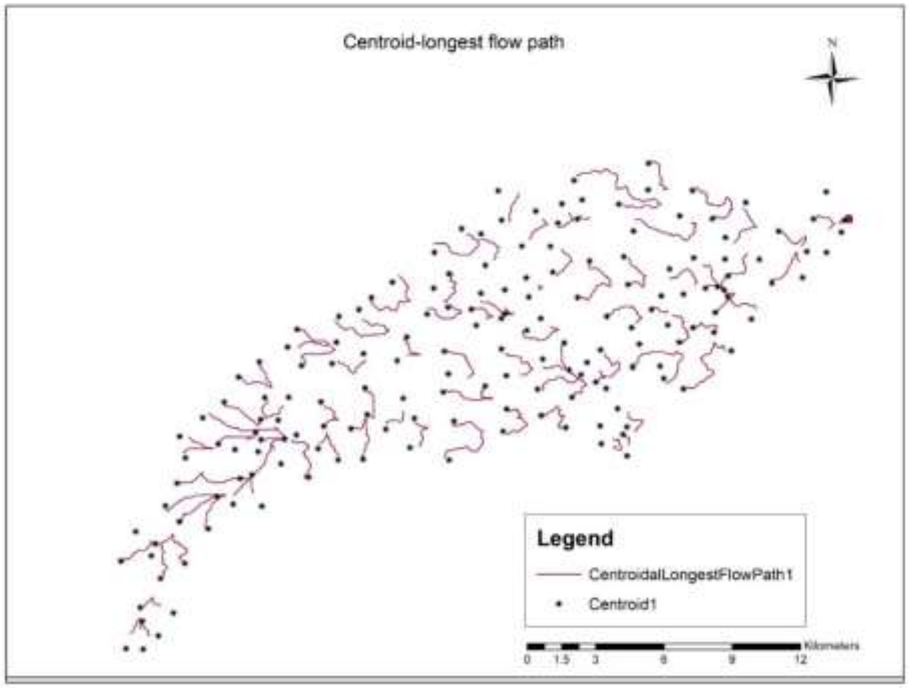


Figure 4. 32: Centroidal longest flow path with centroid points

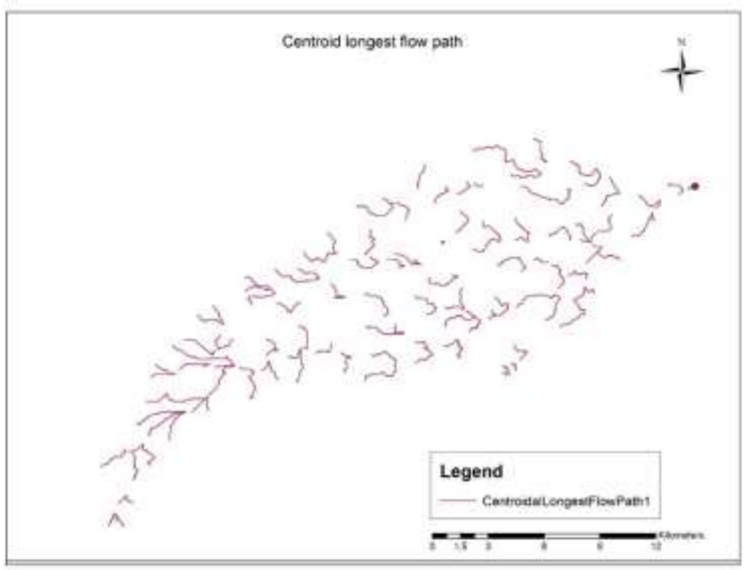


Figure 4. 33: Centroidal longest flow path without centroid points

4.2.4.3 HMS Inputs/Parameters

The hydrologic parameters menu of HEC – Geo HMS has tools to compute and assign watershed and stream parameters. At this stage, the following tools were used;

- HMS processes

  In the HMS process window, the basin name and river name were automatically selected. Then the SCS method was selected for Transform Method and Loss Method, none was selected for Base Flow Type, and Lag time method was selected for Routing Method (channel routing).
- River auto name

  River auto name was used to assign names to the river segments
- Basin auto name

  Basin auto name function was used to assign names to each sub-basin
- Sub-basin parameters from raster

  The Sub-basin parameters from raster took basin as input and curve number grid to populate the data from curve number grid to the basin attribute table.
- CN lag method

  In this process, the CN Lag Method function was used to compute basin lag in hours in which is the weighted time of concentration or time computed from the center of mass of excess rainfall hyetograph to the peak of storm runoff hydrograph

4.2.4.4 HMS project creation

At this stage several activities were accomplished in ArcGIS using the which are, Map to HMS Units, data checking through Check Data tool, HMS schematic, HMS toggling and legend, adding coordinates using the Add Coordinates tool, preparing data for model export, background shape file, basin model, meteorological model created and lastly the HMS project was created making the project ready to be used in the HEC HMS.

4.2.5 HEC-HMS Model Analysis

General

The HEC-HMS 4.2 software used was freely downloaded from the official website of US Army Corps of Engineers through the following link; http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx.

For rainfall-runoff simulation the HEC-HMS model has the following major components;

- Basin model,
- Meteorological model
- Control specification.

The control specification contains time related information (year, starting date and time, end date and time) for the simulation.

The HEC-HMS model analysis;

- Storm runoff modeling using daily rainfall with urbanization effect analysis

4.2.5.1 Storm runoff Modeling Using Daily Rainfall

In this study, daily rainfall datasets were used as inputs to the HEC HMS model for the rainfall-runoff simulation. The HEC-HMS 4.2 used in this study was downloaded from the the US Army Corps of Engineers official website of as the model can be freely downloaded through the following link; http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx

4.2.5.2 Creating a meteorological model

The meteorological dataset used in this study was collected at the Tanzania Meteorological Agency (TMA). The rainfall data available for the case study starts from daily recorded rainfall where the study catchment falls under the Julius Nyerere International Airport rainfall station which also first class rainfall station with automatic recorders.

For this study, the daily of December 2011 was selected which is also the most extreme event recorded to date within the span of the 50 years ago. In order to avoid rainfall variation and ensure equal distribution of rainfall for the selected study years, the daily rainfall dataset from 1st of December 2011 to 31st of December 2011 was selected and applied to 1998, 2009 and 2018 study years.

The rainfall dataset had to be kept constant in order to account for the effect of the land use change. Figure 4.34 below shows the meteorological dataset window in HEC HMS.

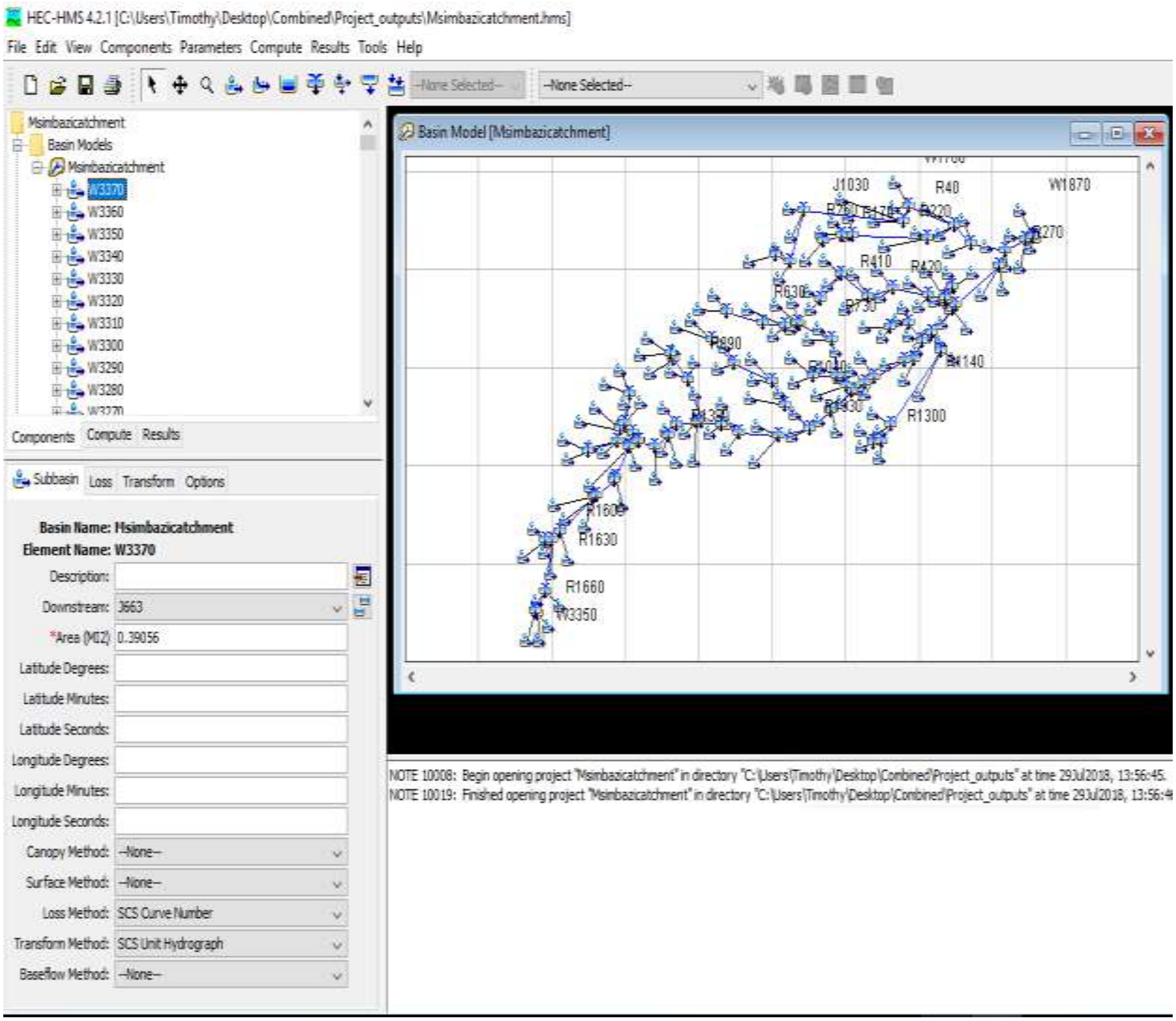


Figure 4. 34: HEC HMS dataset window

4.2.5.3 Checking HMS parameters

All the parameters processed were checked to ensure that they are in good shape for hydrological modeling in HEC HMS. Some of the parameters includes the SCS curve numbers, percentage impervious and lag time which were processed in ArcGIS.

4.2.5.4 Routing method

The other important HMS parameter is routing method determination of reaches which is a key factor in hydrologic modeling. In this study Simple Lag routing method method was used as a routing method.

4.2.5.5 Executing the model and viewing the result

After completing all the processes and checking the HMS parameters entered the HMS model was executed for each of the selected years. The HEC HMS allows to view results in tabular and graphical forms

4.2.6 Reservoirs/Detention basins design

A reservoir is a storage element with one or more inflow and one computed outflow. Inflow comes from other elements in the basin contributing to the particular reservoir. If a reservoir receives water from more than one inflow, all the contributing inflow is added together before computing the outflow. In the process of computing a reservoir storage, it is assumed that the water surface in the reservoir pool is level. In order to define the storage properties of a reservoir, several methods can be used.

4.2.6.1 Merging of sub-basins

The first step in the process of designing detention ponds was merging small sub basins into bigger sub basins, where in this study five bigger sub basins were created with the purpose of placing detention ponds at each outlet of the merged sub basins. The merged sub-basins are the inflow sources to the designed detention ponds as shown in the figure 4.35 below.

The Component Editor was accessed by clicking the reservoir element icon on the "Components" tab of the HEC HMS Watershed Explorer.

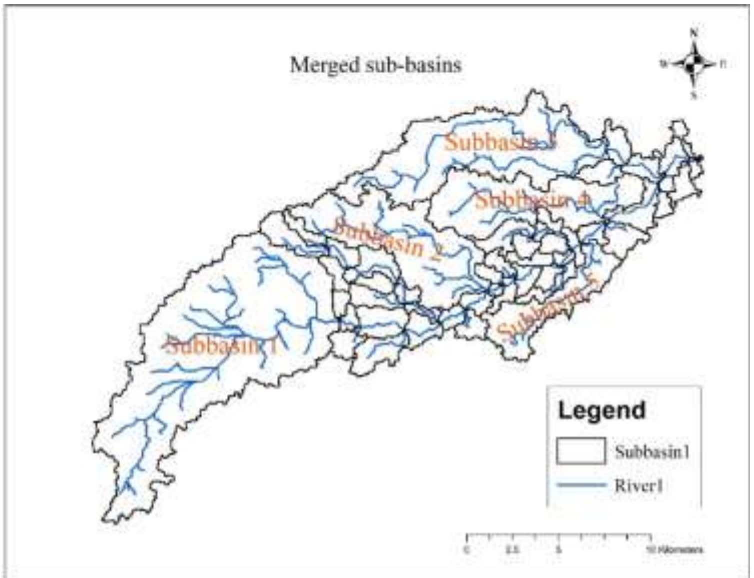


Figure 4. 35: Merged sub-basins

Five reservoirs were created at the outlets of each of the five merged sub-basins, the reservoirs were assigned to their respective sub-basins through reaches and each of the sub-basins was assigned to its precipitation gauge.

The Paired Data Manager file was created in order to create storage- discharge curve. The Storage-Discharge method was used to define the storage method with storage- discharge curve which was created in the Paired Data Manager.

The Inflow=Outflow method was used in the HEC HMS, which takes the inflow to the reservoir at the beginning of the simulation, then it uses the defined storage-discharge curve to determine the storage required to produce that same flowrate as the outflow from the reservoir.

The figure 4.36 below shows the arrangement of reservoirs connected to their respective sub-basins in the study catchment.

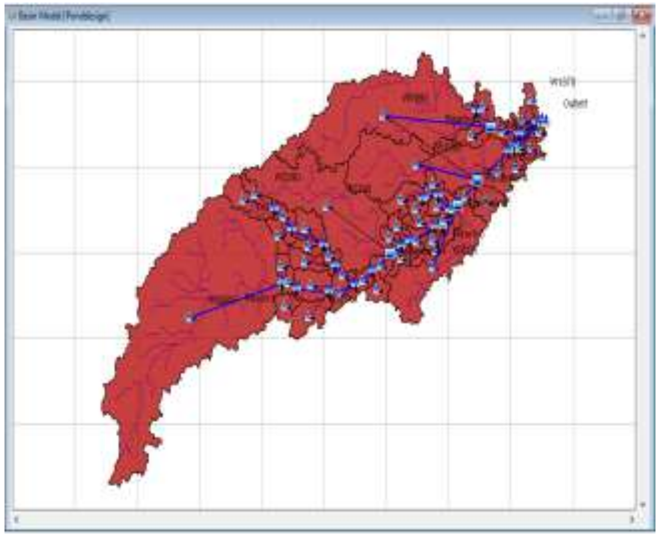


Figure 4. 36: Reservoirs

4.2.6.2 Reservoir routing method

From the Component Editor the routing method for each of the five reservoirs was selected. The routing method for each reservoir was selected by accessing the Component Editor of the Watershed Explorer as shown in the figure 4.37 Below. Then the model was executed and the results were viewed in tabular and graphical forms.

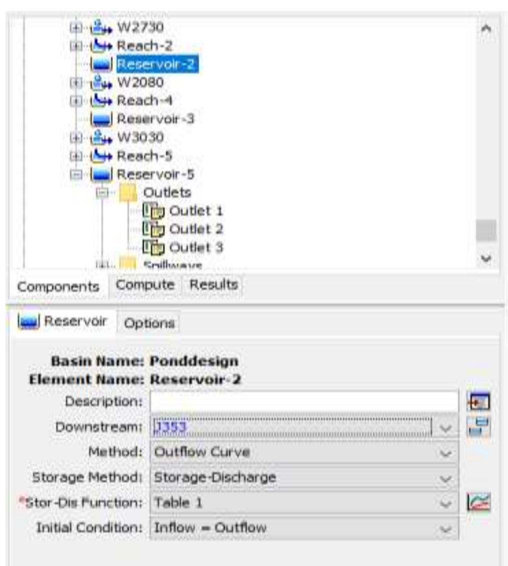


Figure 4. 37: Reservoir routing window

CHAPTER FIVE

5.0 RESULTS AND DISCUSSIONS

5.1 Digital Elevation Model Data Processing

The Msimbazi catchment Digital Elevation Model processing was successfully accomplished where the boundary of the catchment and its streams, were properly computed by the ArcGIS software packages. Figure 5.1 below shows a well-drained catchment with up to four stream orders. In the process, the simulated fourth, third order and most of the second order streams, matched perfectly with existing streams. Although some of the first order streams could not be captured in the delineation process due to DEM resolution and stream threshold issues. The DEM reconditioning process did a good job in localizing streams in their right paths especially for the flat areas such as downstream of the catchment. Generally, the whole process of the GIS-based map delineation of Msimbazi catchment worked well to delineate and localize the natural runoff routes. Also, in the process 151 sub-basins (before merged) and 83 junctions were generated.

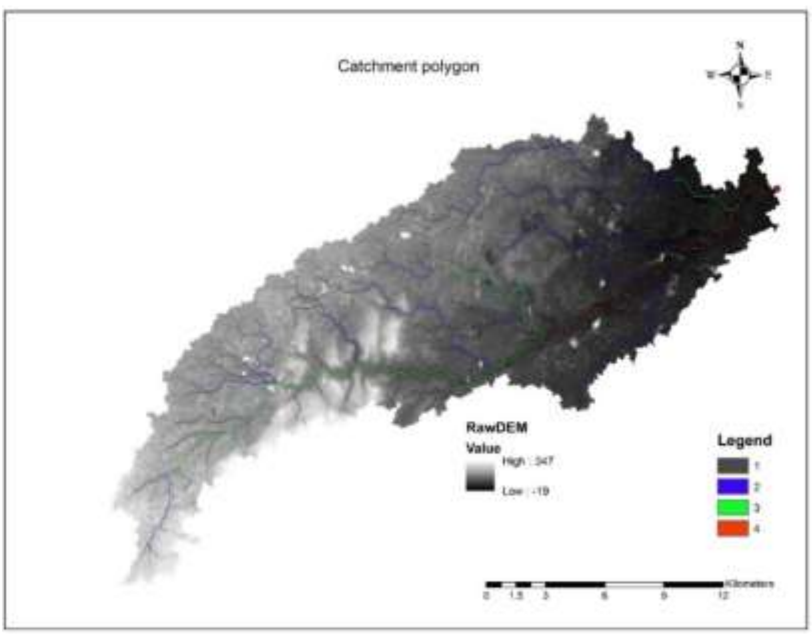


Figure 5. 1: Raw DEM and stream order

5.2 Landsat processing results

In the catchment, the land uses were grouped into five groups namely; water bodies, forest, developed high intensity, developed medium intensity and developed low intensity. It can be vividly seen from the classified image (see figure 5.2 below) that downstream of the catchment which is along the Indian ocean coast is highly developed and the extent of urbanization (development) decreases as you move upstream towards the Kisarawe hills where the catchment originates and it moves from high intensity development to medium intensity development followed low intensity development. The whole phenomenon reflects the reality of the catchment, where forests are also more seen upstream especially in the Kisarawe hills.

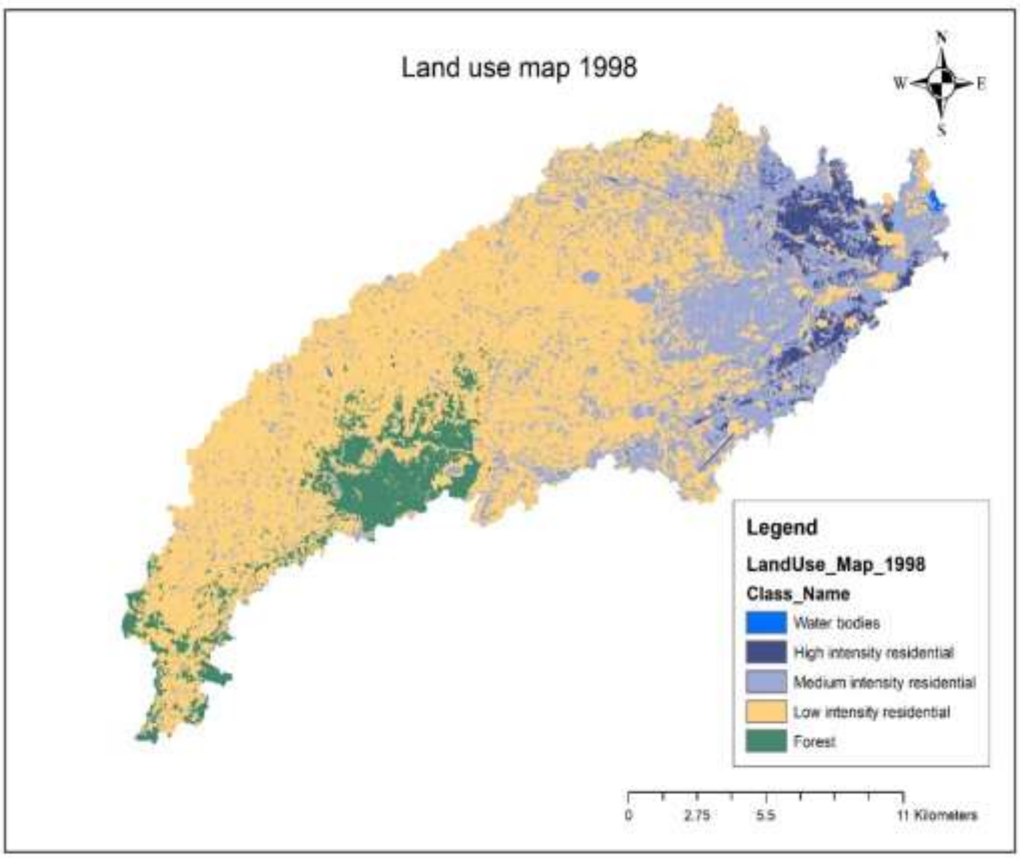


Figure 5. 2: Classified land use map

5.2 Curve Number (CN) Grid Input Preparation results

5.2.1 Land Use Change

Land use analysis was successfully accomplished; from the land use classification, it can be observed from the table 5.1 below of the land use coverage percent that the trend of land use has been changing from time to time.

As the outcome presented in table 5.1 below, in 1998 the large part of the catchment was occupied by the low intensity developed areas by 61.67% which then in 2009 reduced dramatically to 21.13% and also to 16.82% in 2018.

The medium intensity developed areas have been increasing from year to year where in 1998 the land occupied by the medium intensity developed areas was 25.97% then increased to 50.49% in 2009 and to 61.12% in 2018.

It was also observed in this study that the trend of high intensity development has been increasing, in 1998 the coverage of high intensity development was about 3.82% which increased to 13.42% in 2009 and then to 19.77 in 2018. These results tally with the fact Dar es salaam is one of the fastest growing cities in Africa (AfDB,2014), where the effect of urbanization is also felt in the study catchment.

Table 5. 1 Land use change

Type of land use	Coverage percent of land use (%)		
	Year: 1998	Year: 2009	Year: 2018
Water bodies	0.128609	0.258491	0.436798
Forest	8.415803	14.69457	1.858241
Developed, high intensity	3.823405	13.42444	19.76884
Developed, medium intensity	25.96702	50.48973	61.1165
Developed, low intensity	61.66516	21.13276	16.81962
Total	100	100	100

From the figure 5.3 below, the blue line represents high intensity developed areas, the orange line represents the areas covered by medium development areas and the gray line represents areas covered by low developed areas. It can be clearly observed that there was a sharp decrease in the extent of low developed areas coverage from 1998 to around 2010 where the trend seems to be of gradual change. The catchment is experiencing sharp increase in the medium level of development as it can be observed in the figure 5.3 below. Also, it can be observed that the extent of the areas covered by high intensity developed areas has been increasing since 1998 although at a slower rate compared to that of medium level.

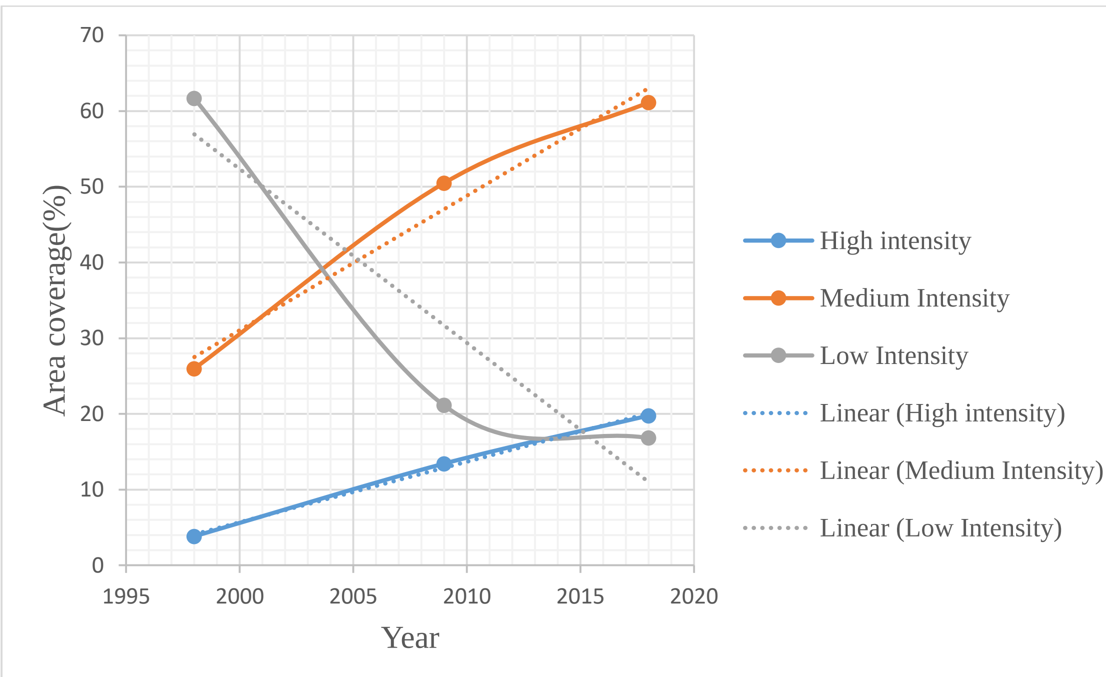


Figure 5. 3: Land use coverage graph

From the figures (5.4, 5.5 and 5.6) of the land use in 1998, 2009 and 2018 respectively, it can have observed that the red color which represents the high developed areas has with been increasing towards the upstream of the catchment as years keeps on moving and the green color which represents the medium level of development also increases towards upstream of the catchment and the yellow color which represent the low developed areas has been reducing as years move-by of which reflects the reality of what has been happening in the catchment.

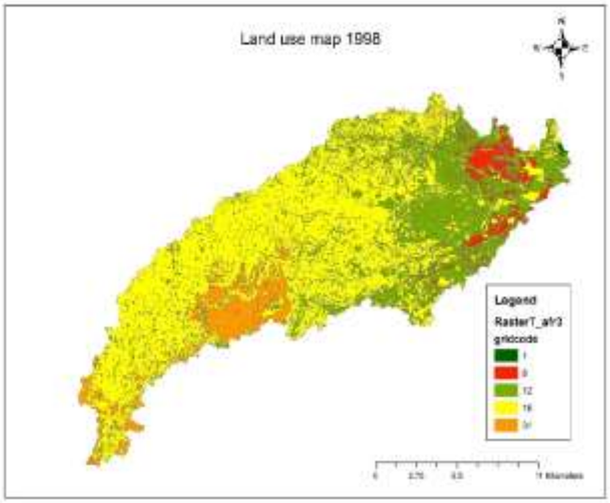


Figure 5. 4: Land use 1998

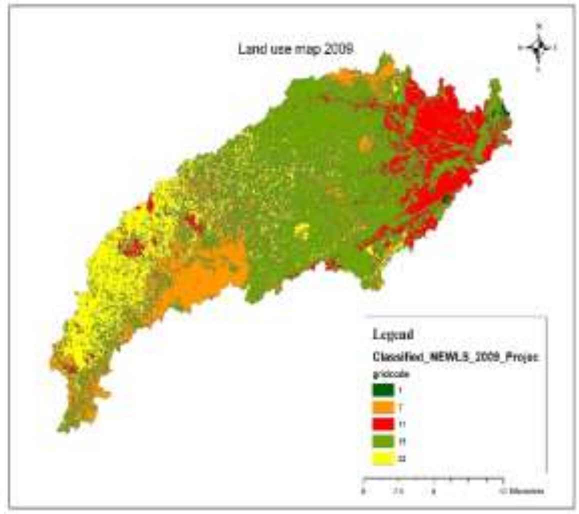


Figure 5. 5: Land use 2009

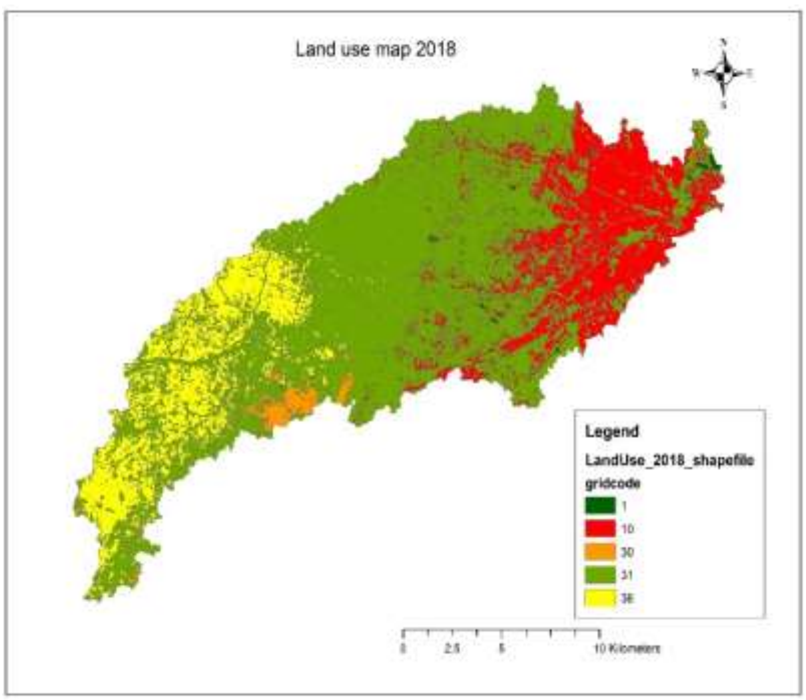


Figure 5. 6: Land use 2018

5.3 Hydrologic Model Development results

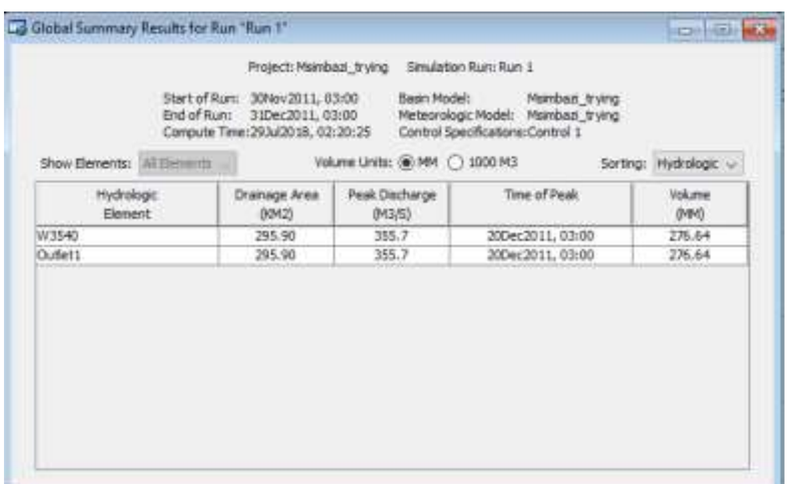
The SCS loss method relies on curve number (CN) to determine excess precipitation and losses within each sub-basin. Based on the simulated daily rainfall, peak discharge of each study year was obtained. Table 5.2 below shows the peak runoff discharges, which are 355.7 m^3, 402.7 m^3 and437.8 m^3 for the year 1998, 2009 and 2018 respectively, which is an increase of 23.08% from 1998 to 2018.

Table 5. 2: Summary of the simulated peak discharges for each study year

Year	Simulated Peak Discharge (m^3/s)
1998	355.7
2009	402.7
2018	437.8

5.3.1 Global simulation results from the 1998 datasets

The HEC HMS allows to visualize results in tabular and graphical forms. Figures 5.7 and 5.8 below show global summary of the simulated results from the study year 1998 datasets.


Global Summary Results for Run "Run 1"

Project: Msimbazi_trying Simulation Run: Run 1

Start of Run: 30Nov2011, 03:00 Basin Model: Msimbazi_trying
End of Run: 31Dec2011, 03:00 Meteorologic Model: Msimbazi_trying
Compute Time:29Jul2018, 02:20:25 Control Specifications:Control 1

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W3540	295.90	355.7	20Dec2011, 03:00	276.64
Outlet1	295.90	355.7	20Dec2011, 03:00	276.64

Figure 5. 7: Global summary table for the 1998 datasets

From the figure 5.8 below it can be observed that there is significant relationship between precipitation and outflow runoff, where the peak runoff discharge corresponds to the highest precipitation event. It can also be observed that in low precipitation, the amount of precipitation falling almost equals the amount of precipitation due to the fact that the SCS Curve Number (CN) model estimates precipitation excess in a catchment as a function of cumulative precipitation, land use soil cover and antecedent moisture.

The graph reflects the reality where normally the process of runoff generation in a watershed continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil as it can be observed in the 5.8 below, but the rainfall-runoff process stops as soon as the rate of rainfall drops below the actual rate of infiltration.

During extreme rainfall events, the intensity of rainfall also becomes high which means more water is added to a watershed and soils become fully saturated in a very short time.

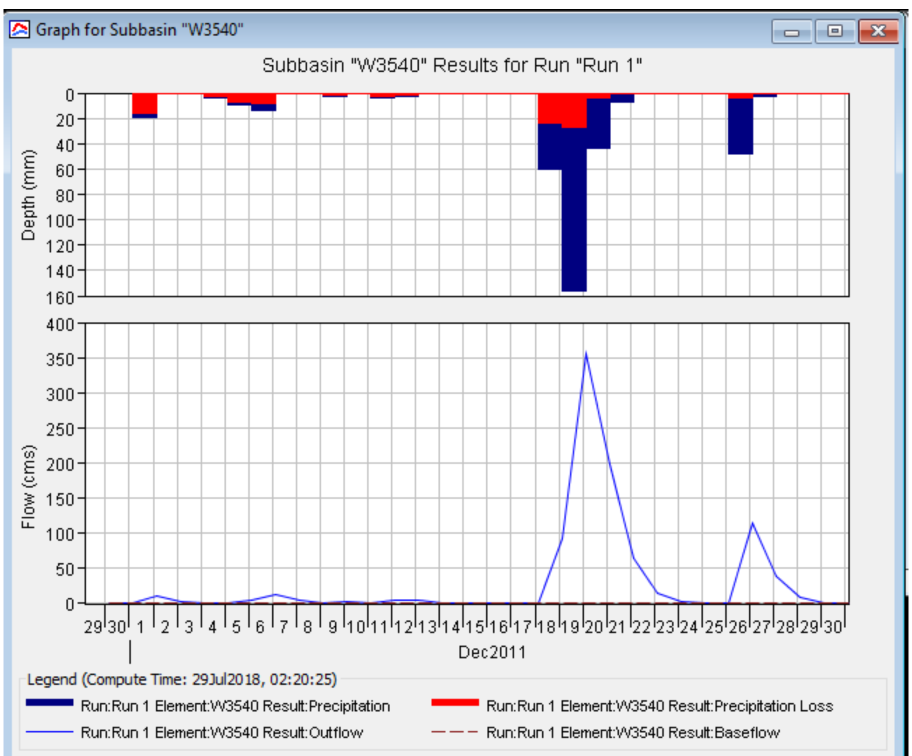
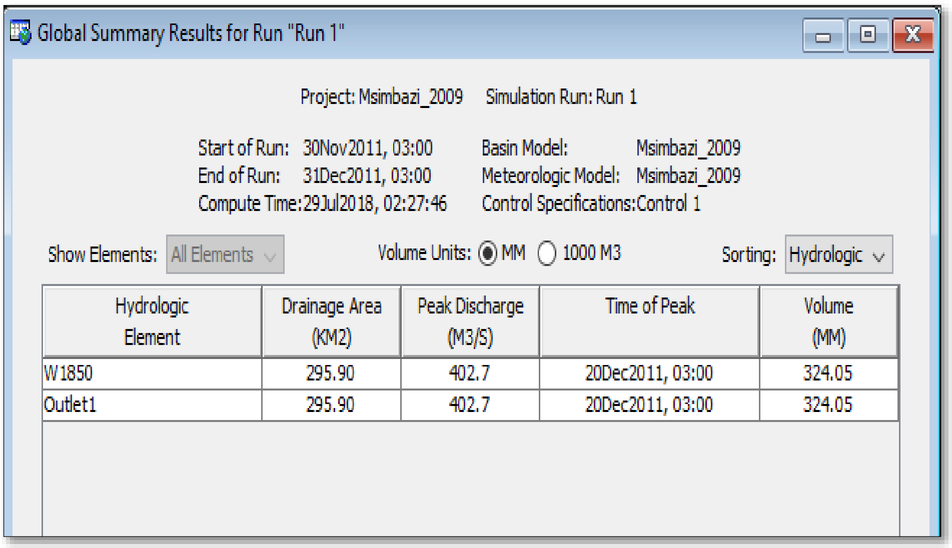


Figure 5. 8: Global summary graph for the 1998 datasets

5.3.2 Global simulation results from the 2009 datasets

The study year 2009 datasets produced a higher runoff outflow discharge compared to that of 1998. The peak runoff discharge is obtained from the 20 December rainfall extreme event as shown in figure 5.9 below. It has to be noted that in this study only land use parameter is changing of which the increase of peak runoff discharge from the 2009 datasets compared to that of 1998 shows an impact of land use change on storm water runoff.



Global Summary Results for Run "Run 1"

Project: Msimbazi_2009 Simulation Run: Run 1

Start of Run: 30Nov2011, 03:00 Basin Model: Msimbazi_2009
End of Run: 31Dec2011, 03:00 Meteorologic Model: Msimbazi_2009
Compute Time: 29Jul2018, 02:27:46 Control Specifications: Control 1

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W1850	295.90	402.7	20Dec2011, 03:00	324.05
Outlet1	295.90	402.7	20Dec2011, 03:00	324.05

Figure 5. 9: Global summary table for the 2009 datasets

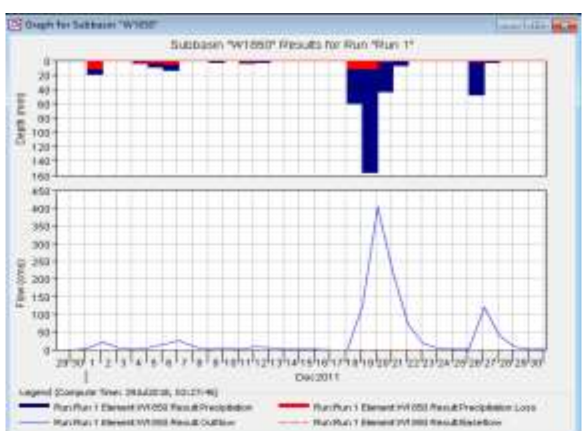
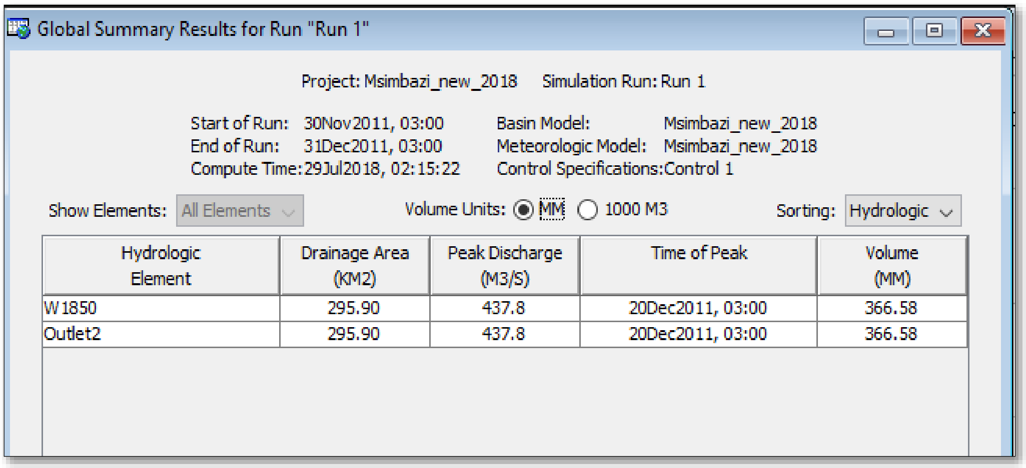


Figure 5. 10: Global summary graph for the 2009 datasets

5.3.3 Global simulation results from the 2018 datasets

The study year 2018 datasets produced a higher runoff outflow discharge compared to that of 1998 and 2009. Which also shows the impact of land use change on storm water runoff. The difference in peak discharges from the 1998 datasets to the 2018 datasets is about 82.1m^3/s which is about 23.08% increase from 1998. The peak runoff discharge is obtained from the 20 December rainfall extreme event as shown in figure 5.11 below.



Global Summary Results for Run "Run 1"

Project: Msimbazi_new_2018 Simulation Run: Run 1

Start of Run: 30Nov2011, 03:00 Basin Model: Msimbazi_new_2018
End of Run: 31Dec2011, 03:00 Meteorologic Model: Msimbazi_new_2018
Compute Time: 29Jul2018, 02:15:22 Control Specifications: Control 1

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W1850	295.90	437.8	20Dec2011, 03:00	366.58
Outlet2	295.90	437.8	20Dec2011, 03:00	366.58

Figure 5. 11: Global summary table for the 2018 datasets

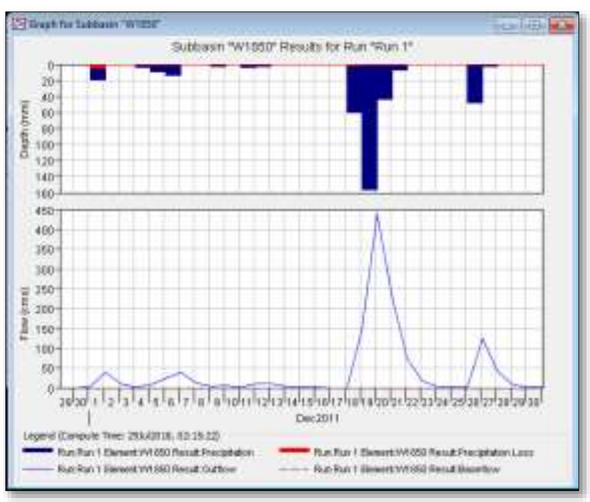


Figure 5. 12: Global summary graph for the 2018 datasets

5.3.4 Individual simulated parameters results

The figures 5.13 to 5.39 show graphs of individual simulated parameters contributing to storm water runoff generation

5.3.4.1 Simulated outflow graphs

There is noticeable change in outflows as years move-by, from graphs in figures 5.13 to 5.15, the outflows have been increasing with years from 1998 to 2018 which can be directly linked with the impact of land use change as the only varying parameter. The impact is more easily noticed during the low precipitation periods as shown in figures 5.13 to 5.15 below.

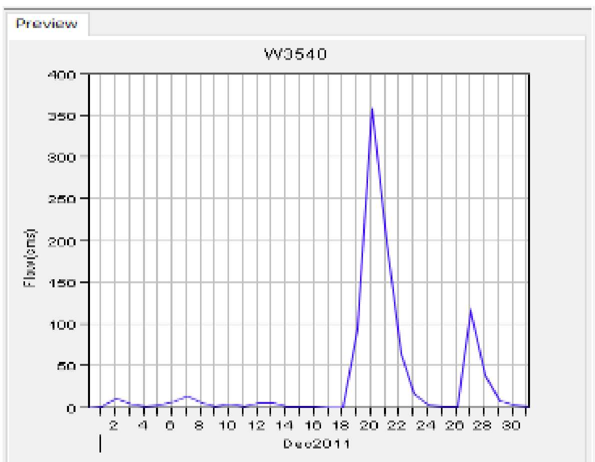


Figure 5. 13:1998

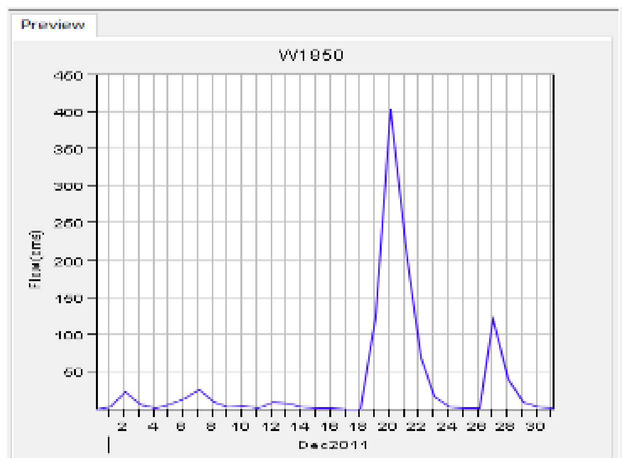


Figure 5. 14: 2009

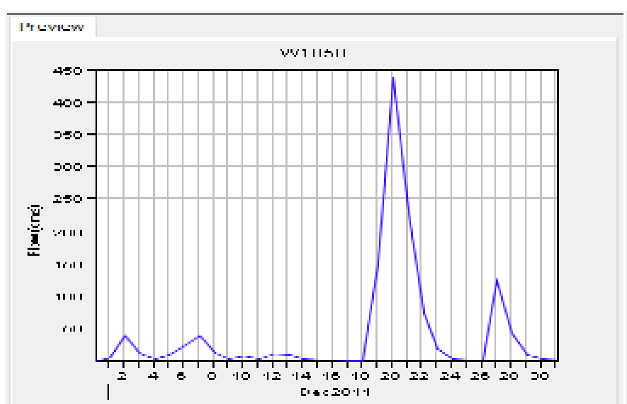


Figure 5. 15: 2018

5.3.4.2 Simulated precipitation graphs

The same rainfall dataset was used in all selected study years to avoid rainfall variation and account for the impact of land use change as shown in figures 5.16 to 5.18 below.

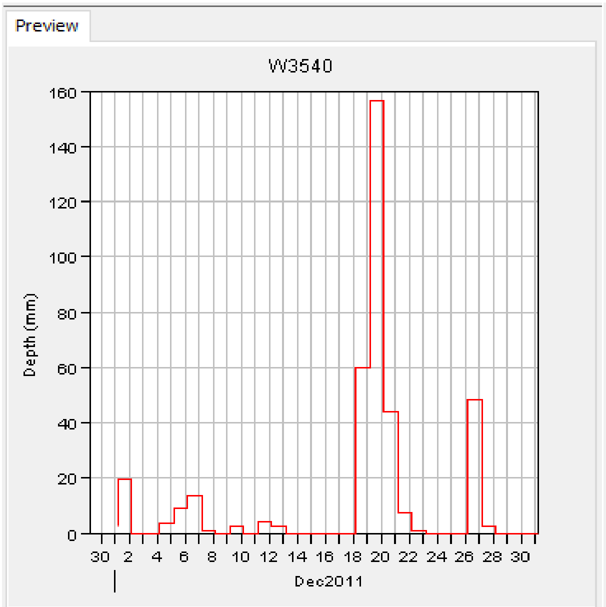


Figure 5. 16: 1998

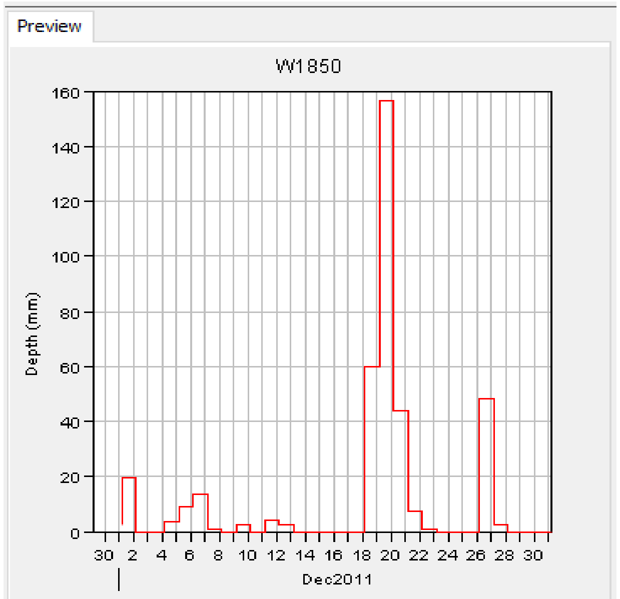


Figure 5. 17: 2009

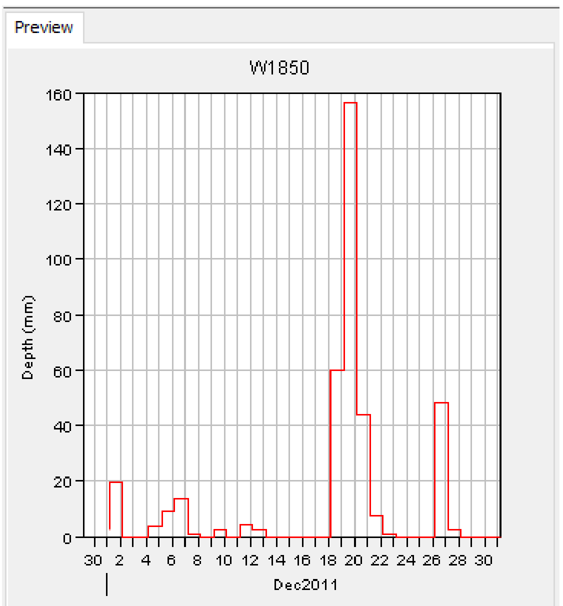


Figure 5. 18: 2018

5.3.4.3 Simulated Cumulative precipitation graphs

It can be observed in the figures 5.19 to 5.21 that, there is sharp increase from the cumulative precipitation graphs as a result of the 20th December extreme event.

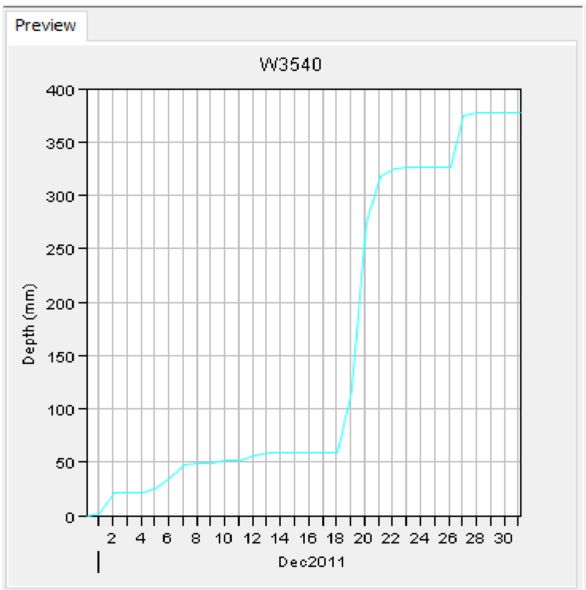


Figure 5. 19: 1998 CP graph

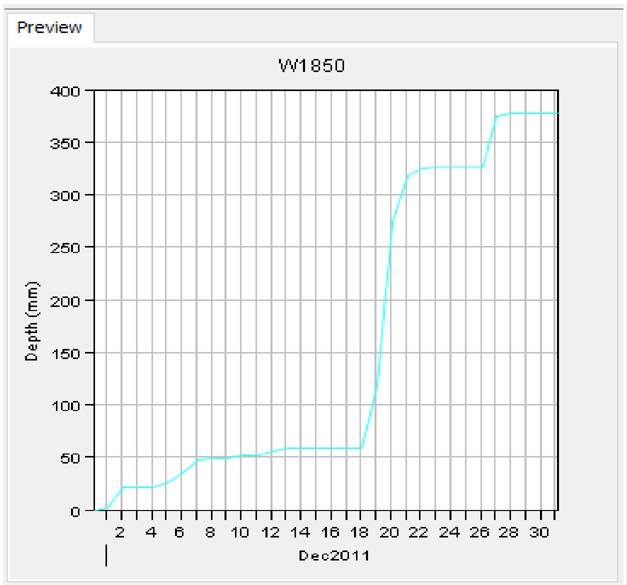


Figure 5. 20: 2009 CP graph

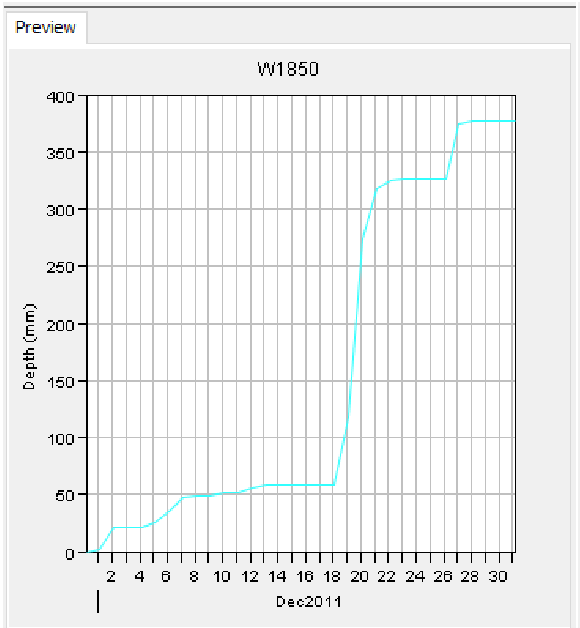


Figure 5. 21: 2018 CP graph

5.3.4.4 Simulated Soil infiltration graphs

Significant change on the soil infiltration response against the same amount of rainfall with changing land use patterns can be observed from the figures below. From the graphs in figures 5.22 to 5.24 it can be observed that the ability of soil to accept precipitation has been decreasing as years move-by from 1998 to 2018.

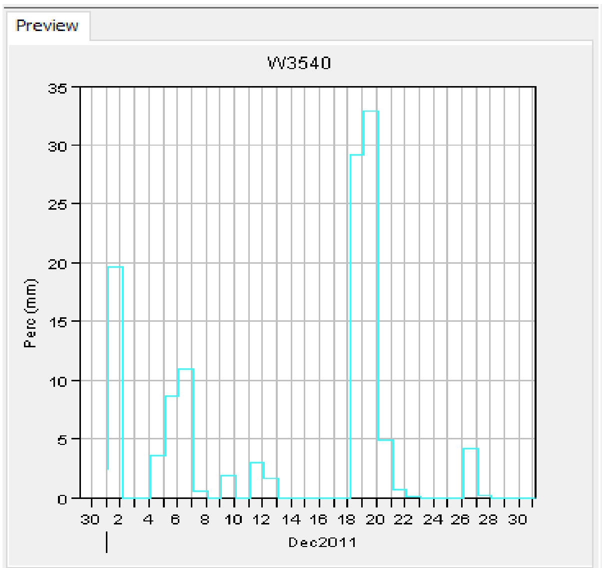


Figure 5. 22:1998 SIn graph

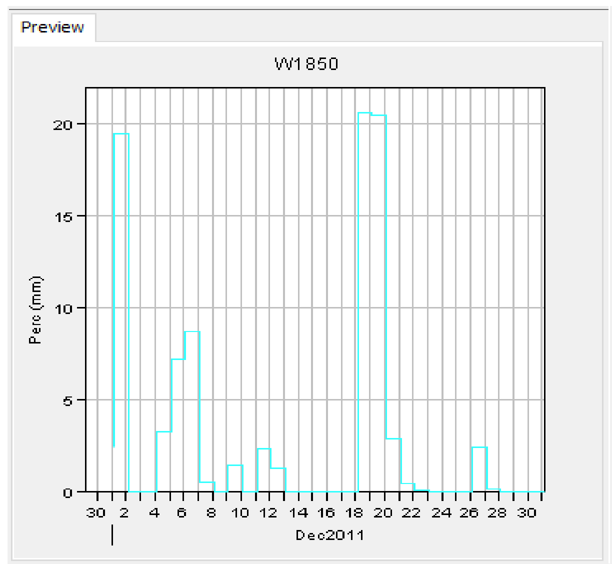


Figure 5. 23: 2009 SIn graph

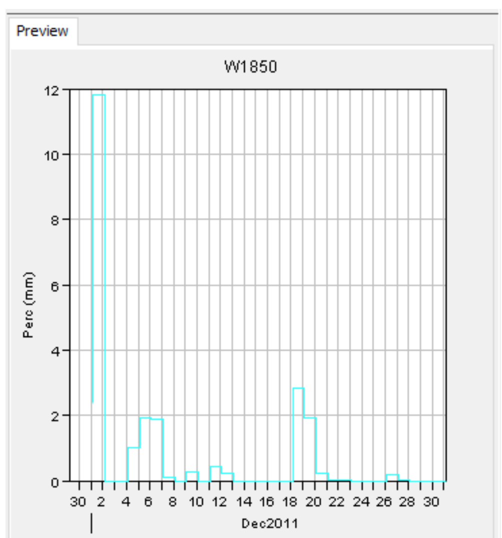


Figure 5. 24: 2018 SIn graph

5.3.4.5 Simulated Excess precipitation graphs

Excess precipitation is the volume of precipitation available for direct surface runoff. It is a result of the total amount of precipitation minus all abstractions including interception, depression storage, and infiltration. The increase in precipitation excess can be observed from figures 5.25 to 5.27 below.

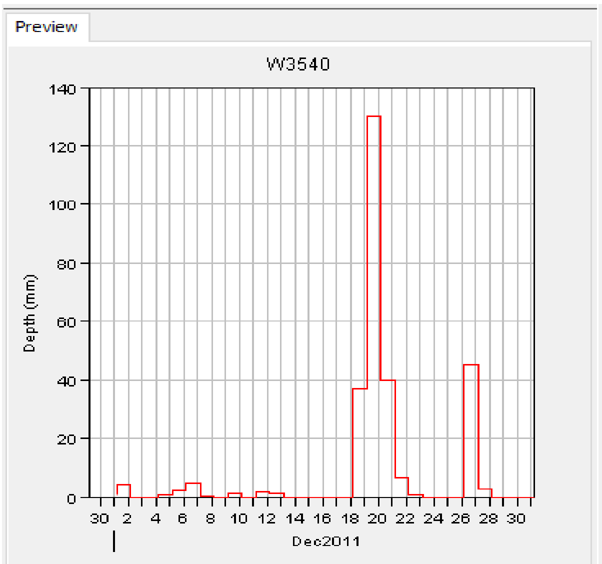


Figure 5. 25: 1998 EP graph

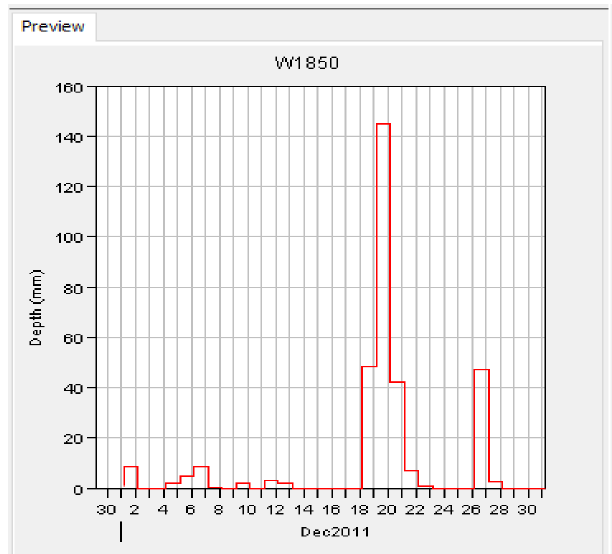


Figure 5. 26: 2009 EP graph

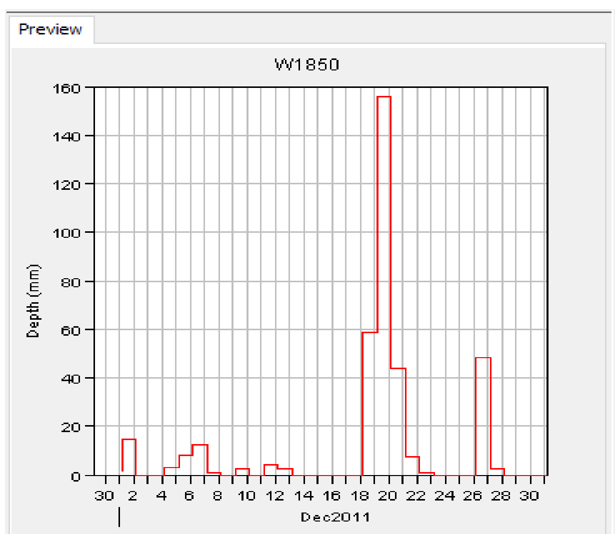


Figure 5. 27: 2018 EP graph

5.3.4.6 Simulated Cumulative excess precipitation graphs

As in the cumulative precipitation graphs, it can also be observed in the figures 5.28 to 5.30 that, there is sharp increase from the excess cumulative precipitation graphs as a result of the 20th December extreme event.

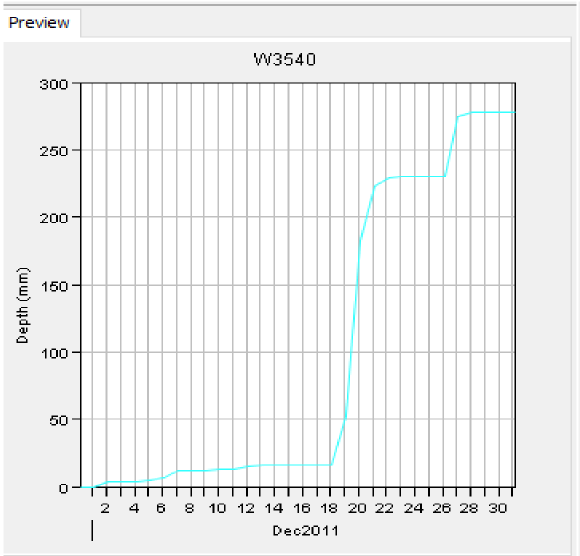


Figure 5. 28: 1998 CEP graph

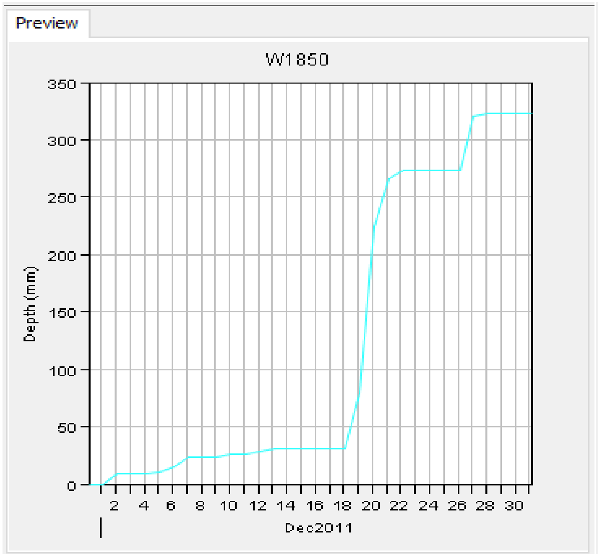


Figure 5. 29: 2009 CEP graph

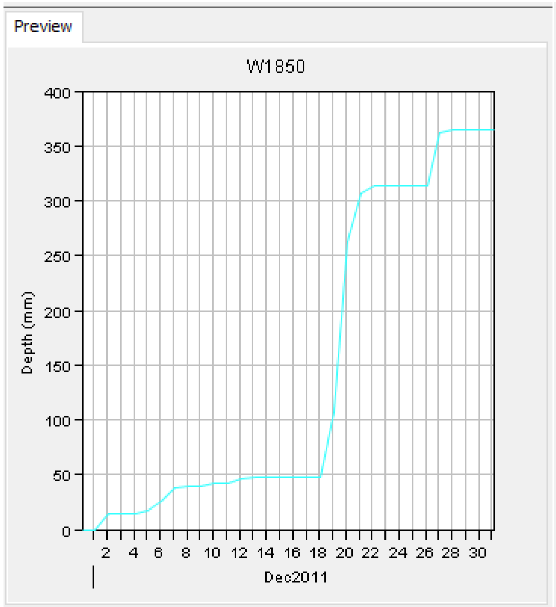


Figure 5. 30: 2018 CEP graph

5.3.4.7 Simulated Precipitation loss graphs

Precipitation loss is a result of interception, evaporation, transpiration, depression storage and infiltration. It can be observed from the figures 5.31 to 5.33 that; the precipitation loss has been decreasing as years move-by from 1998 to 2018 as an impact of land use change.

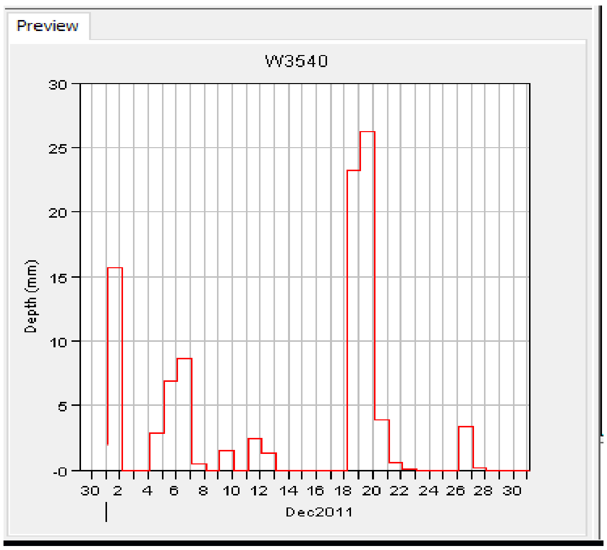


Figure 5. 31: 1998 PL graph

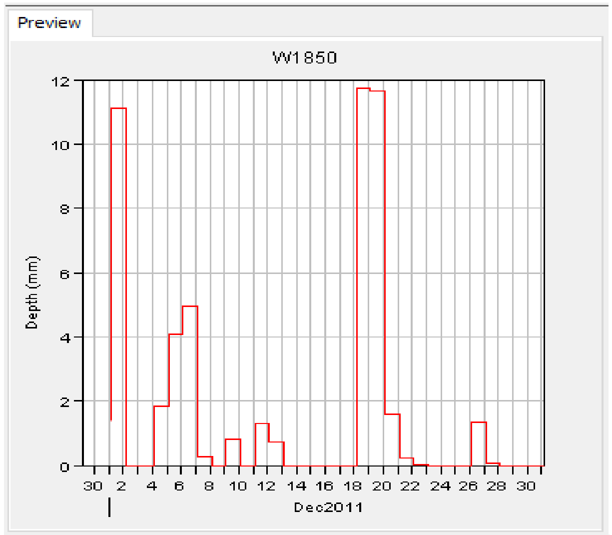


Figure 5. 32: 2009 PL graph

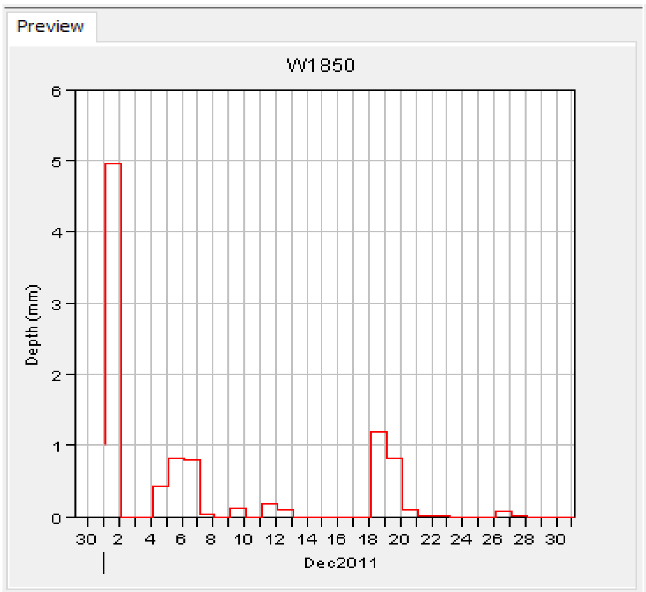


Figure 5. 33: 2018 PL graph

5.3.4.8 Simulated cumulative precipitation loss graphs

It can be observed in the figures 5.34 to 5.36 that, there is sharp increase from the cumulative precipitation loss graphs as a result of the 20th December extreme event.

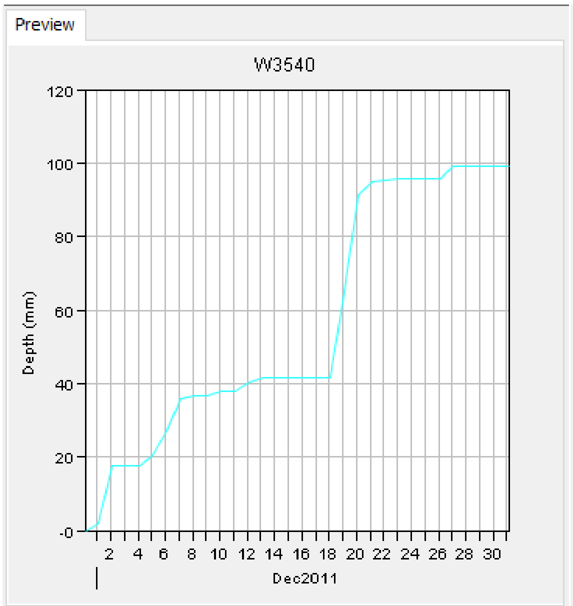


Figure 5. 34: 199 CPL graph

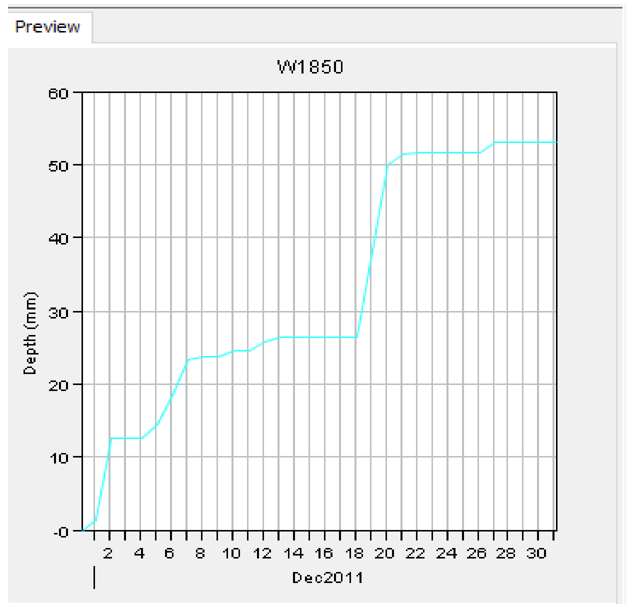


Figure 5. 35: 2009 CPL graph

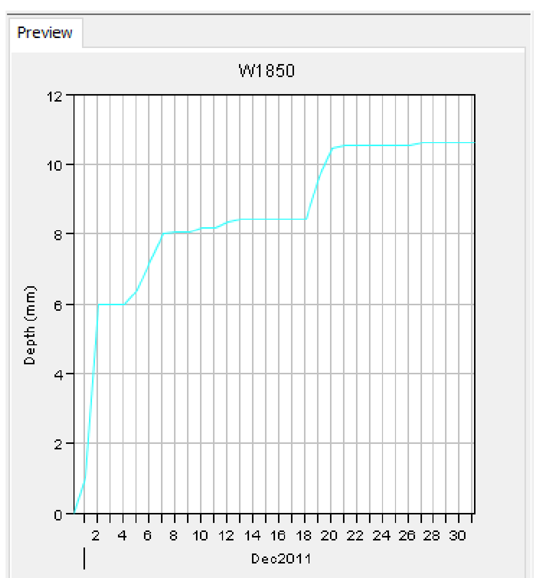


Figure 5. 36: 2018 CPL graph

5.3.4.9 Simulated direct runoff graphs

Direct runoff is amount water from precipitation that flows over the ground surface directly into streams, rivers, or lakes. It can be observed in the figures 5.37 to 5.39 that; the direct runoff has been increasing with years from 1998 to 2018 which can be directly linked with the impact of land use change as the only varying parameter in the study.

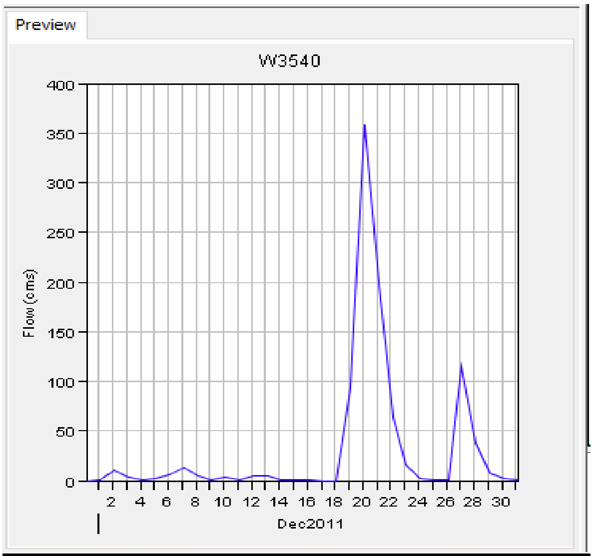


Figure 5. 37: 1998 DR graph

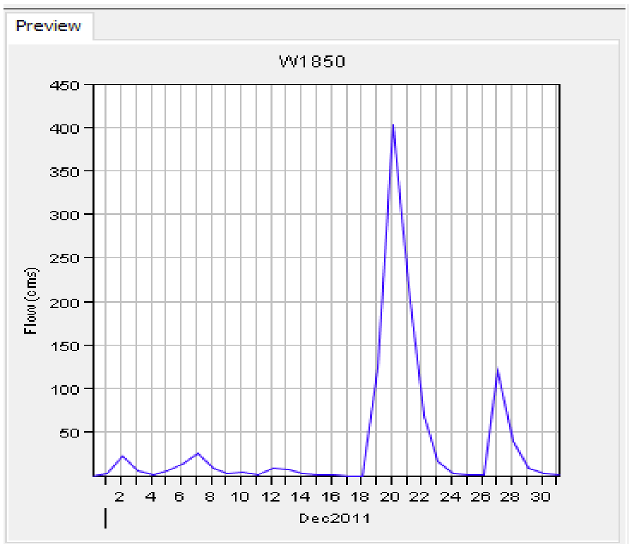


Figure 5. 38: 2009 DR graph

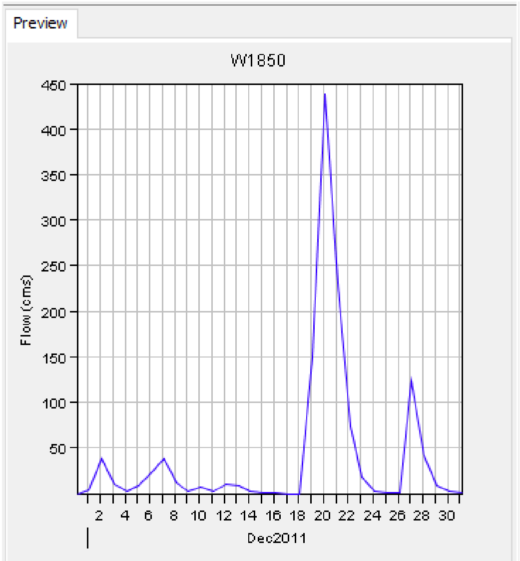


Figure 5. 39: 2018 DR graph

5.4 Reservoir/detention ponds design results

In this part, the results obtained from the detention basins design in HEC HMS are presented in tabular and graphical forms. The results include the calculated area coverage for each sub-basin contributing to the designed reservoirs in km^2 and percentage as well as inflows, storages and outflows of the designed reservoirs are presented. In HEC HMS the reservoirs/detention basins were connected to their corresponding sub-basins through reaches.

5.4.1 Area coverage of the merged sub-basins

The area of each merged sub-basin was calculated along with its percentage coverage compared to the total area of the study catchment (295.9 km^2). The summary of the calculated area coverages for the sub-basins can be observed in table 5.4 below.

The sub-basin 1 discharges water to reservoir 1, sub-basin 2 discharges water to reservoir 2, sub-basin 3 discharges water to reservoir 3, sub-basin 4 discharges water to reservoir 4 and sub-basin 5 discharges water to reservoir 5.

The storage capacity of each of the designed reservoirs/detention basins also depends on the area coverage of the sub-basin discharging water to the reservoir.

Table 5. 3: Area of each contributing sub-basin to the designed reservoirs

Sub-basin	Area (km^2)	Coverage (%)
1	92.7465012	31.343867
2	32.2856224	10.910991
3	27.6817482	9.3551025
4	44.3242012	14.979453
5	14.6250142	4.942553

5.4.2 Reservoirs/detention ponds routing

The designed detention basins are located at each outlet of the corresponding sub-basins, that means reservoir 1 receives water from detention basin 1, reservoir 2 receives water from sub-basin 2, reservoir 3 receives water from sub-basin 3, reservoir 4 receives water from sub-basin 4 and reservoir 5 receives water from sub-basin 5.

The peak inflows for all detention basins were observed in the extreme event of 20 December 2011, where reservoir 1 had 123.6 m^3/s, reservoir 2 had 43.5m^3/s, reservoir 3 had 37.5 m^3/s, reservoir 4 had 60.5 m^3/s and reservoir 5 had 19.2 m^3/s as shown in figures 5.40 to 5.44 below. A total of 284.5 m^3/s which is about 65% of the peak runoff discharge generated in the catchment.

5.4.2.1 Summary tables of the designed detention basins

Summary Results for Reservoir "Reservoir-1"

Project: Ponddesign   Simulation Run: Run 1
Reservoir: Reservoir-1

Start of Run:	30Nov2011, 03:00	Basin Model:	Ponddesign
End of Run:	31Dec2011, 03:00	Meteorologic Model:	Ponddesign
Compute Time:	30Jul2018, 19:47:42	Control Specifications:	Run1_control

Volume Units: ◉ MM ○ 1000 M3

Computed Results

Peak Inflow:	123.6 (M3/S)	Date/Time of Peak Inflow:	20Dec2011, 03:00
Peak Discharge:	2.3 (M3/S)	Date/Time of Peak Discharge:	29Dec2011, 03:00
Inflow Volume:	343.46 (MM)	Peak Storage:	26719.4 (1000 M3)
Discharge Volume:	57.91 (MM)		

Figure 5. 40: Reservoir 1 summary table

Summary Results for Reservoir "Reservoir-2"

Project: Ponddesign   Simulation Run: Run 1
Reservoir: Reservoir-2

Start of Run:	30Nov2011, 03:00	Basin Model:	Ponddesign
End of Run:	31Dec2011, 03:00	Meteorologic Model:	Ponddesign
Compute Time:	30Jul2018, 19:47:42	Control Specifications:	Run1_control

Volume Units: ◉ MM ○ 1000 M3

Computed Results

Peak Inflow:	43.5 (M3/S)	Date/Time of Peak Inflow:	20Dec2011, 03:00
Peak Discharge:	2.1 (M3/S)	Date/Time of Peak Discharge:	29Dec2011, 03:00
Inflow Volume:	351.49 (MM)	Peak Storage:	8014.1 (1000 M3)
Discharge Volume:	112.68 (MM)		

Figure 5. 41: Reservoir 2 summary table

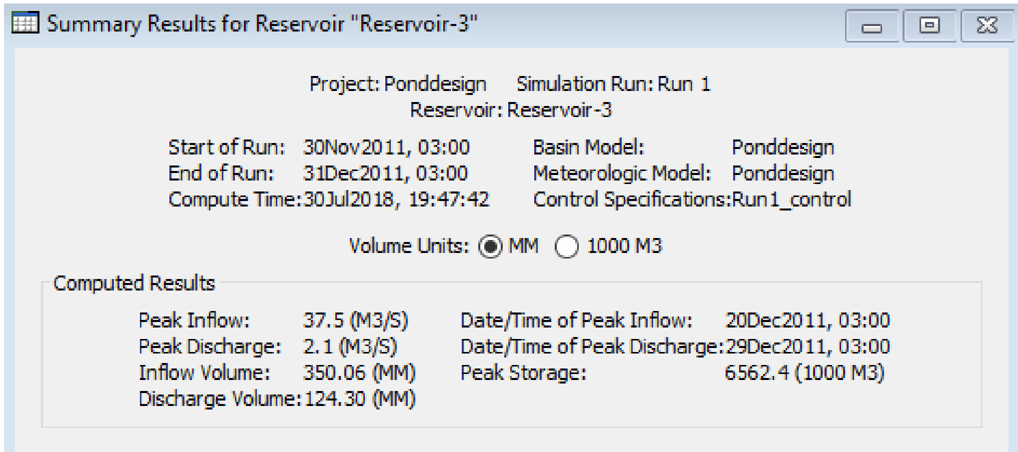


Figure 5. 42: Reservoir 3 summary table

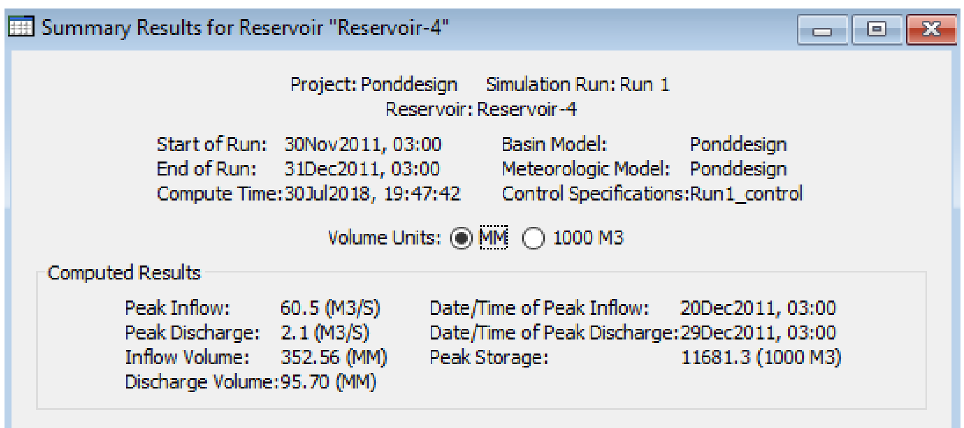


Figure 5. 43: Reservoir 4 summary table

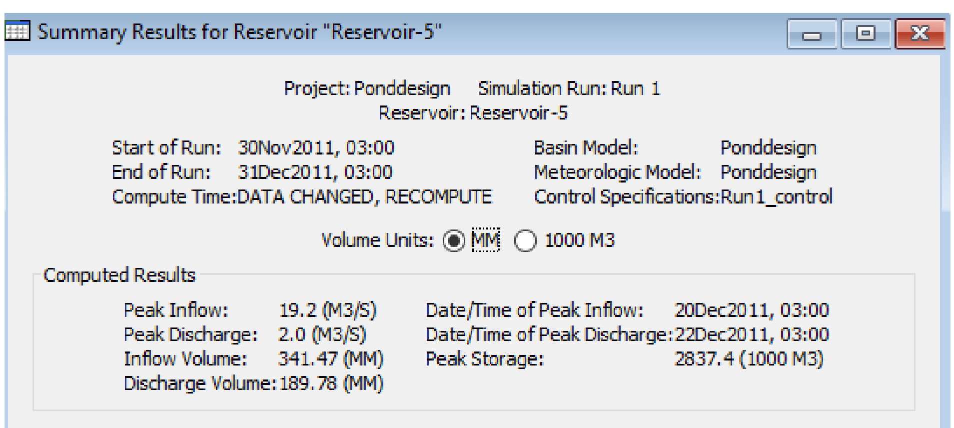


Figure 5. 44: Reservoir 5 summary table

5.4.2.2 Reservoirs inflow-storage relationship

The figures 5. 45 to 5.49 show the reservoirs inflow-storage relationship, which the amount of water to be stored in the reservoir is dependent on the inflow rate and outflow rate. It can be observed from the graphs that from the extreme event water in the reservoirs started accumulating which means the inflows were higher the outflows and it might take some time before the storage graph recedes depending on the amount of inflow and the way amount of outflow is controlled. It can also be observed from the graph in figures 5.45 to 5.49 below that, when the precipitation is low, the reservoirs storage remains almost empty since the reservoirs were not designed to permanently store water but rather capture the runoff and release at controllable rate.

Therefore, the amount of inflow to the reservoirs almost equals the outflow amount during low precipitation to ensure optimum flow in the stream downstream of the reservoirs. During extreme precipitation event, the reservoirs start accumulating water because outflow is being controlled to ensure that the amount of outflow is safe enough to the receiving stream downstream. The reservoirs are designed to be able to withstand extreme precipitation event.

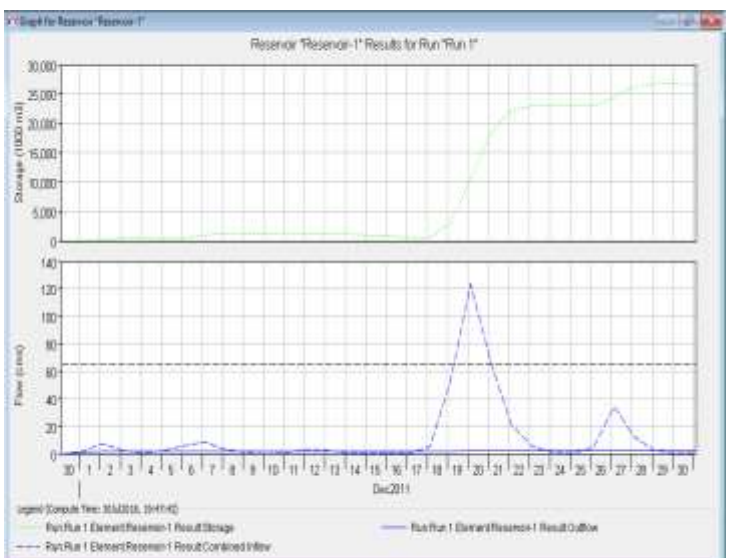


Figure 5. 45: Reservoir 1: Inflow-Storage relationship

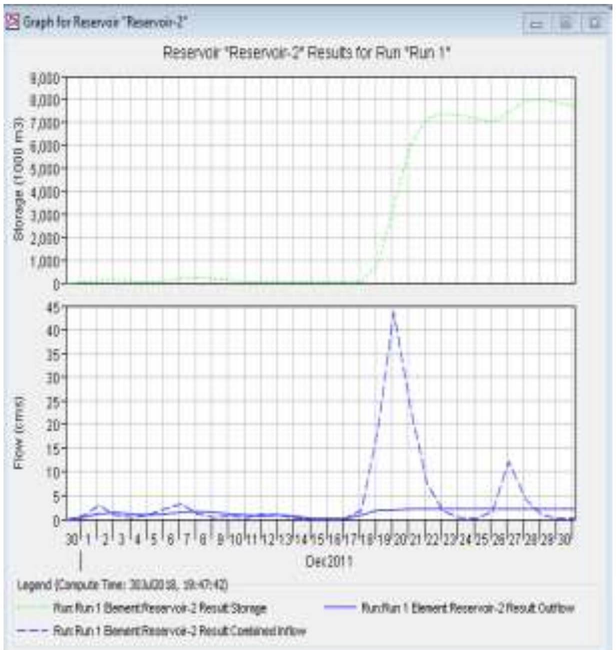


Figure 5.46: Reservoir 2 Inflow-Storage relationship

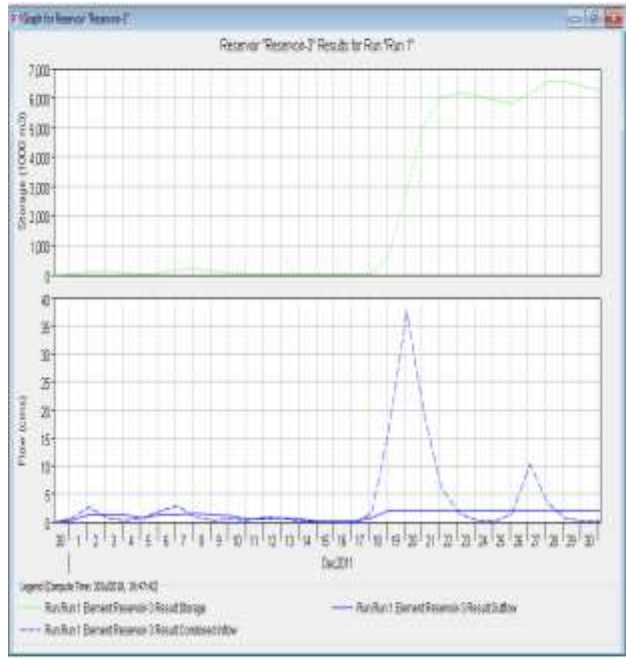


Figure 5.47: Reservoir 3; Inflow-Storage relationship

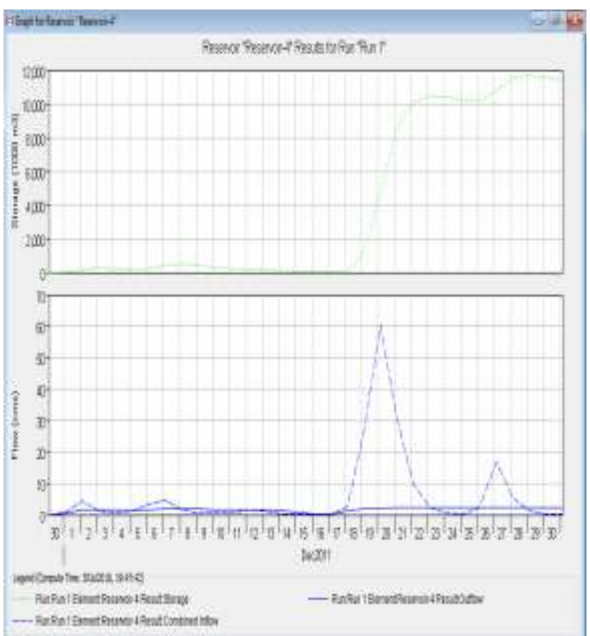


Figure 5. 46: Reservoir 4; Inflow-Storage relationship table

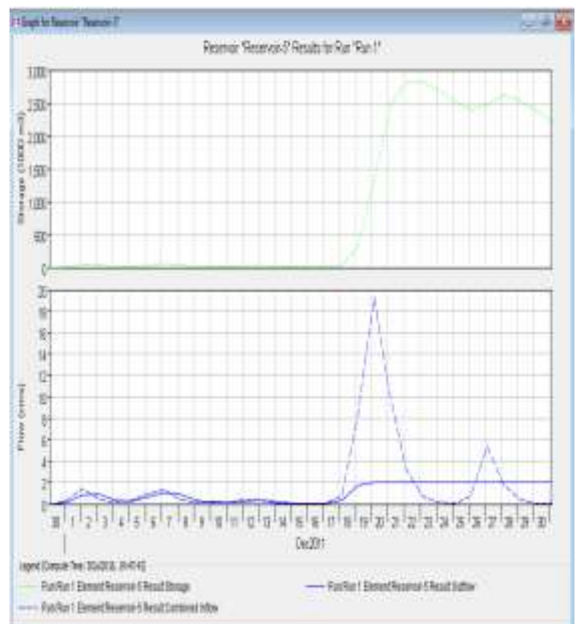


Figure 5. 47: Reservoir 5; Inflow-Storage relationship table

5.4.2.3 Simulated reservoirs storage graphs

Detention reservoirs/basins are designed to store water for a relatively brief period of time, the water in a detention basin is stored or retained until the downstream stream can be able to safely carry the ordinary flow plus the released water. Therefore, in this study the storage capacities of the reservoirs were designed to purposely retain and then released at a controllable rate to ensure safe flow in the receiving streams downstream.

The rapid storage increase as observed in figures 5.50 to 5.54 is a result of the 20th December extreme event of which the reservoirs are designed to capture the most extreme rainfall event in the span of more than 50 years to date.

It can be observed from the graphs that from the extreme rainfall event, water in the reservoirs started accumulating which means the inflows were higher than the outflows and it will take a longer time before the storage graph recedes depending on the amount of inflow and the controlled outflow.

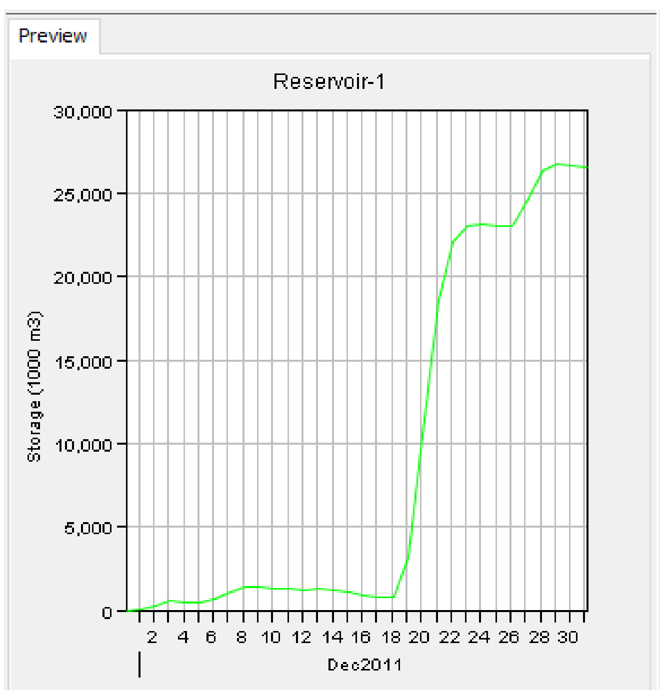


Figure 5. 48: Reservoir 1; storage graph

The figures 5.51 to 5.54 below show the storage graphs of the designed reservoir 2 to reservoir 5

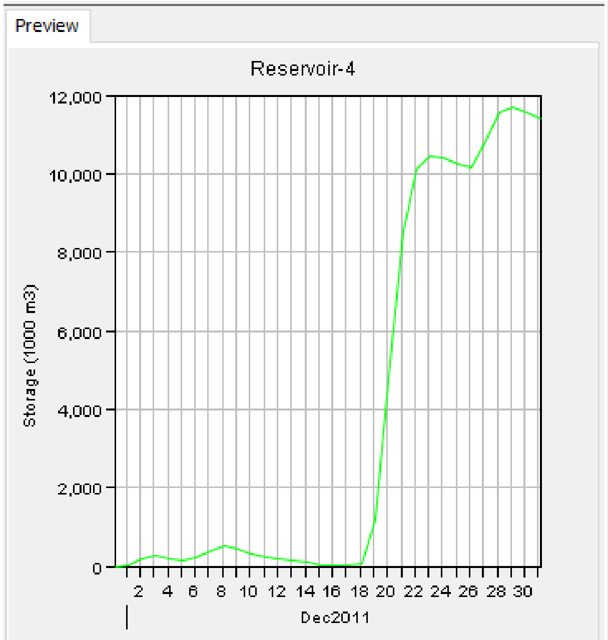


Figure 5.51: Reservoir 2; storage graph

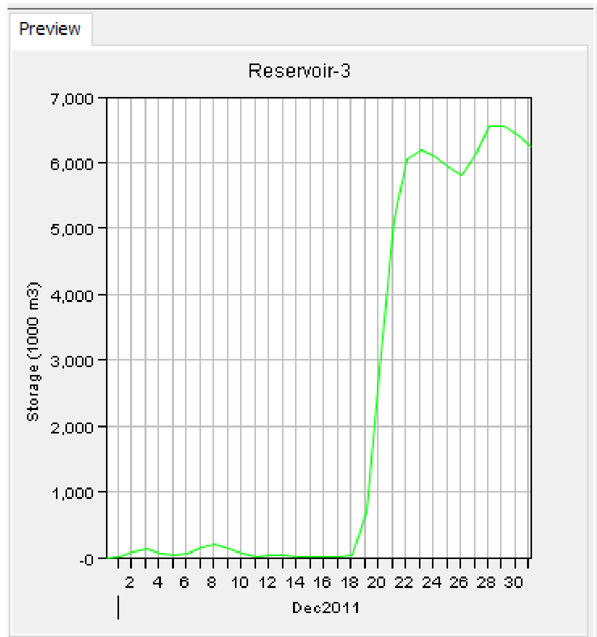


Figure 5.52: Reservoir 3; storage graph

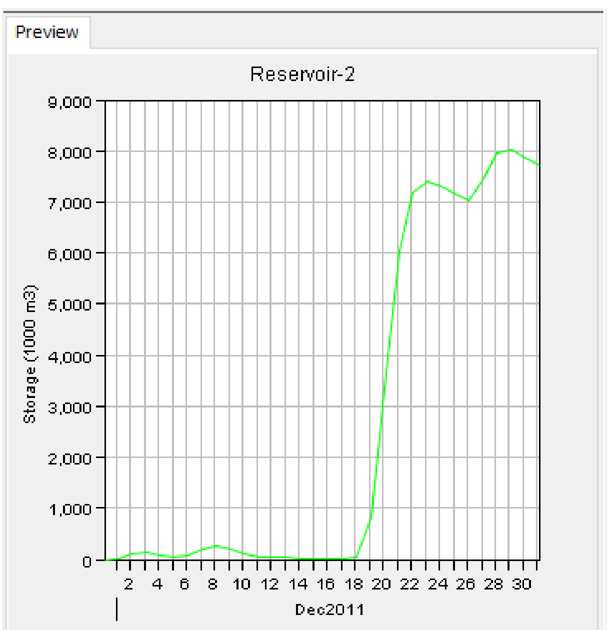


Figure 5.53: Reservoir 4; storage graph

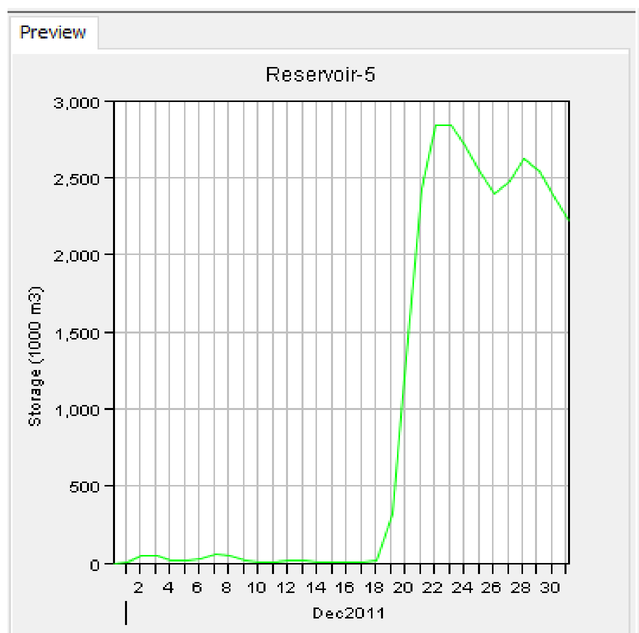


Figure 5.54: Reservoir 5; storage graph

5.4.2.4 Simulated reservoirs outflow graphs

In the process of computing reservoirs outflow the Reservoir Curve routing method was used which represents the reservoir with a user-provided or user-defined storage- discharge relationship. The Inflow=Outflow method in the HEC HMS takes the inflow to the reservoir at the beginning of the simulation, then it uses the defined storage-discharge curve to determine the storage required to produce that same flowrate as the outflow from the reservoir. Therefore, in this process the storage is interpolated from the storage-discharge curve.

The figures 5.55 to figure 5.59, the outflow graphs simulated from reservoir curve routing method for the five designed reservoirs are presented. In figure 5.55 below it can be observed that reservoir 1 yields the highest outflow since is the reservoir serving the biggest sub-basin in the catchment and receives the highest amount of inflow compared to the other reservoirs. All the designed reservoirs/detention basins receive the highest inflow from the most extreme rainfall event. It can also be observed from the graphs that after the extreme rainfall event the outflow discharge remains to be high because the reservoirs have accumulated enough water from the extreme rainfall event.

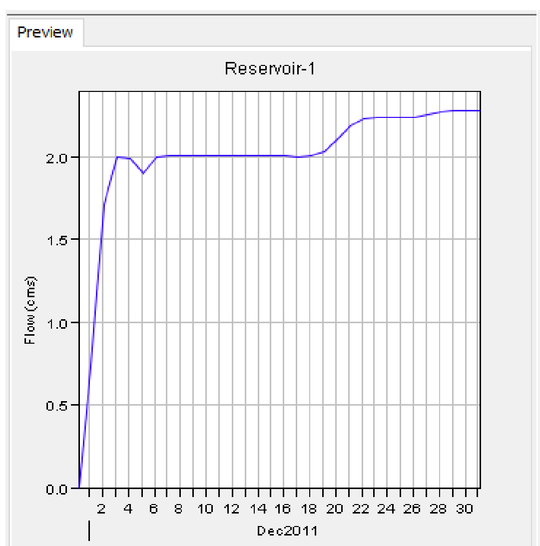


Figure 5. 49: Reservoir 1; storage graph

The figures 5.56 to 5.59 below show the outflow graphs of the designed reservoir 2 to reservoir 5

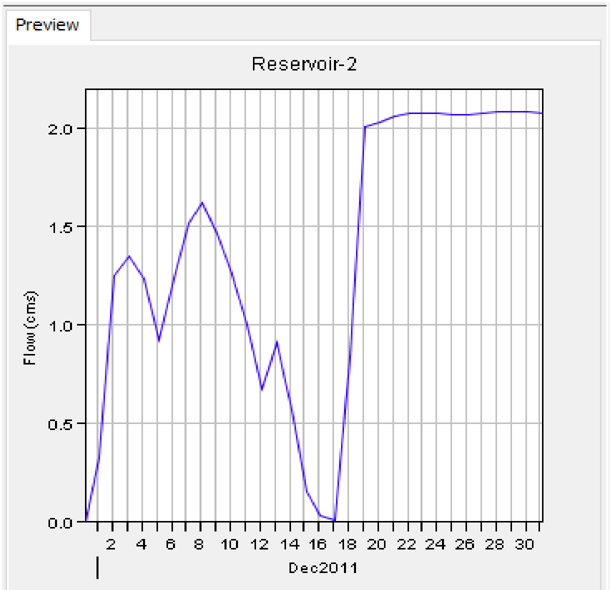


Figure 5.56: Reservoir 2; storage graph

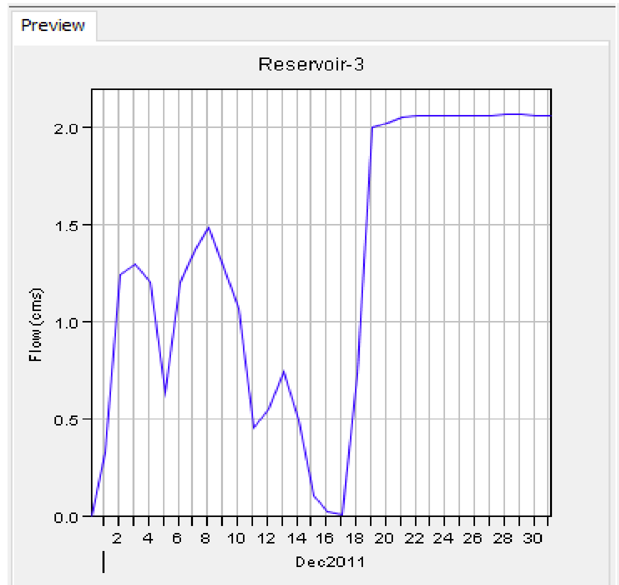


Figure 5.57: Reservoir 3; storage graph

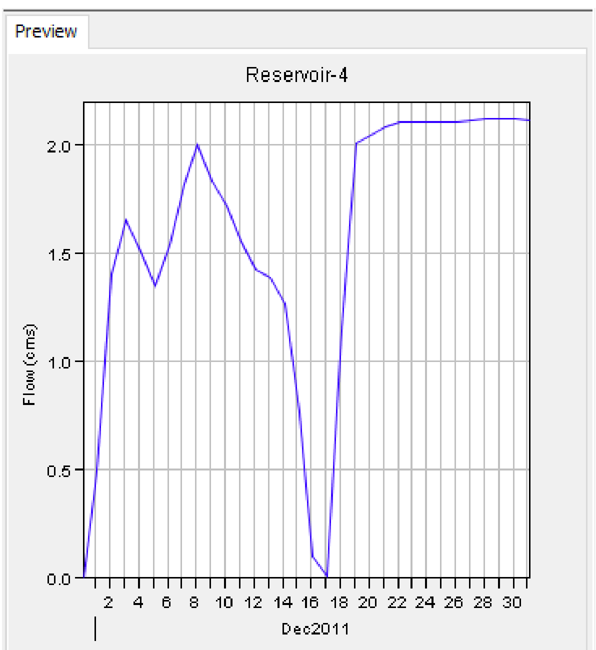


Figure 5.58: Reservoir 4; storage graph

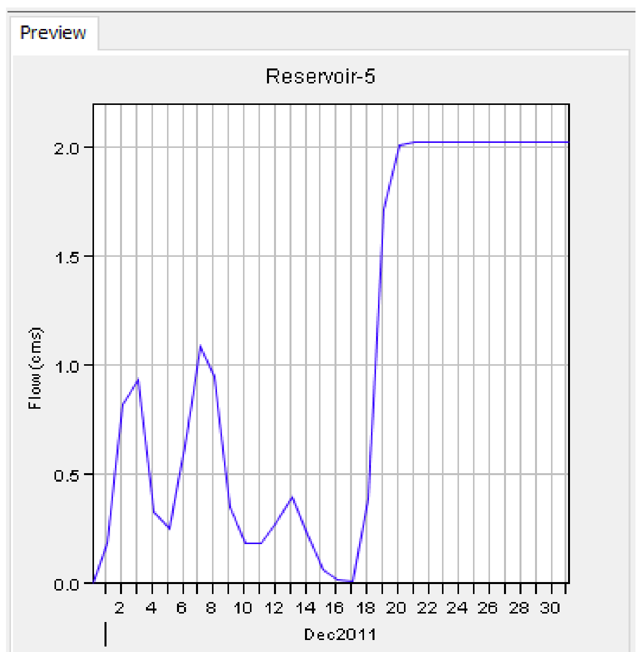


Figure 5.59: Reservoir 5; storage graph

CHAPTER SIX

6.0 PRACTICAL INTERPRETATION AND APPLICATION OF STUDY RESULTS

6.1 Practical interpretation

This study has revealed that land use change has significant impact on hydrological system of a catchment that affects quality and quantity of stormwater runoff generated. Also, this study has shown that detention basins/ponds can be used for protecting a catchment against floods, soil erosion, ecological destruction and supplementing water demand gaps as explained below.

6.1.1 Land use-runoff generation relationship data for management planning

As previously explained, that land use change has a significant impact on the hydrological system of a catchment that affects the quality and quantity of stormwater runoff generated. This study has provided information on the relationship between land use and its hydrological response on stormwater runoff generation. This information is useful for stormwater management planning systems

6.1.2 Flood control system

This study has revealed that detention basins can significantly be used as a flood control system in a highly urbanized catchment by retaining stormwater runoff and then released at a controlled rate in which a receiving stream downstream can safely pass the stormwater. The design of the flood control basins takes into account the impact of land use change which can be very useful for a highly urbanized catchment.

6.1.3 Soil erosion control system

Safely released stormwater can have less negative impact on soil. We have seen in this study that detention basins are capable attenuating floods and allow safe flow in a stream under rapid urbanization. This reduces the erosive power of stormwater runoff generated in catchment and protect the catchment against soil erosion.

6.1.4 Ecological conservation system

This study has shown that, detention basins are capable of controlling flash floods and allow gradual stream flow which in turn extends the stream flow period as flash floods prolongs drier periods. This helps in ecological conservation through providing water for water dependent organisms and save them from extinction.

6.1.5 Water supply systems

Retained water from the designed basins can be used to supplement water demand gaps especially for non-portable uses such as car washing, garden irrigation and so on. For a highly urbanized catchment, the demand on water supply also increases of which stormwater can potential water resource for the water demand fixing.

6.2 Practical application

The impact of land use change lead to an increase of about 23.08% from 1998 to 2018 which can be very useful information in stormwater management planning. This study portrays the need of incorporating the impact of land use change in stormwater management systems.

Detention basins attenuate floodwater through controlling the amount of stormwater released to a receiving stream downstream. The designed detention basins are capable of capturing up to 65% of more than 50 years' extreme event peak discharge.

As the floodwater is attenuated, the reduction in erosive power of stormwater runoff is achieved while extending stream flow period which conserves ecological system of a catchment and provide water especially for non-portable uses.

CHAPTER SEVEN

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Efficient storm water runoff management practices can protect one of our most important natural resources, properties and human lives. Increased impervious surfaces due to land use changes magnifies the demolishing power of floods as a result of storm water runoff. However, estimation of rainfall-runoff and its relation to flood is a difficult task due to influence of different factors. Surface runoff estimation in a watershed or catchment based on its land geomorphological characteristics and the received precipitation by quantifying discharge generated is important aspect in hydrologic studies. The storm runoff estimation in basins is very important for optimum flood management, water quality preservation as well as soil and ecological conservation.

In this study, HEC-HMS hydrological model version 4.2 was used to simulate rainfall-runoff process in Msimbazi catchment located between latitudes 6°C and 7°C south of the Equator and between longitudes 39°C and. 39° C East of Greenwich with the use of daily rainfall data of the December 2011 most extreme event to date in the span of 50 years. The total area of the study watershed is 295.90km^2.

The focus of the study was to quantify the amount of rainfall that ends up being surface runoff for the detention facilities design. The first task in this study was to delineate the watershed and calculate the characteristics of the catchment including land use classification for three years (1998,2009 and 2018) in ArcGIS. Where, the catchment was well-drained with up to four stream orders and five land use classes were identified, namely water bodies, forests developed low intensity, developed medium intensity and developed high intensity.

The study was able to identify potential land use changes from 61.67% in 1998 to 21.13% in 2018 for the low intensity developed areas while those of medium intensity development increased from 25.97% in 1998 to 61.12% in 2018. It was also observed that the areas covered by high intensity developed areas have increased from 3.82% in 1998 to 19.77% in 2018.

The direct runoff for each study year was computed in HEC HMS by the use of SCS curve number method where the peak discharges for the study years were compared. The computed peak discharge for the 1998 study year was 355.7m^3/s, 402.7m^3/s in 2009 and 437.8m^3/s in 2018 which is an increase of about 23.08% from 1998 to 2018.

Five sub-basins were formed and detention basins were placed at each outlet of the five sub-basins of the study catchment. Inflow and outflow discharges for each detention basin were computed in HEC HMS. The peak inflows for all detention basins were observed in the extreme event of 20 December 2011, where reservoir 1 had 123.6 m^3/s, reservoir 2 had 43.5m^3/s, reservoir 3 had 37.5 m^3/s, reservoir 4 had 60.5 m^3/s and reservoir 5 had 19.2 m^3/s. A total of 284.5 m^3/s which is about 65% of the peak runoff discharge generated in the catchment.

The detention basins are designed to capture and slow stormwater runoff to prevent downstream flooding, reduce the extent of soil erosion, extend water flow period in the river which will also provide water for ecological conservation as well as provide water for none portable uses.

7.2 RECOMMENDATIONS

On the basis of the findings of this study, the following recommendations are given;

Hydrologic modeling software packages should provide simple and clear directions on their error message logs by suggesting the source of an error and procedures to follow towards handling the particular error. Simple and clear direction will make the hydrologic modeling procedures easy and less time-consuming.

This study has investigated the implications of a change in land use for surface runoff generation in a catchment. This has demonstrated the importance of considering changes in land use when planning for storm water management practices especially in places where rapid urbanization is witnessed.

The detention basins should be promoted as a technology for stormwater runoff management in flood-threatened areas because they can serve multiple purposes including recreational purposes, soil conservation, water supply and many more.

Further studies should be focused on determining the impact of an individual land use class on surface runoff generation especially in places where only one land use class is dominant.

REFERENCES

African Development Bank (2014). Tracking Africa's progress in figures. Statistics Department in the Chief Economist Vice Presidency of the African Development Bank, Tunis Tunisia.

Alexander, C.S. (1969). Beach ridges in north-eastern Tanzania. Geographical Review, New York. 59 (1), 104–122.

Amutha R, Porchelvan P (2009) Estimation of surface runoff in Malattar sub-watershed using SCS-CN method. J Soc Remote Sens 37(2):291–304

Arthurton, R.S., (1992). Beach erosion: Case studies on the East African Coast, pp. 91–95. In: Proceedings of the International Convention on the Rational Use of the Coastal Zone. UNESCOIOC and Bordomer Organisation, Bordeaux.

Bansode A, Patil KA (2014) Estimation of runoff by using SCS curve number method and arc GIS. Int J Sci Eng Res 5(7):1283–1287

Casmiri, D (2008). Vulnerability of Dar es Salaam City to Impacts of Climate Change. EPMS, Dar es Salaam, 22 pp.

Dauphin County Conservation District (2013). Detention Ponds. Best Management Practices Fact Sheet, Dauphin.

Engineering Staff (1993). National Engineering Handbook. USDA-NRCS, Engineering Division. U.S. Gov. Print. Office, Washington, DC. Part 630, Section 4, Chapter 7.

FAO (2015). World Reference Base for Soil Resources 2014, International Soil Classification System for naming soils and Creating Legends for Soil maps, Update 2015.

FAO – UNESCO (1974). Soil Map of the World, Paris.

Fay, M., Griffith, C.J, Hemed, I.A. and Lwiza, K.M (1988). Beach erosion along Kunduchi Beach, north of Dar es Salaam. Beach Erosion Monitoring Committee, Dar as Salaam, National Environment Management Council, 55pp.

Google Earth 6.0. (2018). Kisarawe. 7.2623° S, 38.7368° E, elevation 37M. 3D map, Buildings, Borders and Labels, Places, Roads data layer, viewed 17 July 2018. <http://www.google.com/earth/index.html>.

Hydrologic Engineering Center (HEC). (2013). Geospatial hydrologic modeling extension HEC-Geo HMS. User's Manual 10.1. U.S. Army Corps of Engineers, Davis, California.

Hydrologic Engineering Center (HEC). (2010a). Hydrologic Modeling System, HEC-HMS. User's Manual. U.S. Army Corps of Engineers, Davis, California.

Hydrologic Engineering Center (HEC). (2000). Hydrologic Modeling System, HEC-HMS. Technical Reference Manual. U.S. Army Corps of Engineers, Davis, California.

ICWRCOE (2015). A Review on Hydrological Models. Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, 575 025, Mangalore, Karnataka, India.

Jerome J. Lohr (2015). Watershed Modeling Using Arc Hydro Tools. Geo-HMS, and HEC-HMS. Department of Civil and Environmental Engineering, and Water and Environmental Engineering Research Center. South Dakota State University, Brookings, South Dakota.

NASA Earth Observatory. (2009). The Water Cycle. [online] Available at: https://earthobservatory.nasa.gov/Features/Water/page2.php [Accessed 18 April 2018].

Raphael Mwlyosi (2014). Local roads, surface water drainage and Infrastructure upgrading. Environmental and social management Framework (esmf) and environmental codes of Practice (ecops) for the dar es salaam Metropolitan development project (dmdp), Dar es salamm, Tanzania.

Nyandwi, N (2001). Reassessment of the nature of beach erosion north of Dar es Salaam, Tanzania. In: Richmond, M.D., Francis J., (eds), Marine Science Development in Tanzania and Eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania, 28 June – 1 July 1999, Zanzibar, Tanzania. IMS/WIOMSA, p. 107-120.

Natural Resources Conservation Service (NRCS). (1986). Small Watershed Hydrology, Win- TR55. User Guide. United States Department of Agriculture, Washington, DC.

Makota, V., Sallema, R. and Makika, C. (2004). Monitoring Shoreline Change using Remote Sensing and GIS: A Case Study of Kunduchi Area, Tanzania. Western Indian Ocean Journal of Marine Science, 3(1), 1-10.

UNICEF (2012). UNICEF Annual Report. UNICEF, United Republic of Tanzania, ESARO. Dar es salaam, Tanzania.

U.S. Environmental Protection Agency (EPA). (2012). What is a Watershed? Retrieved June 30, 2013, from http://water.epa.gov/type/watersheds/whatis.cfm.

U.S. Geological Survey (USGS). (2012). Frequently Asked Questions, Multi-Resolution Land Characterization (MRLC) Consortium. Available at: http://mrlc.gov/faq.php. [Accessed 18 April 2018].

USACE Hydrologic Engineering Center (2008). HEC-HMS Application guide.

US Environmental Protection Agency (2009). Stormwater Wet Pond and Wetland Management Guidebook.

USACE Hydrologic Engineering Center (2018).(HEC-HMS).Available at: http://www.hec.usace.army.mil/software/hec-hms/features.aspx [Accessed 18 April 2018].

USDA Natural Resources Conservation Service (2007). Hydrologic Soil Groups. National Engineering Handbook. Independence Avenue, SW, Washington.

U.S. Geological Survey (USGS). (2013a). Elevation. Available at: http://nationalmap.gov/elevation.html. [Accessed 18 April 2018].

U.S. Geological Survey (USGS). (2013b). National Hydrography Dataset. Available at: http://nhd.usgs.gov. [Accessed 18 April 2018].

Wenban-Smith, Hugh. (2014). "Population Growth, Internal Migration and Urbanization in Tanzania: 1967-2020: A Census Based Regional Analysis," IGC Working Paper.

World Bank (2014). Dar es Salaam Metropolitan Development Project (P123134). Prime Minister's Office – Regional Administration and Local, Dar es salaam, Tanzania.

APPENDICES

APPENDIX A

Hydrologic modeling summary tables

I: 1998

(a) Basin summary table

Date	Time	Precip(mm)	Loss(mm)	Excess(mm)	Direct flow(m3/s)	Total flow(m3/s)
30-Nov-11	3:00				0	0
1-Dec-11	3:00	2.4	1.92	0.48	1.2	1.2
2-Dec-11	3:00	19.6	15.68	3.92	10.3	10.3
3-Dec-11	3:00	0	0	0	2.9	2.9
4-Dec-11	3:00	0	0	0	0.6	0.6
5-Dec-11	3:00	3.6	2.88	0.72	1.9	1.9
6-Dec-11	3:00	9	6.91	2.09	5.8	5.8
7-Dec-11	3:00	13.3	8.78	4.52	13.1	13.1
8-Dec-11	3:00	0.8	0.48	0.32	4.3	4.3
9-Dec-11	3:00	0	0	0	0.9	0.9
10-Dec-11	3:00	2.5	1.47	1.03	2.8	2.8
11-Dec-11	3:00	0	0	0	0.7	0.7
12-Dec-11	3:00	4.3	2.43	1.87	4.9	4.9
13-Dec-11	3:00	2.5	1.36	1.14	4.3	4.3
14-Dec-11	3:00	0	0	0	1.1	1.1
15-Dec-11	3:00	0	0	0	0.2	0.2
16-Dec-11	3:00	0	0	0	0	0
17-Dec-11	3:00	0	0	0	0	0

18-Dec-11	3:00	0	0	0	0	0
19-Dec-11	3:00	60	23.58	36.42	92.7	92.7
20-Dec-11	3:00	156.4	26.81	129.59	355.7	355.7
21-Dec-11	3:00	43.8	3.99	39.81	198.7	198.7
22-Dec-11	3:00	7.3	0.59	6.71	64.6	64.6
23-Dec-11	3:00	0.6	0.05	0.55	15.4	15.4
24-Dec-11	3:00	0	0	0	2.4	2.4
25-Dec-11	3:00	0	0	0	0.3	0.3
26-Dec-11	3:00	0	0	0	0	0
27-Dec-11	3:00	48.5	3.44	45.06	114.6	114.6
28-Dec-11	3:00	2.6	0.17	2.43	38.3	38.3
29-Dec-11	3:00	0	0	0	8	8
30-Dec-11	3:00	0	0	0	1.6	1.6
31-Dec-11	3:00	0	0	0	0.1	0.1

(b) Outlet time-series summary table

Date	Time	Inflow (m^3/s)	Outflow (m^3/s)
30-Nov-11	3:00	0	0
1-Dec-11	3:00	1.2	1.2
2-Dec-11	3:00	10.4	10.4
3-Dec-11	3:00	2.9	2.9
4-Dec-11	3:00	0.6	0.6
5-Dec-11	3:00	2	2
6-Dec-11	3:00	6	6
7-Dec-11	3:00	13.4	13.4

8-Dec-11	3:00	4.4	4.4
9-Dec-11	3:00	0.9	0.9
10-Dec-11	3:00	2.8	2.8
11-Dec-11	3:00	0.8	0.8
12-Dec-11	3:00	5	5
13-Dec-11	3:00	4.3	4.3
14-Dec-11	3:00	1.1	1.1
15-Dec-11	3:00	0.2	0.2
16-Dec-11	3:00	0	0
17-Dec-11	3:00	0	0
18-Dec-11	3:00	0	0
19-Dec-11	3:00	93.6	93.6
20-Dec-11	3:00	355.7	355.7
21-Dec-11	3:00	199.4	199.4
22-Dec-11	3:00	64.8	64.8
23-Dec-11	3:00	15.4	15.4
24-Dec-11	3:00	2.5	2.5
25-Dec-11	3:00	0.3	0.3
26-Dec-11	3:00	0	0
27-Dec-11	3:00	114.9	114.9
28-Dec-11	3:00	38.4	38.4
29-Dec-11	3:00	8.1	8.1
30-Dec-11	3:00	1.6	1.6
31-Dec-11	3:00	0.1	0.1

II: 2009

(a) Basin summary table

Date	Time	Precip(mm)	Loss(mm)	Excess(mm)	Direct flow(m3/s)	Total flow(m3/s)
30-Nov-11	3:00				0	0
1-Dec-11	3:00	2.4	1.37	1.03	2.6	2.6
2-Dec-11	3:00	19.6	11.11	8.49	22.3	22.3
3-Dec-11	3:00	0	0	0	6.2	6.2
4-Dec-11	3:00	0	0	0	1.2	1.2
5-Dec-11	3:00	3.6	1.85	1.75	4.7	4.7
6-Dec-11	3:00	9	4.09	4.91	13.7	13.7
7-Dec-11	3:00	13.3	4.95	8.35	25	25
8-Dec-11	3:00	0.8	0.26	0.54	8	8
9-Dec-11	3:00	0	0	0	1.7	1.7
10-Dec-11	3:00	2.5	0.8	1.7	4.6	4.6
11-Dec-11	3:00	0	0	0	1.2	1.2
12-Dec-11	3:00	4.3	1.31	2.99	7.8	7.8
13-Dec-11	3:00	2.5	0.72	1.78	6.7	6.7
14-Dec-11	3:00	0	0	0	1.7	1.7
15-Dec-11	3:00	0	0	0	0.3	0.3
16-Dec-11	3:00	0	0	0	0	0
17-Dec-11	3:00	0	0	0	0	0
18-Dec-11	3:00	0	0	0	0	0
19-Dec-11	3:00	60	11.74	48.26	122.8	122.8
20-Dec-11	3:00	156.4	11.65	144.75	402.7	402.7
21-Dec-11	3:00	43.8	1.6	42.2	217.2	217.2

22-Dec-11	3:00	7.3	0.23	7.07	69.7	69.7
23-Dec-11	3:00	0.6	0.02	0.58	16.5	16.5
24-Dec-11	3:00	0	0	0	2.6	2.6
25-Dec-11	3:00	0	0	0	0.3	0.3
26-Dec-11	3:00	0	0	0	0	0
27-Dec-11	3:00	48.5	1.35	47.15	120	120
28-Dec-11	3:00	2.6	0.06	2.54	40	40
29-Dec-11	3:00	0	0	0	8.4	8.4
30-Dec-11	3:00	0	0	0	1.7	1.7
31-Dec-11	3:00	0	0	0	0.1	0.1

(b) Outlet time-series summary table

Date	Time	Inflow(m3/s)	Outflow (m3/s)
30-Nov-11	3:00	0	0
1-Dec-11	3:00	2.6	2.6
2-Dec-11	3:00	22.3	22.3
3-Dec-11	3:00	6.2	6.2
4-Dec-11	3:00	1.2	1.2
5-Dec-11	3:00	4.7	4.7
6-Dec-11	3:00	13.7	13.7
7-Dec-11	3:00	25	25
8-Dec-11	3:00	8	8
9-Dec-11	3:00	1.7	1.7
10-Dec-11	3:00	4.6	4.6
11-Dec-11	3:00	1.2	1.2

12-Dec-11	3:00	7.8	7.8
13-Dec-11	3:00	6.7	6.7
14-Dec-11	3:00	1.7	1.7
15-Dec-11	3:00	0.3	0.3
16-Dec-11	3:00	0	0
17-Dec-11	3:00	0	0
18-Dec-11	3:00	0	0
19-Dec-11	3:00	122.8	122.8
20-Dec-11	3:00	402.7	402.7
21-Dec-11	3:00	217.2	217.2
22-Dec-11	3:00	69.7	69.7
23-Dec-11	3:00	16.5	16.5
24-Dec-11	3:00	2.6	2.6
25-Dec-11	3:00	0.3	0.3
26-Dec-11	3:00	0	0
27-Dec-11	3:00	120	120
28-Dec-11	3:00	40	40
29-Dec-11	3:00	8.4	8.4
30-Dec-11	3:00	1.7	1.7
31-Dec-11	3:00	0.1	0.1

III: 2018

(a) Basin summary table

Date	Time	Precip(mm)	Loss(mm)	Excess(mm)	Direct flow(m3/s)	Total flow(m3/s)
30-Nov-11	3:00				0	0
1-Dec-11	3:00	2.4	1.01	1.39	3.5	3.5
2-Dec-11	3:00	19.6	4.96	14.64	38.2	38.2
3-Dec-11	3:00	0	0	0	10.6	10.6
4-Dec-11	3:00	0	0	0	2.1	2.1
5-Dec-11	3:00	3.6	0.43	3.17	8.5	8.5
6-Dec-11	3:00	9	0.82	8.18	23.1	23.1
7-Dec-11	3:00	13.3	0.8	12.5	38.1	38.1
8-Dec-11	3:00	0.8	0.04	0.76	12.1	12.1
9-Dec-11	3:00	0	0	0	2.5	2.5
10-Dec-11	3:00	2.5	0.11	2.39	6.5	6.5
11-Dec-11	3:00	0	0	0	1.7	1.7
12-Dec-11	3:00	4.3	0.17	4.13	10.8	10.8
13-Dec-11	3:00	2.5	0.09	2.41	9.1	9.1
14-Dec-11	3:00	0	0	0	2.3	2.3
15-Dec-11	3:00	0	0	0	0.5	0.5
16-Dec-11	3:00	0	0	0	0.1	0.1
17-Dec-11	3:00	0	0	0	0	0
18-Dec-11	3:00	0	0	0	0	0
19-Dec-11	3:00	60	1.2	58.8	149.6	149.6
20-Dec-11	3:00	156.4	0.81	155.59	437.8	437.8

21-Dec-11	3:00	43.8	0.09	43.71	230.3	230.3
22-Dec-11	3:00	7.3	0.01	7.29	73.1	73.1
23-Dec-11	3:00	0.6	0	0.6	17.2	17.2
24-Dec-11	3:00	0	0	0	2.7	2.7
25-Dec-11	3:00	0	0	0	0.3	0.3
26-Dec-11	3:00	0	0	0	0	0
27-Dec-11	3:00	48.5	0.07	48.43	123.2	123.2
28-Dec-11	3:00	2.6	0	2.6	41.1	41.1
29-Dec-11	3:00	0	0	0	8.6	8.6
30-Dec-11	3:00	0	0	0	1.7	1.7
31-Dec-11	3:00	0	0	0	0.1	0.1

(b) Outlet time-series summary table

Date	Time	Inflow (m3/s)	Outflow (m3/s)
30-Nov-11	3:00	0	0
1-Dec-11	3:00	3.5	3.5
2-Dec-11	3:00	38.2	38.2
3-Dec-11	3:00	10.6	10.6
4-Dec-11	3:00	2.1	2.1
5-Dec-11	3:00	8.5	8.5
6-Dec-11	3:00	23.1	23.1
7-Dec-11	3:00	38.1	38.1
8-Dec-11	3:00	12.1	12.1
9-Dec-11	3:00	2.5	2.5
10-Dec-11	3:00	6.5	6.5

11-Dec-11	3:00	1.7	1.7
12-Dec-11	3:00	10.8	10.8
13-Dec-11	3:00	9.1	9.1
14-Dec-11	3:00	2.3	2.3
15-Dec-11	3:00	0.5	0.5
16-Dec-11	3:00	0.1	0.1
17-Dec-11	3:00	0	0
18-Dec-11	3:00	0	0
19-Dec-11	3:00	149.6	149.6
20-Dec-11	3:00	437.8	437.8
21-Dec-11	3:00	230.3	230.3
22-Dec-11	3:00	73.1	73.1
23-Dec-11	3:00	17.2	17.2
24-Dec-11	3:00	2.7	2.7
25-Dec-11	3:00	0.3	0.3
26-Dec-11	3:00	0	0
27-Dec-11	3:00	123.2	123.2
28-Dec-11	3:00	41.1	41.1
29-Dec-11	3:00	8.6	8.6
30-Dec-11	3:00	1.7	1.7
31-Dec-11	3:00	0.1	0.1

APPENDIX B

Detention basin summary tables

I: Reservoir/Detention basin 1

Date	Time	Inflow(m^3/s)	Storage(m^3)	Outflow(m^3/s)
30-Nov-11	3:00	0	0	0
1-Dec-11	3:00	1.6	36.7	0.7
2-Dec-11	3:00	7.1	308.5	1.7
3-Dec-11	3:00	2.1	548	2
4-Dec-11	3:00	0.6	494.3	2
5-Dec-11	3:00	2.3	451.4	1.9
6-Dec-11	3:00	5.8	632.1	2
7-Dec-11	3:00	8.7	1086.8	2
8-Dec-11	3:00	2.9	1414.1	2
9-Dec-11	3:00	0.8	1400.6	2
10-Dec-11	3:00	1.5	1329	2
11-Dec-11	3:00	0.8	1255.6	2
12-Dec-11	3:00	2.8	1236	2
13-Dec-11	3:00	2.2	1279.8	2
14-Dec-11	3:00	0.6	1228.4	2

15-Dec-11	3:00	0.1	1085.6	2
16-Dec-11	3:00	0	918.2	2
17-Dec-11	3:00	0	745.9	2
18-Dec-11	3:00	4.9	786.4	2
19-Dec-11	3:00	52.8	3106.7	2
20-Dec-11	3:00	123.6	10547.4	2.1
21-Dec-11	3:00	65.9	18544.8	2.2
22-Dec-11	3:00	21.3	22117.3	2.2
23-Dec-11	3:00	5.1	23062	2.2
24-Dec-11	3:00	0.8	23122.7	2.2
25-Dec-11	3:00	0.1	22968.4	2.2
26-Dec-11	3:00	4.7	22981.1	2.2
27-Dec-11	3:00	34.4	24476.3	2.3

28-Dec-11	3:00	12	26285.8	2.3
29-Dec-11	3:00	2.6	26719.4	2.3
30-Dec-11	3:00	0.5	26656.8	2.3
31-Dec-11	3:00	0	26483.2	2.3

II: Reservoir/Detention basin 2

Date	Time	Inflow(m^3/s)	Storage(m^3)	Outflow(m^3/s)
30-Nov-11	3:00	0	0	0
1-Dec-11	3:00	0.6	13.9	0.3
2-Dec-11	3:00	2.9	100.3	1.2
3-Dec-11	3:00	0.9	151.8	1.3
4-Dec-11	3:00	0.3	88.9	1.2
5-Dec-11	3:00	0.9	45.2	0.9
6-Dec-11	3:00	2.2	87.4	1.2
7-Dec-11	3:00	3.3	207.5	1.5
8-Dec-11	3:00	1.1	260.5	1.6
9-Dec-11	3:00	0.3	187.5	1.5
10-Dec-11	3:00	0.6	107.9	1.3
11-Dec-11	3:00	0.3	47.6	1
12-Dec-11	3:00	1	32.5	0.7

13-Dec-11	3:00	0.8	44.5	0.9
14-Dec-11	3:00	0.2	25.9	0.6
15-Dec-11	3:00	0	6.3	0.1
16-Dec-11	3:00	0	1.1	0
17-Dec-11	3:00	0	0.1	0
18-Dec-11	3:00	1.8	42.1	0.8
19-Dec-11	3:00	18.9	814.4	2
20-Dec-11	3:00	43.5	3338	2
21-Dec-11	3:00	23.1	6041	2.1
22-Dec-11	3:00	7.5	7183.4	2.1
23-Dec-11	3:00	1.8	7403.1	2.1
24-Dec-11	3:00	0.3	7313.1	2.1
25-Dec-11	3:00	0	7147.8	2.1
26-Dec-11	3:00	1.6	7041	2.1
27-Dec-11	3:00	12	7452.4	2.1
28-Dec-11	3:00	4.2	7973.6	2.1
29-Dec-11	3:00	0.9	8014.1	2.1
30-Dec-11	3:00	0.2	7881.4	2.1
31-Dec-11	3:00	0	7710	2.1

III: Reservoir/Detention basin 3

Date	Time	Inflow(m^3/s)	Storage(m^3)	Outflow(m^3/s)
30-Nov-11	3:00	0	0	0
1-Dec-11	3:00	0.6	14	0.3
2-Dec-11	3:00	2.7	92.1	1.2

3-Dec-11	3:00	0.7	132.7	1.3
4-Dec-11	3:00	0.2	66.8	1.2
5-Dec-11	3:00	0.8	30.4	0.6
6-Dec-11	3:00	1.9	67.6	1.2
7-Dec-11	3:00	2.8	160	1.4
8-Dec-11	3:00	0.9	194.9	1.5
9-Dec-11	3:00	0.2	123.8	1.3
10-Dec-11	3:00	0.5	53.9	1.1
11-Dec-11	3:00	0.2	19.5	0.5
12-Dec-11	3:00	0.9	24.6	0.5
13-Dec-11	3:00	0.7	37	0.7
14-Dec-11	3:00	0.2	21.2	0.5
15-Dec-11	3:00	0	4.5	0.1
16-Dec-11	3:00	0	0.8	0
17-Dec-11	3:00	0	0.1	0
18-Dec-11	3:00	1.6	36	0.7
19-Dec-11	3:00	16.3	690.3	2
20-Dec-11	3:00	37.5	2842.5	2
21-Dec-11	3:00	19.3	5123.5	2
22-Dec-11	3:00	6.1	6044.9	2.1
23-Dec-11	3:00	1.4	6191.4	2.1
24-Dec-11	3:00	0.2	6084.2	2.1
25-Dec-11	3:00	0	5916.8	2.1
26-Dec-11	3:00	1.4	5801.8	2.1
27-Dec-11	3:00	10.5	6138.3	2.1
28-Dec-11	3:00	3.4	6561.2	2.1

29-Dec-11	3:00	0.7	6562.4	2.1
30-Dec-11	3:00	0.1	6421.3	2.1
31-Dec-11	3:00	0	6249.4	2.1

IV: Reservoir/Detention basin 4

Date	Time	Inflow(m^3/s)	Storage(m^3)	Outflow(m^3/s)
30-Nov-11	3:00	0	0	0
1-Dec-11	3:00	1	21.3	0.5
2-Dec-11	3:00	4.3	168.4	1.4
3-Dec-11	3:00	1.2	274.1	1.6
4-Dec-11	3:00	0.4	204.2	1.5
5-Dec-11	3:00	1.3	151	1.3
6-Dec-11	3:00	3.2	218	1.5
7-Dec-11	3:00	4.6	407.4	1.8
8-Dec-11	3:00	1.4	502.2	2
9-Dec-11	3:00	0.4	416	1.8
10-Dec-11	3:00	0.8	314.6	1.7
11-Dec-11	3:00	0.4	224.7	1.5
12-Dec-11	3:00	1.4	175.3	1.4
13-Dec-11	3:00	1.1	164.9	1.4
14-Dec-11	3:00	0.3	111.2	1.3
15-Dec-11	3:00	0.1	38.3	0.8
16-Dec-11	3:00	0	4.1	0.1
17-Dec-11	3:00	0	0.2	0
18-Dec-11	3:00	2.5	60.4	1.1

19-Dec-11	3:00	26.5	1177.9	2
20-Dec-11	3:00	60.5	4759.6	2
21-Dec-11	3:00	31.1	8538.6	2.1
22-Dec-11	3:00	9.8	10125.1	2.1
23-Dec-11	3:00	2.3	10464.8	2.1
24-Dec-11	3:00	0.4	10396.6	2.1
25-Dec-11	3:00	0	10231.6	2.1
26-Dec-11	3:00	2.3	10150.5	2.1
27-Dec-11	3:00	16.8	10794	2.1
28-Dec-11	3:00	5.5	11576.1	2.1
29-Dec-11	3:00	1.2	11681.3	2.1
30-Dec-11	3:00	0.2	11557.9	2.1
31-Dec-11	3:00	0	11385.1	2.1

V: Reservoir/Detention basin 5

Date	Time	Inflow(m^3/s)	Storage(m^3)	Outflow(m^3/s)
30-Nov-11	3:00	0	0	0
1-Dec-11	3:00	0.4	7.6	0.2
2-Dec-11	3:00	1.4	41.5	0.8
3-Dec-11	3:00	0.4	45.4	0.9
4-Dec-11	3:00	0.1	14	0.3
5-Dec-11	3:00	0.4	10.7	0.2
6-Dec-11	3:00	0.9	29.7	0.6
7-Dec-11	3:00	1.4	55.3	1.1
8-Dec-11	3:00	0.4	45.8	0.9

9-Dec-11	3:00	0.1	14.8	0.3
10-Dec-11	3:00	0.2	7.9	0.2
11-Dec-11	3:00	0.1	7.7	0.2
12-Dec-11	3:00	0.4	11.9	0.3
13-Dec-11	3:00	0.3	16.7	0.4
14-Dec-11	3:00	0.1	9.3	0.2
15-Dec-11	3:00	0	2.3	0.1
16-Dec-11	3:00	0	0.4	0
17-Dec-11	3:00	0	0.1	0
18-Dec-11	3:00	0.8	16.5	0.4
19-Dec-11	3:00	8.2	311.3	1.7
20-Dec-11	3:00	19.2	1333.9	2
21-Dec-11	3:00	10.2	2431	2
22-Dec-11	3:00	3.3	2837.4	2
23-Dec-11	3:00	0.8	2837.1	2
24-Dec-11	3:00	0.1	2700.9	2
25-Dec-11	3:00	0	2532.1	2
26-Dec-11	3:00	0.7	2390	2
27-Dec-11	3:00	5.4	2481.5	2
28-Dec-11	3:00	1.9	2621	2
29-Dec-11	3:00	0.4	2543.4	2
30-Dec-11	3:00	0.1	2389.3	2
31-Dec-11	3:00	0	2218.4	2

APPENDIX C

Msimbazi basin characteristics summary table

OBJECTID	Shape_Length	Shape_Area	HydroID	DrainID	Name	BasinSlope
1	10689.95	2735526	170	170	W1700	21.41586
2	26847.74	7344118	171	171	W1710	13.40106
3	14499.01	3500794	172	172	W1720	13.6923
4	8969.726	1232355	173	173	W1730	20.49368
5	6020.775	1013437	174	174	W1740	8.040486
6	12225.86	3702726	175	175	W1750	14.16522
7	10567.07	1621122	176	176	W1760	14.26805
8	10198.45	2402431	177	177	W1770	9.255845
9	7126.631	1063449	178	178	W1780	12.24215
10	7310.941	1266325	179	179	W1790	10.3233
11	11611.49	2304296	180	180	W1800	8.555858
12	4054.807	424624.6	181	181	W1810	13.75465
13	7065.195	1006832	182	182	W1820	15.31592
14	25864.76	6961012	183	183	W1830	16.76868
16	1228.729	40575.24	185	185	W1850	11.58343
17	10382.76	2068394	186	186	W1860	9.158801
18	8723.98	1002114	187	187	W1870	6.006278
19	4914.918	582207.5	188	188	W1880	6.39082
20	6880.886	1015325	189	189	W1890	10.58362
21	11795.8	1974032	190	190	W1900	7.146411
22	9952.71	1766438	191	191	W1910	16.87799
23	10505.64	2422247	192	192	W1920	9.355728
25	9891.272	2201443	194	194	W1940	10.91762

26	4546.299	633162.4	195	195	W1950	8.744947
27	6942.322	834151.4	196	196	W1960	14.06391
28	21195.59	5044540	197	197	W1970	17.6774
29	10075.58	1723032	198	198	W1980	14.95013
30	9645.527	1908923	199	199	W1990	10.74002
31	10382.77	2615687	200	200	W2000	10.07617
32	15973.48	3854648	201	201	W2010	13.24269
33	7310.94	1050238	202	202	W2020	9.273473
34	10751.38	2368462	203	203	W2030	12.4993
35	10259.89	1910811	204	204	W2040	19.13877
36	9399.782	2203330	205	205	W2050	11.53559
37	11181.44	1669246	206	206	W2060	12.46406
38	10935.69	2790255	207	207	W2070	16.7938
39	7863.87	1083264	208	208	W2080	10.17423
41	6389.394	767155.1	210	210	W2100	12.09226
42	9768.4	2716654	211	211	W2110	13.50369
43	6635.14	900204.2	212	212	W2120	18.77571
44	8846.853	1783423	213	213	W2130	18.11801
45	11365.75	3798031	214	214	W2140	11.4048
46	7310.941	1253114	215	215	W2150	11.7537
47	5590.719	1052125	216	216	W2160	10.68654
48	2518.895	124556.5	217	217	W2170	25.24964
49	6635.139	1134219	218	218	W2180	18.79401
50	2580.332	144372.4	219	219	W2190	32.01125
51	2457.459	174567.9	220	220	W2200	34.50384
52	7740.996	1505058	221	221	W2210	15.98553

53	13024.53	2457161	222	222	W2220	18.50136
55	9215.471	1812675	224	224	W2240	15.58898
56	23345.86	7432817	225	225	W2250	16.12745
57	11980.11	3122406	226	226	W2260	17.98136
58	16649.28	3287538	227	227	W2270	12.85887
59	5406.41	651091	228	228	W2280	11.77843
61	7372.377	1315393	230	230	W2300	16.35753
62	7126.631	1015325	231	231	W2310	14.63409
64	1720.221	33970	233	233	W2330	14.13562
65	3993.371	402921.5	234	234	W2340	15.80481
66	6819.449	1303126	235	235	W2350	13.25091
67	7310.941	1533367	236	236	W2360	13.48384
68	7310.94	1478637	237	237	W2370	15.30688
69	8846.852	1271043	238	238	W2380	11.34382
70	11058.57	1757946	239	239	W2390	21.05077
71	5713.592	924738	240	240	W2400	13.93391
72	8293.924	1834378	241	241	W2410	15.99845
73	6696.576	1253114	242	242	W2420	12.32418
74	12840.22	3093154	243	243	W2430	19.27313
75	9522.654	1875897	244	244	W2440	14.44711
76	8293.924	1765495	245	245	W2450	13.17255
77	15113.37	3875407	246	246	W2460	17.61358
78	5283.537	728467.1	247	247	W2470	13.15906
79	9031.163	1279535	248	248	W2480	16.35659
80	23161.55	5922097	249	249	W2490	14.74106
81	3993.371	351966.6	250	250	W2500	26.0096

82	7372.377	1503171	251	251	W2510	16.09035
83	10812.82	1764551	252	252	W2520	19.06396
84	10874.26	2249567	253	253	W2530	17.13283
85	14499.01	3665926	254	254	W2540	17.61068
86	13946.08	3343211	255	255	W2550	19.12088
89	14191.83	3497019	258	258	W2580	18.02773
90	10014.14	1694724	259	259	W2590	17.30892
91	9952.709	1974033	260	260	W2600	16.43573
92	11427.18	3366801	261	261	W2610	14.2935
93	9276.908	1471088	262	262	W2620	12.94669
94	9338.344	2005172	263	263	W2630	15.1197
95	7618.123	1236129	264	264	W2640	8.913645
96	10751.38	1921190	265	265	W2650	14.64418
97	9768.4	1438062	266	266	W2660	20.69623
98	6758.013	1125727	267	267	W2670	15.96763
99	4546.299	376500.4	268	268	W2680	18.8521
100	8539.67	1624897	269	269	W2690	16.54933
101	7065.195	1266325	270	270	W2700	14.62894
102	3747.625	473692.3	271	271	W2710	16.4054
103	12471.6	2654375	272	272	W2720	8.12961
104	4423.426	361402.7	273	273	W2730	11.9882
105	12041.55	2561902	274	274	W2740	16.63511
106	8539.67	1691893	275	275	W2750	15.96041
107	9768.4	1488073	276	276	W2760	21.30177
108	13638.9	4158490	277	277	W2770	16.96163
109	11795.8	2563789	278	278	W2780	17.29863

110	12717.35	3103534	279	279	W2790	19.32511
111	10137.02	1570167	280	280	W2800	18.32341
112	11734.37	2645883	281	281	W2810	22.695
113	7495.25	1405036	282	282	W2820	14.60765
114	8539.67	1057787	283	283	W2830	18.06244
115	6020.775	1152148	284	284	W2840	22.16527
116	9092.599	1953273	285	285	W2850	11.66454
117	5160.664	493508.1	286	286	W2860	24.67412
118	2764.642	176455.1	287	287	W2870	22.85291
119	11795.8	2258059	288	288	W2880	20.37611
120	5590.719	887937.1	289	289	W2890	21.45199
121	11488.62	2367518	290	290	W2900	21.85341
122	8293.924	1338983	291	291	W2910	18.52933
123	7249.505	1115347	292	292	W2920	19.33328
124	8723.98	1111573	293	293	W2930	13.61244
125	12471.6	4173588	294	294	W2940	13.60088
127	10505.64	2574169	296	296	W2960	20.22671
128	6143.648	1376727	297	297	W2970	26.44949
129	10137.02	2200499	298	298	W2980	20.43097
130	14007.52	2882729	299	299	W2990	14.97513
131	24144.54	4492528	300	300	W3000	22.43394
132	7003.759	1015325	301	301	W3010	20.07962
133	9829.836	1948555	302	302	W3020	17.62416
134	2703.205	142485.1	303	303	W3030	11.73645
135	8662.544	931343.3	304	304	W3040	18.4304
136	9215.472	1823998	305	305	W3050	11.27106

137	6266.52	1228580	306	306	W3060	15.51096
141	7188.067	1125727	310	310	W3100	14.59403
143	8355.361	1127614	312	312	W3120	14.65953
144	10628.51	1428626	313	313	W3130	14.00105
146	7003.759	1284253	315	315	W3150	20.59137
147	12471.6	3221485	316	316	W3160	17.18414
148	15113.37	4222656	317	317	W3170	14.45546
149	8846.852	2153318	318	318	W3180	13.8212
151	11058.57	1771156	320	320	W3200	16.65371
152	31578.35	9146414	321	321	W3210	16.46147
154	15236.25	2450556	323	323	W3230	17.37257
155	16895.03	2733639	324	324	W3240	17.38115
157	13147.41	2526988	326	326	W3260	15.2107
158	10935.69	1217257	327	327	W3270	17.12991
159	6266.521	1045520	328	328	W3280	17.74298
160	9952.709	1735299	329	329	W3290	16.27396
161	1228.729	35857.18	330	330	W3300	14.14168
162	12102.99	3465880	331	331	W3310	17.14294
163	13085.97	3225260	332	332	W3320	16.1993
164	9092.598	1740017	333	333	W3330	13.08618
165	8109.615	1108742	334	334	W3340	15.9513
166	9031.161	1220088	335	335	W3350	11.18442
167	8355.361	1523930	336	336	W3360	9.669262
168	8785.416	1011550	337	337	W3370	8.309205

ANNEX

Research grant

Title: Proposal Budget		
	Activity	**Amount**
Personnel		
1.Total station operator 1	Data collection and site-investigations	$280.00
2.Total station operator 2	Data collection and site-investigations	$280.00
3. Local government	Stamp fee and authorization	$10.00
	Category Total:	**$570.00**
Tools and Equipments		
1. GPS	Taking location data	$100.00
2. Protection gears	Safety purposes	$200.00
3.Softwares	Preparation and analysis of data	$300.00
4. Total Station	Data collection	$700.00
5. Books and stationaries	Data recording and documentation	$300.00
6. Communication bundles	Literature review and communications	$150.00
1.Meteorological data fee	Collection of meteorological data from Tanzania Meteorological Agency	$100.00
2.Maps	Maps acquisition from Lands Office	$100.00
3.Software training fee	Software operation	$250.00
	Category Total:	**$2,200.00**
Data		
1.High resolution DEM	Extraction of land surface data	$110.00
2.Streamflow data	Streamflow characteristics	$60.00
3.Soil data	Extraction of soil data	$60.00
	Category Total:	**$230.00**
	TOTAL	$3,000.00