HYDRAULIC PERFORMANCE EVALUATION OF URBAN DRAINAGE SYSTEM AND PROPOSED MITIGATION MEASURES: A CASE STUDY AT KOFE KEBELE IN DILLA TOWN.

MSC. THESIS

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JUNE, 2023

HYDRAULIC PERFORMANCE EVALUATION OF URBAN DRAINAGE SYSTEM AND PROPOSED MITIGATION MEASURES: (CASE STUDY OF KOFE KEBELE IN DILLA TOWN).

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A THESIS SUBMITTED TO THE

FACULTY OF BIO-SYSTEM AND WATER RESOURCE ENGINEERING
DEPARTMENT OF WATER RESOURCE AND HYDRAULIC ENGINEERING
HAWASSSA UNIVERSITY INSTITUTE OF TECHNOLOGY, SCHOOL OF

GRADUATE STUDIES

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE IN HYDRAULICS ENGINEERING

(SPECIALIZATION HYDRAULICS ENGINEERING)

Declaration

I, the undersigned, declare that the thesis is entitled HYDRAULIC PERFORMANCE EVALUATION OF URBAN DRAINAGE SYSTEM AND PROPOSED MITIGATION MEASURES: (CASE STUDY OF KOFE KEBELE IN DILLA TOWN)''. is my original work and has not been presented or submitted for any degree in any other university. It has been submitted for the degree of Master of Science in Hydraulic Engineering, and all sources of material used for this thesis have been fully acknowledged.

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ADVORS'S APPROVAL SHEET

This is to certify the thesis entitled HYDRAULIC PERFORMANCE EVALUATION OF URBAN DRAINAGE SYSTEM AND PRPOSED MITIGATION MEASURES: CASE STUDY OF KOFE KEBELE IN DILLA TOWN. Submitted in partial fulfilment of the requirements for the degree of Master's Science in Hydraulic Engineering (specialization: Hydraulic engineering) Graduate Program of the Department of WATER RESOURCE AND HYDRAULICS ENGINEERING, and carried out by AMANUEL MESKELE WERKU ID-No:(GPHYdrR/002/13**)**. Therefore, we recommend that the student fulfill the requirements and, hence, can submit the thesis to the institute.

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We, the undersigned members of the Board of Examiners of the final open defense by Amanuel Meskele Werku, read and evaluated his MSc. Thesis entitled HYDRAULIC PERFORMANCE EVALUATION OF URBAN DRAINAGE SYSTEM AND PROPOSED MITIGATION MEASURES: CASE STUDY AT KOFE KEBELE IN DILLA TOWN, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the MSC requirements.

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Acknowledgment

First, I would like to thank God for his unspeakable gifts and protection in my life.

I would like to thank Dr. Tewodros Meles from the bottom of my heart for his guidance and support from the initial to the final level of the thesis. He enabled me to understand the model and complete the thesis.

I have received data from different institutions such as the Ethiopia National Metrological Agency, Dilla Town municipality, South nation nationalities, urban planning and management, and other bodies. I would like to thank them for their support.

Finally, I want to thank my father, Mother, Cousin, and other family members, who are always with me. Giving me with all the necessary support.

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Abbreviation

DEM: Digital Elevation Model

. EPA: Environmental Protection Agency (United States of America)

ERA: Ethiopian Road Authority

GEV: General Extreme Value

GIS: Geographical Information System

HEC-HMS: Hydrologic Engineering Centre's Hydraulic Modelling System

IDF: Intensity Duration Frequency

LID: Low Impact Development

LULC: Land Use Land Cover

SUDS: Sustainable Urban Drainage Systems

MOWIE: Ministry of Water Irrigation and Energy

SWMM: Stormwater Management Model

USDA: United States Department of Agriculture

WMO: World Meteorological Organization

USGS: United States Geological Survey

Abstract

This thesis aims to provide a comprehensive evaluation of the hydraulic performance of an urban drainage system and propose effective mitigation measures to address the negative impact of flooding in Kofe Kebele of Dilla town using the Stormwater Management Model (SWMM) 5.1. The study area covers 180 hectares of land; it has three outlets, the catchment is classified into 34 sub-catchments, and the drainage system has 144 junction nodes and 191 conduit links. Flow routing was computed using kinematic waves and Green-Ampt was used for the infiltration model. Rainfall data for Dilla were obtained from the National Meteorological Agency and twenty-five years of data were used (1997–2021). The normal ratio method was used to fill in missing data. A double mass curve was used to check consistency, outlier identification was performed to check for higher and lower outliers, and rainfall frequency analysis and frequency distribution fitting were performed to evaluate the goodness of fit. A goodness-of-fit test was performed, and it was found that Gumbel, or GEV (I), has a good fitness value, and IDF curves were developed based on the ERA standard. A 25-year return period was used as the design storm. The United States Environmental Protection Agency's Storm Water Management Model (EPA SWMM 5.1) and the Geographic Information Systems (ArcGIS) tool were used to model and analyze stormwater characteristics. recorded water levels and velocities were used to calibrate and validate the EPA SWMM 5.1 model. Three conduits were selected for calibration and validation. The results obtained for the calibration of the performance indicator of the Nash-Sutcliffe efficiency (NSE) for each conduit (C78, C97, and C184) were 0.87, 0.91, and 0.85, respectively, and for the coefficient of determination (R^2) were 0.75, 0.84, and 0.77, respectively. The other indicator considered was the relative error, where the errors were 8.3%, 4%, and 7%. Referring to the validation, the performance of the model for Nash-Sutcliffe efficiency (NSE) for the aforementioned conduits was 0.91, 0.88, and 0.88, respectively; it was 0.88, 0.99, and 0.78 for the coefficient of determination (R^2), with a relative error of 3.7%. These results show that the model has a good performance and can perform the analysis for the study area. Low-impact development (LID) techniques were investigated based on land use and land cover conditions to sustainably solve the flooding problem. From various LID alternatives, three LID techniques were chosen based on site conditions: bioretention cells, infiltration trenches, and rain barrels. The simulation results indicated that the combination of bioretention cells, infiltration trenches, and rain barrels had a better capacity to minimize runoff. This study suggests using low-impact development (LID) to address flooding issues in a sustainable manner.

Keywords :SWMM, LID, calibration, validation, Urban Drainage

1 Introduction

1.1 Background of the study

Disasters are continuing natural hazards on Earth; hence, it is necessary to study their causes and effects and understand their processes. Floods have the greatest damage potential in the environment compared to other natural disasters. Floods are also considered both social and economic disasters (Schmitt & Thomas, 2009). Growth in population and continuing accumulation of value assets, both the frequency and magnitude of floods are expected to increase in there-by aggravating the existing flood risk in urban areas (Ouma & Tateishi, 2014). Ongoing urbanization puts more and more pressure on existing drainage systems. connecting new areas to existing sewer systems increases surface runoff , consequently runoff in pipes and discharge to receiving waters (Kleidorfer et al., 2014).

According to a study conducted in Holeta on drainage performance assessment, the majority of drainage systems are not adequate to carry the design flood for 15 minutes intensity rainfall with a return period of 10 years. The SWMM output indicated that in most junctions, the flood level was greater than the designed water level (Chali & Zewdie, 2020).

Dilla Town is one of the rapidly urbanizing towns in Ethiopia, the portion of permeable land is rapidly changing to the impermeable land surface because of the increasing population and increased built-up areas for different purposes (residential, commercial, institutions ...etc) these have aggravated the occurrence of urban flooding, especially in rainy seasons.

The Stormwater Management Model (SWMM) is widely used for urban drainage system planning, analysis, and design. The Stormwater Management Model (SWMM) is a dynamic rainfall-runoff simulation model that is widely used to simulate the quantity and quality of runoff generated from urban areas for single events as well as long-term (continuous) simulations (Rossman, 2012).

With the particular design and right combination, for developing countries such as Ethiopia, where structural measures are difficult to implement owing to financial limitations, non-structural measures such as environmental protection and proper watershed management play a paramount role in combating stormwater runoff effects (Tamrat & Wagari, 2016).

Appropriate performance of urban drainage systems (UDS) plays an important role in preventing urban flooding (Niksokhan et al., 2018).

However, few studies have been conducted on this topic in the study area. This study addressed the aforementioned problems. In general, this particular study is intended to find out the major problems, evaluate the existing drainage system in Dilla Kofe Kebele, and propose effective mitigation measures of low-impact development works that will help to provide a sustainable solution for the problems seen.

1.2 Problem statement

In Ethiopia, there is inadequate coverage of the main drainage system (Dibaba, 2018). Dilla is one of the oldest and most rapidly urbanizing towns in Ethiopia. Even-though the town is in rapid expansion and the population is increasing, as in other towns in Ethiopia in Dilla kofe kebele there is no sufficient coverage of drainage systems due to these eroded lands are visible in some areas, some drainages structures aren't well connected, there is lack of regular maintenance damaged drainage structures and stagnant water is observed in flat areas.

In Kofe kebele, societies use the drainage system, as the damping of both solid and liquid waste materials and the lack of regular clearance have caused the filling of the drainage system with a huge amount of garbage, solid waste, liquid waste, and vegetation accumulation. This has an impact on the intended waterway opening, which will be so reduced that flood water cannot flow as intended. Flood water returns up or ponds on the upstream side of the culvert and may eventually overflow the road embankment (ERA, 2013). Because of blockage and accumulation, the drainage-carrying capacity was greatly reduced. This has led to overtopping and flooding in some of the study areas, especially in rainy seasons where properties are damaged, posing a threat to human life, disrupting traffic flow, affecting the business, destroying the environment, excessive water remaining on the surfaces combined with traffic action causing potholes, and the bad smell leading to discomfort to the community.

Hence, considering the above-mentioned problems and the expansion of the town, it is necessary to know the current performance of the drainage system of the town, the major problems of the drainage system, and to propose a sustainable solution to the existing drainage system problems of Kofe kebele in Dilla town.

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study was to evaluate the hydraulic performance of the drainage system and to propose possible flood mitigation measures for selected drainage lines in Kofe Kebele of Dilla town.

1.3.2 Specific objectives

The specific objectives of this study were as follows:

1. To evaluate the performance of the existing drainage system using the EPA SWMM.

2. To identify the major problems of the drainage system

3. Proposing low-impact development works as an alternative mitigation measure.

1.4 Research questions

- Does the existing drainage system perform well?
- What are the major problems with drainage systems?
- What practices can sustainability solve the existing problems?

1.5 Significance of the study

This study has the benefit of identifying existing current problems and proposing possible mitigation measures. Generally, managing an urban stormwater drainage system has many advantages such as protecting against the possible destruction of infrastructure and property, avoiding possible threats to human life, and using stormwater to support human life.

Sustainable urban drainage systems help to solve problems sustainably. Proposed LID measures have an additional benefit; for instance, rain barrels can help solve the water supply problem in the town, Bioretention Cells and infiltration which can help in groundwater recharge, greening the area, and making the town environmentally friendly and suitable for living.

This study supports the current efforts made by the government and other organizations to solve the drainage problem by showing alternative mitigation measures. This can also serve as a reference for future studies.

1.6 Scope of the study

This study will be limited to a specific area, Kofe Kebele, located in the town of Dilla. In general, this study addressed issues related to urban stormwater drainage performance and proposed possible mitigation measures.

The specific focus of this study is to evaluate the hydraulic performance of the existing system, identify major problems of the drainage system, and propose LID techniques as a sustainable solution to the existing problem.

2 Literature review

2.1 Urbanization and Urban Flooding

An urban flood can be understood in terms of stormwater runoff management failure(Gupta, 2016). cities are growing fast and the natural landscape is being replaced by large amounts of impervious surfaces(Niksokhan et al., 2018).urbanization results in to the conversion of agricultural land, natural vegetation and wetlands to built-up environments and construction on natural drainages as well as an increase in the population of those living in flood-vulnerable areas such as flood plains and river beds (Ouma & Tateishi, 2014).(Copeland, 2016) stated that urbanized areas have around 45% or more of land surfaces that is impervious to rainfall compared to forested areas, due to hard surfaces such as parking lots, roads, and rooftops. the impervious surface makes the rain unable to absorb in to ground and instead it flows in to ditches and sewers and directly in to rivers and streams.

impermeable surfaces in urban areas are the major causes of flooding (Belete, 2011), there are also other causes of flooding, such as the blockage of urban stormwater Drainage lines and poor integration between road and urban stormwater infrastructures (Chali & Zewdie, 2020).

In Ethiopia the increase in urbanization and modernization resulted in deforestation and replacement of forested areas with impervious covers (Warati, 2015). this will lead to increase rain drop intensity and consequently accelerated runoff (Belete, 2011). in unplanned cities and towns urbanization has negative impact. in cities and towns where population is dense, they are facing water logging and flooding during heavy rainfall (Besha, 2016).

The interaction between the natural water cycle and human activity makes adequate drainage systems essential (Besha, 2016).without providing adequate side canals, main canals and appropriate outlets construction of buildings and roads in the urban area leads to urban flooding, considerable changes in hydrological processes due to urbanization results to an increase in built-up and decrease in infiltration(Bemanjo, 2021). (B .Wilson, 2015) stated that the alteration of natural flow patterns (both in terms of the total quantity of runoff and the peak runoff rates) may lead to flooding and channel erosion downstream of the development. the decrease of percolation in to the soil can result low base flows in watercourses, damage to stream, reduced aquifer recharge, damage to in-stream and streamside habitats.

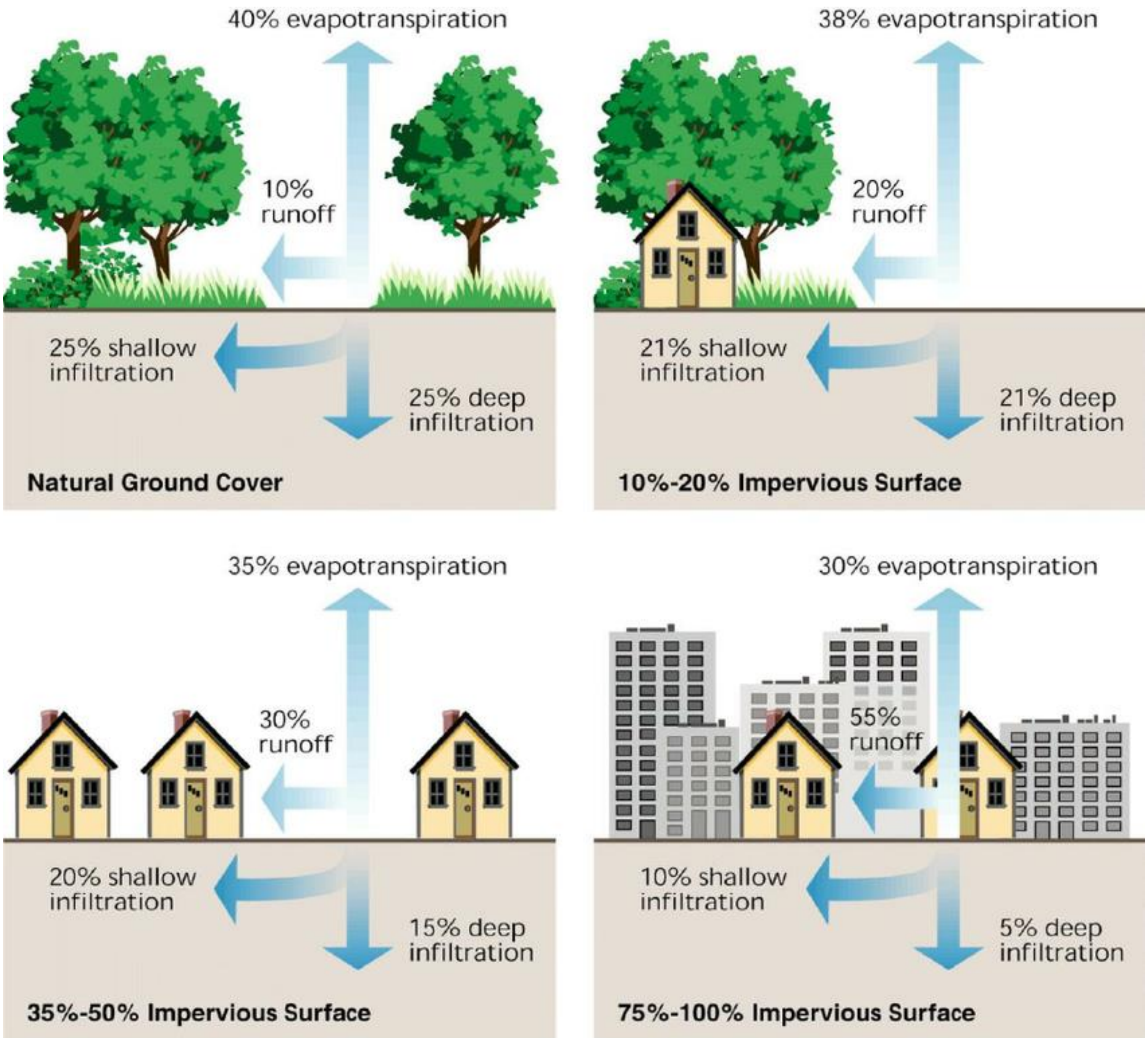


Figure 2. 1 Change-in-watershed-characteristics-after-urbanization
source www.researchgate.net

2.2 Stormwater Management

Stormwater management is the management of the quantity and quality of stormwater. Stormwater management has many importance such as to provide the economic benefits, mitigation the damage to the property, protection of the natural water bodies from pollution, and to promote public health (Sirishantha et al., 2017). LID techniques are configured as a sequence of stormwater practices and technologies they work together to form a management train, that is designed to store, treat surface water and in so doing, reduce runoff attenuate and flooding. not only these LID have an additional role in greening the environment. they are a way in which ecosystems are used to address enormous sustainability challenges, they will give people access to nature to improve health and wellbeing(Cotterill & Bracken, 2020).

Stormwater runoff refers to water that is not absorbed by soil (because the surface is saturated or sealed), and flows on impermeable land cover, such as roads (Bassi et al., 2017) states that in urban environments, stormwater runoff can be a major cause of deterioration of waterways. The storm runoff flushes pollutants from surrounding areas in to waterways and can cause overflow of combined sewers. Efficient stormwater management infrastructure helps decrease public infrastructure investments in the drainage system and also the implementation of stormwater management infrastructure decreases the peak flow requirement. Costs decline as the pipe's diameters would be smaller, without losing system efficiency (Bassi et al., 2017).

2.3 Drainage systems

There are two major classification of road drainage systems. These are surface drainage and subsurface drainage (Warati, 2015). drainage systems consist of all of the elements of the landscape through which or over which water travels. these elements consists the soil and the vegetation that grows on it, the geologic materials underlying that soil, the stream channels that carry water on the surface, and the zones where water is held in the soil and moves beneath the surface. it also include are any constructed elements, including pipes and culverts, cleared and compacted land surfaces, and pavement and other impervious surfaces that are not able to absorb water at all (Booth & Derek, 1991). it is necessary that sufficient drainage systems provisions are made for road surface to ensure that a road pavement performs satisfactorily. there is dilemma in the planning and design. on the one hand it is observed that uncertain future drivers like climate change or spatial development will affect the basics condition of the urban drainage systems during their long operational life span on the other hand with the design of urban drainage systems long-lasting decisions have to be made (Eckart, 2011).

Urban drainage systems are essential part of city infrastructure which has drawn public attention due to some devastating flooding of the urban environment (Schmitt & Thomas, 2009) the other benefits from effective stormwater infrastructure are obtained through a reduction in total runoff volume. lower runoff volumes enter the public drainage system, which implies reduced water flow to be processed by wastewater treatment facilities (Kleidorfer et al., 2014) the avoided costs (energy, material and savings) are direct benefits from a reduction of stormwater runoff (Bassi et al., 2017).the minor system handle the frequently recurring storms. the minor system includes of underground piping, natural waterways and required appurtenances to protect against the average storms. the major system to handle the large infrequent flows. The major system consists street flow and other overflow provisions to pass the infrequent, large flows and protect against excessive property loss and ponding depth .thus, lthe drainage system, with good integration with pavement and water handling system should be designed (Warati, 2015).

2.4 Problems of the Drainage System

In urban areas there is a large amount of impervious cover and low forested areas because such phenomena are followed by increase in runoff volume and peak flow rates. this means that even when there is a drainage system with acceptable functionality, the design capacity of the system is inadequate for extreme events and flood occurrence (Niksokhan et al., 2018).on the other hand, lack of adequate infrastructure is a long-standing issue that has had low priority, resulting in increased urban flood risks, and contamination of drinking water, soil and creating public health problems. with a rapid expansion of the infrastructures, the hard surfaces that replace the permeable soil have been increased and do not allow the water infiltration and its rapid channelling to the pipes. the combined effect of these problems results in increased rainwater accumulation and, consequently, in surface runoff (Belete, 2011)

In developing countries solid waste management became a serious challenge. High rates in urbanization and challenges in the life styles and rapid rise in living standards have resulted in the increase of solid waste both in volume and types (Aklilu et al., 2021). (Parkinson, 2002) stated that the operational problems caused by poor solid waste management are increased by a lack of effective work for drain cleaning. these can also be related to a lack of manpower and resources, and inappropriate equipment. But, to make matters worse, there is poor integration between different department of government. Parkinson stated in many cities in the developing world, there is often no real control over new developments due to deficiencies in the administrational systems for urban planning and control. In these conditions, buildings are constructed having no consideration of natural drainage pathways where these occupy flood plains, due to the downstream flow constrictions the problems of stormwater drainage increased. in contrast, isolated or low-income societies normally have no access to the main drainage system (Dibaba, 2018).

The local drainage system consist of storm drain pipes, curb inlets, manholes, minor channels, roadside ditches and culverts. this system is intended to convey storm flows efficiently to the community's primary drainage system, such as the main river channel or the nearest large body of water (WMO, 2008) .there is no satisfactory and fair road and drainage infrastructure expansion for some citizens (Besha, 2016).in addition to this the existing drainage has operation problems. but, often most of them face reduction of functionality and capacity for transferring the runoff flow, and their level of service reduces due to degradation in time, improper maintenance, inappropriate design, aging, sedimentation and siltation, increase in materials' roughness, and structural deterioration (Niksokhan et al., 2018). the author stated the appropriate performance of urban drainage systems (UDS) play a key role in preventing urban flooding.

2.5 Low Impact Development

Conventional drainage systems were designed and implemented with the main goal of managing storm water volumes to avoid or reduce urban flooding. conventional drainage systems are consisted of many structural components, e.g., concrete pipes, manholes and storage facilities. therefore, the building and installation costs of conventional drainage systems are high. additionally, the burden on the existing drainage systems is high because of increased stormwater flows resulting from climate change and urbanization. therefore, new building is necessary if the authorities are to rely on conventional drainage systems. However, such construction disrupts the general public. So, this solution is not sustainable. Conventional drainage systems are more challenging. LID can overcome these issues (Sirishantha et al., 2017).surface water drainage systems developed in-line with the ideals of sustainable development is collectively referred to as sustainable drainage systems. At a particular site, these systems are designed both to manage the environmental risks resulting from urban runoff and to contribute wherever possible to environmental enhancement (B .Wilson, 2015).LID have augmented conventional drainage pipe networks with their environmentally and economically friendly benefits. they have proven to be a good solution for stormwater management. these systems avoid floods by providing temporary water storage during extreme rainfall events. they add aesthetical value to the areas in which they are located. furthermore, they can attract wildlife thus creating new habitats promoting bio-diversity. In this way, LID increase the amenity of the environment (Sirishantha et al., 2017).

LID designs should aim to reduce runoff by integrating stormwater controls throughout the site in small, discrete units. through efficient control of runoff at source, the need for large flow attenuation and flow control structures should be minimised (B .Wilson, 2015). LID use a set of techniques that is collectively referred as the "Management Train". this includes four key steps: source control, pre-treatment, retention and infiltration. the other objectives of implementing LID are reducing surface water flooding, improving water quality and enhancing the amenity and biodiversity of the environment. In achieving the above objectives, LID reduce flow rates, the transport of pollution to the environment and increase the water storage capacity (Sirishantha et al., 2017). Typically, LID are configured as a sequence of stormwater practices and technologies that work together to form a management train that is designed to store, attenuate and treat surface water and in so doing, reduce runoff and flooding. LID have a secondary role in greening the environment. they are one way in which ecosystems are used to address mounting urban sustainability challenges, giving people access to nature to improve health and wellbeing (Cotterill & Bracken, 2020).LID offer a sustainable solution to flooding. LID switches from piped engineered system to practices and systems that use and enhance natural processes (i.e., infiltration, evapotranspiration, filtration, retention and reuse). LID today have enhanced capabilities by adding recreational value, ecological protection to aquatic environments and pollutant control along with the provision due other water uses (Sirishantha et al., 2017).

LID have many advantages. they reduce the peak flow in the hydrograph. It helps to improve the water quality and naturally mitigate waterborne diseases. additionally, LID provide a temporary storage in the event of extreme rainfall to keep downstream areas safe from flooding while recharging the ground water table (Sirishantha et al., 2017).So, LID objectives are to minimise the impacts from the development on the quantity and quality of the runoff, and maximise amenity and biodiversity opportunities (B .Wilson, 2015).

2.5.1 How Sustainable Drainage System works

According to (B .Wilsson 2015) suds system controls run off in three ways:

Source control: Measures deal with run-off at, or close to, the surface where rainfall lands.

Site control: measures manage the surface water run-off from larger areas, such as part of a housing estate, major roads or business parks.

The run-off from larger areas can be channeled to a site control measure using swales (shallow drainage channels) or filter drains.

Regional control: measures downstream of source and site controls deal with the gathered run-off from a large area. these systems use the same principles as smaller scale SUDS, but can cope with larger volumes of water.

Rainwater that passes through small SUDS can feed into larger SUDS which deal with the gathered run-off from a wide area. It is best to connect the flows between SUDS components with swales, filter drains or ditches and avoid the use of pipes.

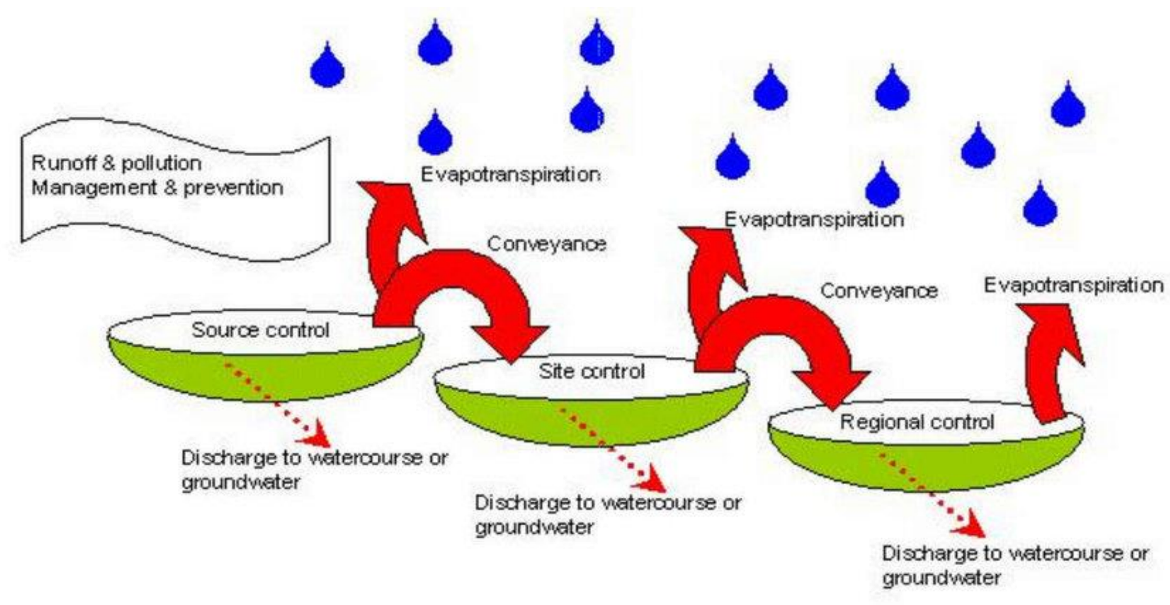


Figure 2. 2 Stormwater-management-train-concept

Source from web www.researchgate.net

the main techniques used contemplate the use of structures that seek to reproduce water infiltration capacity in the soil lost due to impermeabilization. as a result, a smaller volume of surface runoff is created, and there is a reduction in flooding problems. Furthermore, this promotes recharging of underground aquifers and improvements in water quality (Julie et al., 2008).

2.6 Low impact Development (LID) Techniques.

A. Infiltration trenches

Infiltration systems take run-off from a development and they will allow surface waste water to percolate in to the ground, thereby maintaining the water levels, recharging the groundwater in local watercourses, and reducing the volume of water to be disposed of through sewers (B .Wilson, 2015).

Infiltration systems are most suited to areas where run-off is relatively unpolluted and have low sediment loads (egg from roofs) and should be designed to take small incremental run-offs from small catchments. The run-offs should be treated by another system (egg a sediment or oil trap) prior to flowing into the infiltration system if contamination is likely(Julie et al., 2008).

Figure 2. 3 Infiltration Trenches

B. Bioretention cells

Bioretention systems (including rain gardens) are shallow landscaped depressions that can reduce runoff rates and volumes, and treat pollution through the use of engineered soils and vegetation. They have many benefits such as:

- They are particularly effective in delivering Interception and can also provide
- attractive landscape features that are self-irrigating and fertilising habitat and biodiversity.
- Cooling of the local micro climate due to evapo-transpiration. They are a very flexible surface water management component that can be integrated into a wide variety of development landscapes using different shapes, materials, planting and dimensions. In a low-density development, the system might have soft edges and gentle side slopes, while a high-density application might have hard edges with vertical sides.

Figure 2. 4 Bioretention Cells

Bioretention Cells in road and parking lots

C. Rain Barrels (cisterns)

Rainwater harvesting (RWH) is the collection of rainwater runoff for use. Runoff can be collected from roofs and other impermeable areas, stored, treated (where required) and then used as a supply of water for domestic, commercial, industrial and/or institutional properties (B .Wilson, 2015).

Infiltration basins are depressions in the surface that are designed to store runoff and infiltrate the water to the ground. They may also be landscaped to provide aesthetic and amenity value'(B .Wilson, 2015).In general, 'infiltrations systems' include soak always, infiltration trenches and infiltration basins.

Figure 2. 5 Rain Barrel

2.7 Model selection criteria

- MOUSE

Based in Pennsylvania, USA. Mouse the urban and sewer model is created as a comprehensive modelling system. we can use the software for analysis of urban drainage and sewer systems it have link with Gis. In addition, MOUSE can also be used to simulate spatial variations in flows, water levels, sediment transport and pollution in pipes and open drains. single or multiple events can be defined by the user and the time period up to several years. Deterministic mathematical modelling tool is used as mathematical formulation of MOUSE model. With user defined the time interval MOUSE produces output a large number of variables. MOUSE has importance in the aspect of no limits on the size of model area or number of input elements to be included in the simulation and capable to branched and looped network. Continuous type of simulation is used in the MOUSE for nature of simulation. Besides that, this software also can predict the hydraulic deficiencies, overflow sites, flood inundation areas, and effect of real-time control. For rainfall-runoff model, the contributing area and hydrological losses are with in model parameter (Haris et al., 2016).

- DRAINS

DRAINS are used for analysing and designing urban stormwater with a capability to simulate drainage system of all sizes from small to up to 10 km2 by using Subcatchment with ILSAX hydrology and greater using storage routing model hydrology. DRAINS will simulate and change the rainfall patterns to stormwater runoff hydrographs by working through a number of time steps that fall during the course of a storm event. The simulation runoff will route through channel, networks of pipes and streams. It has a connection with CAD and GIS program, automatic design procedure for piped drainage systems and an in-built Help system is also consist in this software (Haris et al., 2016).

- EPA SWMM

The USEPA Storm management model (SWMM) is been widely used model since 1971 it will do detail hydrological and hydraulic Modelling of stormwater watershed of the catchment. Single event and a long continuous period of event can be simulating by using SWMM. The software is also capable to simulate the precipitation movement from the ground surface through channel/pipe network. For a long time, SWMM version is a free software and being maintained by several numbers of individual and organisation Now, SWMM engine has been rewritten and known as a version SWMM 5, SWMM 5 is maintaining by USEPA. In this hydrological model concept, every sub-catchment in a basin is treated as non-linear reservoir with a single inflow or rainfall input and will produce the outflow or discharge in term of infiltration, evaporation and surface runoff (Haris et al., 2016).

SWMM is a physical model for hydrologic and hydrodynamic simulations, with discrete time step, that can be used for single-event and continuous simulation of storm water quality and quantity in urban areas (Niksokhan et al., 2018).

The runoff component on SWMM operates based on a collection of Subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of channels, storage/treatment devices, pipes, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (Gironás et al., 2009).

- MIKE FLOOD

Solves the Saint-Ven ant equations by means of a finite difference scheme Dynamically links two independent software packages: MIKE 11 (1D) and MIKE 21 (2D). MIKE 11. Breaches can be modelled through a “dam break” structure. Breach growth can be described by time series for breach width, crest level and side slope. An erosion model based on the Engelund-Hansen sediment transport equation is also available. Breach flow can be computed by means of two sets of equations: the standard set is based on the equations for flow through a generic structure and the alternative set was obtained from the NWS DAMBRK model. The “classic” version of MIKE 21 uses a rectangular grid and solves the shallow water equations by means of a finite difference scheme (Patel et al., 2018).

- HEC-HMS

HEC-HMS is the successor to HEC-1. Not all of the original HEC-1 functions are available in HMS but many of the original HEC-1 algorithms have been updated and combined with new algorithms. It is a windows-based program. In previous versions, data input/output could be somewhat bulky (Patel et al., 2018).

Table 2. 1 Functionality and accessibility of the representative models

Urban models	Functionality			Accessibility	
	Planning	Operational	Design	Public Domain	Commercial
DRAINS	✓	✓	✓		✓
HEC-HMS		✓		√	
SWMM	✓		✓	✓	
MIKE-FLOOD	√	√	√		√
MOUSE		✓	✓	✓	

Source (Patel et al., 2018).

Urban storm water models can be considered semi-distributed (SD) or fully distributed (FD), depending on the spatial discretization of the rainfall–runoff module (Pina et al., 2016). The necessary resolution and accuracy of the available data requirements, either to define modules connections, hydrological characterization, or even to do a proper calibration, are significantly higher for FD models. In cases where detailed network data are not available and overland surface data are not accurate or do not have the necessary resolution, SD models are a recommended modelling approach (Pina et al., 2016). Traditional urban storm water models have mostly been SD. One of the first widely implemented urban storm water models is the Storm Water Management Model (EPA SWMM). The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas.

Since SWMM is most widely used and efficient model.in countries like Ethiopia where there is lack of quality data and other software’s need quality data and commercially available SWMM is preferable.

3 Material and Method

3.1 Description of study area

3.1.1 Location of study area

Dilla town is found in the Gedeo zone of South Nation, Nationalities and Peoples Regional State and it is the Zone administrative capital. Dilla town administration has 3 sub-cities, which includes 9 kebeles.

The town lies in the eastern escarpment of the Ethiopian rift Valley with fertile green mountains and is also known for the excellent coffee grown in its vicinity. the town is located approximately 360 km south of Addis Ababa and 90km from Awassa town, the capital for the regional state. the town is characterized by gentle slope from east to west, with the 1600 m above sea level in the east dropping to 1,400 m above sea level in the west average elevation: 1,497 m. geographically the town is located at 6o 20' – 6024''N latitude and 38017'-38020''E longitude. the town covers 1123.47 hectares of land.

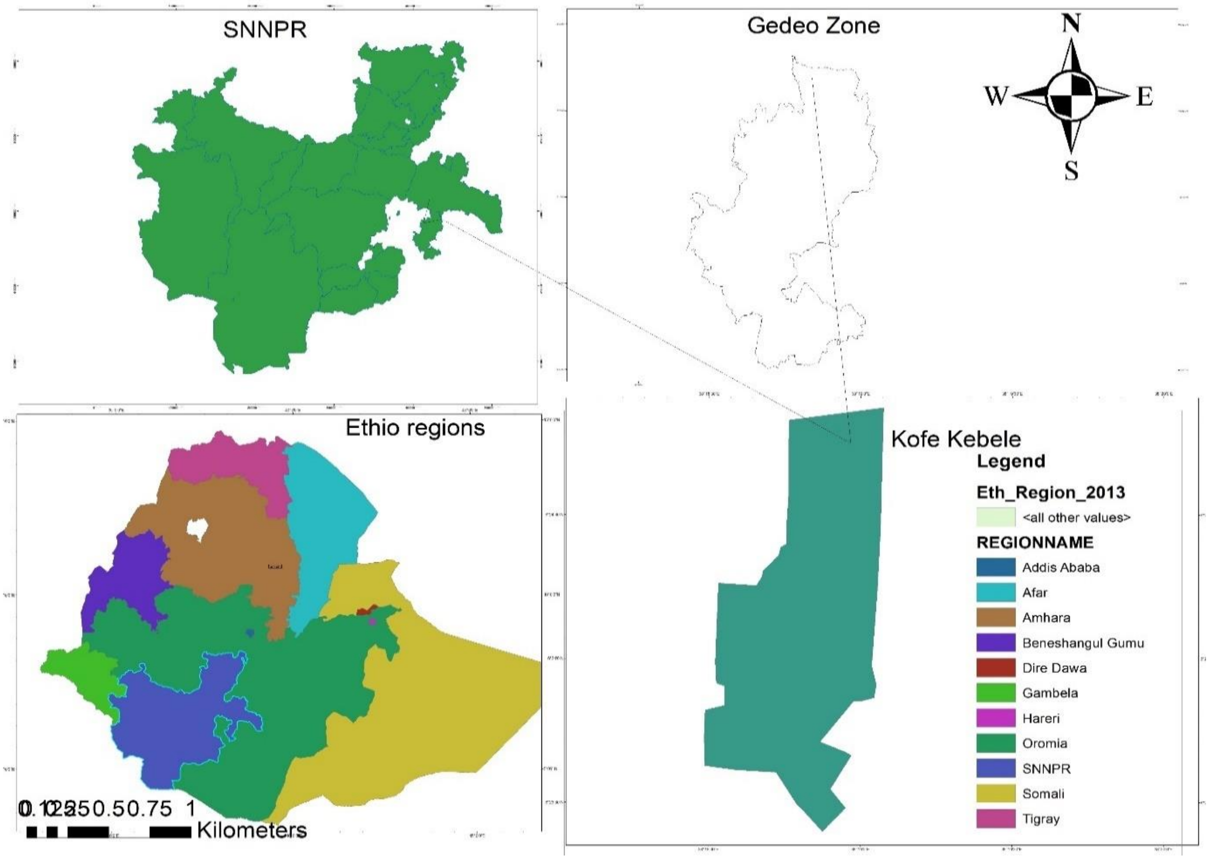


Figure 3. 1 Location map of the study area

3.1.2 Rainfall of Dilla Town

The average rainfall (for the Computation historical period) was 1411mm.based on the data gained from Ethiopian Meteorology Agency for the studied years. The highest total annual rainfall in the studied area was 2779.6mm, recorded in 2008 while the lowest total rainfall was 974.3 mm, which is recorded in 2003 for the last 25 years (1997-2021).

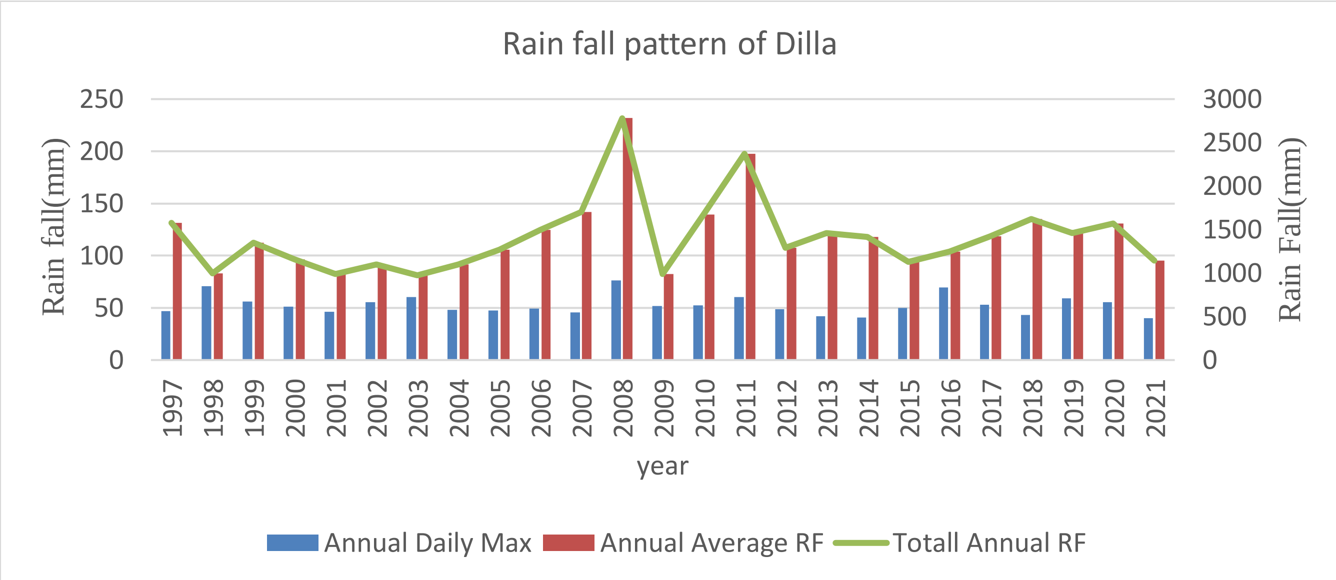


Figure 3. 2 Rain fall pattern of the Dilla Town

3.1.3 Population of the Town

The town has a total population of 91,534 (Source:Gedeo Zone youth office) and it is believed that town is expanding and the number of population is increasing. so It will be important to have draiange structures that can accommodate the increasing number of population, the increasing number of impervious cover and to have sustainable solutions.

3.2 Data collection and analyses

3.2.1 Identification of the major problems of the drainage system

3.2.1.1 Data collection and source's of data's

- ✓ Primary data's
  - ➢ Field survey

Through observation, i have realized the availability of solid and liquid wastes, sediments and siltation. I have taken a photo through camera. dimensions of drainage structure were measured Field visits and survey reveals that there are different challenges, one of the challenges is that the clogging of drainage structures due to accumulation of solid and liquid wastes.

- ➢ Interview of the community and administration

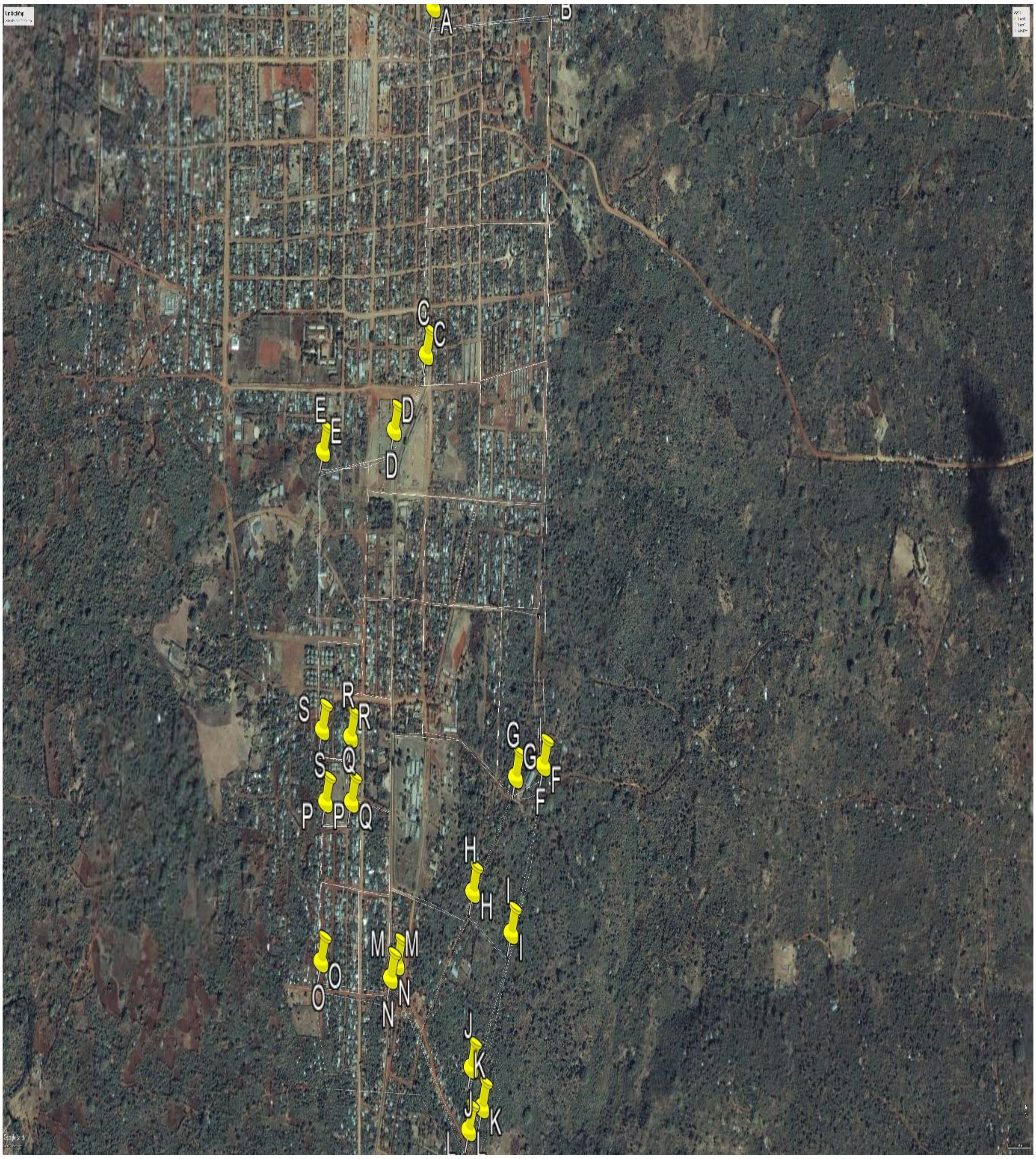
The Community have many complain about the drainage, the bad smell has deteriorated their health, lowland area residents has also raised their risk of vulnerability. The society indicated vulnerable areas and also suggested the possible cause of the problems. municipality authorities had told me there are well known problems in the study area.

3.2.1.2 Data Analysis

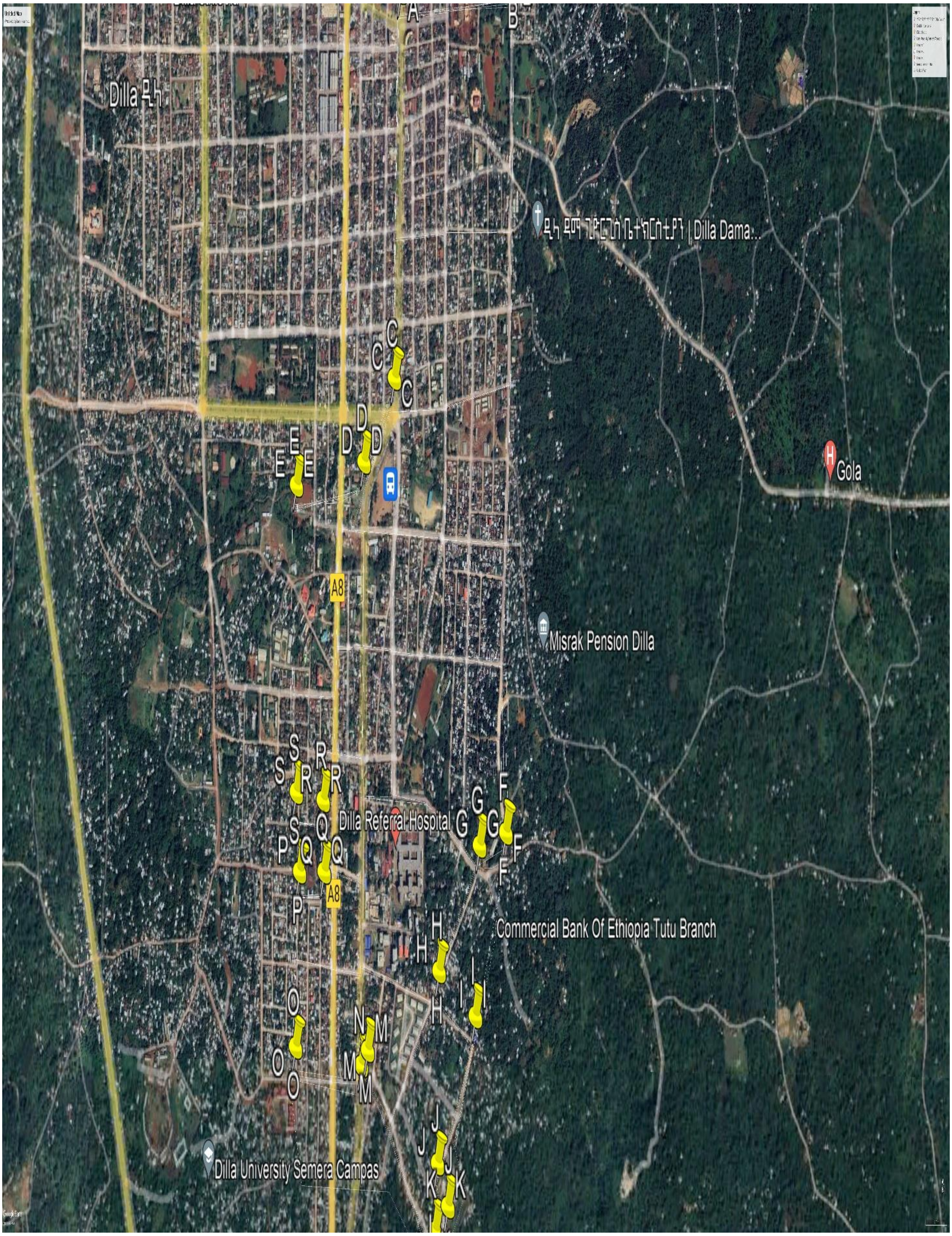
- Land-use land-cover of kofe kebele

Kofe kebele has brought successive land use land cover changes through years. the spread of urbanization and the consecutive increment of imperviousness is one of the reasons for runoff increment in the study area.

The study area has different land use land cover. i have classified the land use land cover in to six representative categories: Asphalt Road, Barren land, green area, Cobblestone, Built up-areas and Agricultural areas.



2005 (a)



2022 (B)

Figure 3. 3 Google Earth images of 2005 (a), 2022 (b)

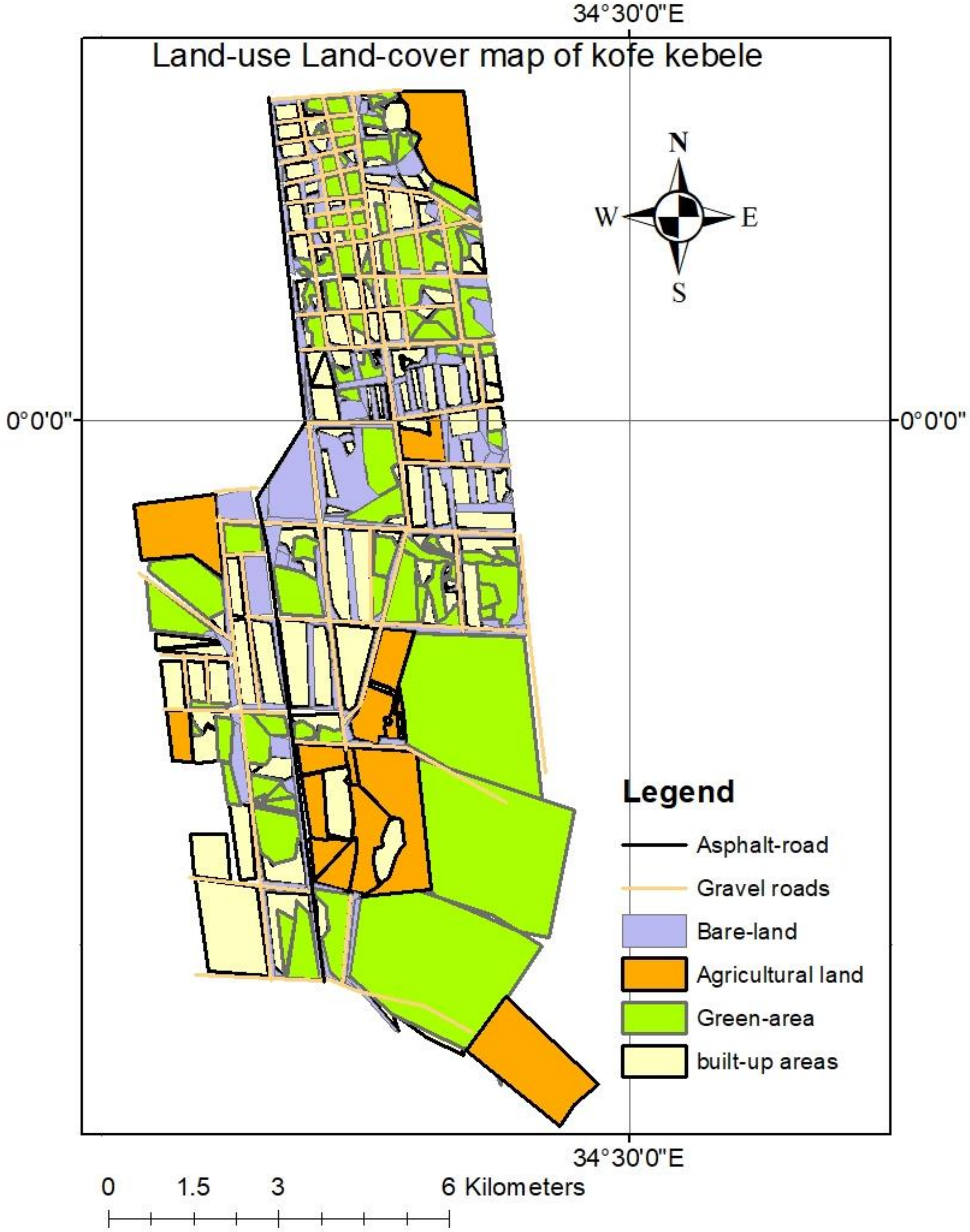


Figure 3. 4 Land-use Land-cover map of 2005

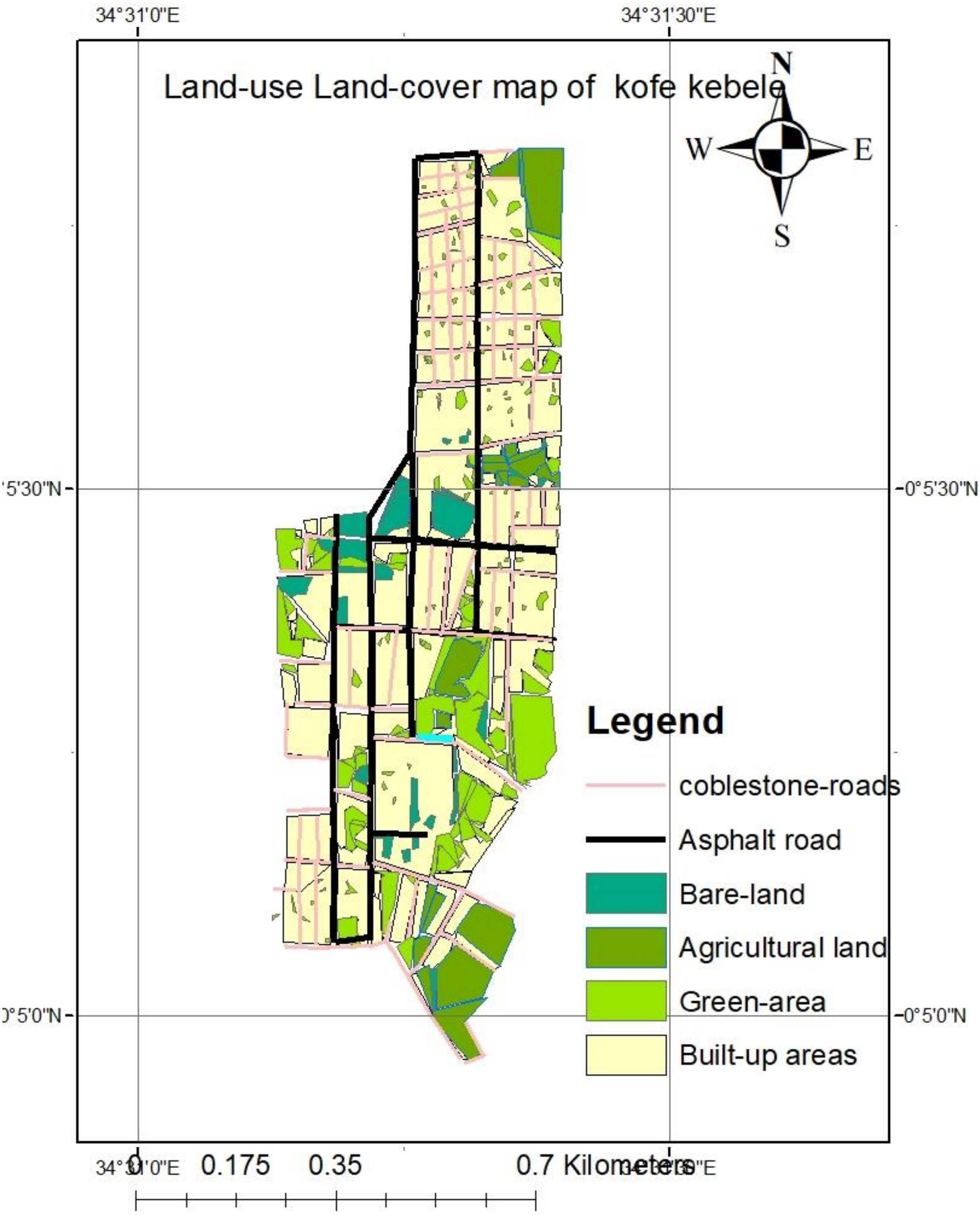


Figure 3. 5 Land-use land-cover map of 2022

Table 3. 1 Land-use land-cover % change from 2005 to 2022

No.	LULC type	LULC% (2005)	LULC% (2022	DIFFERENCE

1	Built-up Areas	30.3260629	64.890846	+34.56478
2	Agricultural-land	13.5379892	12.1669485	-1.37104
3	Green-area	46.193566	4.89659419	-31.0117
4	Bare-land	9.7733066	15.1819107	-4.87671
5	Cobblestone		1.88753278	+1.88753278
6	Asphalt-roads	0.02274169	0.97616797	+0.953426
7	Gravel-roads	0.14633362		

As it is seen in the table above. there is an increase in the impervious areas (built-up areas, asphalt roads.) and there is decrease in pervious areas (Green areas, bare land, agricultural areas.) the increase in imperviousness will create more runoff.

3.2.2 Evaluation of the existing drainage system performance using EPA SWMM.

3.2.2.1 Data collection and source of data's

❖ Data collection

- ➢ Primary data's
- ➢ Field survey

A field survey was made to measure the canal dimensions, type of conduit &junctions, shape of conduit & junction, location of conduit & junctions and the overall conditions of the drainage and to observe the over-all conditions of the drainage system.

✓ Secondary Data's

- ➢ Rainfall Data

Rainfall data and Temperature data were collected from the National Meteorological Agency (NMA). Four stations' rainfall data were collected, with Dilla serving as the base station. Other stations were used to fill in missing rainfall data. IDF curves were computed using rainfall data, and 15-minute intensity rainfall was used for precipitation input in EPA SWMM.

- ➢ Soil data

From FAO soil portals on the web. Soil classification data were downloaded and used to classify the soil type based on the FAO standard.

- ➢ Digital Elevation Model (DEM) of the area (Resolution of 30meter X 30 meter)

Satellite image from USGS (United States Geological Survey) used for slope analysis

3.2.2.2 Hydrologic and Hydraulic Modelling using EPA SWMM

EPA SWMM is a distributed model, which means that a study area can be subdivided in to any number of irregular sub-catchments to best capture the effect that spatial variability in topography, drainage pathways, land. cover, and soil characteristics have on runoff generation. an idealized sub-catchment is conceptualized as a rectangular surface that has a uniform slope and a width that drains to a single outlet channel (Rossman, 2012).

SWMM employs principles of conservation of mass, energy, and momentum wherever appropriate (Girona's et al., 2009).

The hydrologic characteristics of a study area's sub catchments are defined by the following set of input parameters in SWMM:

- ❖ Area
- ❖ Width
- ❖ Slope
- ❖ Imperviousness
- ❖ Roughness Coefficient
- ❖ Depression Storage
- ❖ Percent of Impervious Area Without Depression Storage
- ❖ Infiltration Model
- ❖ Precipitation Input

Precipitation is the principal driving variable in rainfall-runoff-quantity simulation. The volume and rate of storm water runoff depends directly on the precipitation magnitude and its spatial and temporal distribution over the catchment. Each sub catchment in SWMM is linked to a Rain Gage object that describes the format and source of the rainfall input for the sub catchment (Gironás et al., 2009).

SWMM also contains a flexible set of hydraulic modelling capabilities used to route runoff and external inflows through a drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

♣ handle networks of unlimited size

♣ use a wide variety of standard closed and open conduit shapes as well as natural channels

♣ utilize either kinematic wave or full dynamic wave flow routing methods

♣ model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding (Rossman, 2012).

- Flow routing within a conduit link in SWMM is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow (i.e., the Saint-Venant flow equations). Each of these routing methods employs the Manning equation to relate flow rate to flow depth and bed (or friction) slope. For user-designated Force Main conduits, either the Hazen-Williams or Darcy-Weisbach equation can be used when Pressurized flow occurs.

The SWMM user has a choice on the level of sophistication used to solve these equations

- Steady Flow Routing
- Kinematic Wave Routing
- Dynamic Wave Routing

Each of these routing methods employs the Manning equation to relate flow rate to flow depth and bed (or friction) slope.

3.2.2.2.1 Computed parameters for EPA SWMM

- Soil type

According to the town municipalty six major reference soil groups were identified. luvisols are situated at all altitudes, accompanied by Nitisols in the residual landforms of the rolling to hilly plateaus. Leptosols, Regosols and Cambisols mostly occur in dissected relief with outcrops, river gorges and escarpments. Fluvisolls are found on fluvial and alluvial deposits. Some soils in the highland plateaus and plains in the SE part of the area have gleyic properties. highly eroded badlands are situated to the NW of Dilla. Based on FAO. i have done soil classification of my study area and i understood that the soil of my study area is sandy,clay, and loam soil.

Soil Map of Kofe Area

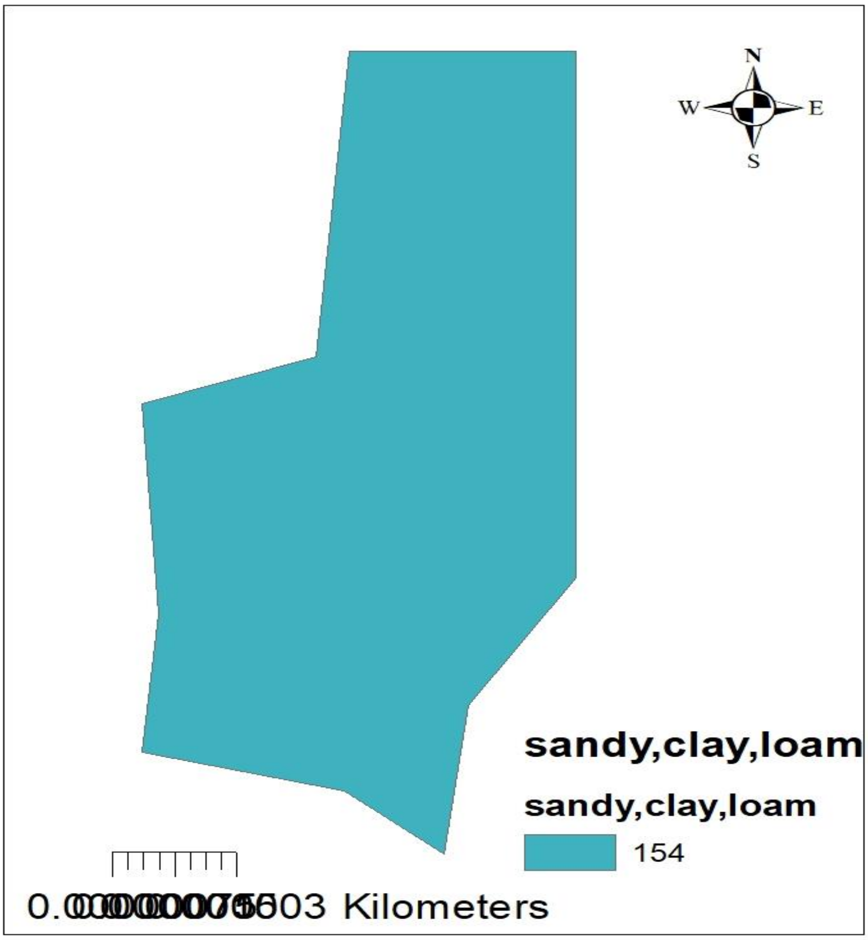


Figure 3. 6 Soil map

❖ Subcatchment

Due to the blocking and guiding effect of roads and pipe networks on water flow in urban areas, Subcatchments divided by watersheds cannot fully reflect the actual flow path. Therefore, in the runoff simulation, roads and pipe networks are often used to divide Subcatchments. The study area was divided into sub catchment based on Topographic map, building blocks, direction of flow in drainage. The study area is divided in to 34 Subcatchments.

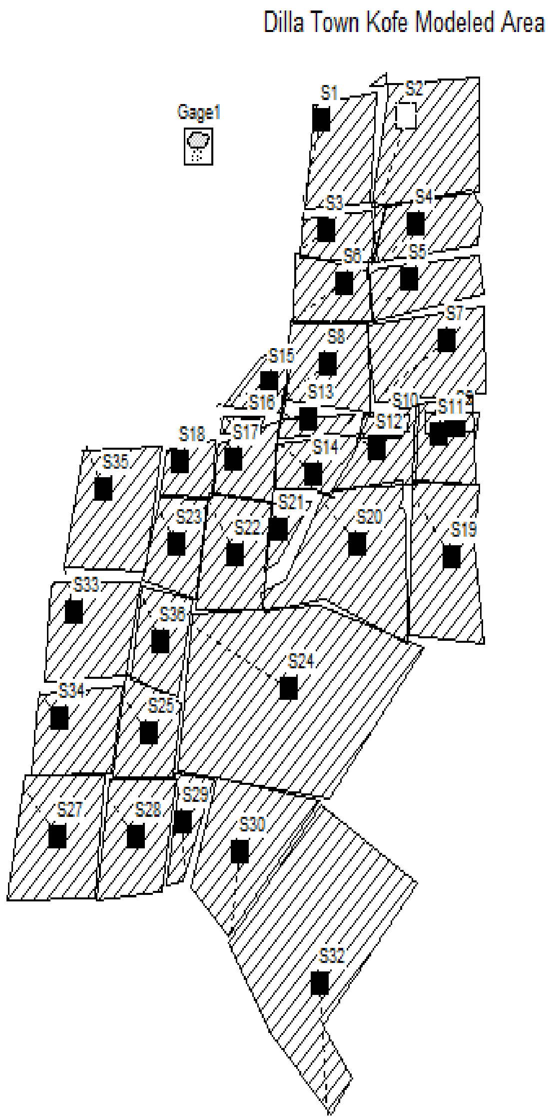


Figure 3. 7 Subcatchment

❖ Slope of The Area

The slope of the study area is analysed using DEM in Arc Gis. the result of the analysis indicates that the slope of the area varies from flat to steep slope types. Flat slope areas have a behaviour to stagnant water where as steep slope areas have high speed of runoff and low infiltration rates.

Slope Map

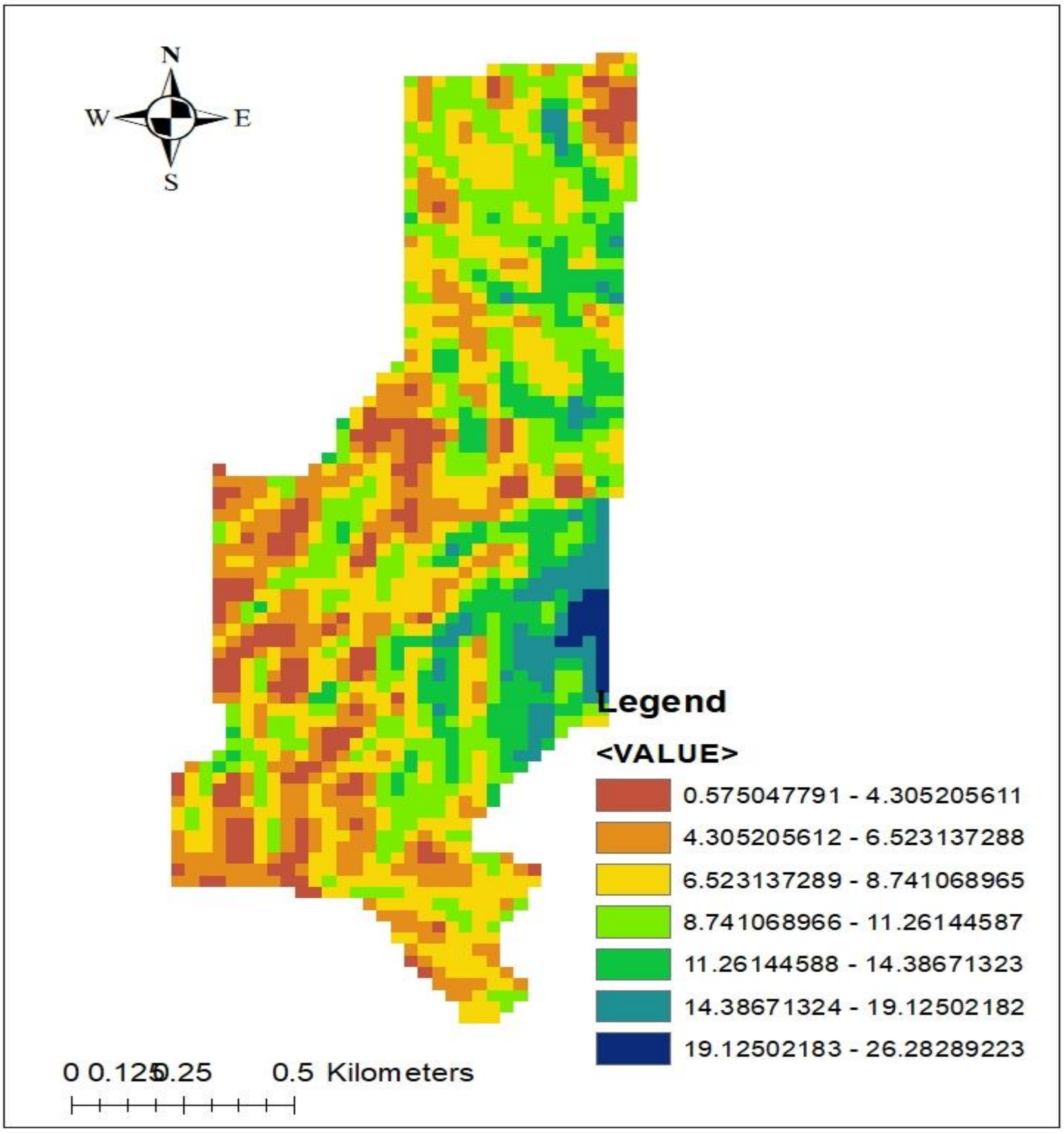


Figure 3. 8 Slope map

The values of other remaining parameters were derived based on the manual . the detail values are available in the appendix.

3.2.2.3 Rainfall analysis

3.2.2.3.1 Filling missing rainfall data

Missing rainfall data can occur due to many reasons such as instrumental failures or human errors. filling missing data's will be necessary.

There are different methods available to estimate missing rainfall data's, some of them are

1.Station-Average Method

2. Normal-Ratio Method

3. Quadrant Method

4. Regression method…etc

From these alternatives I have chosen to use normal-ratio method since the average annual catches between my study area station and near-by stations differ by more than 10%.

$p = \sum_{i=1}^{n} wipi$ ……. Eq..4

Wi = the weight for the rainfall depth Pi at gage i. The weight for station i is computed by

$wi = \frac{AX}{nAi}$ …………. Eq..5

Where

• Ai = the average annual catch at gage i,

• Ax, = the average annual catch at station X,

• n = the number of stations

Table 3. 2 percent of missing Data

Station name	Observed year	Available Data(day)	Observed Data(day)	Missing Data(day)	%Of Missing
Dilla	25	9134	7517	1617	17.703
Bule	12	4380	4134	246	5.6
Fissehagenet	12	4380	3990	397	9.064
Yirgacheffe	12	4380	4045	355	7.648

The area station name is Dilla station, the study area is with in the Town.

3.2.2.3.2 Rainfall frequency analysis

Frequency analysis is used to estimate how often certain values of a variable phenomenon may occur and to assess the reliability of the prediction. it is a tool for determining design rainfall and design discharges for drainage works and drainage structures, especially in relation to their required hydraulic capacity.

The daily highest rainfall data obtained from the National Meteorological Agency of Ethiopia has been statistically analysed using three methods of distribution analysis namely Generalized Extreme Value, Log Pearson-3 and Gumbel's Methods (ERA manual 2013).

Statistical methods followed in this study to perform the frequency analysis: Gumbel Distribution Theory, Log Pearson Type III and Log Normal Distribution, normal distribution.

3.2.2.3.3 Derivation of short Duration Rainfall for IDF

The rainfall depths obtained from gauging station are of 24hr duration depth. Design and analysis of drainage structures require rainfall-intensity-duration relationship of shorter duration. because rainfall data of shorter duration is unavailable, appropriate IDF derivation for shorter duration is required (ERA, 2013).

The IDF curve is developed from 24-hour rainfall data of 25 years i.e., 1997 to 2021 GC, obtained from Ethiopian Meteorological Agency in which the rain gauge is located in Dilla town.

Intensity (mm/hr), $It = Rt/t$, Where It (mm/hr).

$$\mathrm{Rt} = \frac{\mathrm{t(b+24)^n}}{\mathrm{24(b+t)^n}} * \mathrm{R24} \ldots\ldots \text{ Eq..6}$$

$$It = \frac{(R24(b+24)^n}{24(b+t)^n} \ldots\ldots \text{ Eq..7}$$

Using b=0.3 and n=0.92 as suggested by ERA manual results are tabulated

Where: Rt is required precipitation depth for the duration t-hour in mm,

R24 is daily precipitation in mm

t is the time duration in hours for which precipitation depth is required in hours.

The rainfall data is converted to intensity by dividing the rainfall with duration.

By selecting the two most widely used distributions GEV-1, and Log Pearson 3 detail analysis had been made using Microsoft Excel. the r squared value show GEV-1 is the best. the result is available in appendix.

3.2.2.3.3.1 Intensity-duration-frequency curve

Rainfall intensity-duration-frequency (IDF) curves are graphical representations of the amount of water that falls within a given period of time in catchment areas.

By frequency analysis of rainfall observation, for annual maximum daily rainfall of every year. From different distribution alternative's the best fit distribution have been selected by using criteria's such as Chi-square, Kolmogorov Smirnov, Anderson darling. and the best fit distribution obtained is Gumbel extreme value (GEV I). using Gumbel extreme value, rainfall intensity for different return period and different duration had been calculated.

According to ERA recommendation appropriate reduction equation were applied Eq 6&7.

Table 3. 3 IDF Table of Dilla

	Return period T (year)							
Duration (min)	**2**	**5**	**10**	**15**	**25**	**50**	**75**	**100**
5	89.770	115.224	132.12	141.64	153.45	169.73	178.46	185.04
10	75.151	96.4602	110.61	118.57	128.46	142.09	149.40	154.90
15	64.607	82.9268	95.091	101.94	110.44	122.15	128.44	133.17
30	45.769	58.7470	67.364	72.217	78.239	86.538	90.991	94.344
45	35.638	45.7440	52.454	56.233	60.922	67.384	70.851	73.462
60	29.281	37.5838	43.097	46.201	50.054	55.363	58.212	60.357
75	24.906	31.9686	36.658	39.298	42.576	47.092	49.515	51.339
80	23.730	30.4586	34.926	37.442	40.565	44.867	47.176	48.914
90	20.755	26.6405	31.946	36.658	37.103	39.243	41.262	42.783
100	20.006	25.6788	29.445	31.566	34.199	37.826	39.773	41.238
105	20.068	24.7181	28.344	30.385	32.919	36.411	38.285	39.695
120	17.323	22.2351	25.496	27.333	29.612	32.753	68.878	35.708
135	15.754	19.2252	23.187	24.858	26.931	29.787	31.320	32.474
140	15.295	19.6319	22.511	24.133	26.145	28.919	30.407	31.527
150	14.455	18.1992	21.275	22.808	24.710	27.331	28.738	29.797
160	13.703	17.5890	20.169	21.622	23.425	25.909	27.243	28.247
165	13.361	17.1503	17.150	21.082	22.841	25.263	26.563	27.542
180	12.427	15.9513	18.291	19.608	21.244	23.497	24.706	25.616

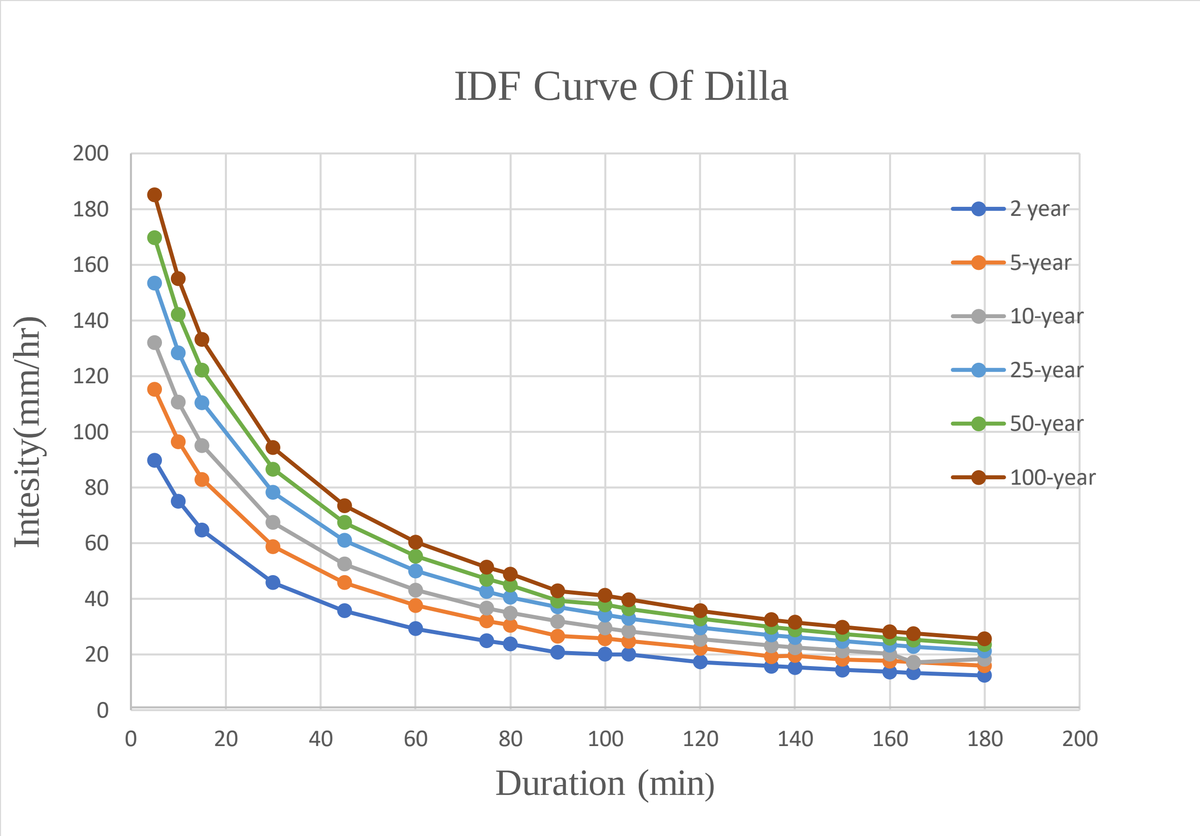


Figure 3. 9 IDF curve of Dilla

3.2.2.3.4 Checking consistency of data Using Double mass curve

The Double mass curve is used to check the consistency of many kinds of hydrologic data by comparing data for a single station with that of a pattern composed of the data from several other stations in the area. the double-mass curve can be used to adjust inconsistent rainfall data (james & clayton, 1960).

If a pattern is used, as in checking the consistency of precipitation records, enough stations should be included to ensure that the average is not seriously affected by an inconsistency in the record for one of the stations.

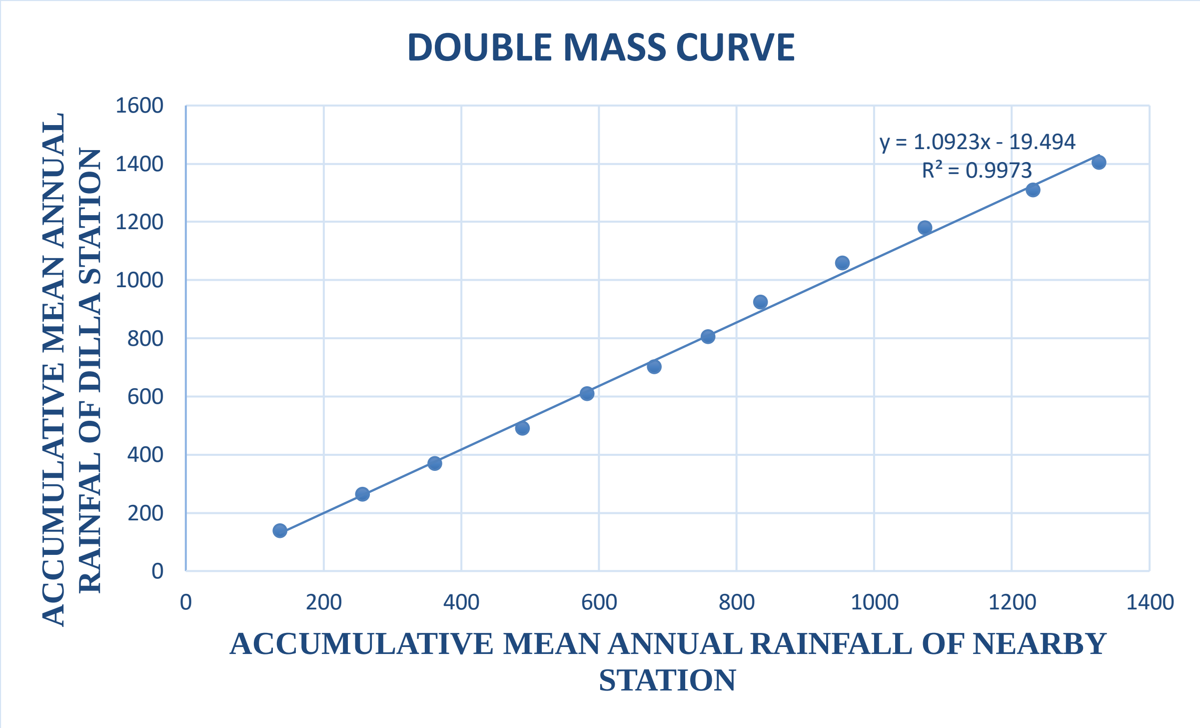


Figure 3. 10 Double mass curve

a plot a showing a corrected Accumulative precipitation of Dilla and Accumulative rainfall of near-by stations. the plot has a slope of 1.02, the plot shows that the record is consistent even if there are some Data's showing a slight variation on both sides.

3.2.2.3.5 Outlier identification

Outliers are data points, which depart significantly from the trend of the remaining data.it can be caused by instrumental error, personal error etc. if outliers are available, they will be excluded from the record.

According to era recommendation

- When the station skew is greater than +0.4, test for high outliers should be considered first;
- When the station skew is less than -0.4 tests for low outliers should be considered first;
- Where the station skew is between ±0.4, test for both high and low outlier should be applied before eliminating any outliers from the data set.

Higher Outlier Test

Yi=ym+(KN*sy)KM ……Eq..8

Lower outlier test

Yi=ym- (KN*sy)……Eq..9

Where ym=mean of the data

KN=value obtained from table for 25 years

Sy=Quantile range

The result of the test show that no outlier is available. detail analysis is in Appendix.

3.2.2.4 Statistical analysis

3.2.2.4.1. Fitting of frequency distributions

Frequency analysis usually involves fitting of theoretical frequency distribution using a selected fitting method, although empirical graphical methods can also be applied. The fitting of a particular distribution implies that the rainfall sample of annual maxima were drawn from a population of that distribution (Garg, 2008).

The practical issue is how to select a reasonable and simple distribution to describe the phenomenon of interest, to estimate that distribution's parameters, and thus to obtain risk estimates of satisfactory accuracy for the problem at hand.

- Gumbel method (Extreme Value Distribution Type I)

It is widely used in hydrologic and meteorological studies for the prediction of flood peaks, maximum rainfall (Subramanya, 2008).

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows (subramanya, 2008). According to this theory of extreme events, the probability of Occurrence of an event equal to or larger than a value X_0 is

$p(X \geq x_0) = 1 - e^{-e^{-Y}}$……. Eq..10

In which y is /ka dimensionless parameter given by

$y = \alpha(x - \alpha)$ $\alpha = \bar{x} - 0.450005\delta_x$

$y = \frac{1.285(x-\bar{x})}{\delta_x} + 0.577$…. Eq..11

Where $\bar{x}$ is mean and δ_x is standard deviation of the variate

$Yp = -\ln[-\ln(1 - P)]$…

T=1/P

$$YT = -[\ln * \ln \frac{T}{T-1}]$$

$YT = -[0.834 + 2.303 \log \frac{T}{T-1}]$

$X_T = \bar{x} + K\delta_x$

$K = \frac{(YT-0.577)}{1.2825}$ ....Eq..12

Above listed are equations that used for estimations of flood magnitude to a given return period based on a total annual flood series.

❖ Log Pearson type III

The hydrology committee of the Water Research Commission (WRC 1981) recommended the use of the log-Pearson type III distribution because it provided the most consistent fit of Peak flow Data.

In this the variate if first transformed in to logarithmic form (base10) and the transformed data is then analysed (Subramanya, 2008).

If x is the variate of a random hydrologic Series, then the series of Z variates where

Z $= \log x$......... Eq ..13

Are first obtained. for this series for any recurrence interval T

$Z_T = \bar{z} + k_z\delta_z$ ......Eq..14

$\bar{z}$=mean of the z values

Where Kz=a frequency factor which is a f unction of recurrence interval T and coefficient of skewness Cs, δz=standard deviation

$\delta_z = \sqrt{(z-\bar{z})^2/N-1}$ .... Eq..15

N=sample size or number of years of record

$Cs = \frac{N\Sigma(Z-\bar{z})^3}{(N-1)(N-2)(\delta_z)}$....... Eq..16

$XT = antilog(Z_T)$....... Eq..17

❖ Normal distribution

The normal or the Gaussian distribution represents the well-known bell-shaped curve, which is characterised by arithmetic mean μ and the standard deviation σ (Subramanya, 2008).The, normal distribution is used in frequency analysis for fitting empirical distributions to hydrological, and in simulation of data.

The probability density function of a normally distributed variable ‘x’ is given by:

$f(x) = \frac{1}{\delta\sqrt{2\pi}} e^{-\frac{1}{2}\frac{(x-\mu)^2}{\delta}}$....... Eq...18

Where μ and σ are the parameters of the distribution, in this exponential function e is the constant 2.71828…, μ is the mean, and σ is the standard deviation.

- Log normal distribution

it is a distribution which is skewed to the right, whose probability density function starts at zero, increases to its mode and decreases thereafter (Subramanya, 2008).It has been observed that whereas the original data show considerable skewness, their logarithms are nearly normally distributed, and hence the original data are said to follow the lognormal distribution. The distribution has been extensively used in many areas of science and engineering.

Formally, a random variable X is said to follow a lognormal distribution if log(X) follows a normal distribution (Subramanya, 2008).

X_t = μ(1+ $K_t C_V$) ………Eq 19

Where

Cv is coefficient of variation (σ/μ)

KT is called the frequency factor1

mean, μ

standard deviation, σ

y = log(x) …….Eq...20

where x is a data point and y is the log-transformed data point.

3.2.2.4.2 The Goodness of fit test

The reliability of the distributions is checked by the goodness of fit tests. The goodness of fit (GOF) tests measure the compatibility of a random sample with a theoretical probability distribution function. In other words, these tests show how well the distribution you selected fits to your data (ERA, 2013).

The Anderson-Darling (AD), the Kolmogorov-Smirnov (KS), and the Chi-Squared tests are used for the goodness of fit test and according to ERA The selection of the best fit method is based on the ranks given by the three fitness methods.

I have used statistical analysis software, Easy Fit 5.5 Professional to compute the Goodness of fit test.

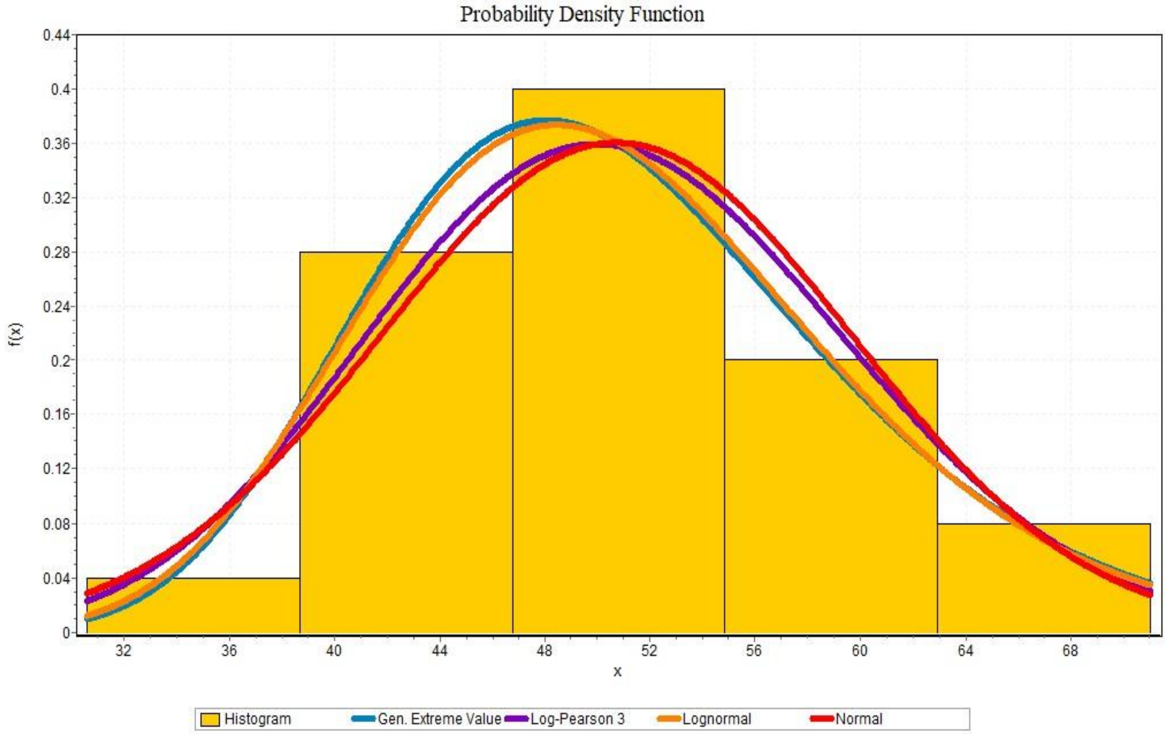


Figure 3. 11 Goodness of fit test

Table 3. 4 Goodness of fit Summary

Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gen. Extreme Value	0.09919	1	0.33306	2	2.4962	3
2	Log-Pearson 3	0.12353	3	0.38091	3	1.3563	1
3	Lognormal	0.10002	2	0.32712	1	2.5058	4
4	Normal	0.13199	4	0.41674	4	2.11	2

Gumbel distribution (GEV) proved to be a good fit

Table 3. 5 fitting results

Fitting Results

#	Distribution	Parameters
1	Gen. Extreme Value	k=-0.12566 σ=7.9495 μ=47.011
2	Log-Pearson 3	α=30.553 β=-0.03238 γ=4.9002
3	Lognormal	σ=0.17534 μ=3.9111
4	Normal	σ=8.938 μ=50.712

Goodness of fit test results with different parameters

3.2.2.4.3 Model Calibration and Validation

Model calibration is a process in which a generalized model is adjusted so that the model predictions better represent site-specific processes and conditions. During calibration, model parameters are optimized in an effort to increase accuracy and reduce model prediction uncertainty. Calibration is performed by carefully selecting model parameter values, adjusting them within their recommended ranges, and comparing predicted output variables with observed data for a given set of conditions (Moriasi et al., 2015).the first of these alternatives can be described as a "trial and error" method whereby the values of the control parameters were modified in a systematic manner to achieve correlation between the monitored parameters and the predicted parameters describing the catchment response. To compare the proposed calibration process with a more traditional calibration process, the evaluation criteria used were the relative error in peak flow and runoff depth and the hydrograph root mean square error. Resulting from this approach, it was found that high accuracy control parameter estimation was obtained. From the comparison of the new and traditional calibration approaches (Patil et al., 2016).

In order to Calibrate and validate the model, flow data was required but flow data is not available. Three conduits were selected for this purpose C97, C78, andC184 since they receive runoff from large area of the catchment.

Water depth and velocity measurements were taken for 10 days in order to calibrate and validate the model. Water depth was measured using tape meter at one hour interval right after the start of the rain until the flow ends. Floating method was used to measure the velocity.by assigning a specified distance and taking the time that it takes to travel, velocity was obtained. Average speed had been taken after repetitive measurement at the time.

The discharge is calculated using a continuity equation. Ten days of data had been taken from National meteorological agency which are in the same days with the measured data. from the ten days of measurement 4 days which are extreme events were taken 3 for calibration and 1 for validation.

Figure 3. 12 Taking measurements

3.2.2.4.3.1 Criteria for Model Performance Evaluation

- Coefficient of determination (r^2)

Pearson's correlation coefficient (r) and coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data (Moriasi et al., 2015).

$$r^2 = \left[\frac{\sum_{i=1}^{n}(Oi-\bar{O})(Pi-\bar{p})}{\sqrt{\sum_{i=1}^{n}(Oi-\bar{O})}\sqrt{\sum_{i=1}^{n}(Pi-\bar{p})}}\right]^2 \text{ ……. Eq..21}$$

With O: Observed values, Ō: mean observed values, P: Predicted (Modelled) values, $\bar{p}$ mean Predicted values

The correlation coefficient, which ranges from −1 to 1, is an index of the degree of linear relationship between observed and simulated data. If r = 0, no linear relationship exists. (Moriasi et al)

- The Nash-Sutcliffe efficiency (NSE)

The NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. describe the difference between model simulations and observations in the units of the variable (Singh et al 2004).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Oi-\bar{p})^2}{\sum_{i=1}^{n}(Oi-\bar{O})^2} \text{ ……Eq..22}$$

With O: Observed values, Ō: mean observed values, P: Predicted (Modelled) values, $\bar{p}$ mean Predicted values

NSE ranges between −∞ and 1.0 (1 inclusive), with NSE =1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Giatu., 2013).

- ❖ Relative error (RE)

Relative error (RE) The relative error is a measure of the accuracy of a measurement.

$$RE=\frac{\sum_{i=1}^{n}(Oi-\bar{p})}{\sqrt{\sum_{i=1}^{n}(Oi)}} \text{ ……. Eq..23}$$

With O: Observed values, Ō: mean observed values, P:Predicted (Modelled) values, $\bar{p}$ mean Predicted values

In general, the error must not exceed ±2 percent over the working range.

Table 3. 6 Performance classification table

Rank	Coefficient of determination (r^2)	Nash-Sutcliffe efficiency	Relative error (RE)
Excellent	>= 0.9	>0.75	<= 5%
Good	0.8-0.9	0.65-0.75	6%-10%
Satisfactory	0.6-0.8	0.50-0.65	11%-20%
Poor	<0.6	<0.50	>20%

3.2.3 Proposing Low Impact Development works as an alternative mitigation measure.

LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible(Rossman, 2012).

In order to select suitable areas for different LID types field survey was done.in single use residential areas using rain barrel helps to minimise runoff. In the other hand in condominium, hospitals, schools, governmental offices, industrial sites, mixed use buildings and other open space areas are suitable for infiltration-based techniques.

This approach emphasizes small, distributed, at-source BMPs and incorporates, as part of stormwater management decisions, design of street layout, and the size, location and configuration of buildings (Zimmerman et al., 2021).

By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions (US EPA).

3.2.3.1 Data Collection and analysis

- ✓ Primary data's

- Field survey

In order to select suitable areas for different LID types, a field survey was done. In single-use residential areas, using a rain barrel helps minimize runoff. Infiltration-based techniques, on the other hand, are appropriate in condominiums, hospitals, schools, government offices, industrial sites, mixed-use buildings, and other open space areas are suitable for infiltration - based techniques. for rain barrels, the number of houses was counted.

- ✓ Secondary data's

- Google Earth :- For visualization of the study area, select appropriate sites. The required volume is computed based on the impervious cover and the sub-catchment area.

- Soil data :- Knowing the type of soil helps to determine the infiltration capacity of the soil. The design infiltration rate is computed based on the infiltration capacity.

- ❖ Data Analysis

EPA SWMM: SWMM helps to calculate the amount of water that is infiltrated. LID modules in SWMM are designed to capture surface runoff and are reflected in the overall runoff infiltration and evaporation calculated for the sub-watershed by SWMM (Rossman, n.d.). Using data from the field survey, Arc Gis, Google Earth, and other necessary data from the manual, LID works simulation was performed for the Bioretention cell, Rain barrel, and Infiltration Trenches.

Microsoft Excel: Using Excel, different charts were generated that describe the situation.

3.2.3.2 Data processing and required parameters

- ❖ Bioretention cell

Procedures that are followed

- Determine the infiltration capacity of the study area based on the soil cover
- Determine the max surface ponding depth and deciding a surface ponding depth for the site.
- Determining the infiltration water storage depth of the practice, d_i which is the depth of water stored by the practice that can drain by infiltration alone
- Calculate the surface area of the practice (A_p) needed to capture the volume of runoff produced from the catchment by the design storm event. Compare required surface area of the practice to available space.

According to the design Guidelines and parameters values obtained from SWMM manual the design had been done.

Table 3. 7 Parameters of Bio-retention cells for the Model

Layer	Parameters	Dimension
Surface	Berm Height (mm) Vegetative Volume Fraction Surface Roughness Surface Slope (%)	300 0.20 0.13 0.04
Soil	Thickness (mm) Porosity (volume fraction) Field capacity (volume fraction) Wilting Point (volume fraction) Conductivity (mm/hour) Conductivity slope Suction head (mm)	700 0.475 0.378 0.265 0.254 45 12.6
Storage	Thickness (height) (mm) Void ratio (voids/solids) Seepage rate (mm/hour) Clogging Factor	350 0.60 0.254 474

Drain	Flow coefficient Flow exponent Offset height (mm)	5 0.5 500

❖ Infiltration Trench

Infiltration trenches are shallow trenches equipped with an underground reservoir comprised of coarse stone aggregate. The void space created by the aggregate provides storage for surface runoff that has been diverted into the trench. This runoff then infiltrates into the surrounding soil, through the bottom and sides of the trench.

Procedures that are followed

- The required volume is computed based on the impervious cover and the Sub-catchment areas
- Compute the Design Infiltration Rate, the design infiltration is obtained as half the of the infiltration of the soil types of the study Area.
- The required maximum Allowable Trench Depth is computed in order to allow the run off to completely empty within 48 hours
- Compute the minimum Allowable Trench Area,
- The trench will be sized based on the Allowable site conditions…and the area above the minimum allowable Trench is used.

According to the design Guidelines and parameters values obtained from SWMM manual the design had been done.

Table 3. 8 Parameters of infiltration trench for the Model

Layer	Parameters	Dimension
Surface	Berm Height (mm) Vegetative Volume Fraction Surface Roughness Surface Slope (%)	500 0.20 0.13 0.04
Storage	Thickness (height) (mm) Void ratio (voids/solids) Seepage rate (mm/hour) Clogging Factor	700 0.6 0.254 474

Drain	Flow coefficient	34
	Flow exponent	0.5
	Offset height (mm)	0.5

❖ Rain Barrel

Rain barrels are a storage low impact development technique. Rain Barrel are used to collect rain water run off this helps in reduction of runoff and protection of flooding.in addition to this rain barrel has many benefits. According to the research done on Dilla Town for rain water harvesting to satisfy water demand of the town showed that, Households with minimum roof size of 40 m^2 have the maximum rain water harvesting potential of 4.86 m^3 during June and minimum water harvesting potential of 0.18 m^3 in August. A household with a roof size 100 m^2 have a maximum potential to harvest 12.91m^3 of rain during June and a minimum of 0.49 m^3 during August. The second maximum and minimum RWH months were 10.65 m3 in January and 2.01 m3 in August respectively (Kanno et al., 2020).

Procedures that are followed

- Counting the number of houses available
- Taking the roof Area of 40m^2 per family

According to the design Guidelines and parameters values obtained from SWMM manual the design had been done.

Figure 3. 13 Sample LID model Area

4 Results and Discussion

4.1 Currently existing major problems of drainage system in the study area

Through field survey, interview, and visit i have observed currently existing problems of the drainage system. some of these problems are: lack of adequate drainage infrastructure, lack of connection between the structures, some of the drainage structures doesn't have a capacity to carry the generated runoff, fracture due to aging and lack of regular maintenance is also clearly visible, especially the major problem in the study area is lack of proper waste management. solid and liquid wastes from household are dumped in to the drainage system. siltation and sedimentation are seen in the channels. as a result, the runoff overflows, erodes walk ways, ditches and roads.

- Dumping of solid and liquid wastes in to stormwater drainages

Solid and liquid wastes from residential, commercial and industrial disposals. Which consists of manufactured materials such as water bottles, cans, plastic and paper wrappings, newspapers, shopping bags, cigarette packets and remains of chat.

Lack of frequent cleaning has made the situation worst, due to this sedimentation and siltation is visible in different drainage systems.

This solid and liquid wastes are aesthetically un attractive and have a potential health hazard to the society not only these as a result of dumping solid and liquid wastes the canals become clogged and overflow had occurred in some drainages.

Figure 4. 1 Solid and liquid waste

- Incapable drainage infrastructure to convey generated runoff

The simulation done by EPASWMM indicated that some main and some sub main canals are incapable to convey the generated runoff.

The conduits which are incapable to convey the generated runoff are those C29, C30, C101, C133, C179, C180, C181. and different junctions has been flooded.

Poor integration between drainage lines is also seen in different parts of structure.

it is one of the reasons for the occurrence of flooding in the study area.

- Impervious area increment

From the total area of the study area different land uses have a different percentage of land cover among this, buildings cover 30%, green area 30%, cobblestone 20%, Asphalt 15%, and barren land 5%. In a town as the population number increase the need for construction of houses will also increase, different infrastructures will be required, because of these more and more area will be vulnerable to deforestation, and imperviousness will also increase side by side. The increase in impervious area will decrease infiltration and will increase surface runoff. As the population of the town increase without appropriate expansion of the drainage infrastructure, the existing structure will become busy and incapable to carry the generated runoff since in the study area there is insufficient drainage distribution, the area is vulnerable to flooding.

4.2 Evaluation of the existing drainage system performance using EPA SWMM

4.2.1 Drainage network of the study area

All runoff generated from the catchment would not flow towards the outlet. Because of the limitation 'that in urban environment runoff flows not only on surface but it also flows through manmade drainage structures such as roadside ditches (Chali & Zewdie, 2020).

due to the blocking and guiding effect of roads and pipe networks on water flow in urban areas, Subcatchments divided by watersheds cannot fully reflect the actual flow path. Therefore, in the runoff simulation, roads and pipe networks are often used to divide Sub-catchments. The study area was divided into sub catchment based on Topographic map, building blocks and direction of flow in drainage. The study area is divided in to 34 Subcatchments.

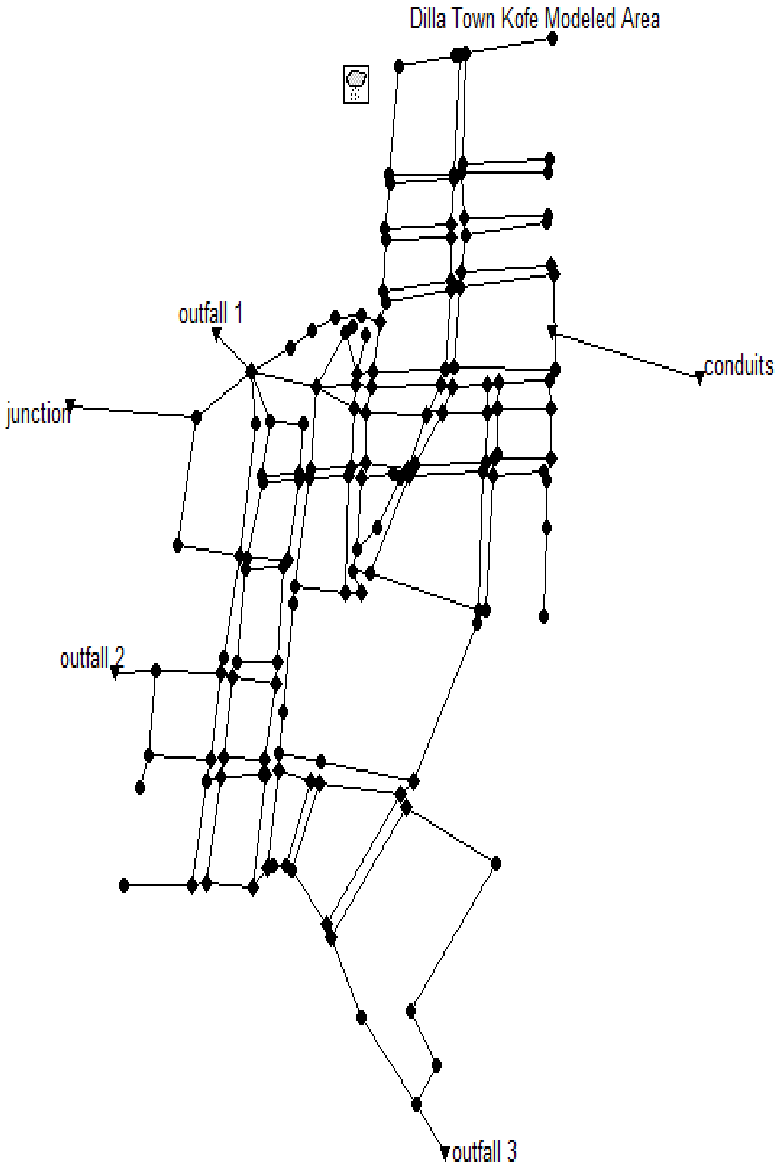


Figure 4. 2 Drainage network of the study area

4.2.2 EPA SWMM 5.1 model results

The study result of the model will give fully understanding of the town drainage system performance. The primary and secondary collected data's were used to produce the parameters needed for EPA SWMM rainfall-runoff modelling. using rainfall data from 1997-2021 and deriving 15minute intensity from it, simulation has been done and results obtained. The major problems of the study area were identified based on the field survey and analysis made using Arc Gis and EPA SWMM. The model result evaluated the drainage performance based on the criteria's of capacity analysis, flow velocity, and peak rate of runoff. identified flooded areas and the cause of flooding, and using LID Works options in SWMM peak discharge reduction and peak volume reduction were assessed and proposed sustainable solution to the problems.

4.2.2.1 Sub-catchment's, Simulated result

The maximum peak runoff occurred in two Sub-catchments. The peak runoff obtained from sub-catchment 24 and 32 with a peak discharge of 3.51m^3/s & 3.02m^3/s respectively. least peak runoff obtained from sub-catchment with less imperviousness, area and slope distribution. The peak runoff obtained for all sub catchments are listed below.

Table 4. 1 subcatchments simulated result

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
S1	134.08	0.00	0.00	3.40	127.32	9.87	1.35	0.950
S2	134.08	0.00	0.00	5.46	122.27	13.91	1.55	0.912
S3	134.08	0.00	0.00	3.34	129.20	4.65	0.77	0.964
S4	134.08	0.00	0.00	4.20	127.64	5.49	0.81	0.952
S5	134.08	0.00	0.00	4.22	127.57	6.51	0.95	0.951
S6	134.08	0.00	0.00	3.79	128.33	5.71	0.89	0.957
S7	134.08	0.00	0.00	5.03	125.01	12.00	1.49	0.932
S8	134.08	0.00	0.00	5.16	124.24	8.70	1.04	0.927
S9	134.08	0.00	0.00	5.08	126.00	1.89	0.26	0.940
S10	134.08	0.00	0.00	4.60	126.98	1.27	0.18	0.947
S11	134.08	0.00	0.00	5.09	125.98	5.04	0.68	0.940
S12	134.08	0.00	0.00	4.87	125.83	4.23	0.55	0.938
S13	134.08	0.00	0.00	4.84	125.97	1.26	0.17	0.940
S14	134.08	0.00	0.00	4.76	126.33	5.05	0.68	0.942
S15	134.08	0.00	0.00	5.35	124.75	2.50	0.31	0.930
S16	134.08	0.00	0.00	4.57	127.12	1.02	0.15	0.948
S17	134.08	0.00	0.00	4.53	127.28	4.42	0.64	0.949
S18	134.08	0.00	0.00	5.05	126.16	5.31	0.73	0.941
S19	134.08	0.00	0.00	5.80	122.09	12.05	1.32	0.911
S20	134.08	0.00	0.00	5.72	122.68	8.71	0.97	0.915
S21	134.08	0.00	0.00	4.81	126.11	2.52	0.34	0.941
S22	134.08	0.00	0.00	4.14	126.71	6.34	0.85	0.945
S23	134.08	0.00	0.00	4.84	125.94	6.30	0.83	0.939
S24	134.08	0.00	0.00	4.21	119.10	33.35	3.51	0.888
S25	134.08	0.00	0.00	4.35	127.02	5.58	0.78	0.947
S27	134.08	0.00	0.00	5.36	124.73	9.54	1.18	0.930
S28	134.08	0.00	0.00	4.80	126.14	6.75	0.90	0.941
S29	134.08	0.00	0.00	6.28	122.85	3.75	0.43	0.916
S30	134.08	0.00	0.00	6.61	120.93	12.00	1.28	0.902
S32	134.08	0.00	0.00	6.78	119.73	29.57	3.02	0.893
S33	134.08	0.00	0.00	5.85	123.64	3.88	0.46	0.922
S34	134.08	0.00	0.00	5.59	124.87	4.68	0.60	0.931
S35	134.08	0.00	0.00	5.47	124.13	3.89	0.47	0.926
S36	134.08	0.00	0.00	4.90	125.65	6.28	0.81	0.937

4.2.2.2 Out Fall Loading

Table 4. 2 Out fall loading

Summary Results

Outfall Loading — Click a column header to sort the column.

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10^6 ltr
out1	95.84	8.213	21.765	170.228
out2	95.84	1.311	4.546	27.170
out3	95.56	2.110	4.908	43.611

The outfalls result indicates that the maximum flow rate at outfall 1, outfall 2, outfall 3 are 21.765 m^3/sec ,4.546 m^3/sec, and 4.908 m^3/sec respectively. Outfall 1 covers large areas because of that the generated runoff is higher than the rest. The total volume of runoff is 170.3*10^3 m^3/sec,27.170*10^3 m^3/sec and 43.611*10^3 m^3/sec.

4.2.3 Drainage system hydraulic analysis

The physical parameters of existing canals, like shape, type, and size, are used to analyse the hydraulic capacity of the study area. a tape meter was used to measure the depth and width of the canals. and as it was discussed in Chapter 3, different needed parameters were filled accordingly. The existing storm drainage facilities were generally classified into closed and open drainage lines and constructed using masonry and most have rectangular and trapezoidal geometry.

The model area was classified into 34 sub-catchments, and the drainage system has 144 junction nodes and 191 conduit links. a total of 8 junctions and 7 conduits have been flooded. In those junctions and conduits flooding occurred due to inadequate drainage capacity. In terms of the capacity analysis made by EPA SWMM the designed water level is below the maximum flood level and those junctions and conduits showed poor performance.

Flow velocity is one of the performance indicators of the drainage system. If the velocity is below the minimum self-cleansing, there is siltation of solid material in the drainage system, that would be a barrier to better system performance. On the other hand, if the velocity is beyond the maximum threshold, the stormwater causes damage to infrastructure. The velocity should be optimum. By taking the recommended flow velocity of 0.8 m/s as the minimum self-cleansing velocity and 3 m/s as the maximum velocity, based on the model simulation, several drains of the system are below their self-cleansing velocity, which has led to siltation and sedimentation. because of siltation and sedimentation, the drainage showed poor performance.

The other indicator used is the peak rate of runoff. based on the simulation made using EPA SWMM results for peak rate of runoff and peak run-off time is obtained. Drainage systems should be designed to transport peak runoff magnitude so as to avoid significant flood hazards.in this study most of the peak flow is observed at early hours. This is due to the increment of impervious areas and the decrement of the infiltration capacity of the soil. Based on the results obtained the drainage system showed poor performance and susceptible to flooding.

4 .2.3.1 Capacity analysis of Drainage system

As the objective of the study the performance of the drainage system can be evaluated by using its capacity analysis and identifications of the overflow locations is assessed. SWMM evaluates the quality of the simulation using continuity error, an error which is <10% is considered to be a good quality.in these simulation I obtained a flow rumoff error of -0.23 and a flow routing error of -0.68 these shows the model is valid.

detail discussion of the capacity analysis of flooded junction and links is available below.

❖ Flooding in the junctions

➢ : Flooded junctions below Dilla referral hospital and Kofe Kera

The maximum designed water level of drainage canal Below Dilla referral hospital of junction 86 were 0.6m and the flooding level was 0.8, and the designed water level of drainage canal around Kofe Kera was 1m and the flooding level was 2m since the Sub catchment covers large area the canal carrying capacity was obtained insufficient for 3hrs rain fall intensity.

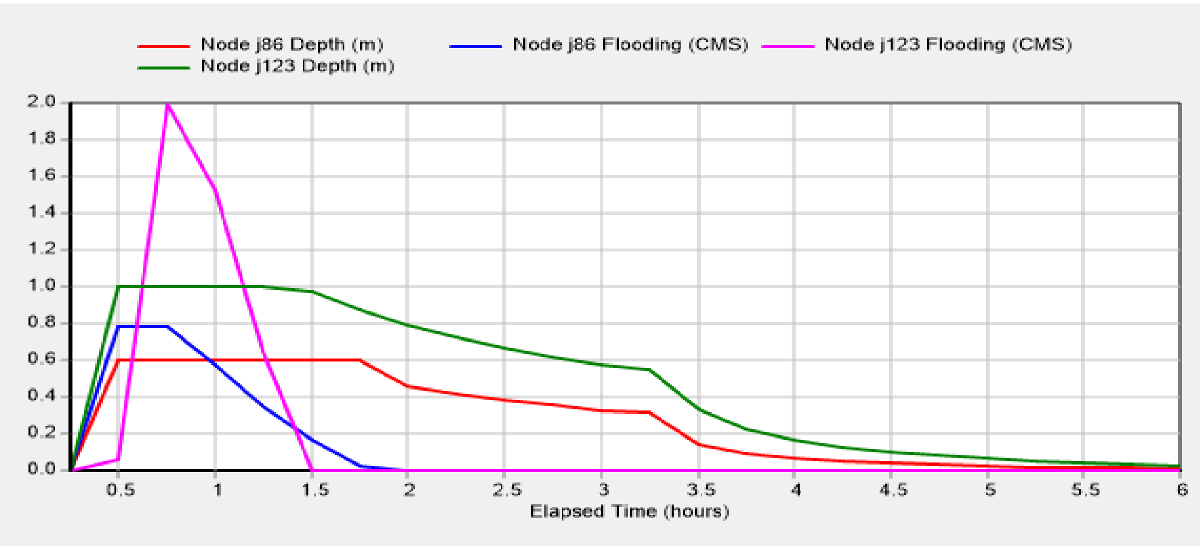


Figure 4. 3 Flooded junctions below Dilla referral hospital and Kofe Kera

➢ : Flooded junctions around Dilla justice office and below Ko fe Gebeya

The maximum designed water level for the canal around justice office was 1m, the flooding level was 1.35m. the designed water level of drainage canal below Kofe Gebeya was 0.9 m and the flooding level was 1.35m. these shows the canal is inadequate to carry 3hrs rain fall intensity. the flood level has risen and over flow has occurred.

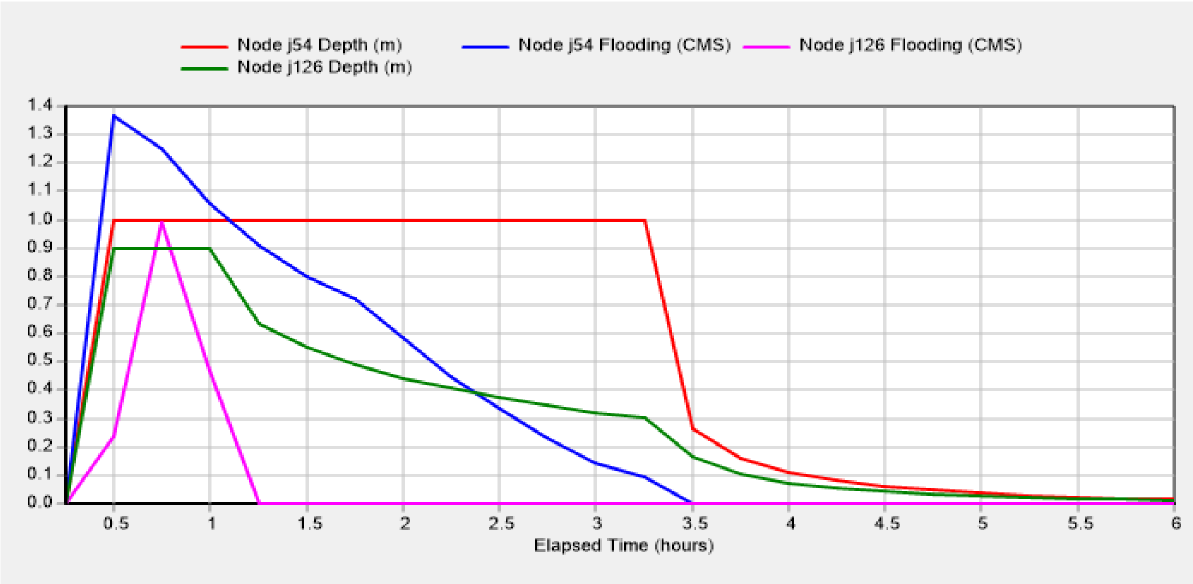


Figure 4. 4 Flooded junctions

- **:** Flooded junction below Kofe condominium

The maximum designed water level for the canal junction 20 was 1m, the flooding level was 1.03m. and water level in junction is also 1m the flood level is 1.12m.the canal is insufficient to carry the water so as a result flooding has occurred.

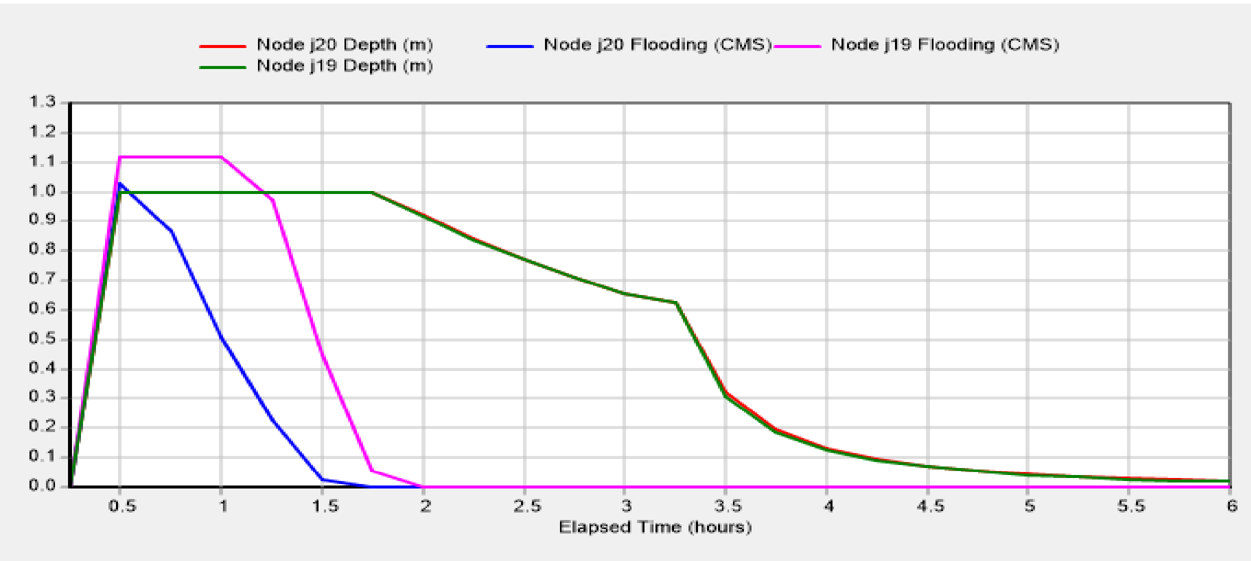


Figure 4. 5 Flooded junction below Kofe condominium

➢ **:** Flooded junctions below Infolink and above Ethiopia commodity exchange

The maximum designed water level for the canal below Infolink divider D10 was 1.45m, the flooding level was 1.81m. the designed water level for the Drainage canal above Ethiopia

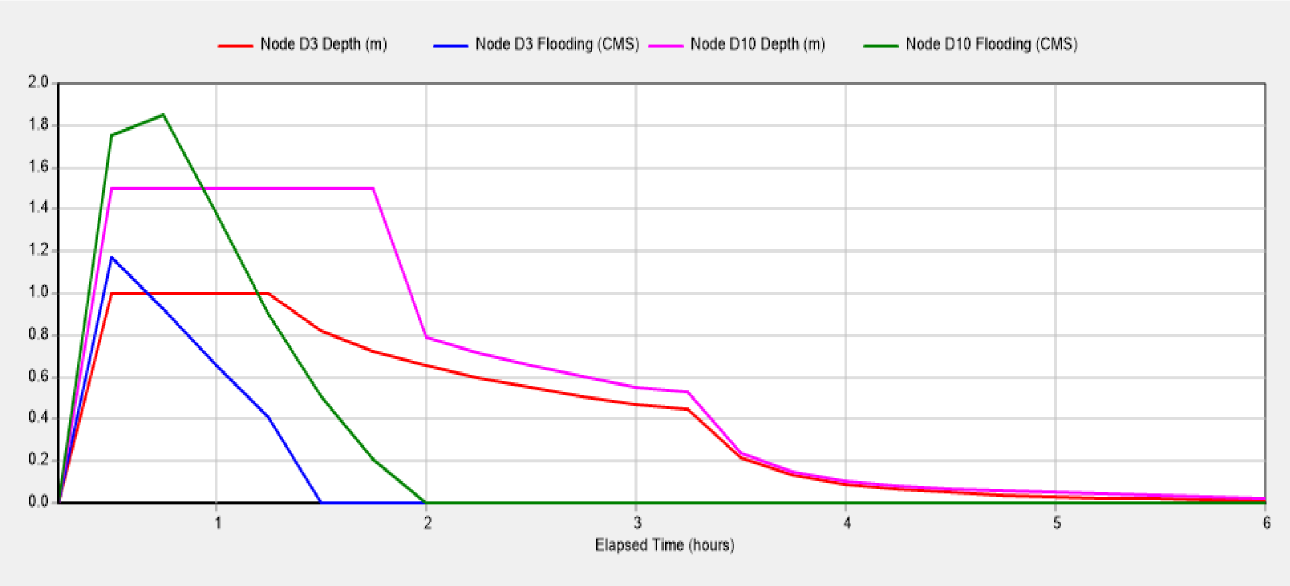


Figure 4. 6 Flooded junctions below Infolink and above Ethiopia commodity exchange

8 junctions are flooded this indicate they have poor performance. Cleaning sediments, garbage's and expanding there sizes as much as they can convey maximum water level can bring temporary solution and to sustainably solve the problem by using alternative mitigation such as LID are recommended.

❖ Water depth and flow in the Links

➢ Conduit Link below kofe condominium

The drainage canal found below Kofe condominium conduit link (C29, C30) as the simulation result indicates the junctions (19,20 and 22) are insufficient to carry the generated runoff as a result there is flooding. But the downstream of the link (C30) junction 22 has the capacity to carry the runoff.

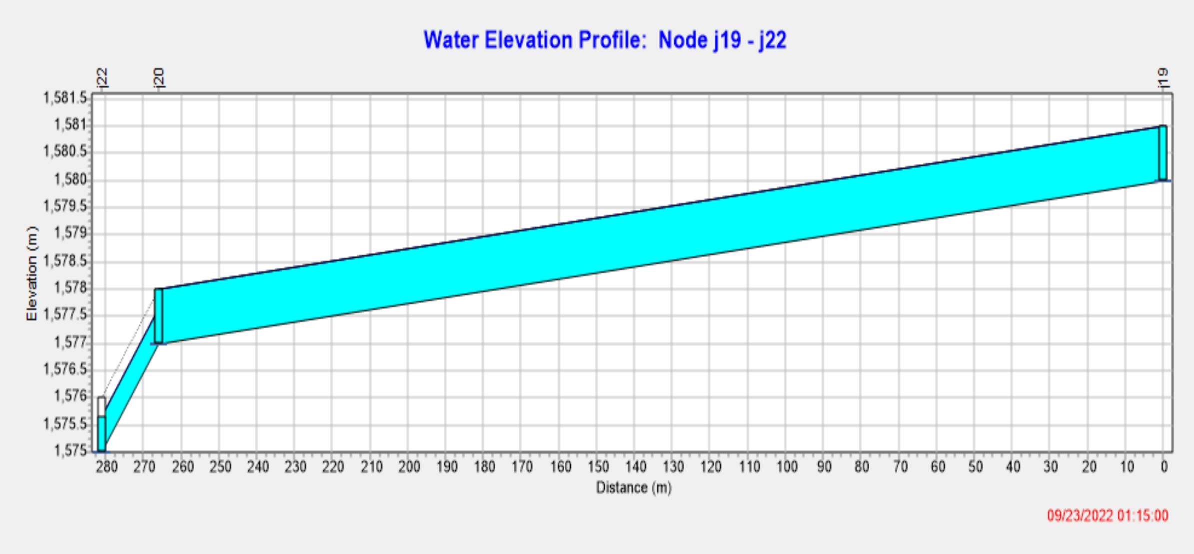


Figure 4. 7 water elevation profile Node J19-J22

➢ : conduit link found below Dilla justice office

The drainage canal found below Dilla justice office conduit link (C101) as the simulation result indicates the junction in the upstream side (j54) has insufficient capacity to convey the simulated runoff whereas the junction in the downstream side (j53) has sufficient capacity to carry the generated runoff.

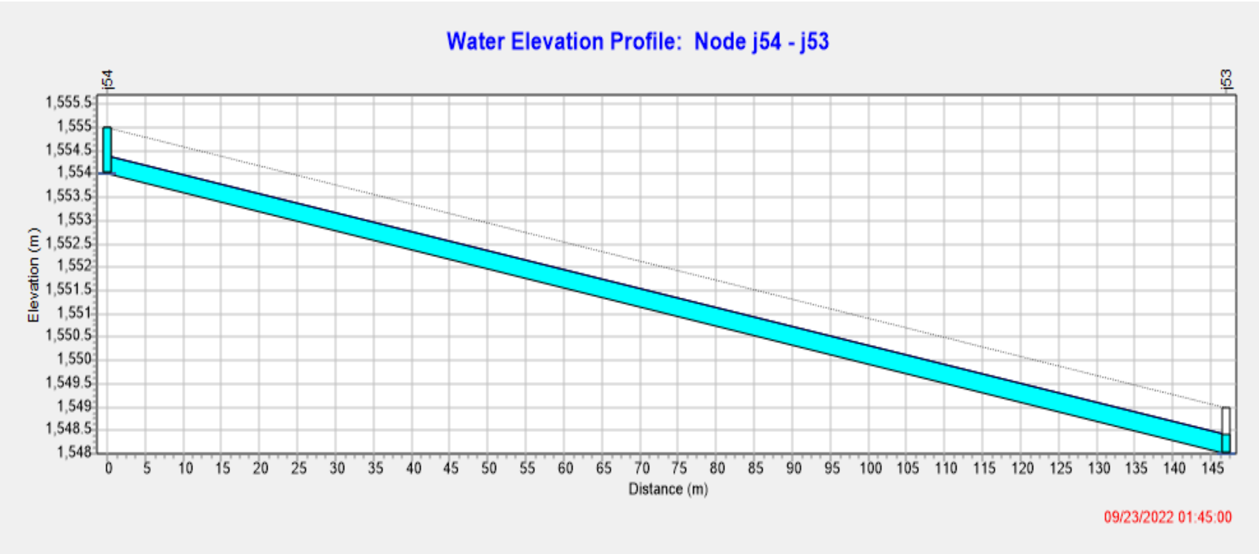


Figure 4. 8 water elevation profile j54-j53

➢ : conduit link below Infolink

The drainage canal found below info link Conduit link (C133) as the simulation result indicates the Divider in the upstream side (D64) has insufficient capacity to convey the simulated runoff as a result overflow has occurred in the other hand the junction in the downstream side (j63) has sufficient capacity to carry the generated runoff.

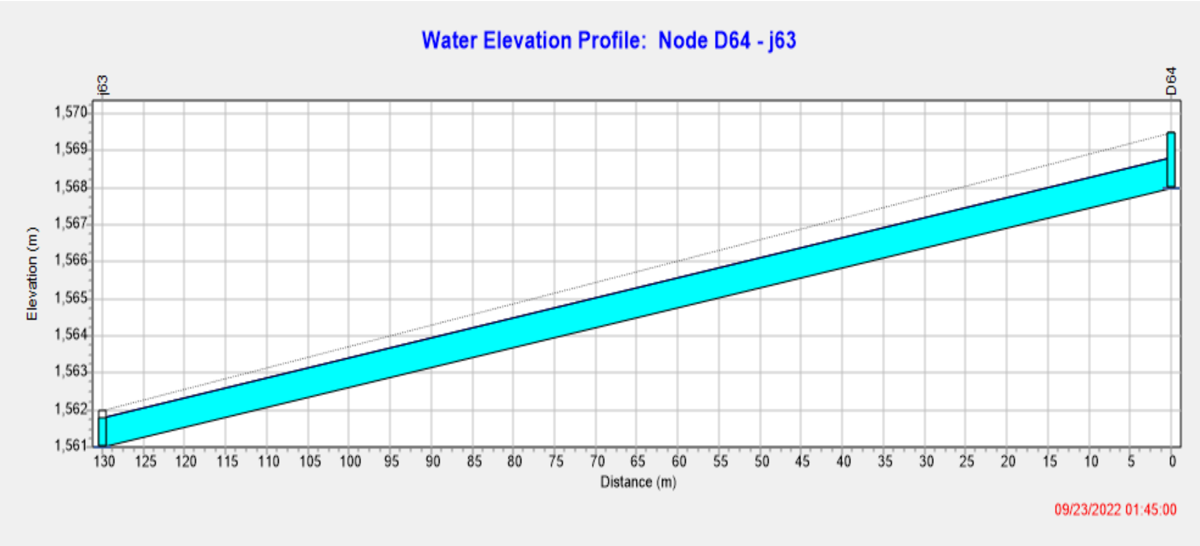


Figure 4. 9 water elevation profile D64-J63

- ➢ flow in the Links to Kofe river outfall(out3)

Exchange of drainage canal for divider D3 is 1m and flooding level is 1.19m the canal is incapable to carry the flood level.

The drainage canal in the way to Kofe river conduit (C179, C180, C181) as shown below shows that the junctions (J115, J118) have a capacity to carry the generated flow whereas junction 123 conduit 181 is insufficient to convey the simulated runoff because of that overflow has taken place.

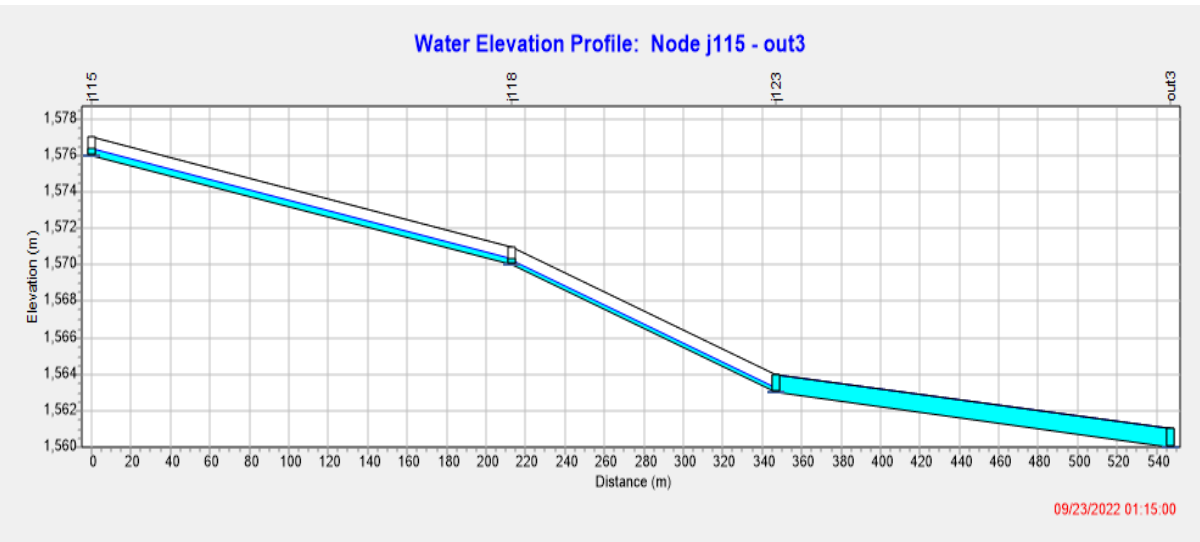


Figure 4. 10 water elevation profile Node j115-out3

In 7 conduit overtopping is seen because of inadequacy in their sizes this indicate they have poor performance. Increasing their dimensions can bring a temporary solution as the town is expanding and impervious covers increasing. Applying alternative mitigation measures can help to give sustainable solution to the problems seen.

4.2.4 Flow Velocity

Flow velocity is one of the indicators of drainage system performance. In areas where the velocity is high there is a vulnerability to flooding and when the velocity is low sedimentation can occur. So appropriate velocity of flow is very important. For adequate transportation of suspended solids, the minimum velocity or self-cleansing velocity is important.

According to the study made in Columbia Bogota for wastewater drainage system, five scenarios were taken into account, varying topography up to 50 percent, and fixing a critical inflow of 1 litter per second at each node of the system. In this kind of systems the self-cleaning restrictions in minimum velocity are 0.3, 0.45 and 0.6m/s (Montes et al., 2017) .

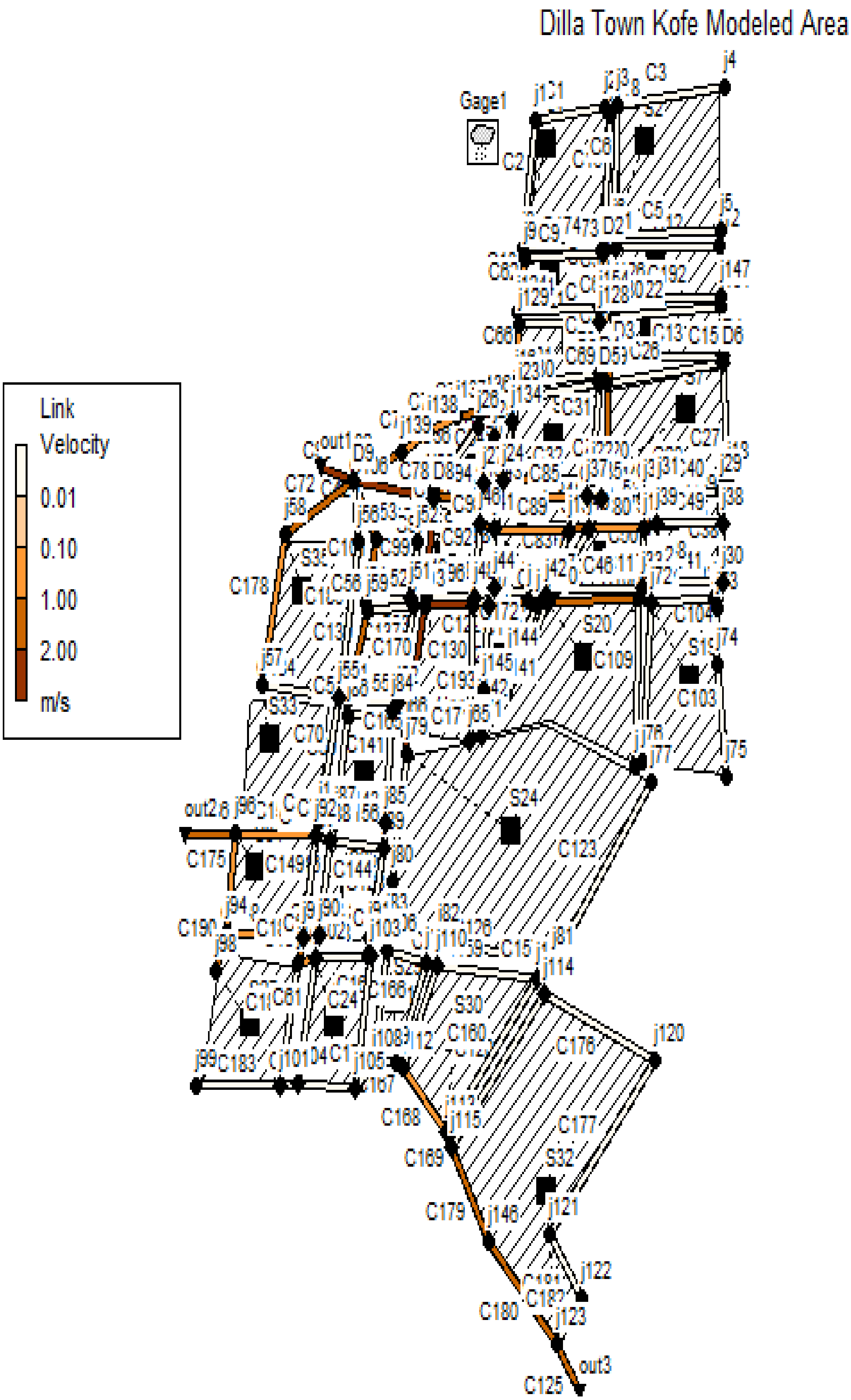


Figure 4. 11 Link velocity

Most of the time the adopted minimum velocity is taken from experience but a more viable approach is to incorporate some aspects of sediment and channel characteristics into self-cleansing design, through incipient motion equation. In the USA the minimum velocity must be 0.60 and 0.90 m/s for full and storm sewer types, respectively; in France the values are 0.30–0.60 m/s; in the UK the values must be 0.75 and 1m/s for storm and combined sewers, respectively. to design the proper self-cleansing velocity, different parameters, such as concentration and size of sediments, depth or hydraulic radius of the flow, and roughness and diameter of the pipe, should be considered to allow the designer to obtain the minimum velocity according to regional conditions (Ebtehaj et al., 2014).

Table 4. 3 Flow velocity

NO.	Criteria	Value
1	Minimum velocity at initial peak flow	0.6 m/s
2	Minimum Velocity at ultimate peak flow	0.8 m/s
3	Maximum Velocity	3 m/s

Source WPCF,ASCE,1982

By taking the recommended flow velocity of 0.8m/s as minimum velocity at ultimate peak for cleansing velocity. Based on the model simulation, several drains of the system are categorized below the cleansing velocity.

Erosion is caused by sand and other gritty material and is compounded by high velocities and hence the maximum velocity shall be limited to 3 m/s. based on the simulation result the maximum velocity shows a good performance.

4.2.5 Peak rate of Runoff

Drainage systems should be designed to convey based on a predetermined peak runoff magnitude so as to avoid significant flood hazards.

Peak runoff time is the time that is needed to reach peak discharge. the higher the intensity of rain, the higher will be the peak runoff.

Table 4. 4 Peak runoff time

Subcatchment	Time (hours)	Runoff (CMS)
S1	0.75	1.6966
S2	1	2.0066

S3	0.5	1.0105
S4	0.5	1.7037
S5	0.5	1.3338
S6	0.5	1.1983
S7	0.5	2.1849
S8	0.5	1.6317
S9	0.5	0.363
S10	0.5	0.2543
S11	0.5	0.9498
S12	0.5	0.77
S13	0.5	0.227
S14	0.5	0.9668
S15	0.5	0.4634
S16	0.5	0.2029
S17	0.5	0.883
S18	0.5	0.9946
S19	0.75	1.8896
S20	0.75	1.3825
S21	0.5	0.4757
S22	0.5	1.2084
S23	0.5	1.1751
S24	1	3.5085
S25	0.5	1.0684
S27	0.5	1.6207
S28	0.5	1.2041
S29	0.75	0.6033
S30	0.75	1.8568
S32	0.75	4.4854
S33	0.75	0.631
S34	0.5	0.8215
S35	0.5	0.6285
S36	0.5	1.7371

As it is seen in the table above, most of the peak flow is observed at an early stage of the simulation. This is due to urbanization; as imperviousness increases, the amount of infiltration decreases, and as a result, early runoff is attenuated. Hence, as the impervious area increases, the drainage system can't accommodate the excess amount of runoff generated, which will increase the area's susceptibility to flooding. using this as one indicator, the drainage system shows poor performance, as shown in the table above.

4.2.6 Model Calibration and Validation

In order to calibrate and validate the model. Ten days of water level and velocity were measured. There similar day rainfall data taken from National Meteorology Agency. Data with highest rainfall values were taken. I have used three data for calibration and one data for validation purpose.

Table 4. 5 Rainfall data source National Meteorological Agency

Year 2022	July 6	July 13	August 15	Aug 25
Daily(mm)	11.4	13.2	12.6	12.3

Detailed measured values are available in Appendix

4.2.6.1 Model Calibration

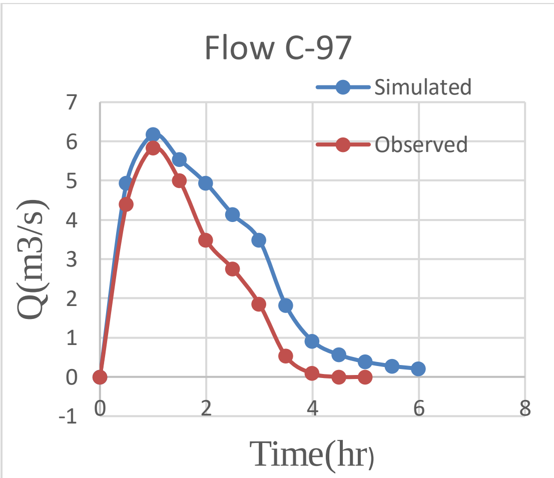
The performance of the model was evaluated using three performance indicators (NSE, RE, R^2). The model calibration was computed by varying the sensitive parameters till acceptable performance values are obtained with observed and simulated values. the below indicated the sensitive parameters were used for optimization in the model calibration.

The values in the table are taken from SWMM manual.

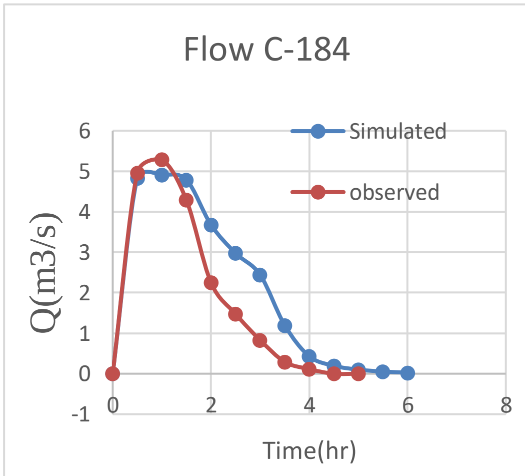
Table 4. 6 Sensitive parameter

Parameter	Description	Value range	Initially used values	Final used Value
Width-K	flow width coefficient	0.2–5	3	2
N-Imperv	Manning's roughness coefficient for impervious-area	0.011–0.015	0.011	0.012

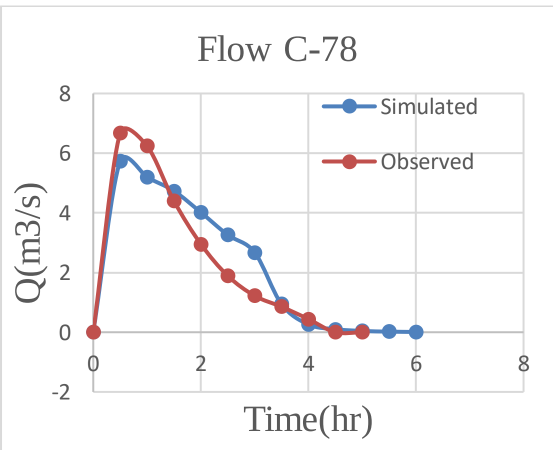
N-Perv	Manning's roughness coefficient for pervious area	0.05–0.8	0.05	0.08
Destore-Imperv	Depth of depression storage on impervious area,	0–3	2	3
Destore-Perv	Depth of depression storage on pervious area	3–10	3	6
Conduit Roughness	Manning's roughness coefficient for conduit	0.011–0.024	0.012	0.011
Drying Time	Time for a fully saturated soil to completely dry	1–7	4	5



(a)



(b)

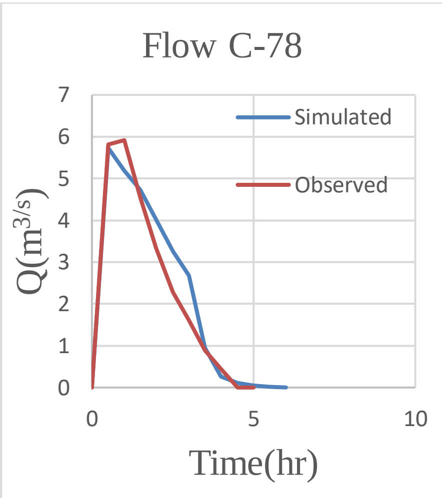


(b)

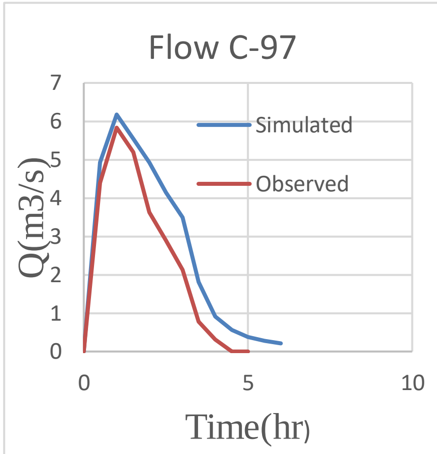
Figure 4. 12 Calibration flow chart (a-c)

4.2.6.2 Model Validation

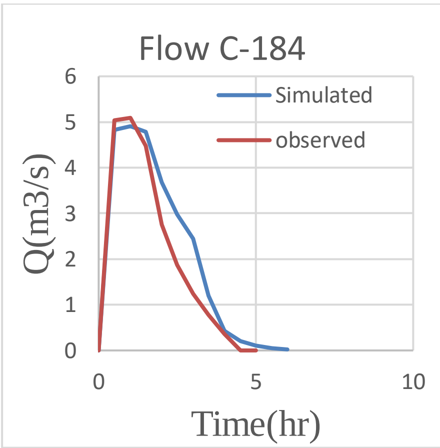
The calibrated model was validated using another day data of observed and simulated results.



(a)



(b)



(c)

Figure 4. 13 validation Flow chart (a-c)

The calibrated model was validated using separate day measured and data taken from National meteorology. The results obtained from model calibration are with-in the range of acceptable limit for different criterions. The results obtained for the calibration for the performance indicator of Nash-Sutcliffe efficiency (NSE) for each conduit (C78,C97 and C184) is 0.87,0,91 and 0.85 respectively and for the coefficient of determination (R^2) 0.75,0.84, and 0.77.the other indictor considered is relative Error there error is 8.3%,4% and 7%. Referring to the validation, the performance of the model for Nash-Sutcliffe efficiency(NSE) for the aforementioned conduits is 0.91,0.88 and 0.88 respectively, it is 0,88,0,9.0.78 for the coefficient of determination (R^2) and have a relative error 0f 3.7%,5%,6% these results show the model has a good performance and the model can do the analysis for the study area.

4.3 Lid works as sustainable urban drainage system solution

Sustainable urban drainage system can be achieved by strategies such as low impact development works, which helps to develop environmentally friendly stormwater management.

Several LID components can be created within the Stormwater Management Model (SWMM) and then added to the corresponding Sub-catchments by varying parameters according to the actual site situation. as we know Lid options have mainly two purposes that are quality and quantity.in this work only quantity had been analyzed.

two types of LID scenarios were selected those are: no LID technique as a baseline scenario and LID technique based on infiltration (bio-retention and infiltration trench), LID technique based on water storage (rain barrel).

Lid practices has produced astonishing achievement in many parts of the world. taking 30-year recurrence period and 2hr rain fall intensity, research was conducted in south Korea Naju-si the result showed that although the peak flow occurrence time did not significantly change from the post development state after the application of LID, the amount of the peak flow decreased by 43.4% from 3.07 m^3/s to 1.74 m^3/s after the application of LID. The total runoff decreased by 42.3% , from 9600 m^3 to 5540 m^3 after applying Lid (Kim & Kim, 2021).

In this work 25-year recurrence period and 3hr rainfall intensity were taken. from different available LID choices, the effectiveness of bioretention cell, infiltration trenches and Rain barrels had been analysed Individually and combining three of them, their effectiveness were tested using SWMM and combination of the three brought the best result in terms of reduction in peak runoff and volume of runoff. with peak discharge reduction of 28.72%,15.62%,30.158% and volume reduction of 32.87%,19.87%, 32.78% for selected sub-catchments.

The selected lid techniques are based on the land use and land cover, available open spaces, Topography, and the soil condition of the study area.The LID parameters were selected by referring to the typical values listed in the SWMM user manual, the area they cover is selected by designing the minimum allowable area.

4.3.1 Application of Rain Barrel

The contribution of rain barrel on mitigating floods in three sub-catchments was assessed for the contributing areas based on the number of houses available. A study done in Addis Abeba Nifas silk lafto sub city showed that LID storage using rain barrels (RB) can reduce peak runoff up to 35%, if it is effectively applied (Jemberie & Melesse, 2021).

Comparing the scenario with no application of Rain barrels. The results showed good performance in terms of peak discharge and run off volume reduction.as shown in the table below.

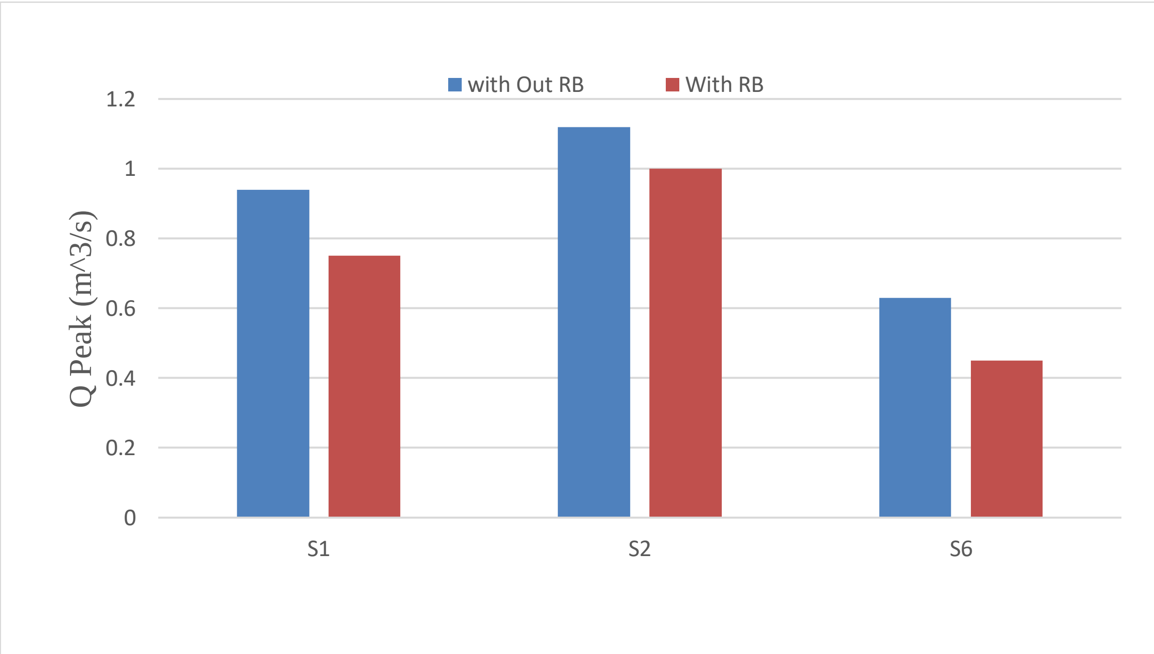


Figure 4. 14 with Lid and with-out Lid comparison for rain barrel

Table 4. 7 rain Barrel peak discharge reduction

Sub-Catchment	S1	S2	S6
Peak discharge reduction%	20.22	10.71	28.57
Run off volume reduction%	22.25	11.8	32.6

4.3.2 Application of infiltration Trench

In different sub-catchments the impact of infiltration in reduction of peak discharge and run off had been assessed, The Assessment showed that infiltration has brought a good performance in terms of reduction in peak discharge and run off volume.

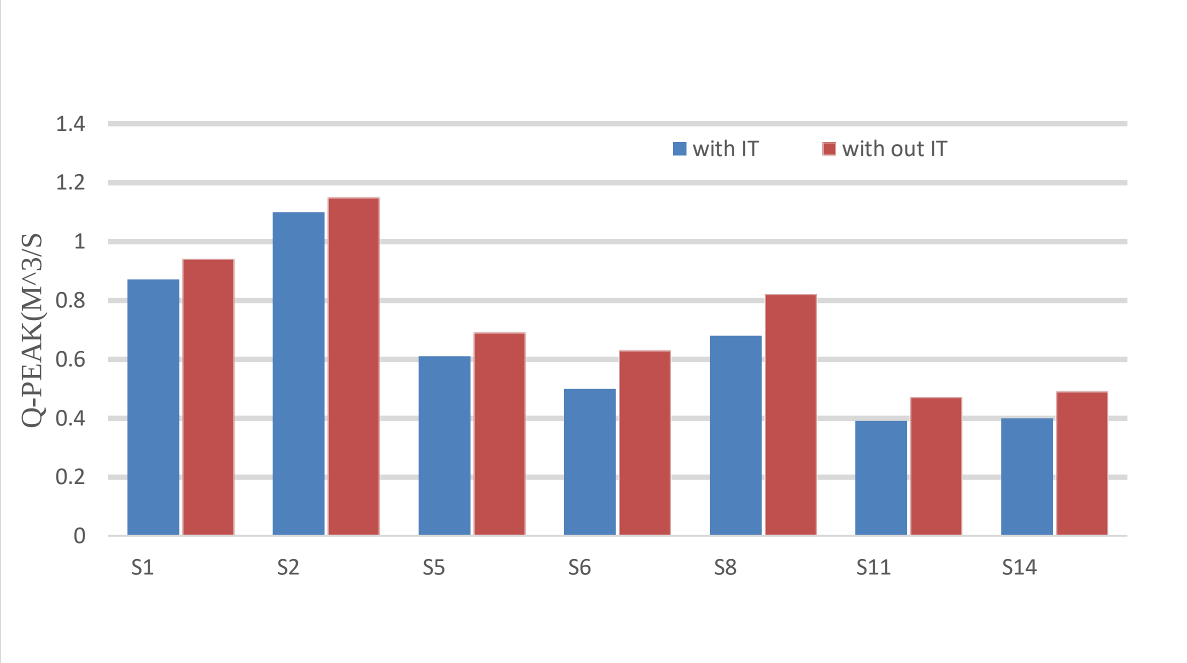


Figure 4. 15 with and without LID comparison for Infiltration Trench

Table 4. 8 Rain Barrel peak discharge reduction

Sub-catchment	S1	S2	S5	S6	S8	S11	S14
Peak Discharge reduction %	7.44	5	13.04	20.63	14	17	18.36
Run-off volume reduction %	7.99	5.35	7.276	12.98	11.765	13.36	14.254

4.3.3 Application of Bioretention cell

The contribution of Bioretention cell was assessed for different Subcatchments result showed decrement in peak discharge and run off volume.

Comparing the scenario with no application of rain barrel. the results showed good performance in terms of peak discharge and run off volume reduction.as shown in the Below.

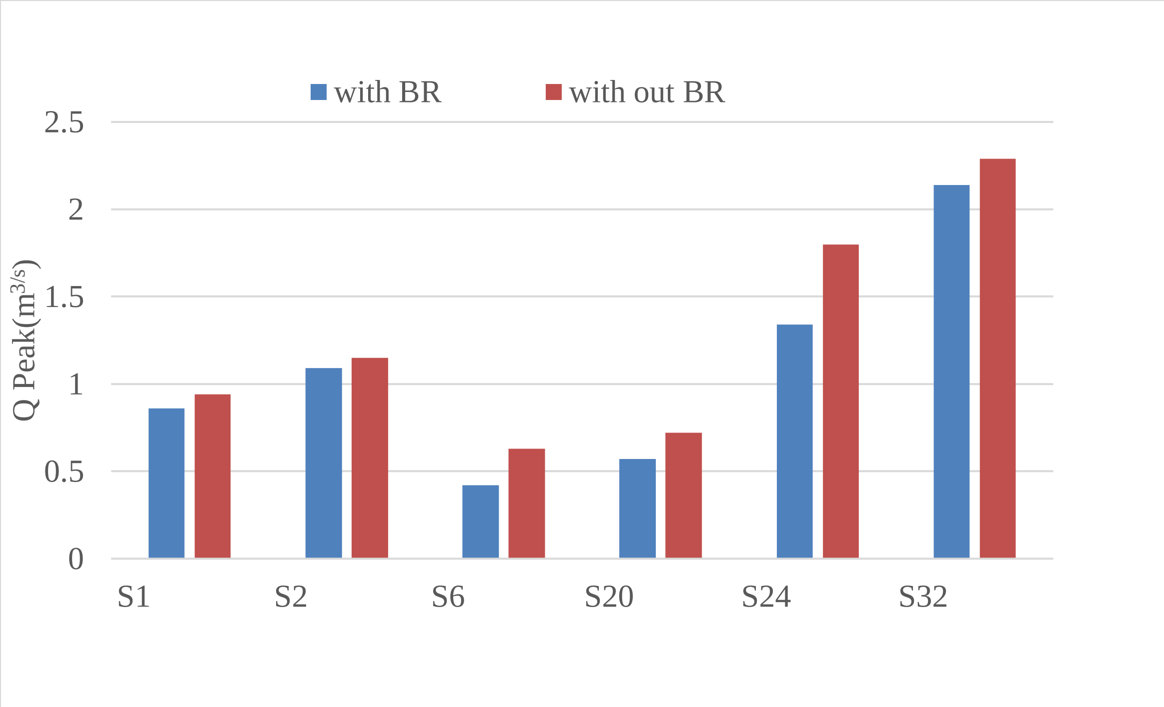


Figure 4. 16 with and without LID comparison for Bio retention cell

Table 4. 9 Bio retention Cell peak discharge reduction

Sub-catchment	S1	S2	S6	S20	S24	S32
Peak Discharge reduction%	8.51	5.217	33.33	20.83	25.55	6.55
Run-off volume reduction%	9.904	6.509	17.76	13.15	8.131	7.841

4.3.4 Application of Combined Lid types (bioretention cell infiltration cell and rain barrels)

Combination of storage and infiltration-based Lid techniques together according to the study site condition Has brought a good performance.

It had seen a great amount of reduction in terms of peak Discharge and run off volume.

Among all scenarios simulated by EPA-SWMM, the combined application of three methods (BRC+ RB+IT) had the most effective performance in the study area. The runoff volume was reduced to 42.95%, and the peak flow delay was up to 24.22% within southern China's storm water collecting systems (Movahedinia et al., 2022).

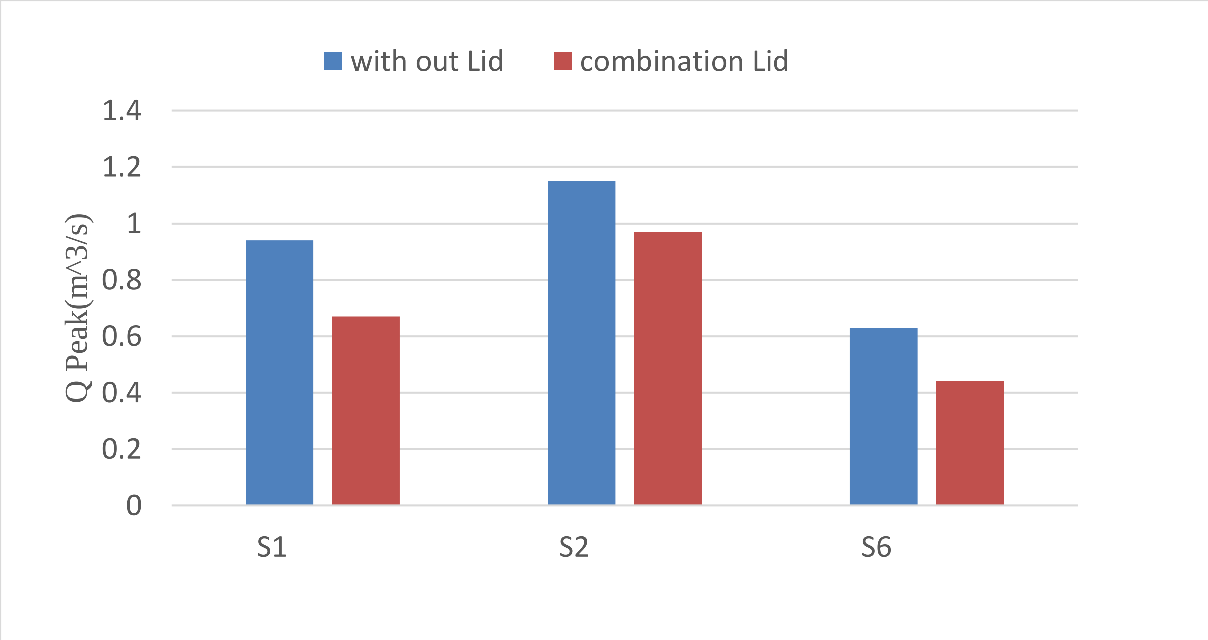


Figure 4. 17 comparison for LID combinations

Table 4. 10 Combined LID peak discharge reduction

Sub-Catchment	S1	S2	S6
Peak discharge reduction %	28.72	15.652	30.158
Run off volume reduction %	32.87	19.87	32.78

Combination of infiltration and storage Lid techniques resulted in large amount of reduction in both the volume and peak discharge with 28.72%,15.62%,30.158% for S1,S2,S6 respectively for peak discharge reduction and 32.87%,19.87%,32.78% run off volume reduction for S1,S2,S6 respectively. So, applying LID techniques combination will bring a good result

5 Summary and Conclusion

5.1 Summary

This thesis aimed to evaluate the hydraulic performance of urban drainage system and propose Low Impact Development works (LID) as alternative mitigation measures. As we know urban drainage systems are essential components of modern cities that help to manage and control the flow of stormwater. Nonetheless, increasing urbanization and climate change have led to significant challenges in urban drainage system management. Hence, the need to evaluate the hydraulic performance of urban drainage systems and propose effective mitigation measures has become more critical than ever.

My study area Kofe Kebele is located in a densely populated urban area, with a high percentage of impervious surfaces. The existing drainage system consists of a network of pipes and culverts designed to convey stormwater runoff to nearby outlets. The study area covers 180 hectares of land, and the drainage network is formed with 3 outlets, 144 junction nodes, and 191 conduit links.

The methodology used in the study area involved various techniques and tools for data collection and analysis. Both primary and secondary data were collected. Primary data sources include field surveys, and interviews with relevant stakeholders. Secondary data sources include local authorities, government agencies, and other relevant organization. Data analysis were made using different software's. The EPA-SWMM model was employed to evaluate the existing drainage system's hydraulic performance, Google Earth was used to visualize the study area, Arc-Gis was used to prepare different maps and Microsoft Excel was also used for analysis of data, and to prepare charts and other necessary software's were also used.

EPA-SWMM served as the main modeling tool. It is a powerful tool for understanding stormwater runoff in urban areas. The model works by dividing the drainage network into a series of nodes and links. Important parameters of EPA-SWMM were computed. This includes preparing a soil map to determine the permeability of the ground, analyzing the slope of the area to determine how water will flow, Land-use and land-cover map was also created in order to determine the extent of impervious surfaces, which tend to contribute to increased stormwater runoff and consequent flooding, Additionally Subcatchments were prepared in order to segment the larger area into more manageable sections, canal dimensions were measured and other necessary parameters were filled accordingly.

To evaluate, identify, and mitigate major problems with drainage systems, collected data were analyzed. For filling in missing rainfall data the normal ratio method was employed, and 15 minutes of rainfall intensity IDF curves were developed based on ERA standards, a double mass curve was used to check consistency, Outlier identification was done to check for higher and lower outliers. Rainfall frequency analysis and fitting of frequency distributions were performed to evaluate the goodness of fit. Model calibration and validation were conducted, and criteria for model performance evaluation were established.

There are major problems that are seen in the study area. the major problems include a lack of adequate drainage infrastructure, a lack of connection between the structures, some of the drainage structures are not having the capacity to carry the generated runoff, fracture due to ageing, and a lack of regular maintenance. The other major problems in the study area include a lack of proper waste management, clogging of drains due to solid waste disposal, and a lack of awareness among the public regarding drainage system use. Not only this the population number, and the impervious area is increasing without appropriate expansion in the drainage system.

The model result evaluated the drainage performance based on the criteria of capacity analysis, flow velocity, and peak rate of runoff. The evaluation results show that the existing drainage system experienced significant problems due to increased runoff, especially during peak storm events. The hydraulic capacity of the pipes and culverts was exceeded, resulting in flooding and the back-up of wastewater into urban areas. Based on the model simulation, a total of 8 junctions and 7 conduits have been flooded, several drains of the system are below their self-cleansing velocity, which has led to siltation and sedimentation. In this study, most of the peak flow was observed in the early hours of simulation. This is due to the increment of impervious areas and the decrement of the infiltration capacity of the soil. moreover, the existing drainage system is deficiently designed, as upstream stormwater is pumped downstream, causing the downstream drainage system to operate beyond its design capacity.

The study conducted model calibration and validation of three conduits by measuring water level and flow velocity for 10 days. The results obtained for the calibration using the performance indicator of Nash-Sutcliffe efficiency (NSE) for each conduit (C78, C97, and C184) are 0.87, 0.91, and 0.85, respectively, and for the coefficient of determination (R^2), 0.75, 0.84, and 0.77. The other indicator considered was the relative error, where the errors were 8.3%, 4%, and 7%. Referring to the validation, the performance of the model for Nash-Sutcliffe efficiency (NSE) for the aforementioned conduits is 0.91, 0.88, and 0.88, respectively; it is 0.88, 0.99, and 0.78 for the coefficient of determination (R^2) and has a relative error of 3.7%. The results show that the EPA-SWMM model performed well in predicting the results accurately. Therefore, the EPA-SWMM model can be used to predict the flow.

To mitigate these problems, low-impact development (LID) was proposed as an alternative mitigation measure. The selected LID techniques are based on the land-use and land-cover, available open spaces, topography, and soil condition of the study area. The LID measures proposed include bioretention cells, rain barrels, and infiltration trenches. The effectiveness of bioretention cells, infiltration trenches, and rain barrels has been analyzed Individually and combining three of them. their effectiveness was tested using EPA-SWMM, and the combination of the three brought the best result in terms of reduction in peak runoff and volume of runoff and can give sustainable solution to the problems. The proposed LID measures will help to improve water quality and provide additional benefits such as increased urban aesthetics, reduced heat, and improved public health.

The hydraulic performance of an urban drainage system can be improved through proper design, construction, and maintenance of the system. However, this requires a comprehensive understanding of the system's hydraulic behavior, the identification of deficiencies, and the implementation of appropriate mitigation strategies.

The study's contribution to existing knowledge lies in its comprehensive analysis of the hydraulic performance of an urban drainage system, identification of major problems, and development of practical mitigation measures. the study highlights the importance of proper drainage system management and the need for effective mitigation measures to ensure their optimal performance. The findings can help to improve the performance of kofe kebele urban drainage system and reduce associated environmental, human life, material, and health risks.

5.2 Conclusion

- Using SWMM version 5.1, the study evaluated the hydraulic performance of the existing urban storm drainage systems for the case of the Dilla Town Kofe kebele. Based on performance indicators such as capacity analysis, the simulation for a 25-year return period revealed that 8 junctions and 7 conduits are flooded, flow velocity results indicate that self-cleansable velocity is not achieved in many conduits, peak rate of runoff shows that peak discharge is attained at early hours, and those results reveal that there is inadequacy in their size, infiltration capacity is lowered, sediment deposition occurs, and in times of high intensity rainfall, the lowland areas are exposed to flooding.
- It has been found that lack of adequate drainage infrastructure and lack of connection between the structures, inadequacy in their capacity to carry the generated runoff, fracture due to aging and lack of regular maintenance, lack of proper waste management solid and liquid wastes from the household are dumped into the drainage system. those problems increased vulnerability to flooding during high-intensity rainfall.
- low impact development (LID) works will help to reduce peak runoff discharge and runoff volume. to understand the effect of LID works two scenarios have been assessed, these are with and without LID scenarios. three LID Techniques had been assessed that are Bioretention cells, Infiltration trenches, and rain Barrels. the result from the simulation indicated that the combination of infiltration and storage techniques has a better capacity to minimize runoff storage Lid techniques resulted in a large amount of reduction in both the volume and peak discharge with 28.72%,15.62%,30.158% for S1, S2, S6 respectively for peak discharge reduction and 32.87%,19.87%,32.78% runoff volume reduction for S1, S2, S6 respectively.
- Generally, the performance of some stormwater drainages was not satisfactory. Therefore, it is recognized that its capacity has shown lower results which need some adjustment or applying Low Impact Development (LID) works to give the best service, and needs a series of regular maintenance, cleaning, increasing drainage infrastructure coverage, and also improving the connection between them. Creating new green areas and parks is also advisable since they are well known for enhancement of infiltration.

5.3 Recommendation

The following recommendations are made for better and sustainable urban stormwater drainage system.

- Increasing community awareness of the importance of using drainage systems in such a way that they can last as long as possible, and the community should also understand how to manage solid and liquid wastes.
- The government authorities should solve problem of Drainage network, increase the size of conduits where overflow happened, repaired damaged drainage structures and to regularly clean the wastes.
- The Government authorities should try sustainable measures to alleviate the flooding problems sustainably low impact development works can help to reduce the volume of runoff and also peak discharge.
- I recommend that future research model the issues with water quality caused by various solid and liquid wastes and identify the effects of contaminants on the environment.

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Appendix

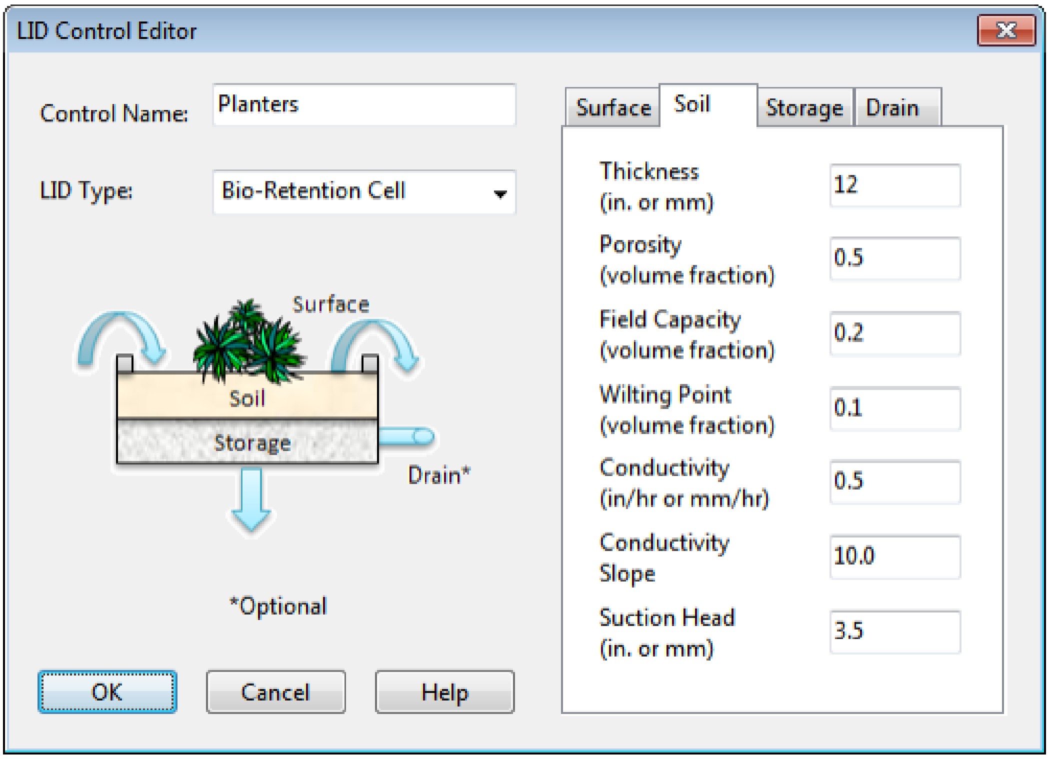
Appendix 1 Rain falls Data of Dilla

Year	Annual Daily Max	Annual Average RF	Total Annual RF
1997	46.7	131.5083333	1578.1
1998	71	82.85	994.2

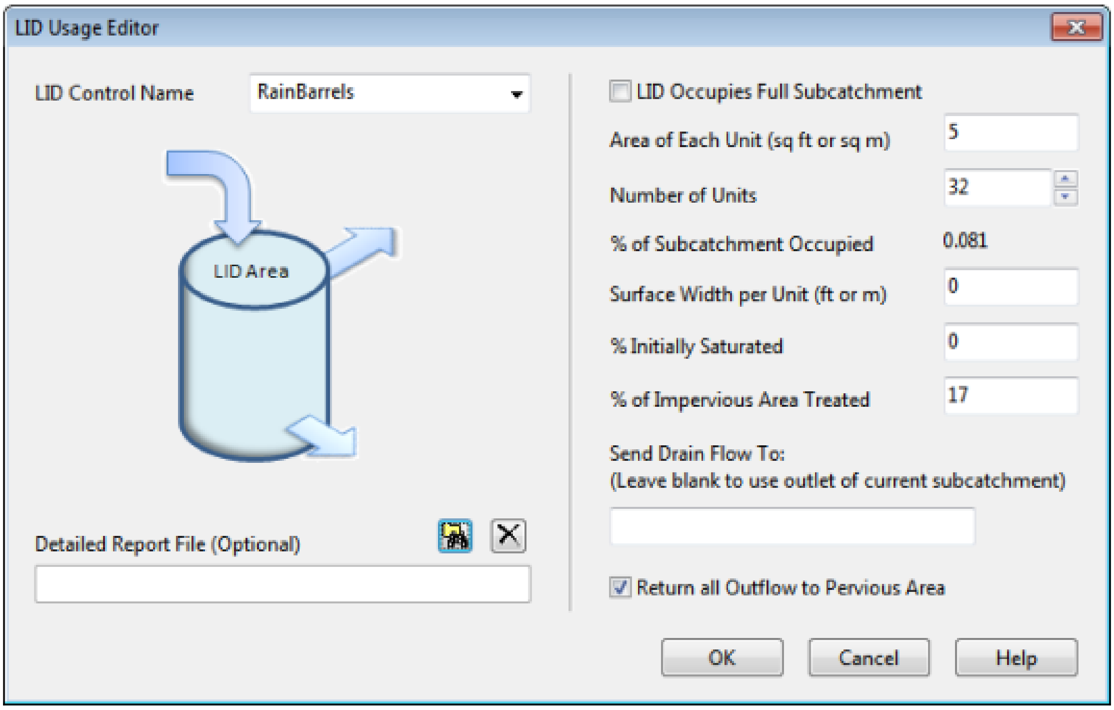
1999	56.3	112.5	1350
2000	51.3	96.45	1157.4
2001	46.2	82.35833333	988.3
2002	55.6	91.79166667	1101.5
2003	60.2	81.19	974.3
2004	48	91.9	1102.8
2005	47.7	105.775	1269.3
2006	49.5	124.45	1493.4
2007	45.5	141.575	1698.9
2008	76	231.633	2779.6
2009	51.7	82.68333333	992.2
2010	52.4	139.6766667	1676.12
2011	60.2	197.35	2368.2
2012	48.5	107.6491667	1291.79
2013	41.8	121.7333333	1460.8
2014	40.7	117.95	1415.4
2015	50.2	93.91666667	1127
2016	69.4	103.8583333	1246.3
2017	52.7	118.6416667	1423.7
2018	43.4	135.3625	1624.35
2019	59.4	121.4	1456.8
2020	55.4	130.6566667	1567.08
2021	40.2	95.14166667	1141.7

Appendix 2 Lid Editor

C.13 LID Control Editor



C.15 LID Usage Editor

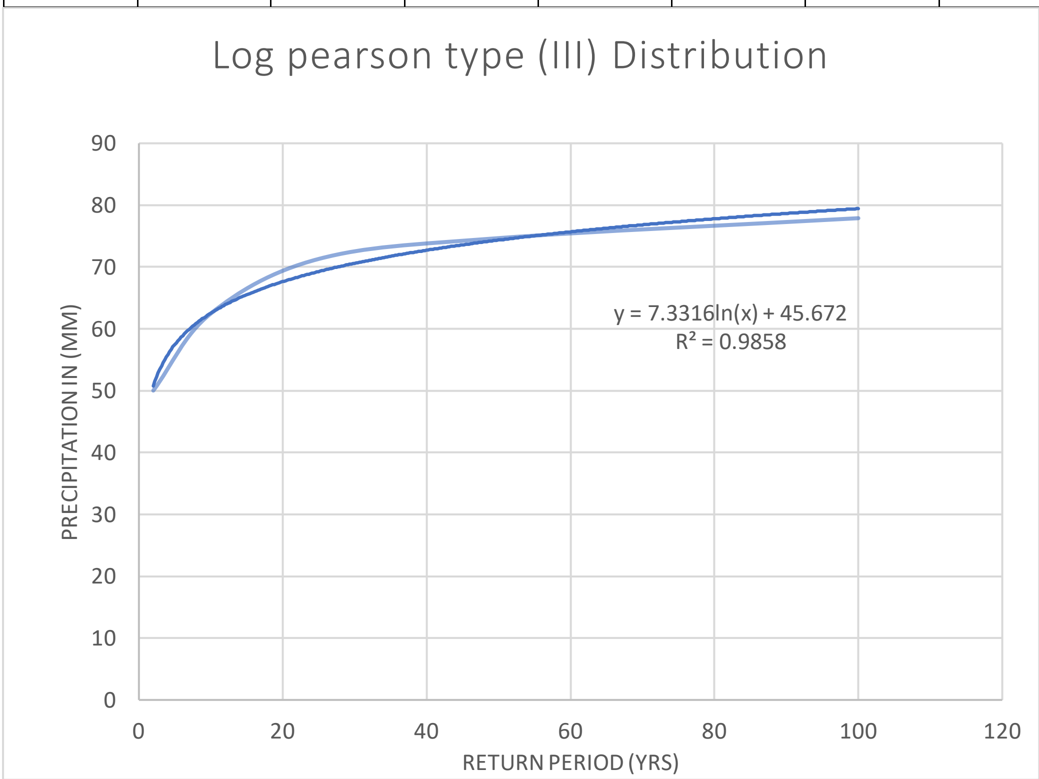


Appendix 3 Log Pearson type iii Distribution

Year	Annual precipitation OF Dilla	Y=log	y mean	(y-ymean^2)	standard dev	n	y-ymean^3	return period
1997	71	1.851258	1.698551	0.023319431	0.076149731	25	0.003561041	26
1998	69.4	1.841359		0.020394162			0.002912452	13
1999	60.8	1.783904		0.007285005			0.000621791	8.666666667
2000	60.2	1.779596		0.006568317			0.00053233	6.5
2001	59.4	1.773786		0.005660321			0.000425855	5.2
2002	55.6	1.745075		0.002164432			0.000100697	4.333333333
2003	55.4	1.74351		0.00202126			9.08727E-05	3.714285714
J 2004	52.7	1.721811		0.000540994			1.25831E-05	3.25
2005	52.4	1.719331		0.000431806			8.97291E-06	2.888888889
2006	51.7	1.713491		0.00022318			3.33413E-06	2.6

2007	50.2	1.700704		4.63273E-06			9.97139E-09	2.363636364
2008	50.2	1.700704		4.63273E-06			9.97139E-09	2.166666667
2009	50	1.69897		1.7528E-07			7.33838E-11	2
2010	49.5	1.694605		1.5572E-05			-6.14494E-08	1.857142857
2011	48.5	1.685742		0.000164086			-2.10187E-06	1.733333333
2012	48	1.681241		0.00029964			-5.18679E-06	1.625
2013	47.7	1.678518		0.000401319			-8.03962E-06	1.529411765
2014	46.7	1.669317		0.000854654			-2.49853E-05	1.444444444
2015	46.2	1.664642		0.001149845			-3.89905E-05	1.368421053
2016	45.5	1.658011		0.001643487			-6.66269E-05	1.3
2017	43.4	1.63749		0.00372852			-0.000227669	1.238095238

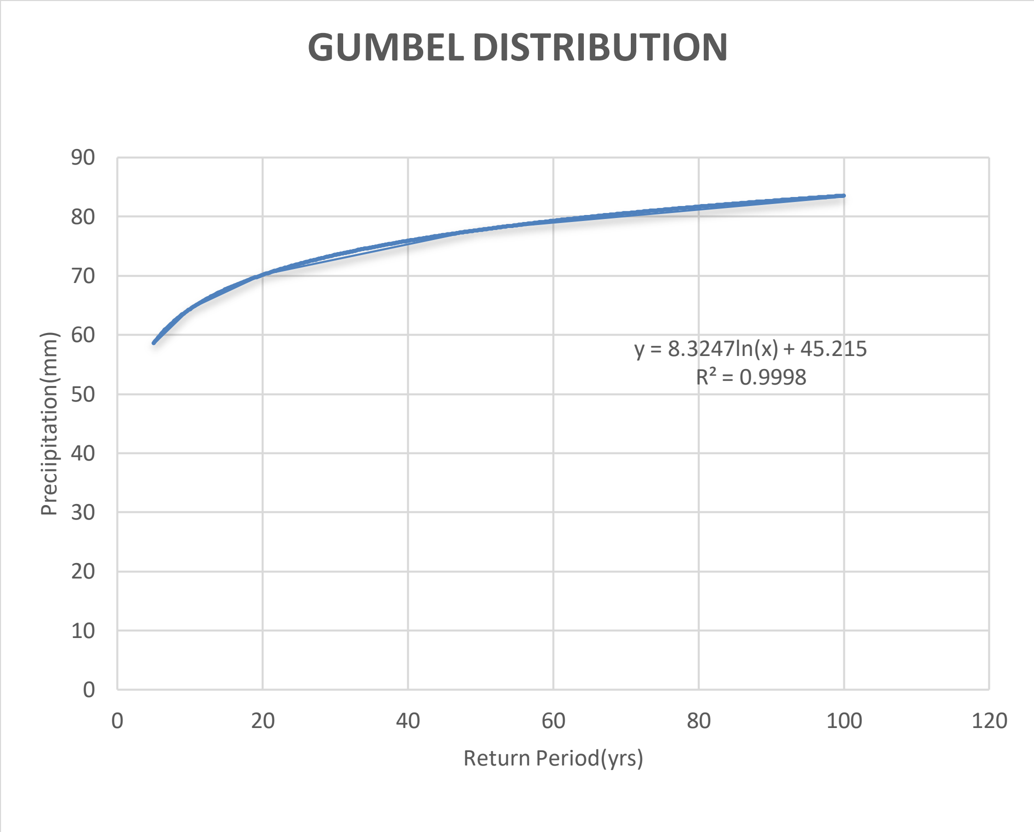
2018	41.8	1.621176		0.0059869			-0.000463237	1.181818182
2019	40.7	1.609594		0.007913335			-0.000703946	1.130434783
2020	40.2	1.604226		0.00889726			-0.000839237	1.083333333
2021	30.6	1.485721		0.045296572			-0.009640465	1.04



Appendix 4 Gumbel Distribution

Year	Annual precipitation Dilla	mean	x-mean^2	mean	standard deviation	
1997	46.7	50.712	16.096144		8.757457165	

1998	71		411.602944			
1999	30.6		404.492544			
2000	50		0.506944			
2001	46.2		20.358144			
2002	55.6		23.892544			
2003	60.2		90.022144			
2004	48		7.354944			
2005	47.7		9.072144			
2006	49.5		1.468944			
2007	45.5	50.712	27.164944	1917.326		
2008	60.8		101.767744			
2009	51.7		0.976144			
2010	52.4		2.849344			
2011	50.2		0.262144			
2012	48.5		4.892944			
2013	41.8		79.423744			
2014	40.7		100.240144			
2015	50.2		0.262144			
2016	69.4		349.241344			
2017	52.7		3.952144			
2018	43.4		53.465344			
2019	59.4		75.481344			
2020	55.4		21.977344			
2021	40.2		110.502144			



Appendix 5 Mean annual cumulative of Dilla and nearby stations for double mass curve development.

Year	cumulative of Dilla	cumulative of nearby stations
2010	138.9930475	137.0179167
2011	263.0495585	256.3520833
2012	370.1718581	361.8089583
2013	491.3093923	488.5879167
2014	608.68211	582.8820833
2015	702.1391205	680.4875
2016	805.4891403	758.2375
2017	923.5501394	835.088125
2018	1058.250135	953.4814583
2019	1179.055967	1073.804375
2020	1309.073162	1230.883264
2021	1403.749177	1326.716597

Appendix 6 Conduit properties

; Conduit	From Node	To Node	Length	Roughness	Shape	length	width
C1	j2	j1	205	0.012	RECT_OPEN	0.7	0.5
C2	j1	j8	446	0.012	RECT_CLOSED	1	0.6
C3	j4	j3	300	0.012	RECT_OPEN	0.5	0.4
C4	j148	j39	400	0.012	RECT_OPEN	1	1
C5	j5	j6	290	0.012	RECT_OPEN	0.6	0.5
C6	j3	j6	443	0.012	RECT_OPEN	0.9	0.6
C7	j127	j72	400	0.012	RECT_OPEN	1	1
C8	j125	j102	111	0.012	RECT_OPEN	1	1
C9	D2	j9	400	0.012	RECT_OPEN	1	1
C10	j9	j124	159	0.012	RECT_OPEN	1.5	2
C11	j119	j109	40	0.012	RECT_OPEN	1	1
C12	j12	j11	308	0.012	RECT_OPEN	0.52	0.3
C13	D1	D3	305	0.012	RECT_OPEN	0.5	0.4
C14	j11	j126	161	0.012	RECT_OPEN	0.9	0.6
C15	D1	D6	10	0.012	RECT_OPEN	0.5	0.3
C16	j118	j151	430	0.012	RECT_OPEN	0.5	0.3
C17	j108	j105	30	0.012	RECT_OPEN	0.7	0.6
C18	j128	j129	201	0.012	RECT_OPEN	1	1
C19	j129	j16	162	0.012	RECT_OPEN	1.5	2.5
C20	j128	D4	168	0.012	RECT_OPEN	0.5	0.3
C21	D4	j16	211	0.012	RECT_OPEN	0.8	0.6
C22	j131	j130	284	0.012	RECT_OPEN	0.6	0.4
C23	j106	j83	10	0.012	RECT_OPEN	1	1
C24	j103	j105	204	0.012	RECT_OPEN	0.7	0.3
C25	j130	D3	166	0.012	RECT_OPEN	0.8	0.6
C26	D6	j19	302	0.012	RECT_OPEN	0.5	0.4
C27	D6	j18	270	0.012	RECT_OPEN	0.5	0.3
C28	j18	j20	289	0.012	RECT_OPEN	0.7	0.4
C29	j19	j20	266	0.012	RECT_OPEN	0.8	0.7

C30	D5	j23	215	0.012	RECT_OPEN	0.7	0.6
C31	D5	j22	246	0.012	RECT_OPEN	0.8	0.8
C32	j22	j24	211	0.012	RECT_OPEN	1	0.9
C33	j105	j104	109	0.012	RECT_OPEN	0.7	0.5
C34	j25	j27	166	0.012	RECT_OPEN	0.7	0.6
C35	j52	j53	108	0.012	RECT_OPEN	1	1
C36	j26	j28	200	0.012	RECT_OPEN	0.6	0.95
C37	j27	j28	130	0.012	RECT_OPEN	1	0.9
C38	j30	j38	157	0.012	RECT_OPEN	1	1
C39	j38	j29	68	0.012	RECT_OPEN	1	1
C40	j29	j31	160	0.012	RECT_OPEN	0.5	0.46
C41	j30	j32	161	0.012	RECT_OPEN	0.7	0.5
C42	j56	D9	80	0.012	RECT_OPEN	1	1
C43	j39	j31	68	0.012	RECT_OPEN	1	1
C44	j34	j35	122	0.012	RECT_OPEN	0.5	0.4
C45	j154	j128	8	0.012	RECT_OPEN	0.5	0.3
C46	j33	D7	220	0.012	RECT_OPEN	0.7	0.5
C47	D7	j40	193	0.012	RECT_OPEN	1	1
C48	j40	j35	60	0.012	RECT_OPEN	1	1
C49	j38	j39	155	0.012	RECT_OPEN	1.07	1
C50	j33	j133	161	0.012	RECT_OPEN	1	1
C51	j133	j34	54	0.012	RECT_OPEN	1	1
C52	j31	j34	10	0.012	RECT_OPEN	0.5	0.4
C53	j16	j23	13	0.012	RECT_OPEN	1.2	1
C54	j154	j124	200	0.012	RECT_OPEN	1	1
C55	D2	j154	150	0.012	RECT_OPEN	0.5	0.3
C56	j59	j54	12	0.012	RECT_OPEN	1	0.5
C57	j86	j61	10	0.012	RECT_OPEN	0.5	0.3
C58	j6	j11	12	0.012	RECT_OPEN	0.8	0.5
C59	j87	j86	214	0.012	RECT_OPEN	1	1
C60	j102	j90	10	0.012	RECT_OPEN	0.5	0.3
C61	j104	j102	209	0.012	RECT_OPEN	0.6	0.5

C62	j8	j9	10	0.012	RECT_CLOSED	1.2	1
C63	j92	j116	10	0.012	RECT_OPEN	0.6	0.4
C64	j126	j130	12	0.012	RECT_OPEN	1	0.6
C66	j124	j129	10	0.012	RECT_OPEN	1	1
C68	D3	j19	18	0.012	RECT_OPEN	0.8	0.5
C69	D4	D5	13	0.012	RECT_OPEN	0.5	0.3
C70	j116	j55	227	0.012	RECT_OPEN	0.5	0.3
C71	j88	j87	10	0.012	RECT_OPEN	1	1
C72	j58	D9	60	0.012	RECT_OPEN	1	1
C73	j136	j137	30	0.012	CIRCULAR	2	0
C74	j137	j138	100	0.012	RECT_CLOSED	2	2
C75	j138	j139	150	0.012	RECT_OPEN	2	1
C76	j20	j22	15	0.012	RECT_OPEN	0.65	0.55
C77	j24	j27	12	0.012	RECT_CLOSED	0.9	0.7
C78	j28	D8	20	0.012	RECT_OPEN	1.45	1.25
C79	j39	j133	10	0.012	CIRCULAR	1	0
C80	j133	j40	152	0.012	RECT_OPEN	1	1
C81	j40	j132	15	0.012	CIRCULAR	1	0
C82	j35	j37	10	0.012	RECT_OPEN	0.5	0.3
C83	j42	j132	140	0.012	RECT_OPEN	0.6	1
C84	j132	j37	50	0.012	RECT_OPEN	1	1
C85	j37	j43	235	0.012	RECT_OPEN	0.7	0.6
C86	j42	j44	124	0.012	RECT_OPEN	0.6	0.4
C87	j44	j48	400	0.012	RECT_OPEN	1	1
C88	j44	j41	156	0.012	RECT_OPEN	1	1
C89	j132	j41	190	0.012	RECT_OPEN	1.6	1.2
C90	j41	j43	45	0.012	RECT_OPEN	1	1
C91	j43	j45	400	0.012	RECT_OPEN	1	1
C92	j48	j46	170	0.012	RECT_OPEN	1	1
C93	j46	j45	63	0.012	RECT_OPEN	1	1
C94	j45	D8	144	0.012	RECT_OPEN	0.7	0.4
C95	D9	out1	15	0.012	RECT_OPEN	4	5

C96	j48	j49	136	0.012	RECT_OPEN	0.5	0.6
C97	j49	D8	172	0.012	RECT_OPEN	1.3	1
C98	j41	j46	25	0.012	CIRCULAR	1	0
C99	j51	j52	152	0.012	RECT_OPEN	0.5	0.3
C100	j51	j54	111	0.012	RECT_OPEN	0.5	0.3
C101	j54	j53	147	0.012	RECT_OPEN	0.4	0.3
C102	j139	D9	70	0.012	RECT_OPEN	2	2
C103	j75	j74	146	0.012	RECT_OPEN	1	0.98
C104	j74	j73	242	0.012	RECT_OPEN	1	1
C105	j53	D9	100	0.012	RECT_OPEN	1	1
C106	D8	D9	200	0.012	RECT_OPEN	3	3
C107	j76	j72	366	0.012	RECT_OPEN	1	1
C108	j72	j68	12	0.012	RECT_OPEN	0.67	0.48
C109	j69	j68	369	0.012	RECT_OPEN	1	1
C110	j32	j33	12	0.012	RECT_OPEN	1	1
C111	D7	j42	12	0.012	RECT_OPEN	0.7	0.8
C112	j68	j140	223	0.012	RECT_OPEN	0.5	0.6
C115	j71	j142	58	0.012	RECT_OPEN	0.4	0.3
C116	j140	j141	211	0.012	RECT_OPEN	1	1
C117	j141	j142	32	0.012	RECT_OPEN	0.4	0.3
C118	j140	j143	18	0.012	RECT_OPEN	1	1
C119	j143	j67	118	0.012	RECT_OPEN	1.5	1
C120	j55	j56	245	0.012	RECT_OPEN	0.6	0.3
C121	j104	j101	10	0.012	RECT_OPEN	0.5	0.3
C122	j102	j100	400	0.012	RECT_OPEN	1	1
C123	j100	j93	12	0.012	RECT_OPEN	1	1
C124	j98	j94	10	0.012	RECT_OPEN	0.5	0.6
C125	j73	j30	400	0.012	RECT_OPEN	1	1
C126	j147	j126	300	0.012	RECT_OPEN	0.7	0.4
C127	j142	j145	10	0.012	RECT_OPEN	0.6	0.4
C128	j23	j134	30	0.012	RECT_OPEN	1	0.8
C129	j134	j24	172	0.012	RECT_OPEN	0.8	0.6

C130	j65	j64	295	0.012	RECT_OPEN	0.6	0.4
C131	j67	j64	15	0.012	CIRCULAR	1	0
C132	j67	j44	10	0.012	RECT_OPEN	0.8	0.7
C133	j64	j63	130	0.012	RECT_OPEN	0.4	0.4
C134	j63	j49	12	0.012	RECT_OPEN	1	0.8
C135	j64	j48	400	0.012	RECT_OPEN	1	1
C136	j96	out2	20	0.012	RECT_OPEN	1	1
C137	j62	j60	213	0.012	RECT_OPEN	0.5	0.3
C138	j62	j61	112	0.012	RECT_OPEN	1	1
C139	j61	j59	211	0.012	RECT_OPEN	0.5	0.5
C140	j60	j59	109	0.012	RECT_OPEN	1	1
C141	j85	j84	231	0.012	RECT_OPEN	0.4	0.3
C142	j84	j86	114	0.012	RECT_OPEN	1	1
C143	j85	j87	112	0.012	RECT_OPEN	0.5	0.3
C144	j91	j89	200	0.012	RECT_OPEN	0.6	0.5
C145	j91	j90	108	0.012	RECT_OPEN	1	1
C146	j90	j88	209	0.012	RECT_OPEN	0.6	0.6
C147	j89	j88	118	0.012	RECT_OPEN	0.6	0.6
C148	j93	j94	164	0.012	RECT_OPEN	0.95	0.95
C149	j93	j92	181	0.012	RECT_OPEN	0.8	0.6
C150	j134	j136	15	0.012	CIRCULAR	1	0
C151	j92	j96	162	0.012	RECT_OPEN	1	0.96
C152	j60	j51	10	0.012	RECT_OPEN	0.5	0.4
C153	j88	j92	12	0.012	RECT_OPEN	1	1
C154	j90	j93	12	0.012	RECT_OPEN	1	1
C155	j84	j62	10	0.012	RECT_OPEN	0.5	0.3
C156	j89	j85	12	0.012	RECT_OPEN	0.5	0.3
C157	j81	j111	13	0.012	RECT_OPEN	1	1
C158	j103	j91	12	0.012	RECT_OPEN	0.6	0.3
C159	j111	j110	219	0.012	RECT_OPEN	0.65	0.5
C160	j111	j113	296	0.012	RECT_OPEN	1	1
C161	j110	j112	197	0.012	RECT_OPEN	1	1

C162	j110	j107	14	0.012	RECT_OPEN	1	1
C163	j107	j106	91.6	0.012	RECT_OPEN	1	1
C164	j106	j108	205	0.012	RECT_OPEN	1	1
C165	j79	j66	13	0.012	RECT_OPEN	1	1
C166	j107	j109	225	0.012	RECT_OPEN	1	1
C167	j109	j112	10	0.012	RECT_OPEN	1	1
C168	j112	j113	123	0.012	RECT_OPEN	1	1
C169	j113	j115	10	0.012	RECT_OPEN	1	1
C170	j66	j63	301	0.012	RECT_OPEN	1	1
C171	j71	j65	8	0.012	RECT_OPEN	0.5	0.3
C172	j117	j144	206	0.012	RECT_OPEN	0.5	0.2
C173	j151	D2	10	0.012	RECT_OPEN	0.5	0.3
C174	j151	j8	202	0.012	RECT_OPEN	1	1
C175	j94	j96	118	0.012	RECT_OPEN	1	1
C176	j114	j120	241	0.012	RECT_OPEN	0.5	0.3
C177	j120	j121	174	0.012	RECT_OPEN	1	1
C178	j57	j58	257	0.012	RECT_OPEN	1	1
C179	j115	j146	213	0.012	RECT_OPEN	1	1
C180	j146	j123	134	0.012	RECT_OPEN	1	1
C181	j121	j122	84	0.012	RECT_OPEN	0.7	0.5
C182	j122	j123	64	0.012	RECT_OPEN	0.93	0.56
C183	j101	j99	164	0.012	RECT_OPEN	0.6	0.5
C184	j55	j57	196	0.012	RECT_OPEN	1	1

Appendix 7 Subcatchment properties

[SUBCATCHMENTS]					
; Subcatchment	Outlet	Area	%Imperv	Width	%Slope
;;--------------	----------------	--------	--------	--------	--------
S1	J8	7.753	60	173.83	8
S2	J6	11.376	40	256.8	7

S3	J124	3.6	55	226.41	7
S4	J130	4.3	45	267	8
S5	D3	5.1	45	307.22	9
S6	J16	4.45	50	264.88	9
S7	J20	9.6	40	355.55	10
S8	J24	7	40	284.55	10
S9	J31	1.5	35	93.75	8
S10	J35	1	40	65.78	8
S11	J39	4	35	248.44	7
S12	J40	3.36	40	152.72	7
S13	J43	1	40	47.33	6
S14	J41	4	40	210.5	8
S15	J28	2	35	100	9
S16	D8	0.8	40	55.55	7
S17	D8	3.47	40	244.8	7
S18	J53	4.21	35	277	6
S19	J72	9.87	35	269.12	7
S20	J140	7.1	35	211.94	7
S21	J67	2	40	98.522	8
S22	J63	5	50	166.11	9
S23	J59	5	40	234.74	8
S24	J79	28	60	472.17	7
S25	J88	4.395	45	210.28	7
S26	J86	5	40	216.45	6
S27	J98	7.65	35	329.74	6.5
S28	J102	5.35	40	256	5.5
S29	J109	3.05	25	135.55	6
S30	J113	9.92	25	335.13	6
S31	J58	3.13	35	121.78	5.6
S32	J123	24.7	25	711.8	6.5
S33	J57	3.14	30	138.325	6

Appendix 8 Table of outlier test computation

Year	maximum rainfall	y=logx
1997	46.7	1.669317
1998	71	1.851258
1999	56.3	1.750508
2000	50	1.69897
2001	46.2	1.664642
2002	55.6	1.745075
2003	60.2	1.779596
2004	48	1.681241
2005	47.7	1.678518
2006	49.5	1.694605
2007	45.5	1.658011
2008	60.8	1.783904
2009	51.7	1.713491
2010	52.4	1.719331
2011	50.2	1.700704
2012	48.5	1.685742
2013	41.8	1.621176
2014	40.7	1.609594
2015	50.2	1.700704
2016	69.4	1.841359
2017	52.7	1.721811
2018	43.4	1.63749
2019	59.4	1.773786
2020	55.4	1.74351
2021	40.2	1.604226

Sum	1293.5	42.72857
Average	51.74	1.709143
Standard deviation	7.952043762	0.06441

KN	2.486	2.486
Coefficient of skewness (Cs)	0.5811	0.4225

Higher outlier	77.9983	1.948690636
Lower outlier	23.9517	1.466080385

Appendix 9 Conduit 184 observed values

Time	time(hr)	depth(m)	width(m)	Time(s)for 4m	velocity(m/s)	Area(m^2)	Q(m^3/S)
7:00	0	0	0	0	0	0	0
7:30	0.5	0.63	1	0.5	8	0.63	5.04
8:00	1	0.7	1	0.55	7.272727	0.7	5.090909
8:30	1.5	0.65	1	0.58	6.896552	0.65	4.482759
9:00	2	0.55	0.75	0.6	6.666667	0.4125	2.75
9:30	2.5	0.5	0.6	0.64	6.25	0.3	1.875
10:00	3	0.45	0.48	0.693333	5.769231	0.216	1.246154
10:30	3.5	0.4	0.36	0.738333	5.417607	0.144	0.780135
11:00	4	0.35	0.2	0.783333	5.106383	0.07	0.357447
11:30	4.5	0.2	0	0.828333	4.828974	0	0
12:00	5	0.1	0	0.873333	4.580153	0	0

Appendix 10 Conduit 78 observed

Time	time in (hr)	depth(m)	width(m)	Time(s) for 4m	velocity(m/s)	Area(M^2)	dischage(m^3/s)
8:00	0	0	0	0	0	0	0
8:30	0.5	0.66	1.32	0.6	6.666666667	0.8712	5.808
9:00	1	0.65	1.32	0.58	6.896551724	0.858	5.917241379
9:30	1.5	0.6	1.1	0.58	6.896551724	0.66	4.551724138
10:00	2	0.55	0.95	0.63	6.349206349	0.5225	3.317460317
10:30	2.5	0.5	0.8	0.7	5.714285714	0.4	2.285714286
11:00	3	0.45	0.65	0.73	5.479452055	0.2925	1.602739726
11:30	3.5	0.4	0.47	0.84	4.761904762	0.188	0.895238095
12:00	4	0.35	0.3	0.95	4.210526316	0.105	0.442105263
12:30	4.5	0.3	0	1.02	3.921568627	0	0
13:00	5	0.25	0	1.09	3.669724771	0	0

Appendix 11 Conduit 97 observed values

Time	time(hr)	depth(m)	width(m)	Time(S)for 4m	velocity(m/s)	Area(m^2)	dischage(M^3S)
1:00	0	0	0	0	0	0	0
1:30	0.5	0.55	1	0.5	8	0.55	4.4

2:00	1	0.7	1	0.48	8.333333	0.7	5.833333
2:30	1.5	0.65	1	0.5	8	0.65	5.2
3:00	2	0.6	0.8	0.53	7.54717	0.48	3.622642
3:30	2.5	0.57	0.7	0.55	7.272727	0.399	2.901818
4:00	3	0.55	0.58	0.6	6.666667	0.319	2.126667
4:30	3.5	0.33	0.4	0.68	5.882353	0.132	0.776471
5:00	4	0.28	0.2	0.73	5.479452	0.056	0.306849
5:30	4.5	0	0	0.8	5	0	0
6:00	5	0	0	0.85	4.705882	0	0

Appendix 12 Manning's n – Overland Flow

Surface	**N**
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.05
Cultivated soils Residue cover < 20% Residue cover > 20%	0.06 0.17
Range (natural)	0.13
Grass Short, prairie Dense Bermuda grass	0.15 0.24 0.41

Woods Light underbrush Dense underbrush	0.40 0.80

Appendix 13 Manning's n – Closed Conduits

Conduit Material	**Manning n**
Asbestos-cement pipe	0.011 - 0.015
Brick	0.013 - 0.017
Cast iron pipe - Cement-lined & seal coated	0.011 - 0.015
Concrete (monolithic) - Smooth forms	0.012 - 0.014
- Rough forms	0.015 - 0.017
Concrete pipe	0.011 - 0.015
Corrugated-metal pipe (1/2-in. x 2-2/3-in. corrugations)	
- Paved invert	0.018 - 0.022
- Spun asphalt lined	0.011 - 0.015
Plastic pipe (smooth)	0.011 - 0.015
Vitrified clay - Pipes - Liner plates	0.011 - 0.013 - 0.015 0.017

Source: ASCE (1982). *Gravity Sanitary Sewer Design and Construction*, ASCE Manual of Practice No. 60, New York, NY.

Appendix 14 Depression Storage

Impervious surfaces	0.05 - 0.10 inches
Lawns	0.10 - 0.20 inches

Pasture	0.20 inches
Forest litter	0.30 inches

Source: ASCE,(1992).Design & Construction of Urban Stormwater Management Systems, New York, NY.